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VOL. 10

ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC COMMITTEE FOR CO-ORDINATION OF JOINT PROSPECTING FOR MINERAL RESOURCES IN ASIAN OFFSHORE AREAS (CCOP)

December, 1976

ECONOMIC AND SOCIAL COMMISSION
FOR ASIA AND THE PACIFIC

COMMITTEE FOR CO-ORDINATION OF JOINT PROSPECTING FOR MINERAL RESOURCES IN ASIAN OFFSHORE AREAS (CCOP)

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PREFACE

Since 1968, the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (referred to briefly as the Co-ordinating Committee for Offshore Prospecting, and abbreviated to CCOP) has been issuing Technical Bulletins annually, containing technical and scientific studies on marine geology and offshore prospecting for mineral resources as well as the results of surveys undertaken through CCOP's sponsorship. Apart from contributions to scientific knowledge, these studies and survey reports have helped in arousing interest in the mineral potentials of the marine shelves of the region, particularly for petroleum, and have played an important part in attracting risk capital from industry to east Asia. The publication of the Technical Bulletin series is contributed by the Government of Japan, with the Geological Survey of Japan responsible for editing and printing.

The Committee is an inter-governmental body, established under the aegis of the United Nations Economic Commission for Asia and the Far East (ECAFE) which is now known as the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) and, since 1972, assisted by the United Nations Development Programme (UNDP) through a project entitled "Technical Support for Regional Offshore Prospecting in East Asia." The Committee consists of the following member countries: Cambodia, Indonesia, Japan, the Republic of Korea, Malaysia, the Philippines, Viet-Nam, Singapore and Thailand.

Three main types of publications are produced by the Committee: Technical Bulletins, Reports of CCOP sessions and CCOP Newsletters. All CCOP publications, including Technical Bulletins, are distributed to the appropriate organizations and authorities concerned in member countries of CCOP. Enquiries as to their availability to institutions and organizations in other countries may be directed to: Office of the Project Manager/Coordinator, CCOP, ESCAP, UN Building, Sala Santitham, Bangkok 2, Thailand.

FOREWORD

It has been a privilege and honour for us to publish the Technical Bulletin of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP). I am very pleased to present the tenth volume here.

CCOP is being celebrated the Tenth Anniversary after its birth in 1966. The achievement made to the development of mineral resources and science of the earth of the western Pacific region is very significant and well known. I wish to offer my congraturations and sincerely hope its brilliant future. This volume is presented to commemorate the Tenth Anniversary. I deeply appreciate the co-operation of the authors, the staff of the UNDP/CCOP Project Office and the editorial staff for producing this volume.

Isamu Kobayashi
Director,
Geological Survey of Japan

NOTE BY THE EDITOR

It is a great pleasure for the editor to present Volume 10 of the CCOP Technical Bulletin to the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP). The articles included in this volume were submitted or recommended in response to the solicitation made by Dr. C. Y. Li, Secretary to CCOP on behalf of the Committee, based on the resolution made at the twelfth session of CCOP held in Tokyo in August 1975, that Volume 10 of its Technical Bulletin be devoted to the results of CCOP's ten years of its activity in order to commemorate the Tenth Anniversary of CCOP in 1976. It was, however, agreed at the thirteenth session of CCOP held in Kuala Lumpur, Malaysia from 22 November to 6 December 1976 that the Tenth Anniversary Volume would be limited to the ten-year review of developments in the region relating to CCOP activities. Accordingly, this volume were edited as a regular one.

The first paper in this volume concerning the western Pacific and its margin, which was originally prepared as one of the frontier reports of the International Geodynamics Project is of primary importance for scientific activity of the Committee. This work is really a foundation for understanding of tectonic development of this region and the debate should be invited and encouraged between those who are working on the different approaches, for example, by either geological or geophysical basis. The editor commented briefly on this paper in the hope of further discussion by the readers. The reply from the authors will be appeared in the next issue. The second paper on petroleum geology around the Japanese Islands is significant as it disclosed general structure of the sedimentary basins around Japan. The editor wishes to express his gratitude for the permission of releasing isopach contour map given by the Japanese authorities concerned. The third paper on magnetic interpretation describes a method employed for determination of basement configuration of offshore sedimentary basin and is thus complementary to the second paper. The fourth paper is a precious results of the efforts of many years done by the Mineral Fuels Division, Bureau of Mines for assessment of petroleum potential in the Philippines. The editor is very glad to have an outstanding and comprehensive article by the authors who have been studied the petroleum development in China as the fifth paper in this volume, which may attract attention of many readers.

Non-referee status of the Bulletin was questioned in the previous sessions of CCOP and establishment of an editorial board has been discussed. The editor felt that the scope and the objectives of the Bulletin, and its circulation should be reconsidered so that the referee system would fulfil its function and the Bulletin would maintain the scientific standards. The following proposals was accordingly submitted by him to the twelfth session of the Technical Advisory Group of CCOP, which was concurrently held with the thirteenth session of CCOP in 1976, and were accepted:

(1) The Special Advisers are requested (a) to select appropriate papers from the documents submitted to the sessions and to make recommendations for improvement of their contents wherever necessary; (b) to suggest specialists who can review the papers and make comments to the authors for further improvement; and (c) to solicit informative papers on subjects of the member countries' interest, particularly along the new trend of CCOP activities.
(2) The Permanent representatives are requested (a) to encourage local scientists to prepare papers for publication in the Technical Bulletin, either as documents to CCOP meetings or manuscripts directly submitted to the editor; (b) to solicit contributions to the Bulletin from universities, research institutions or scientific associations, which are not directly associated with the CCOP activities; (c) to expand distribution of the Bulletins to relevant scientific organizations in their countries if some of them do not receive the Bulletins; and (d) to explore the means of supporting the cost of reprints to the authors in their countries.
(3) The editor of the UNDP/CCOP Project Office is requested to continue the editing of manuscripts and also to serve as a reviewer.

The editor express his sincere gratitude to Dr. C. Y. Li, Project Manager/Co-ordinator of the UNDP Technical Support for Regional Offshore Prospecting in East Asia for his kind co-operation and valuable suggestion. His deepest thanks are extended to the Director of the Geological Survey of Japan for the printing of this volume, as well as to the members concerned of the Geological Survey, particularly its Publication and Library Office, and Dr. Yoshiaki Sato, for their co-operation in completing this volume.

December 1976

Shun-ichi SANO
Editor-in-Chief

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EVOLUTION OF THE WESTERN PACIFIC AND ITS MARGIN

By

T. W. C. HILDE[1], S. UYEDA[2]
and
L. KROENKE[3]

ABSTRACT

An evolutionary history of the Western Pacific is presented by reconstructing the spreadnig systems of the region since middle Mesozoic time on the basis of marine magnetic lineations, paleomagnetic data, DSDP results, and selected other data. Subduction along the Asian plate margin throughout this time has resulted in general northward movement of the plates surrounding Asia. An E-W spreading ridge system, offset by N-S transform faults of great length, extended from the Pacific into the Tethys Sea and migrated north as the oceanic plates to the north were being subducted along Asia. Segments of this ridge system were subducted at different times along the Asian margin, in some cases initiating marginal sea formation. As the plates south of these ridge segments started to subduct at the Asian margin, new spreading ridges formed far to the south, rifting India from Antarctica at about −100 m.y. and Australia from Antarctica at about −52 m.y. Subduction of the Pacific ridge system in the north and southwest Pacific resulted in a change of direction in Pacific plate motion from NNW to WNW at about −45 m.y. The long N-S transform faults of the Western Pacific provided zones of weakness along which new subduction was initiated. This occurred along the present N-S trend of the Philippine arc, along the Kyushu-Palau ridge, in an original position farther east, and along the approximate present position of the Lau-Harve ridge. Oceanic crust in the west Philippine Sea and possibly the south Fiji basin was entrapped by development of the new subduction zones. Subduction of the Pacific plate accelerated as the system became well established by about −25 m.y. Back-arc spreading was initiated as a result of the faster subduction and formed the Miocene and younger eastern portions of the Western Pacific marginal seas. The marginal seas at both ends of the Sunda arc have more complex histories, being formed by a combination of processes including entrapment and rifting of the plates along transform plate boundaries.

INTRODUCTION

The theories of sea-floor spreading and plate tectonics have, in the last decade,

1) Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP), United Nations, Bangkok, Thailand.
2) Earthquake Research Institute, University of Tokyo, Tokyo, Japan.
3) Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC), United Nations, Suva, Fiji.
4) Reprinted from Tectonophysics.

allowed for the explanation of the origin and development of vast regions of the oceans and continents. The most classical application of these theories, and paleomagnetic evidence, has been to explain the origin of the Atlantic and the break up of Gondwanaland (*e.g.* Dietz and Holden, 1970, Pitman III and Talwani, 1972). However, because of its complicated structures, the Western Pacific, its island arcs and marginal seas, has remained an enigma. Although theories have been offered for the origin of the island arcs and marginal seas, these have not succeeded in establishing a coherent tectonic history for the region as a whole. In this paper we attempt such a comprehensive reconstruction by relating the development of these features to the origin and evolution of the surrounding major lithospheric plates. This paper is a preliminary version of a paper being prepared on the same subject by Hilde, Uyeda and Kroenke which is to be published as one of the Geodynamics Project Frontier Reports.

We have assumed that Antarctica and Asia have remained fixed in their present positions during the period of our reconstruction because paleomagnetic evidence indicates they have been subject to relatively little movement when compared to the other plates involved. Our reconstruction relies primarily on the oceanic magnetic lineations, other paleomagnetic data, and the Deep Sea Drilling Project (DSDP) results. We rely also on the motion of the Pacific plate relative to the Hawaiian hot-spot as inferred from the age progression of the Hawaiian-Emperor seamount chain. Where data is lacking or is believed to have been destroyed by subduction we have located our hypothetical ancient ridge system by linearly projecting both direction and offset patterns of the preserved magnetic lineations.

Our proposed evolutionary history is presented in *Figures 3* through *7*. In these figures solid lines indicate locations of ridges, fracture zones and subduction zones which are based on data. Dashed lines indicate hypothetical features and short dashed lines in *Figures 5*, *6* and *7* indicate the traces of data supported features from previous figures. All the figures are drawn on a Mercator projection and the various features are therefore distorted with latitude.

MAJOR FEATURES OF THE WESTERN PACIFIC

The age of the ocean basins (Pitman III, Larson, and Herron, 1974) has been revealed from mapping of the magnetic lineation patterns and the results of DSDP. For the Western Pacific (Larson and Chase, 1972; Hilde, 1973; Hilde, Isezaki and Wageman, 1976) and for the Northeast Indian Ocean (McKenzie and Sclater, 1971; Sclater and Fisher, 1974) it has been shown that the oceanic crust was produced from a Mesozoic sea-floor spreading system (*Fig. 1*). The oldest part of the oceans, which has not been consumed in subduction, has been suggested to be in the Western Pacific at a present position of about 15°N, 155°E. It is believed that the Pacific plate originated at a ridge triple junction represented by this point, at an original position far to the southeast (Hilde, 1973). In contrast to the ancient crusts of the Pacific and Indian Oceans, the region separating them is occupied by the Western Pacific island

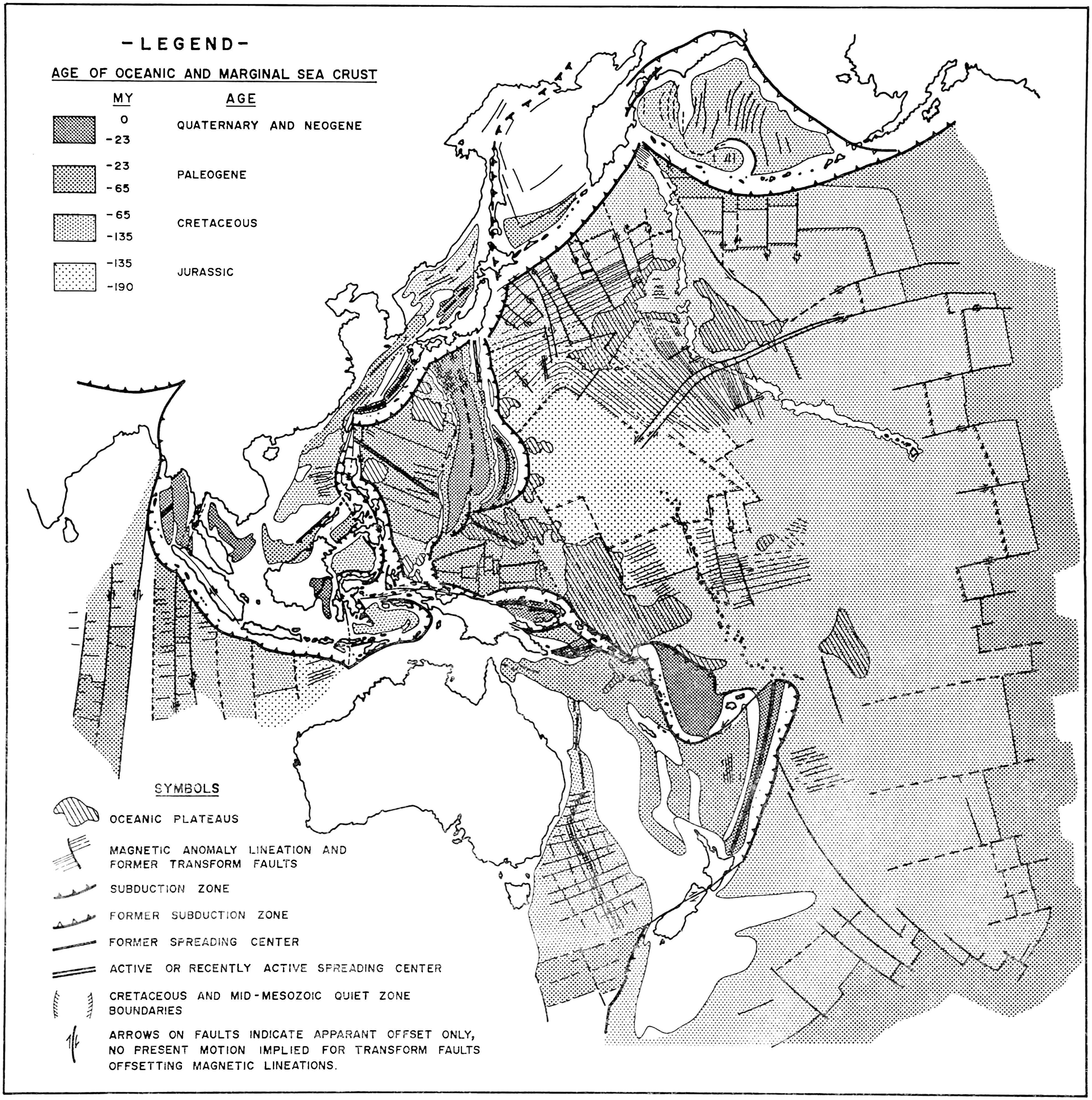

Figure 1. Age of the oceanic and marginal sea crust in the Western Pacific. Primary sources of data are the magnetic lineations and DSDP results. For sediment filled marginal seas adjacent to Asia the ages have been obtained from oil industry reports and private communications.

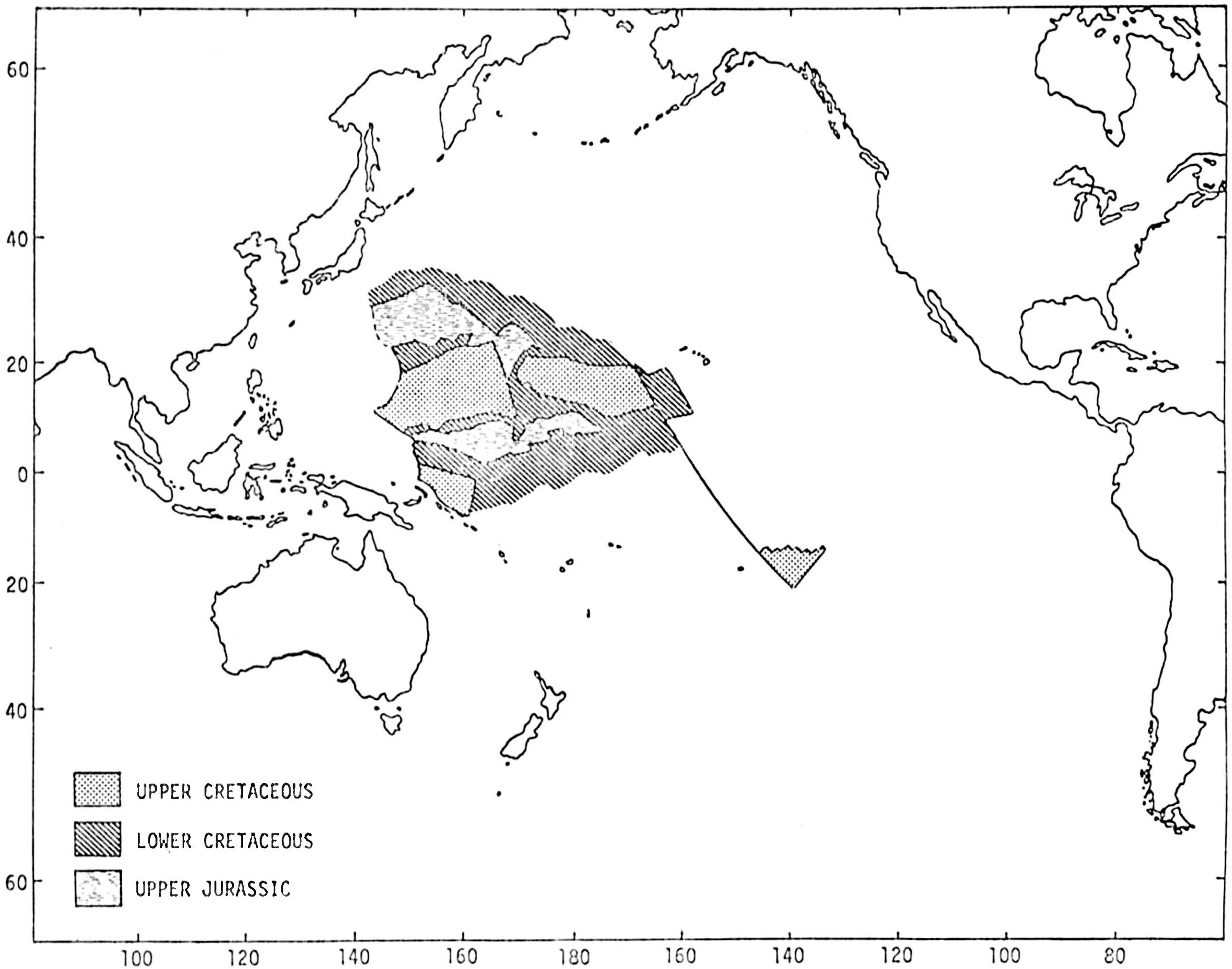

Figure 2. Possible ages of Western Ocean crust for the case of Cretaceous intraplate spreading (Kroenke, in preparation).

arcs and marginal seas which are believed to be of much younger, Tertiary ages and formed as a result of subduction of the oceanic plates (Karig, 1971; Matsuda and Uyeda, 1971; Morberly, 1972; Packham and Falvey, 1971; Dickinson, 1973). In some cases the marginal seas may be older, and possibly trapped ocean crust (Uyeda and Ben-Avraham, 1972; and Cooper, Scholl and Marlow, in press). Seismic activity along the trenches and island arcs indicate that, at this time, three major plates, the Pacific, Indian-Australian, and Asian plates are converging (Fitch, 1970). It is here that the island arcs and marginal seas have formed. Both the Pacific and Indian Ocean Mesozoic magnetic lineations project into this most complicated mosaic of younger seas, in the Southeast Asia region (*Fig. 1*).

For the oldest part of the Pacific we have shown the more-or-less orthodox interpretation in *Figure 1,* which has the oldest crust in the region of the Mariana Basin with the implication that the surrounding Mesozoic magnetic lineations were formed by a ridge system which started from a point (Hilde, Isezaki and Wageman, 1976). This view, however, does not account for the Cretaceous ages found in this region by the Deep Sea Drilling Project. An alternative possibility, favored by one of the authors, L. Kroenke, is presented in *Figure 2.* In this case topographic lineations and the Cretaceous DSDP ages are suggested to the evidence of intra-Pacific plate spreading which occurred between −100 and −85 m.y. This would have been during the Cretaceous magnetic quiet period and account for the lack of reversal anomalies in the region. In either case it is still clear that during the Mesozoic, spreading ridges existed in both the Pacific and Indian Oceans which extended roughly east-west.

In the following sections we will attempt to explain, briefly, the origin of the marginal seas, island arcs and trenches as a consequence of the major plate evolution and movement, in which the key feature is a Mesozoic to mid-Tertiary ridge system connecting the Tethys-Indian and Pacific Oceans.

EVOLUTION

During Mesozoic time the spreading ridge system in the Pacific Ocean consisted of at least three major ridges which bordered the Pacific plate on the northwest, northeast, and south sides. This is shown by the magnetic lineation pattern for the Mesozoic reversal period (*Fig. 1*). Evidence for how these ridges were related to each other in the west has been destroyed by subduction of thousands of kilometers of the western part of the Pacific plate as the plate has moved north and west relative to Asia (Larson and Chase, 1972). It has been suggested by Hilde, Isezaki and Wageman (1976) that the ridges surrounding the Pacific plate originally formed a closed triangle with the Kula-Pacific and Pacific-Phoenix ridges meeting in the west. If the system is projected back in time the Pacific plate disappears leaving a ridge triple junction between the Kula, Farallon and Phoenix plates at about −190 m.y. The ridge separating the Kula and Phoenix plates extended into the Tethys Sea (*Fig. 3*).

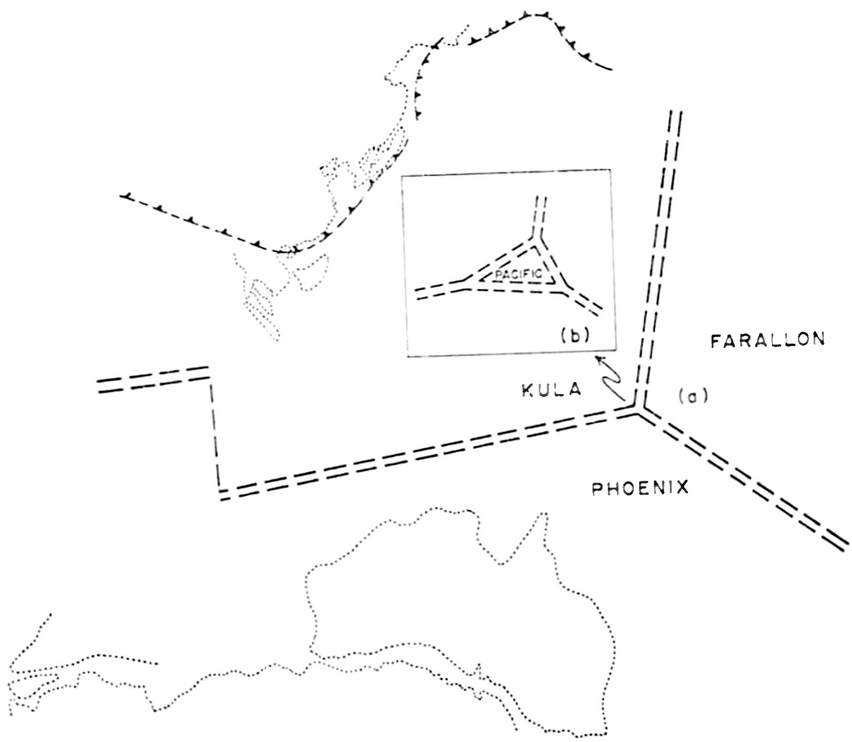

Figure 3. (a) Plate, ridge, transform fault, and subduction zone locations in the Western Pacific at −190 m.y. (b) Pacific plate origin at about −185 m.y. Features shown in this figure and *Figures 4–7*, except for Asia and Antarctica, are schematically located on a Mercator projection in their paleopositions as determined from paleomagnetic data. Because of the complex and less certain paleomagnetic determination for Asia and because Asia and Antarctica have apparently been subject to relatively little movement for most of the period of our reconstruction (−190 m.y. to present) when compared to the other plates involved, we have assumed they have remained fixed in their present positions.

Configuration of the Kula-Phoenix or Tethys ridge at −190 m.y. is completely hypothetical because all Tethys ocean crust of this age has apparently been destroyed during the subsequent breakup of Gondwanaland. The oldest evidence of the ridge is found in the Argo Abyssal Plain of the northeastern Indian Ocean where DSDP results indicates ocean crust of Jurassic age (Heirtzler, 1974; Heirtzler *et al.*, 1974) and east-northeast trending magnetic lineations have been identified as M-22 to M-25 (Larson, 1975). These and the other Mesozoic lineations east of the Ninetyeast ridge are all progressively younger to the north (Sclater and Fisher, 1974). DSDP results in the northeast Indian Ocean likewise indicate progressively younger crust to the north (Luyendyk, 1974). Since there is no evidence for southward subduction in northwest Australia (Powell, 1976), it can be concluded that this ridge was migrating north relative to Australia at that time and during its subsequent spreading history. Subduction was taking place along the southern and eastern margin of Asia during this time (Dickinson, 1973; Uyeda and Miyashiro, 1974; Terman, 1974; Hutchison, 1975) suggesting that a general northward movement of at least the oceanic plate was taking place. Paleomagnetic studies of Pacific seamounts (Vacquier and Uyeda, 1967; Francheteau *et al.*, 1970) and the shape of the Mesozoic magnetic anomalies (Larson and Chase, 1972; Hilde, 1973) indicate that the Pacific plate has moved north 40° to 45° of latitude since Mesozoic time and that there has been little east-west rotation. According to the paleomagnetic evidence, India and Australia also later moved north by 60° and 40° of latitude respectively (McElhinny, 1974).

The general northward movement of the plates in the Western Pacific-Indian Ocean rigion, and the later west-northwest movement of the Pacific plate as indicated by the Hawaiian-Emperor hot spot seamount chain (Wilson, 1965; Morgan, 1971), will be shown to be the major controlling factors on the origin of the Western Pacific island arcs and marginal seas.

We have shown, in *Figure 3*, a major north-south fracture zone in the Tethys ridge with the western portion of the ridge offset several hundred km to the north. This fracture zone is shown in the same location now occupied by the Ninetyeast ridge and we suggest it is the proto-Ninetyeast ridge. The significance of this feature will be discussed later.

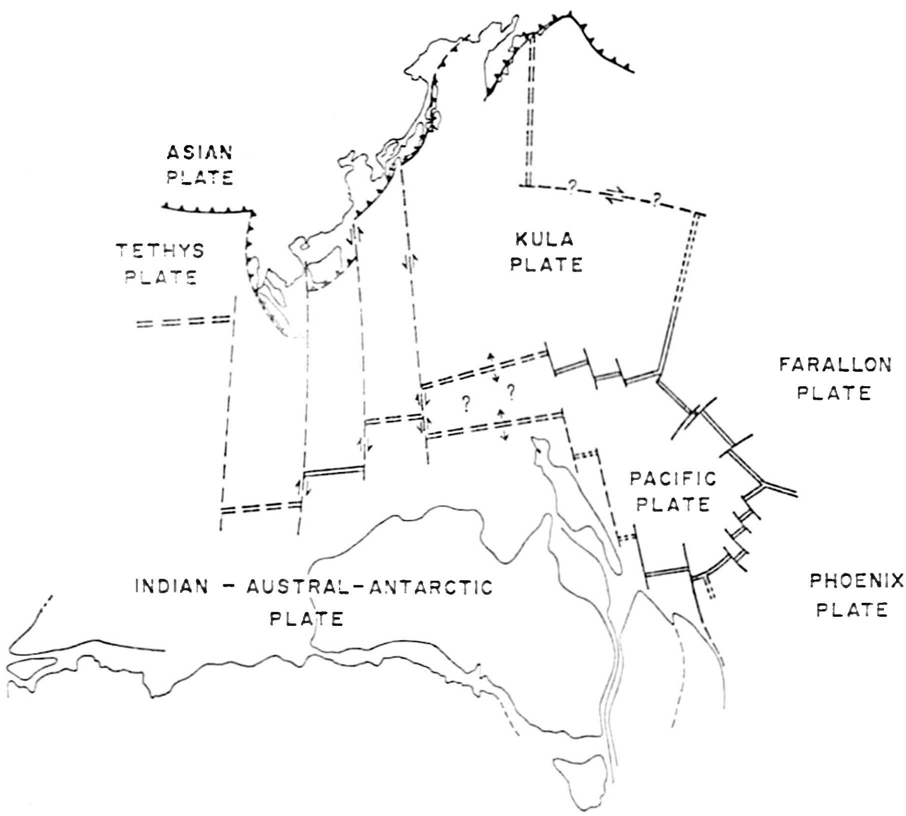

Figure 4. Plate, ridge, transform fault and subduction zone locations at —135 m.y.

Formation of the Pacific plate shortly after -190 m.y. is shown in *Figure 3(b)*. Location of the ridge triple junction in *Figure 3* and the Pacific plate at -135 m.y. (*Fig. 4*) is based on the paleo-latitudes determined from the Pacific seamounts and the Mesozoic anomalies. Configuration of the Pacific plate at -135 m.y. is derived from the Mesozoic lineations. We show the hypothetical western portion of the Pacific plate bordered by two east-west sub-parallel ridges and a north-south fracture zone. While it is possible that the ridge-fracture zone configuration in this region was somewhat different from what we have shown, it is clear from the Japanese and Phoenix lineations (*Fig. 1*) that two ridges extended to the west on the north and south margins of the Pacific plate. At the same time there is no evidence to require more than one ridge farther to the west in the Tethys Sea. The fracture zone extending south from Japan forms a plate boundary between the Kula and Tethys plates in addition to being the western boundary of the Pacific plate.

If spreading rates on the Tethys ridge and the ridges bordering the Pacific plate were similar and there was little or no subduction to the south, the Kula plate would have moved north considerably faster than the Tethys plate due to the combined velocities of spreading from the ridges north and south of the Pacific plate.

The eastern three of the four north-south fracture zones shown in *Figure 4* extending to the Asian plate are most important for the later development of the eastern Indonesian and Philippine arcs and the arc-trench system surrounding the Philippine Sea. At this time (-135 m.y.), Mesozoic ocean crust between these fracture zones was also moving north and the above mentioned trench-arc systems were not yet developing (Dickinson, 1973; Murphy, 1973). Watts, Weissel and Larson (1976) have identified east-west lineations in the west Philippine basin north and south of the Central Basin Fault as either M-0 to M-7 becoming younger to the north, or Cenozoic anomalies 18 through 22 becoming older away from the Central Basin Fault. The latter view, favored by the authors, supports the earlier view of Louden (1976). In this case, the Central Basin Fault may be an extinct spreading center as maintained by Ben-Avraham, Bowin and Segawa (1972) and Uyeda and Ben-Avraham (1972). However, the origin of the west Philippine basin is still uncertain as mentioned again in the last part of this paper.

Cooper, Marlow and Scholl (1976) have mapped north-south Mesozoic lineations M-1 to M-13 in the Bering Sea, with the sequence becoming younger to the east. They conclude that the Bering Sea is a trapped portion of the Kula plate formed by spreading from the Kula-Farallon ridge. We show this in *Figure 4* and *5* but find it necessary to have an east-west fracture zone offsetting the Kula-Farallon ridge. This fracture zone may be of similar importance to the above mentioned north-south fracture zones for later trench-arc development.

By -100 m.y. (*Fig. 5*) the Pacific plate had increased in size with continued spreading along its margins and had moved farther north so that the western end of the Kula-Pacific ridge was about to be subducted beneath the Asian margin in the

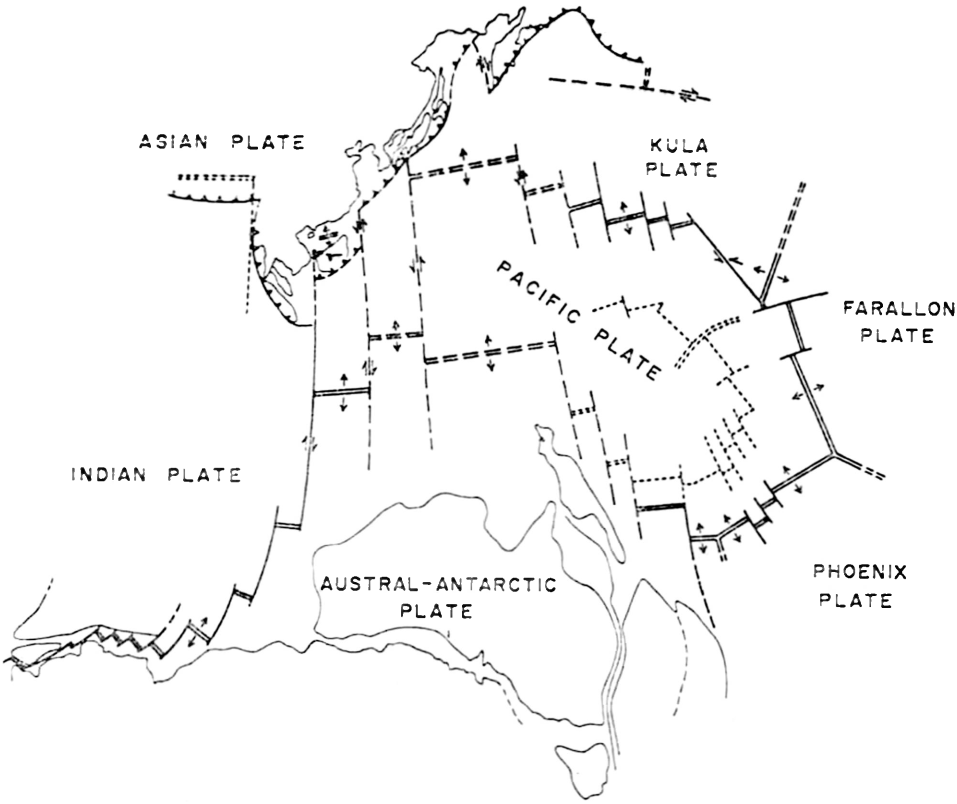

Figure 5. Plate, ridge, transform fault and subduction zone locations at —100 m.y. The —135 m.y. magnetic lineation and fracture zone pattern of the Pacific plate is shown by short dashed lines.

vicinity of Japan (Uyeda and Miyashiro, 1974; Hilde, Isezaki and Wageman, 1976). Uyeda and Miyashiro (1974) suggested that the Sea of Japan started to open during late Cretaceous or early Tertiary time as a result of the Kula-Pacific ridge subduction. Murauchi (1971) and Hilde and Wageman (1973) also concluded that the Japan Sea originated at this time, based on the general tectonic considerations, its high heat flow (Yasui *et al.*, 1968), its oceanic crustal structure, and seismic reflection studies. Isezaki (1975) reached the similar conclusion from the analysis of magnetic lineations of the Japan basin (Isezaki and Uyeda, 1973). The important point is that the subduction of the Kula-Pacific ridge was roughly coincident with Japan Sea origin during the late Cretaceous and may have been the cause of its formation. Other marginal seas of the Western Pacific may have also been formed in response to ridge subduction but, at the same time, many of the marginal seas appear to be of a different origin. One case where it seems clear that ridge collision with a continental plate has initiated marginal sea formation is the Gulf of California. Here, it appears that the ridge retained its identity and continuation with the oceanic ridge after subduction (Atwater, 1970). What happens when an active ridge collides with a trench is a matter of debate. The ridge will eventually cease its activity but it is considered here that extinction will take place only some time after the collision (Uyeda and Miyashiro, 1974).

Subduction of the Kula plate along its north and west margin continued and by −100 m.y. the crust of the Bering Sea had been formed. Scholl, Buffington and Marlow (1975) have shown that the northern margins of the Bering Sea were sites of subduction throughout middle and late Mesozoic time. They concluded that subduction along the Aleutian arc started during latest Cretaceous time. This new subduction zone probably took up the convergence of the Kula plate from this time and trapped the Mesozoic crust of the Bering Sea. It is suggested here that the Aleutian trench may have initially formed along the east-west fracture zone and its westward trace that we show in *Figures 4* and *5*.

The Pacific-Phoenix ridge continued to move south during this time while the ridge system north of Australia moved north. One or more of the fracture zones between these two segments of the ridge on the southern margin of the Pacific plate apparently formed a plate boundary between the Phoenix and the Austral-Antarctic plates.

We suggest that the western portion of the Tethys ridge was subducted beneath south-central Asia at about −100 m.y. (*Fig. 5*). Assuming that subduction continued after this time, a new ridge is required to form to the south. Sclater and Fisher (1974) have shown that a new ridge system was indeed initiated at this time and rifted India away from Antarctica (*Fig. 5*). Larson and Ladd (1973) speculated that, from the M-sequence magnetic lineations in the south Atlantic, the breakup of Gondwanaland started at about −125 m.y. If this is correct, we should probably also take −125 m.y. for the subduction of Tethys ridge.

The South China Sea rifting and marginal sea spreading was probably initiated at about this time (Ben-Avraham and Uyeda, 1973). Hayes and Ludwig (1967) have mapped east-west magnetic lineations in the South China Sea and Hutchison (1975) mapped ophiolites in Borneo of this age which indicate convergence from the north. Heat flow is high in the South China basin (M. Langseth, private communication). Apparently the evolution of the South China Sea had several stages and their details are still to be clarified. The distribution of ophiolites throughout Indonesia indicate that plate convergence has taken place in Southeast Asia since at least early Mesozoic to mid-Mesozoic time (Hutchison, 1975). McElhinny, Haile and Crawford (1974) have concluded that Malaysia was not part of Gondwanaland on the basis of paleomagnetic studies. These various lines of evidence all suggest that the evolution of Southeast Asia has taken place in roughly its present location in response to convergence from the south (Katili, 1973; Hamilton, 1973, in press).

In the Indian Ocean by the time of −65 m.y., the Indian sub-continent was approaching the subduction zone along southern Asia (*Fig. 6*) with that part of the northern Indian plate which had been previously formed by the Tethys ridge (*Fig. 4*) being mostly consumed by this time. Ninetyeast ridge was a transform fault between segments of the spreading ridge separating the Indian and Austral-Antarctic plates. Its northward trace is along the same trace as the former western-most transform fault

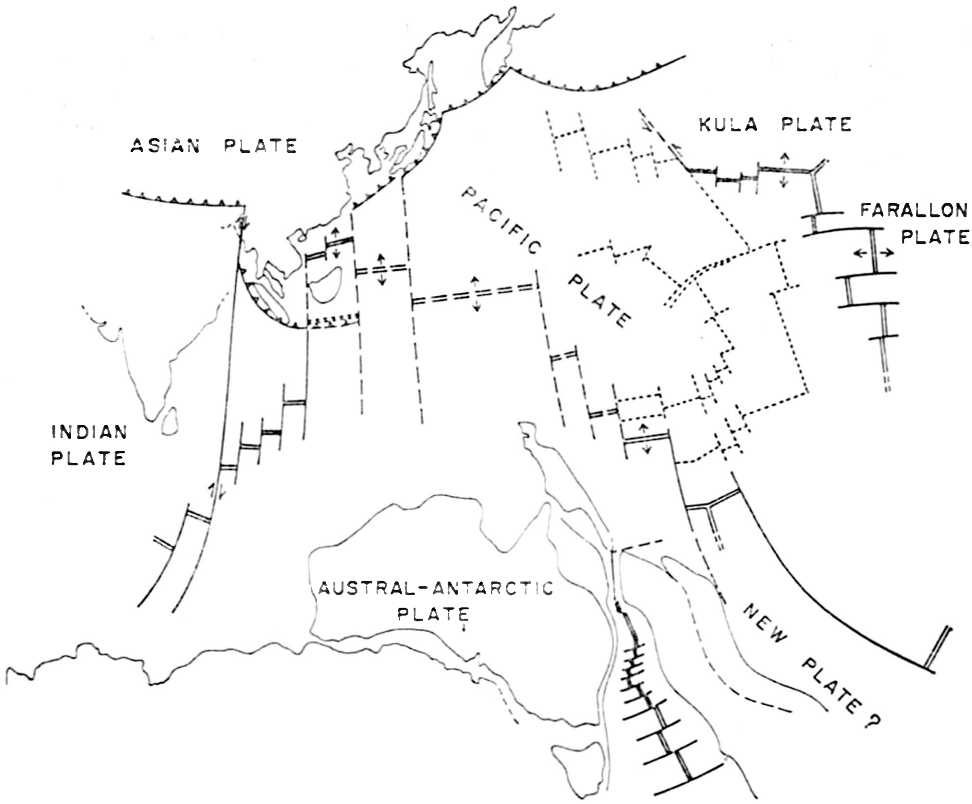

Figure 6. Plate, ridge, transform fault and subduction zone locations at −65 m.y. The −135 m.y. and −100 m.y. magnetic lineation and fracture zone pattern of the Pacific plate is shown by short dashed lines.

we show on the Tethys ridge at − 135 m.y. and earlier (*Figs. 3* and *4*). Our placement of the ridge system in the Indian Ocean and the collision history of India with Asia is taken from Sclater and Fisher (1974) with essentially no modification.

Northward movement of the Indian, Pacific and Kula plates continued between −100 m.y. and −65 m.y. (*Fig. 6*) as the ridge system on the southern margin of the Indian and Pacific plates also moved north with new crust being accreted to the Austral-Antarctic plate. Portions of this ridge system started to subduct beneath south-eastern and eastern Asia at about this time. That portion of the ridge north of Australia was subducted at about −53 m.y. Then, a new ridge was required to form to the south, in a similar manner that a new ridge formed earlier to rift India from Antarctica when the Tethys ridge was subducted beneath south-central Asia at −100 m.y. In this case the Austral-Antarctic ridge rifted Australia away from Antarctica (Weissel and Hayes, 1972) and at its western end became connected with the Indian Ocean ridge at the Ninetyeast fracture zone offset (Sclater and Fisher, 1974). The Indian-Australian plate was created by these events.

During the time of −100 m.y. to −65 m.y. the Tasman Sea formed by rifting of

Lord Howe and Norfolk rises away from Australia (Griffiths, 1971; Packham, 1973). The magnetic lineation and fracture zone pattern in the Tasman Sea indicates this was accomplished between −80 m.y. and −60 m.y. (Hayes and Ringis, 1973).

Evidence from the Ontong Java Plateau suggests that this feature is a thick section of sediment and oceanic crust formed due to slow spreading and massive volcanism during Cretaceous time (Kroenke, 1974). This segment of the ridge is shown on *Figures 5* and *6* to the west of the ridge triple junction at the northwest corner of the Phoenix plate. Because of different spreading rates either side of the fracture zone just west of this triple junction, the length of the fracture zone increased as the Pacific-Phoenix ridge migrated rapidly to the southeast. This fracture zone and the Marshall-Gilbert-Louisville fracture zone apparently both separated ridge segments with greatly different spreading rates. These fracture zones may have been plate boundaries of the questioned "New plate" shown in *Figure 6* occupying the region between them. The ridge triple junction between these fracture zones is shown on the basis of the north-south and east-west lineations in the south Fiji Basin (Weissel and Watts, 1975; Kroenke, in preparation).

By −65 m.y. much of the ridge system bordering the northern margin of the Pacific plate had been subducted along the east Asia margin and the western Aleutians with all of the Kula plate west of the Emperor trough having been consumed (Hilde, Isezaki and Wageman, 1976). The only remaining portion of the Kula plate at −65 m.y. was east of the Emperor trough and it continued to move north to be subducted beneath the eastern Aleutian arc and Alaska. The Emperor trough formed a ridge to trench transform fault boundary between the Pacific and Kula plates.

Roughly coincident with the final subduction of the ridge system along the northern margin of the Pacific plate (Grow and Atwater, 1970), motion of the plate changed from north-northwest to west-northwest. This is reflected by the bend in the Emperor-Hawaiian hot spot chain dated at approximately −45 m.y. (Clague and Jarrard, 1973).

When spreading ridges were subducted along the southern margin of Asia new ridges formed to the south. This did not happen with the subduction of the ridge system on the northern margin of the Pacific plate because a ridge system already existed at its southern and eastern margins. Forsyth and Uyeda (1975) have examined the various possible driving mechanisms for plate motion and concluded that subduction is the controlling mechanism. We have noted three cases where major sections of former spreading ridges have been subducted bringing existing plates into new contact with these subduction zones. In each case the plates being newly subducted have undergone major changes in motion, which supports the conclusion of Forsyth and Uyeda (1975) that subduction is the driving mechanism.

With the formation of the Indian-Australian plate and its northward movement following −52 m.y. (Sclater and Fisher, 1974), part of the ridge system bordering the Pacific plate on the south (northeast of New Guinea in *Figure 6*), which had been

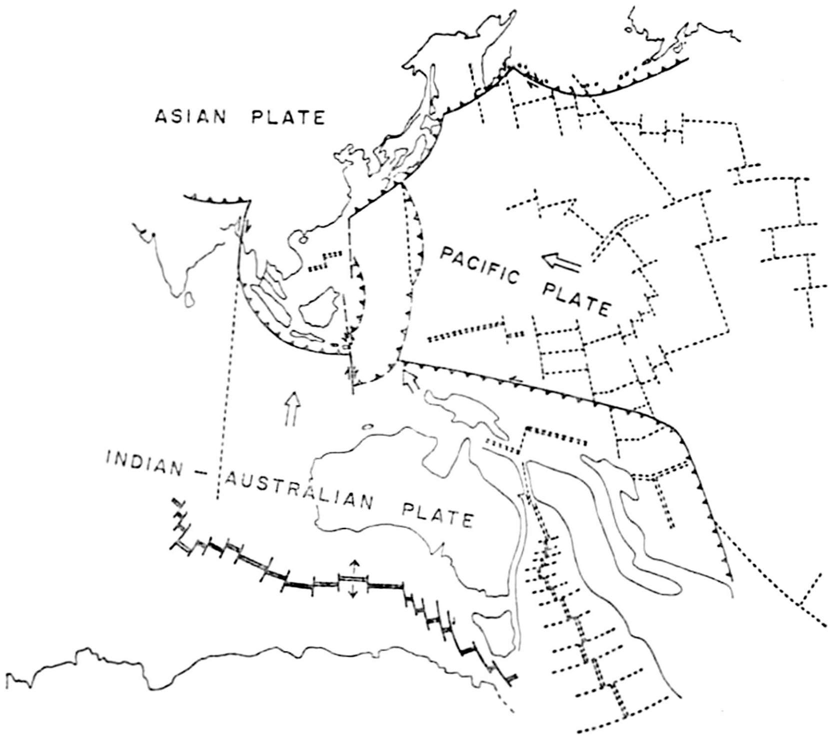

Figure 7. Plate, ridge, transform fault, and subduction zone locations at −25 m.y. The −135 m.y., −100 m.y., and −65 m.y. magnetic lineation and fracture zone pattern of the Pacific plate and other inactive features are shown by short dashed lines.

migrating southward, was soon subducted along the northeast margin of the Indian-Australian plate (*Fig. 7*). This cut off the western-most part of the ridge system on the southern margin of the Pacific plate from that part east of the Marshall-Gilbert-Louisville fracture zone and it probably ceased spreading. The exact age of this event is unclear, however, it was probably shortly after −52 m.y., during early or mid-Eocene time. While the ridge system on the south and southeast Pacific plate margin continued spreading with southward migration, the subduction zone on the north margin of the Indian-Australian plate fully developed and extended west to Southeast Asia (*Fig. 7*). Polarity of subduction along this zone has apparently alternated (Packham, 1973; Halunen and von Herzen, 1973) but has predominantly involved subduction of the Pacific plate. Development of the Coral Sea and rotation of New Guinea to the northwest started in mid-Eocene time (Andrews, 1973) in response to the subduction of the Pacific plate.

The Pacific plate was bordered on its northwest and north margins and western portion of its south margin by subduction zones at about −45 m.y. and changed its motion to the west. Prior to −45 m.y. the evolution of the Western Pacific was dominated by northward movement of the various plates bordering Asia with long north-south fracture zones having been developed. These were the three extending southward from southeast Asia and along the east margin of the Austral-Antarctic plate (*Fig. 6*). With the change in direction of Pacific plate motion to the west, these fracture zones provided zones of crustal weakness along which new subduction started in a manner similar to that proposed by Uyeda and Ben-Avraham (1972) for the Kyushu-Palau ridge in the Philippine Sea. We suggest that the Philippine, Bonin, Mariana, Yap, Palau, and Tonga trench-arc systems were all initiated along former north-south fracture zones shortly after −45 m.y. (*Fig. 7*). The newly developed subduction along these zones apparently trapped previously produced ocean crust in the West Philippine Sea similarily to the entrapment of ocean crust in the Bering Sea earlier, and also possibly in the south Fiji basin. The Mesozoic magnetic lineations in the West Philippine Sea mapped by Watts, Weissel and Larson (1976) become younger to the north which would suggest that the ridge that produced them has been subducted to the north. This was probably beneath southwest Japan since the Kyushu-Palau fracture zone would have originally been further east and moved west as subduction took place along the Ryukyus and the Philippines.

Yamato basin in the Japan Sea, Parece Vela basin and the Mariana trough in the Philippine Sea, Okinawa trough in East China Sea, and Lau trough west of the Tonga trench are all believed to be Miocene or younger in age, and the Shikoku basin possibly as old as late Oligecene (Karig, 1971; Hilde and Wageman, 1973; Tomoda *et al.*, 1975; Kobayashi and Isezaki, 1976; Watts, Weissel and Larson, 1976; Lawver *et al.*, in press; and many others). Van Andel (1974) has presented evidence based on analysis of the depositional history of the central equatorial Pacific that indicates the rate of rotation of the Pacific plate increased more than three times at about −25 m.y. Subduction rates had therefore increased along the western Pacific with back-arc spreading (Karig, 1974) becoming predominant for further development of the marginal seas (*Figs. 1* and *7*). Earlier development of the marginal seas appears to have been related to rifting due to ridge subduction and entrapment of older ocean crust by formation of subduction zones along former transform faults.

The Sulu, Celebes and Banda Seas are more difficult to understand. The Banda Sea may be ocean crust (*Fig. 7*) which was trapped during development of eastern Indonesia by plate convergence since mid-Pliocene time in the manner suggested by Audley-Charles, Carter and Milsom (1972) and Ben-Avraham (pre-print). The Sulu and Celebes Seas appear to be back-arc developed basins behind the Philippine arc (*Fig. 7*), although they could also be either trapped ocean crust or basins formed by rifting along transform plate boundaries. The Andaman Sea appears to be an example of the last case (Lawver, Curray and Moore, 1976).

Bracey (1975) has mapped and identified east-west magnetic lineations in the Caroline basin as −25 m.y. to −42 m.y. in age and Hamilton (1974) has shown that the entire region of the Caroline basin and Caroline ridge is Oligocene to Miocene in age based on DSDP results and separated from older Pacific crust to the east by a northwest trending transform fault. This fault is the one we show extending north-northwest from northeast of New Guinea in *Figure 7*. In our reconstruction we have reinterpreted Bracey's data as showing symmetrical spreading which ceased at −33 m.y. from a ridge which formed after the ridge on the western-most south margin of the Pacific plate ceased spreading as referred to earlier. Note that the two fossil ridge segments due north of New Guinea in *Figure 7* are not the same as the older ridge shown in *Figure 6*, but newly formed ones. Alternatively, it is possible that the Caroline basin was generated by the segments of the older ridge on the southwest margin of the Pacific plate. In this case our hypothetical ridge at the western-most south margin of the Pacific plate would have to be located differently than we have shown it.

From −25 m.y. (*Fig. 7*) to Present (*Fig. 1*), with continued westward movement of the Pacific plate and rapid subduction of the southern portion of the West Philippine Sea basin along the Philippine trench, the southern part of the Mariana subduction zone moved to the west. This has evolved into the Yap-Palau arc. Rotation of volcanic rocks on Guam 55° clockwise since Miocene time (Larson *et al.*, 1975) further indicates how this subduction evolved into its present arcuate structure as back-arc extension of the northern Mariana arc continued.

The west Philippine and Caroline basins are most difficult to reconcile with any reconstruction of the Western Pacific. Magnetic data from the west Philippine basin indicate two possibilities. One is the case where the basin consists of Mesozoic crust north of the Central Basin Fault and Cenozoic crust to the south, and the other is the case where both sides of the fault have Cenozoic crust (Watts, Weissel and Larson, 1976). While favoring the latter possibility, these authors noted that the skewness of the magnetic profiles north and south of the fault is much different, and the depth of the basin is too great for normal Cenozoic sea-floor. More importantly the strike of the Central Basin Fault is different from that of magnetic lineations. Heat flow values are high along the Central Basin Fault (Hilde *et al.*, in preparation) and generally higher south of the fault (Sclater *et al.*, 1976). DSDP basement ages are Eocene both north and south of the fault (Ingle *et al.*, 1975). Basalt dredged from the Central Basin Fault has been dated at younger than −10 m.y. and the fault resembles a spreading ridge in topography and sediment distribution (Hilde *et al.*, in preparation). We speculate that it and the rift in the Caroline Ridge may be a young spreading center or a young fault formed roughly, but not exactly, along a former spreading center or a fault; although ocean bottom seismograph measurements for 63 hours in 1973 showed no seismic activity in the Central Basin Fault area (Shimamura, Tomoda and Asada, 1975).

SUMMARY

Our reconstruction of the Western Pacific since mid-Mesozoic time is, as we stated in the introduction, a preliminary study which we are continuing. We expect our proposed evolution to be modified as paleo-plate locations are more accurately established and regions of apparently conflicting geologic histories are further examined. However, we have arrived at several conclusions which we believe are basic to development of the Western Pacific and may be of significance for the theory of plate tectonics.

1) The Pacific plate evolved from the center of a former ridge triple junction between the Kula, Farallon, and Phoenix plates.
2) The Mesozoic spreading ridge systems of the Pacific Ocean and the Tethys-Indian Oceans were connected by roughly east-west ridges offset by north-south transform faults of great length.
3) Subduction of spreading ridges resulted in new spreading ridge formation in the plate being newly subducted, at great distances from the subduction zone. The rifting of India and Australia from Antarctica was caused by this process.
4) Marginal seas have formed by rifting of continental margins after ridge subduction, entrapment of ocean crust, back-arc extension, and in shear zones along transform plate boundaries. Active sea floor spreading is associated with each process except entrapment of ocean crust.
5) Changes in direction and velocity of plate motion result from spreading ridge subduction and reconfiguration of subducting plate boundaries.
6) New subduction zones are initiated along former transform faults with changes in direction of plate motion. Entrapment of ocean crust results.
7) Transform faults may change in length due to asymmetrical spreading or different rates of symmetrical spreading. In the latter case, extensions of the faults beyond the ridge become plate boundaries.

We look forward to the testing of these ideas during the further investigation of the Western Pacific.

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COMMENT TO "EVOLUTION OF THE WESTERN PACIFIC AND ITS MARGIN"

Shun-ichi SANO
Geological Survey of Japan
Shinjuku-ku, Tokyo, JAPAN

The paper by Hilde, Uyeda and Kroenke, describing the evolutional history of the western Pacific and northeastern Indian Ocean is a great contribution to plate tectonic interpretation of the continental margins of east and southeast Asia. This work is really the foundation for understanding of tectonic development of the region as all syntheses on the development of continental margins should conform with history of the surrounding oceanic plates and this paper should thus provide the guidelines for further investigations. The writer wishes to congratulate for this outstanding achievement made mainly by reconstructing oceanic plates since middle Mesozoic time.

On the other hand, plate tectonic reconstruction of the marginal fold belts of southeastern Asia has been studied by various investigators based on geological evidence such as magmatic arcs, metamorphic belts, ophiolites or mélanges, particularly exposed on land areas. Amongst others, evolution of Sundaland which is a cratonic area extending from the Malay Peninsula through Sumatra, Sunda Shelf and western Java to western Borneo. For example, Hutchison (1973) described his conclusion mainly based on palaeomagmatic arcs as follows: "In lower Palaeozoic time, the Malay Peninsula lay along the subducting contact between an easterly oceanic and a westerly Precambrian continental plate, with the trench occupying the eastern foothills of the Main Range. . . . The Malayan plate became detached from its Precambrian foreland in the mid Palaeozoic and drifted eastwards ahead of the ocean spreading of a new marginal basin. From late Carboniferous onwards, Sundaland played the role of a small continental plate, with active eastwards oceanic subduction underneath it from a trench located along the axis of Sumatra, and westwards subduction from a trench located in the South China Sea. . . . The (opposite-facing) trenches moved progressively away from the Malay Peninsula as Sundaland grew by sedimentary accretion on its eastern and western sides. By late Cretaceous, the western Sumatran and the eastern South China Sea arc-trench systems formed one convoluted arc wrapped around the southern end of Sundaland. The arc-trench system has straightened in the late Cenozoic, and now occupies the southern coast of Java and western coast of Sumatra." Similar ideas were developed by Hamilton (1973), Katili (1973, 1974, 1975) and others.

In the above synthesis, the sea-floor spreading in east-west direction was presumed as continued since lower Palaeozoic age. In the oceanic areas surrounding southeast Asia, the sea-floor created before middle Mesozoic was already consumed or destroyed. In addition, the reconstruction based on the geological evidence is usually fixed with the present sites of the corresponding tectonic elements, nevertheless real direction of spreading might be lost by migration or rotation after their emplacement. Therefore, the writer wishes to limit his comment to late Cretaceous onwards.

In the article by Hilde, Uyeda and Kroenke, a little mentioned about Sundaland, mainly referring the objection against an hypothesis that southeast Asia was part of Gondowana. However, Borneo is illustrated in *Figures 4* to *6* as if it migrated southwards from its postulated position adjacent to the China Mainland. This idea originally proposed by Ben Avraham and Uyeda (1973) is inconsistent with the evolutional history of Sundaland deduced by geological consideration and according to Hutchison (1975), this is clearly impossible because of the different nature and ages of these ophiolite lines (Song Ma and Black River lines in northern Vietnam, and Serabang and Lupur lines in Borneo).

As described in the article, the important point perhaps is that marginal seas of the Western Pacific may have been formed in response to ridge subduction as Uyeda and Miyashiro (1974) suggested that the Sea of Japan started to open during late Cretaceous or early Tertiary time as a results of the Kula-Pacific ridge subduction. The Cretaceous to early Tertiary ridge system separating the Indian and Pacific plates from the Austral-Antarctica plate was migrating north and the portion of the ridge north of Australia was subducted in early Eocene (about −53 m.y.). Although no further description appears in the text with respect to the southeast Asian continental margins, *Figures 4* to *6* indicate that the authors have in mind the correlation between subduction of the active ridge and spreading of the South China Sea. However, the geological features of Sundaland region likely request an alternative interpretation. In addition, eastern part of Java and the Lesser Sunda Islands were probably formed by sedimental accretion and magmatism associated with subduction at about this time. It might be concluded that subduction of active ridge does not necessarily cause spreading of marginal seas or that the ridge ceased its activity before subduction or collision and the subduction was then initiated so as to form an island arc of Java and the Lesser Sunda Islands.

The writer strongly feels that the debate should be invited and encouraged between those who are working on the different approaches from oceanic plates mainly on geophysical basis, from continental margins mainly on geological basis, and also from main continents. More important at this stage, however, may be to collect more evidential information, particularly of the marginal seas.

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PETROLEUM GEOLOGY OF OFFSHORE AREAS AROUND THE JAPANESE ISLANDS

By

Yasufumi ISHIWADA[1] and Katsuro OGAWA[2]

ABSTRACT

The geology of offshore areas around the Japanese Islands was reviewed in relation to hydrocarbon potential. In conclusion, 1) development of sedimentary basins of the Japan Sea margin presents a striking contrast to that of the Pacific margin; 2) besides the Japan Sea margin of northeastern Japan, in which oil and natural gas are currently produced, hydrocarbon production can be expected in the other offshore areas; 3) favorable areas for hydrocarbon exploration will be greatly enlarged if exploitation become possible down to the depths of about 1,000 m or more; and 4) the most important target will be the Neogene System, while the Paleogene System may be a secondary target. Geochemical evaluation of the source rocks suggests that gas discoveries may be more likely than oil.

BRIEF HISTORY OF OFFSHORE HYDROCARBON EXPLORATION IN JAPAN

In 1880, the first drilling for seaward extention of an oil producing structure was conducted from a man-made island constructed off the coast of Amaze, Niigata Prefecture. After the last War, traditional cable drilling was tried in 1952 off the coast of Michikawa, Akita Prefecture, and the late Prof. H. Niino stressed the importance of offshore development. The application of modern techniques, however, started later in 1956 under the so-called First Five-Year Plan, namely, "Integrated Development Scheme for Petroleum Resources", established in 1954 by the Ministry of International Trade and Industry (MITI). One of the fundamental policies of the plan was to promote exploration in the continental shelf areas. The Japan Petroleum Exploration Co., Ltd. (JAPEX), established under aegis of the Government of Japan, introduced marine seismic exploration techniques and imported a sea-bottom gravimeter from the United States in 1956. In 1958, the jack-up rig *Hakuryu 1* was constructed, and 51 wells totally 82,638 m deep, including production wells, were drilled into 14 structures off Akita and Niigata Prefectures, whereas 17 wells drilled into 4 structures were successful.

Since then, the Japanese petroleum industry placed emphasis on overseas development. A new cycle of offshore exploration activities around Japan started with establishment of the Japan Petroleum Development Corporation (JPDC), financed fully by the Government. In order to promote offshore exploration in the Japan Sea margin of northeastern Japan, a 120 KJ sparker was imported in 1967; an air gun-digital seismic

1) Technology Research Center (TRC), Japan Petroleum Development Corporation, Minato-ku, Tokyo, Japan.

2) Geophysics Laboratory, TRC, JPDC. Now at Geological Survey of Japan.

profiling system was introduced in 1968; and the semi-submersible rig *Hakuryu II* was constructed in 1971. Meanwhile, the Geological Survey of Japan, Agency of Industrial Science and Technology, had developed the aeromagnetic survey technique and initiated a systematic survey project over offshore areas in 1966. The Idemitsu Kosan Co., Ltd. began exploration over the Japan Sea jointly with AMOCO in 1966 and sponsored a reconnaissance aeromagnetic survey over the offshore area from the Noto Peninsula to southernmost Hokkaido.

In 1969, Nishi-Nihon Sekiyu Kaihatsu Co., Ltd. was founded by joint investment of Royal Dutch/Shell and the Mitsubishi Group, and undertook exploration over its concession off San'in and Tsushima. This movement of the private sector provided an impetus to the Government, and MITI initiated the Fourth Five-Year Plan beginning from 1969, which put emphasis on strengthening marine geophysical surveys in the basic exploration projects and implementation of systematic surveys for geological structures of the continental shelves around Japan. The reconnaissance seismic surveys were completed by the end of fiscal 1974. This seismic survey project was then expanded into the slope areas, being continued towards the end of fiscal 1976.

Since *Hakuryu II* was launched, the wells drilled by modern offshore rigs include 6 wells off Akita (total 18,292 m), 1 well off Yamagata (2,002 m), 16 wells off Niigata (total 44,119 m; among these were 9 wells off Aga with a total of 26,785 m), 8 wells off San'in and Goto (total 26,791 m), 9 wells off Joban (total 32,169 m), 2 wells off Kyushu (total 8,020 m) and 1 well off Okinawa (3,040 m). Grand total is 43 wells drilled in water depths of 34 m to 215 m with a total drilling depth of 132,276 m. Among these wildcat wells, 9 were successful. The rigs used were *Hakuryu II* for 21 wells, *Investigator* for 2 wells, *Ocean Prospector* for 13 wells, *Hakuryu III* for 6 wells and *Western Offshore* for 1 well.

A recent trend of offshore hydrocarbon exploration is increasing activity in deeper water depths. Some exploration tests have already been drilled in several hundred metres of water. Even if future exploration is limited to water depths around 1,000 m, investigation of continental margins should be extended to deeper slopes and trenches so as to study the possibility of hydrocarbon genesis beneath the deeper water portion of the continental margin and migration updip into the continental slope area.

In this paper, the writers will discuss the geology of the continental margins of the Japanese Islands in relation to petroleum potential based on the reconnaissance seismic surveys (Atake, 1973) and the reconnaissance aeromagnetic surveys, as well as on various scientific publications.

FEATURES OF SEA FLOOR TOPOGRAPHY

The Japanese Islands constitute typical arc-trench systems in the western Pacific. On the Pacific side, the Chishima (Kuril)-Kamchatka Trench and the Japan Trench are adjacent to the Hokkaido-Northeast Japan arcs, and the Nankai Trough and the

Ryukyu Trench are adjacent to Southwest Japan and the Nansei (Ryukyu) Islands respectively. On the other hand, the Okhotsk Sea, the Japan Sea, and the East China Sea (Okinawa Trough) are marginal seas located behind the island arcs.

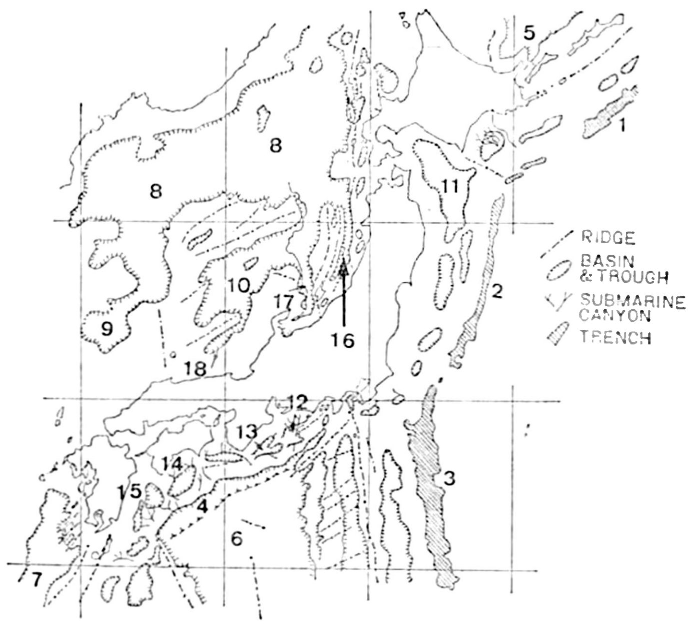


Figure 1 Sea floor physiography around Japanese islands. (after T. SATO, 1970)

1. Chishima (Kuril)- Kamchatka Trench
2. Japan Trench
3. Izu-Ogasawara (Bonin) Trench
4. Nankai Trough
5. Chishima (Kuril) Basin
6. Shikoku Basin
7. Okinawa Trough
8. Jápan Basin
9. Tsushima Basin
10. Yamato Basin
11. Hidaka Trough
12. Enshu-nada Deep-sea Terrace
13. Kumano-nada Deep-sea Terrace
14. Tosa Deep-sea Terrace
15. Hyuga Deep-sea Terrace
16. Mogami Trough
17. Toyama Trough
18. Oki Trough

The shelves around Japan occupy an area of about 280,000 km^2. The total area comprising continental crust covered by seas is about 760,000 km^2; the area includes slopes and continental borderland, but excludes the Izu-Mariana Arc and the East China Sea. The land area occupies about 370,000 km^2. The continental shelves are generally narrow, but the area off San'in and Tsushima, extending to the Korean Peninsula, is the widest, and those off northeastern and western Hokkaido also are relatively wide. *Figure 1* shows the features of the sea floor topography around the Japanese Islands.

A remarkable feature of the Japan Sea margin is well developed chains of submarine banks, while they exist sporadically in the Pacific margin. The area northeast of the Toyama Trough, particularly, shows typical continental borderland structure named by K. O. Emery (1960) for the margin off southern California.

The continental shelf is topographically a flat gently sloping surface. Flat surfaces of more limited extent, called deep sea terraces, are frequently observed on the continental slope. On the Japan Sea margin, the deep sea terrace is the surface of the sediments filling troughs between ridges comprising a series of submarine banks. On the Pacific margin, the deep sea terrace occurs from Hokkaido to Kyushu, showing terrace-like topography with several steps. The Tosa Terrace and the Hyuga Terrace named by R. Tayama (1950) are representative, and many deep sea terraces of various sizes are known in the Kii Channel, the Kumanonada (the Sea of Kumano), and the area off Sanriku and Hokkaido. The Hidaka Trough, a deep sea terrace between Honshu and Hokkaido named by T. Sato (1973), is about 16,000 km^2 in area.

The genesis of deep sea terrace was discussed by various investigators. According to recent results of seismic profiling, most of them are the surface of late sediments deposited in depressions of the basement (Uyeda, 1974). They are thus interesting targets for hydrocarbon exploration if age, volume, thickness, structure and lithology of the sediments are appropriate for hydrocarbon generation and accumulation, and if the water depth is suitable for exploration and exploitation in the future. Based on multi-channel seismic profiling records across trenches, the idea that accretion of mélange and ophiolite mainly constitutes the inner slope of the trench was proposed by a number of investigators (for example, Seely *et al.*, 1974). This model might be applicable to the genesis of sedimentary basins under deep sea terraces, but further investigation by multi-channel seismic profiling across the Japan Trench and the Nankai Trough is necessary to confirm this idea.

DISTRIBUTION OF SEDIMENTARY BASINS

Strata producing commercial quantities of oil and natural gas in Japan are contained in the Neogene System along the Japan Sea coast of northern Honshu and western Hokkaido, while the Sagara oil field of Shizuoka Prefecture along the Pacific coast produced minor oil from a Neogene formation. The Palaeogene System has yielded only hydrocarbon shows, except for very minor oil production from the Poronai Formation in the Yufutsu District of Hokkaido and for dry gas production from coal mines. The Cretaceous System has been explored as a new target since the First Five-Year Plan started, but not successfully yet. Besides source rock characteristics described in the latter part of this paper, difficulties for Cretaceous exploration may arise from the fact that generally the target horizons are deep and the sediments in Hokkaido and western Kyushu, which are overlain by thick Palaeogene and Neogene, were strongly compacted. In conclusion, the first target for hydrocarbon exploration should be Neogene sediments in offshore areas, as well as on land, and the second may be the Palaeogene. Cretaceous sediments may not be the object of exploration with the possible exception of the uppermost less compacted layers.

An isopach map (*Fig. 2*) showing the sedimentary basins filled by Quaternary and Neogene strata with a thickness of more than 1 km was prepared based mainly on the

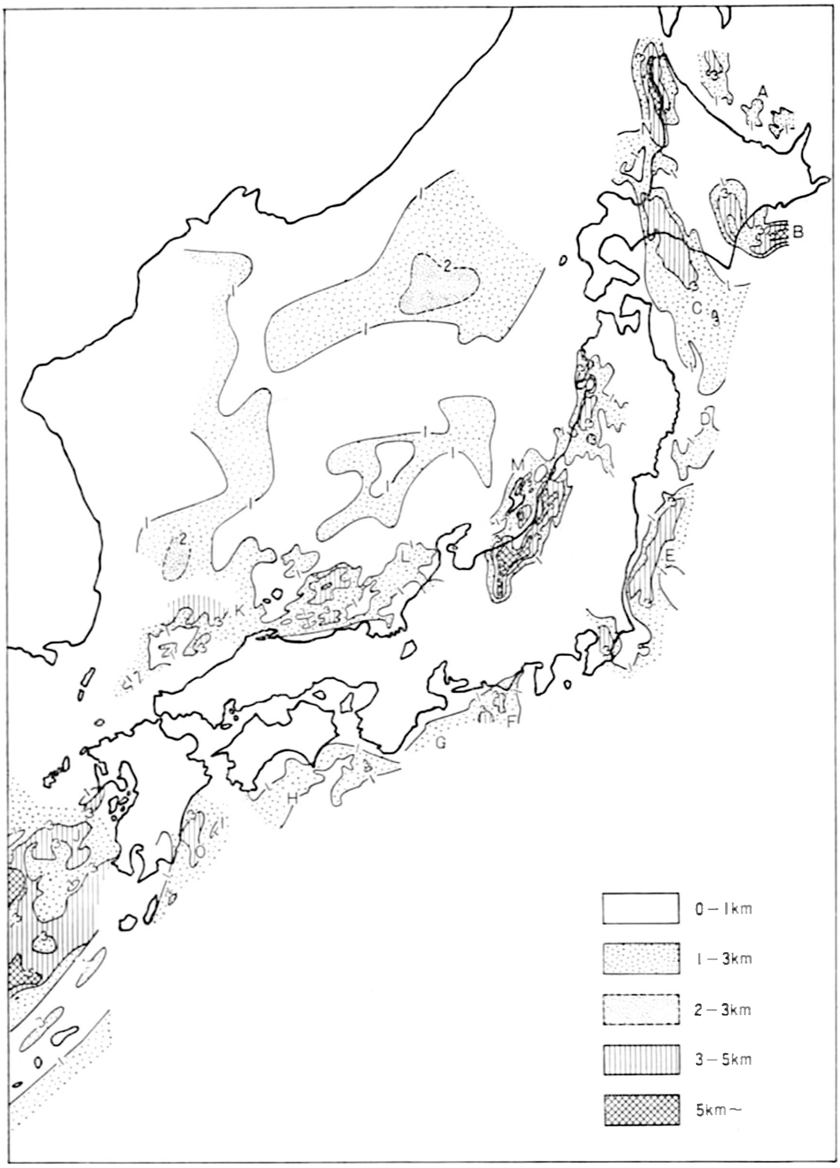


Figure 2. Distribution of Neogene Tertiary basins of Japanese islands. Figure shows sedimentary thickness in km

A Soya-Abashiri basin
B Tokachi basin
C Ishikari-Hidaka basin
D Kitakami basin
E Joban basin
F Enshunada basin
G Kumanonada basin
H Tosa and Toki basins
I Miyazaki basin
J Danjo basin
K Tushima basin
L Oki basin
M Akita-Yamagata and Niigata basins
N Tenpoku basin

seismic reflection profiles collected by the reconnaissance surveys sponsored by the Government, of which the geological interpretation was made utilizing various data such as velocity analysis of reflection profiling, P-wave velocities obtained by refraction surveys, and the geology of the adjacent land areas.

Northern Hokkaido

Beneath the Okhotsk Sea off northeastern Hokkaido, a Neogene sedimentary basin (A[1]), whose maximum sediment thickness is about 4 km, was recently revealed by the Government reconnaissance surveys. It may continue directly to the basin in Aniva Bay of South Sakhalin along the coast of which a gas discovery was reported, whereas the basin disappears along the coast of Hokkaido.

The Japan Sea

The Japan Sea, a marginal sea partly comprising of oceanic crust, is covered by relatively thin sediments, the thickness being generally less than 2 km in the central part (Kaseno, 1972; Hilde and Wageman, 1973; Ludwig *et al.*, 1975). The thin sedimentary cover, at least in the sense of petroleum geology, may be due to the young age of the opening of this marginal sea (late Cretaceous to late Eocene according to Uyeda and Miyashiro, 1974) and to the lack of large rivers supplying sediments, although thick sedimentary basins developed along its shelf areas.

The Japan Sea margin

The continental borderland of the Japan Sea margin, extending from Itoigawa in the south and to Rebun Island in the north (M and N), is the structural extension of the oil and gas producing area on land. Both grabens and horsts formed by block faulting of pre-Tertiary basement are filled with and covered by sediments of lower

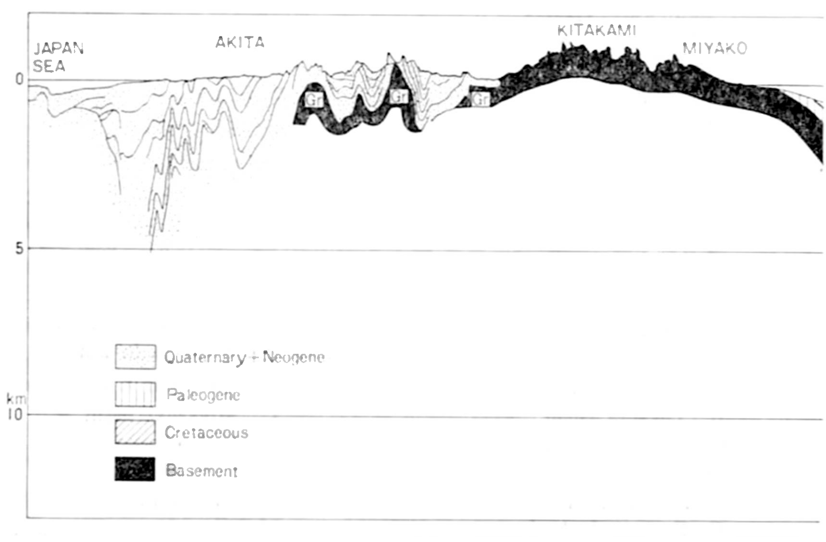


Figure 3. Geological cross section of

1) Alphabetical symbol corresponds to the sedimentary basin in *Figure 2*.

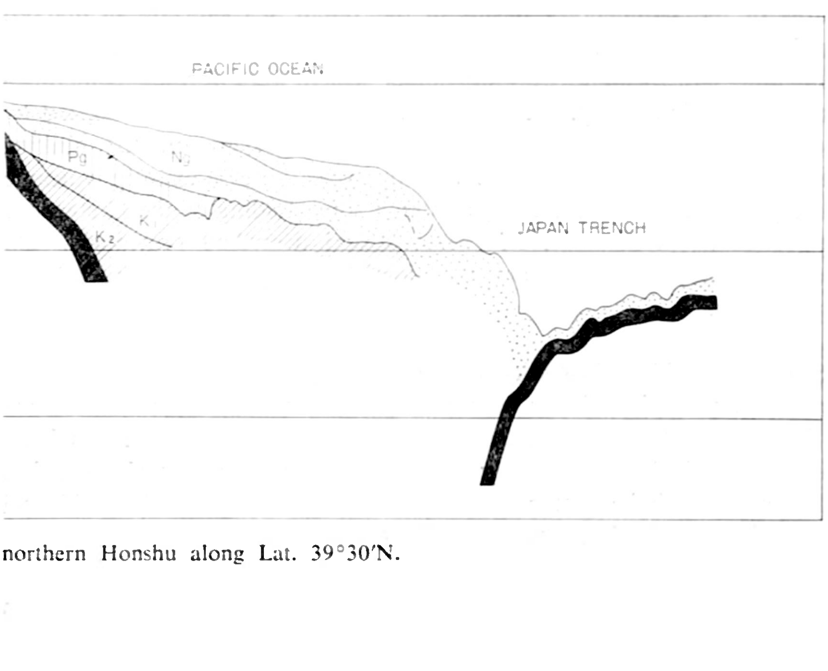
Miocene to Quaternary age successively from the land to the sea. Therefore, the sedimentary fill becomes thin westward and only fills up grabens on the slope so that the surface eventually forms a deep sea terrace within a small basin or a trough. Seismic profiles in this area indicate that basement horsts trapped terrigenous sediments and that tectonic movement was continuously active even after the main basement structures had been formed before deposition (Ishiwada, 1975).

The thickness of Cenozoic sediments in the land area and the continental shelf of the Niigata District is approximately 6 km, but it rapidly decreases across the slope area. The result of the recent geophysical surveys shows that the sedimentary thickness of the Mogami Trough is less than 2 km. In conclusion, the target for hydrocarbons in this area should be the continental shelf, and the potential beneath the slope may not be favourable in general.

No detailed information has been disclosed yet for the Japan Sea margin west of the Toyama Trough. Although extensive exploration has been undertaken by Royal Dutch/Shell and the Mitsubishi Group, the efforts were not successful. A wide sedimentary basin (K) occupies the wide continental shelf off San'in, the maximum sedimentary thickness being 6 km, and basins containing more than 3 km of sediments may exist under the adjacent slope facing the Tsushima Basin.

The Pacific margin

The offshore sedimentary basins of the Pacific margin underlie the continental shelf and slope. Off Sanriku (Pacific side of northern Honshu), Cenozoic sediments



northern Honshu along Lat. 39°30′N.

are likely distributed widely with a thickness of 2 km or more, while the Cenozoic sediments can hardly be traced on land. These Cenozoic sediments overlying Mesozoic or Palaeozoic formations, which are exposed on land in the Sanriku District, may continue to the Hidaka Trough in the north and to the basins off Joban in the south.

The Hidaka Trough (C), which is the widest Japanese deep sea terrace and occurs at depths of 1,500 to 2,000 m, is a large sedimentary basin filled up by more than 8 km of sediments. Its center may be located at a free air gravity anomaly of – 175 mgal, pointed out by Tomoda (1971) as a gravity basin off Urakawa. The seismic profiles indicate that under the terrace off Erimo-Misaki (Cape Erimo), Quaternary and Neogene sediments overlie unconformably folded older sediments of probable Mesozoic age (Ishiwada, 1975).

The sedimentary basins of Neogene, Palaeogene, and Cretaceous ages in the area off the Joban coal field (E), in which subcommercial gas pools were recently discovered within Lower Miocene and Palaeogene formations, are not well correlated with those off Sanriku.

To the west of Suruga Bay, a sea floor topographic feature extending from the Nankai Trough, a number of offshore sedimentary basins are known behind the trough. The basins under the Enshunada (The Sea of Enshu) (F) and the area off Miyazaki (O) are beneath the continental shelf, whereas the ones under the Kumanonada (The Sea of Kumano) (G) and the areas off Tosa (H) and Hyuga (I) are located in the slope.

Figure 3 shows a structural cross-section along 39°30′ North extending from the Sea of Japan to the Pacific Ocean passing through northern Japan. It may be pointed out that the features of the sedimentary basins in the Japan Sea side are in marked contrast to those of the Pacific side. The Japan Sea side is characterized by folded Miocene sediments filling grabens and burying horsts which were formed contemporaneously with violent volcanic activity. In contrast, the Pacific side is characterized by almost undeformed Cretaceous and Cenozoic sediments deposited on the sinking Palaeozoic basement along the arc-trench gap and by weak or non-existing volcanic activity since probably the Middle Cretaceous, although some folding of the Cretaceous sediments occurred, such as in the area off Erimo-Misaki described previously. On this side, the Neogene sediments, which are the dominant target for hydrocarbons, generally form hemi-basins.

The East China Sea and the Nansei (Ryukyu) Islands margin

Since the petroleum potential of this area was pointed out by a reconnaissance survey conducted by Emery *et al.* (1969), almost no systematic exploration has been undertaken yet due to political conflicts over this shelf common to several countries. Exploration activity by the private sector has been conducted in part of the Nansei (Ryukyu) Islands and its margin, but not successfully yet.

It is pointed out by Emery *et al.* (1969) that the East China Sea is in the process of sedimentation by sediments derived from the mainland. Actually, the sedimentary basin in the East China Sea shelf is filled up by thick sediments of 5 km or more, although it is divided into several sub-basins to the shelf edge. The multi-channel seismic profiles show that this area, for the most part, is occupied by a prominent unconformity. This unconformity was reported to be the Neogene-Palaeogene boundary by Wageman *et al.* (1970) and was later correlated with Pleistocene-Pliocene boundary by Leyden *et al.* (1973). The stratigraphic sequence can be divided into two by this unconformity. The upper sequence which consists of Upper Miocene to Quaternary sediments, has not been deformed. On the contrary, the lower sequence, which is composed of Lower Miocene and probably Palaeogene sediments, has been markedly folded.

On multi-channel seismic profiles, the Taiwan-Sinzi folded zone reported by Emery and Niino (1968), lying beneath the East China Sea shelf edge trending between Japan and Taiwan, is recognized as a crystalline basement (continental basement) high rather than a folded zone. This is supported by data from a well, as well as from the geology of the neighboring onshore areas, such as the Goto Islands.

The deepest part of the Okinawa Trough is located in the southwestern part which reaches 2,000 m of water depth, but it is generally covered by sediments less than 1 km thick. However, the northeastern part of the Trough, near Kyushu, is covered by thicker sediments, 1 km on the average and 5 km maximum thickness.

Along the Ryukyu Ridge, the sediment is generally thin, except the area near Miyako Island where a Neogene hemi-basin with more than 5 km of sediment thickness is developed.

Many faults can be seen in the Okinawa Trough and the Ryukyu Ridge. Most of them are expressed by sea floor topography, and hence this area may be the site of young and active tectonic movement with a high rate of crustal heat flow.

HYDROCARBON POTENTIAL

Although hydrocarbon potential of a sedimentary basin is primarily evaluated by the basin size and average sediment thickness, there are many large basins of no production. Accordingly, various geochemical methods have been developed for the assessment of the sediments, for example, by analysing richness and maturity of organic materials. *Figure 4* is a simplified summary of geochemical assessment for the land areas of Japan, mainly utilizing core samples collected from the stratigraphic wells drilled by the Government.

Large values of total organic carbon content, which represents richness of organic matter, were obtained for the areas currently producing such as Akita, Niigata, or Hokkaido. Hydrocarbon maturity can be estimated from, for instance, the ratio of hydrocarbon content to total organic carbon content. The geochemical parameter values shown in *Figure 4* indicate fair hydrocarbon potential in some areas and poor potential in other areas. The data were mostly derived from the stratigraphic wells drilled near the basin centres away from the existing oil and gas fields, nevertheless the figure may be useful for a relative criterion for adjacent offshore areas. According to the worldwide standard, the data suggest that generally oil potential is not so high and that gas discoveries may be more likely in the offshore areas around Japan.

Another important factor for generation of hydrocarbons is the thermal environment which may be directly expressed by temperature gradient. The measurements of terrestrial heat flow, namely the product of temperature gradient and thermal conductivity of rock, have been accumulated in and around Japan (Uyeda, 1972), and these data enable us to infer the general distribution of temperature gradient. The offshore areas off Sanriku and Joban show small values of heat flow suggesting deep generation of liquid hydrocarbons unless the palaeo-temperature gradient was high in these areas. The oil producing areas, however, are located on high heat flow anomalies in the Japan Sea margin of northeastern Japan.

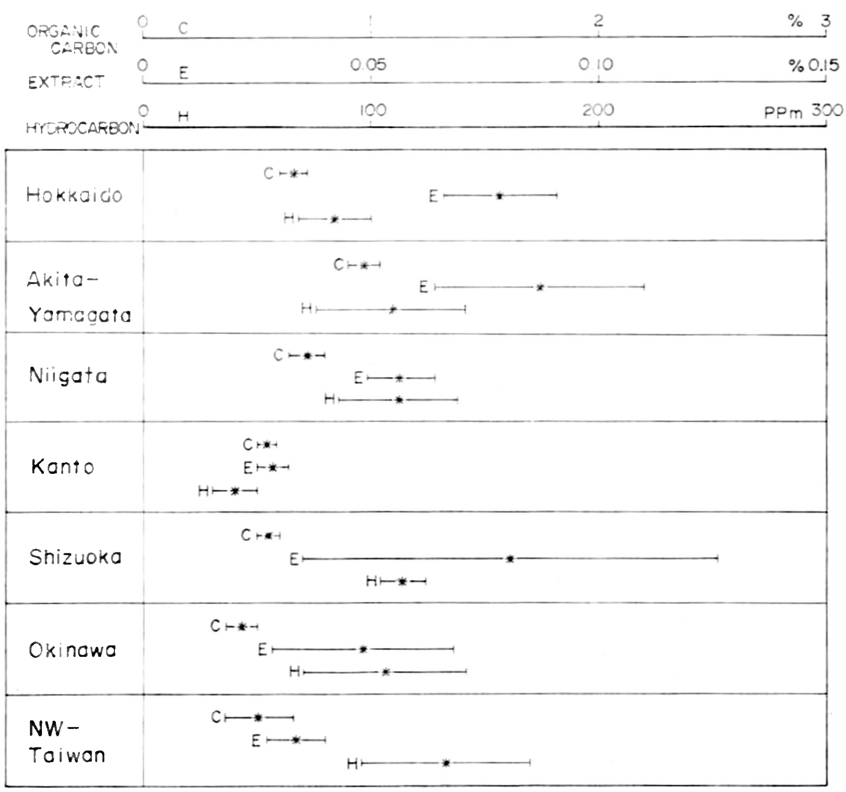


Figure 4. Contents of organic matters in the Neogene Tertiary shaly rocks of Japan and North-west Taiwan (on-shore data).
The asterisk shows mean value and the range indicates 95% confidence limit.
The Japanese samples were mainly collected from the stratigraphic drillings sponsored by the Government.

CONCLUDING REMARKS

The geology of offshore areas around the Japanese Islands was reviewed in relation to hydrocarbon potential. From this review we conclude that 1) development of sedimentary basins of the Japan Sea margin presents a striking contrast to that of the Pacific margin; 2) the target areas for exploration should not be limited to the northeastern Japan Sea margin which is now producing oil and gas; and 3) the first target horizon is Neogene sediments and the second Palaeogene. Geochemical evaluation of source rocks suggests gas discoveries may be more likely than oil.

ACKNOWLEDGMENT

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MAGNETIC INTERPRETATION USING INTERACTIVE COMPUTER GRAPHICS[1)]

by

Katsuro OGAWA[2)] and Hiroji TSU[3)]

ABSTRACT

A new approach to magnetic interpretation by means of a man-machine communication technique using an interactive computer graphics terminal (IBM-2250) connected to an IBM 370/145 computer is described. A combination of automatic and manual curve-matching procedures realized by the present system named "IMIS" may not only greatly reduce the interpretation time, but also give the most reasonable estimate of parameters describing the magnetic body such as depth, width and effective susceptibility.

Two practical applications using a two-dimensional dike model and a three-dimensional prism model are presented.

INTRODUCTION

The computer curve matching method for magnetic interpretation has been proposed by several authors, e.g., Johnson (1969), McGrath and Hood (1970), and Tsu and Ogawa (1973), all of which employ a non-linear least squares technique for finding a model body which most closely fits an observed magnetic anomaly. However, the non-linear technique not only requires a time-consuming computational process, but often fails to reach the best fit model.

In this paper, an interactive technique for overcoming this difficulty is proposed as follows:

1) The observed magnetic anomaly is displayed on screen.
2) An initial model is entered by the interpreter.
3) The theoretical magnetic anomaly is computed and displayed.
4) Trial-and-error adjustments are made until the theoretical anomaly agrees well with the observed anomaly by the combination of i) automatic adjustments by an interactive least-squares procedure, and ii) manual adjustments by the interpreter.

The greatest advantage of the interactive approach is evident in step 4 which is very time-consuming in the non-interactive computer approach. The interpreter can easily get the best fit model by proper use of manual and automatic adjustments.

Another advantage of the interactive approach is that the display of the observed magnetic anomaly is easily achieved by the following steps:

1) Reprinted from Report of the Technology Research Center, Japan Petroleum Development Corporation, No. 3, 1976.

2) Geophysics Laboratory, Technology Research Center, Japan Petroleum Development Corporation. Now at Geological Survey of Japan.

3) Geophysics Department, Geological Survey of Japan.

1) Magnetic contours including the anomaly to be interpreted are displayed on screen provided that the magnetic values are stored on disc or magnetic tape in the form of a Grid Data File (G. D.F).
2) A profile line crossing the target anomaly is entered by the interpreter.
3) The anomaly profile along the selected profile line is computed by means of the spline interpolation technique and displayed.

The time-consuming data preparation necessary for non-interactive computer interpretation such as digitizing the anomaly profile and punching data cards has become unnecessary.

Two types of magnetic models, i.e., a two-dimensional vertical dike with inclined top and a three-dimensional vertical prism with horizontal top, are available at present. Both models can have an arbitrary magnetization vector.

SYSTEM DESCRIPTION

The outline of the present interpretation system named IMIS (Interactive Magnetic Interpretation System) is shown in *Figure 1.* The system consists of (1) pre-processing and (2) IMIS operation on the CRT (Cathod Ray Tube) unit.

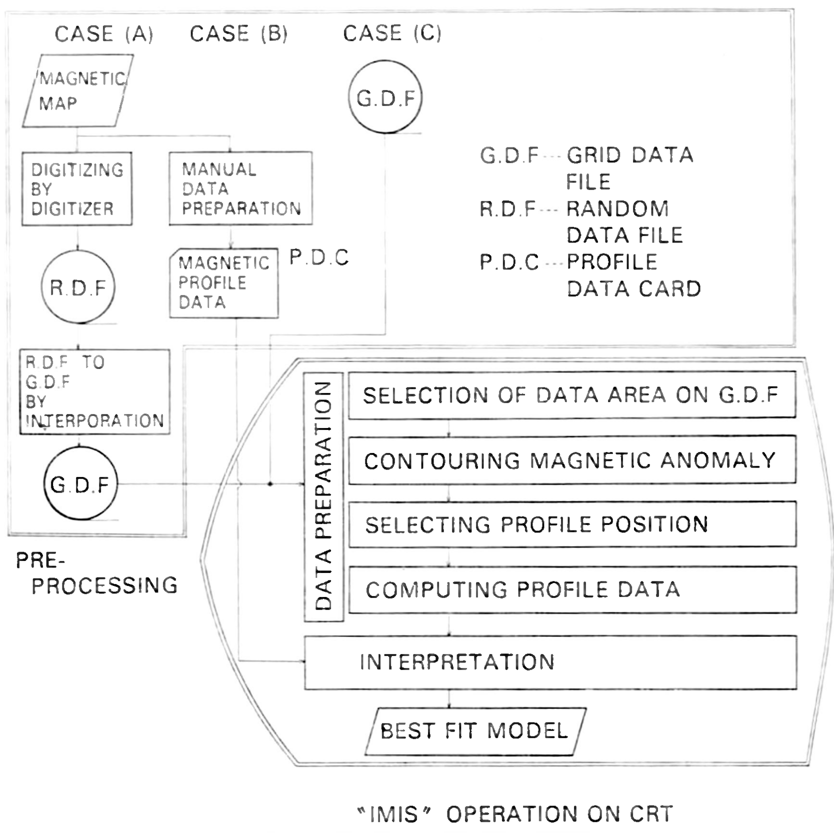

Figure 1. Flow chart of "IMIS".

(1) Pre-processing

The magnetic anomaly can be input to the IMIS operation in two forms, i. e., 1) grid data file (G. D. F) or 2) profile data cards (P. D. C.). In the case where the magnetic anomaly is available on a map instead of G. D. F, the best way to make full use of the system is to provide a G. D. F from the map by using a digitizer and employing some interpolation method as shown in *Figure 1* (Case (A)). When a G. D. F is not available, P. D. C should be prepared (Case (B)). Once the input data are available on a G. D. F, no further preprocessing is necessary.

(2) IMIS operation

IMIS operation consists of 1) data preparation and 2) interpretation. Data preparation consists of preparing the anomaly profile which will be used as input data for interpretation and displaying the profile on the screen. When the data are input by P. D. C, the following steps can be omitted. The first step is to select the data area which includes the target anomaly. The second step is to display the magnetic contour map of the area selected. The third step is to select a profile position crossing the target anomaly. The final step of data preparation is to interpolate equally-spaced profile values from the G. D. F by using the spline method and to display the resulting profile on the screen. The above procedure is done automatically if the interpreter supplies a set of information to the computer through the CRT unit.

Next, we go into interpretation to find the best fit model which most reasonably explains the observed profile. This may be realized by interactive trial-and-error adjustments. Two ways of adjustment are available. The first one is manual adjustment. An interpreter changes the parameters of the model through the CRT unit. The second one is automatic adjustment. The parameters giving the minimum error squares between the observed and the theoretical profile are automatically searched by using the non-linear least squares method proposed by the authors (Tsu and Ogawa, 1973).

It is well known that the non-linear least squares method is a mathematically "ill-conditioned" problem especially in the case where the number of parameters to be computed is large. In the opinion of the authors, the best way to eliminate this ill-condition is to employ a combination of automatic and manual adjustments. In the present system, the interpreter can use either adjustment at any step of the interpretation. When the interpreter judges that the acceptable model has been obtained, he enters a message indicating the termination of the interpretation.

Finally, the resulting best fit model is output in any form such as line printer, curve plotter or film image.

MAGNETIC MODEL

Figure 2. illustrates the parameters of the three-dimensional prismatic body model with an arbitrary magnetization vector ($\boldsymbol{J}$) in the earth's magnetic field ($\boldsymbol{T}_0$). The total intensity magnetic anomaly ($\Delta\boldsymbol{T}$) due to this body is given by the following formula,

$$\Delta\boldsymbol{T}(x, y, H)=\boldsymbol{J}\times G\ (x, y, H)$$

$$G(x, y, H)=\left(\frac{\alpha_{23}}{2}\log\left(\frac{r_0-\alpha_1}{r_0+\alpha_1}\right)+\frac{\alpha_{13}}{2}\log\left(\frac{r_0-\beta_1}{r_0+\beta_1}\right)-\alpha_{12}\log\left(r_0+H\right)\right.$$

$$-lL\tan^{-1}\left(\frac{\alpha_1\beta_1}{r_0^2+r_0H-\beta_1^2}\right)-mM\tan^{-1}\left(\frac{\alpha_1\beta_1}{r_0^2+r_0H-\alpha_1^2}\right)$$

$$+nN\tan^{-1}\left(\frac{\alpha_1\beta_1}{r_0H}\right)\Bigg)\Bigg|_{\alpha_l}^{\alpha_u}\Bigg|_{\beta_l}^{\beta_u} \qquad (1)$$

H = depth to the top of the prism from the plane of observation (x, y),
L_x, L_y = half-width of the prism,
$\boldsymbol{J}$ = magnetization vector of the prism,
J = intensity of $\boldsymbol{J}$,
$\boldsymbol{T}_0$ = vector of the earth's main magnetic field,
T_0 = total intensity of the earth's main magnetic field,
l, m, n = direction cosine of the magnetization vector $\boldsymbol{J}$
$(l, m, n) = (\cos i \cos b, \cos i \sin b, \sin i)$,
L, M, L = direction cosine of the earth's magnetic field $\boldsymbol{T}_0$
$(L, M, N) = (\cos I \cos B, \cos I \sin B, \sin I)$,
i = angle of inclination of $\boldsymbol{J}$,
I = angle of inclination of $\boldsymbol{T}_0$,
b = angle between the horizontal projection of $\boldsymbol{J}$ and the positive x axis,
B = angle between the horizontal projection of $\boldsymbol{T}_0$ and the positive x axis,
$\alpha_{12} = Lm + Ml$, $\alpha_{13} = Ln + Nl$, $\alpha_{23} = Mn + Nm$,
$\alpha_1 = \alpha - x$, $\beta_1 = \beta - y$,
$\alpha_u = L_x - x$, $\alpha_l = -L_x - x$,
$\beta_u = L_y - y$, $\beta_l = -L_y - y$,
$r_0^2 = (\alpha - x)^2 + (\beta - y)^2 + H^2$,

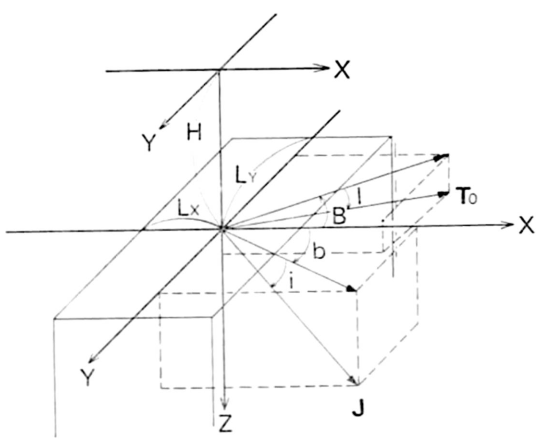

Figure 2. Oblique view of the three-dimensional prism with an arbitrary magnetization vector in the earth's magnetic field. (Bhattacharrya, 1964)

With the notation given in *Figure 3*, the total intensity magnetic anomaly ($\varDelta T$) due to the two-dimensional dike model is approximately given by

$$\varDelta T(x, 0) = c \times J_{xz} \times \delta T_{xz}(x, 0) \qquad (2)$$

where

$c = \cos I \ \cos B \ \cos i' + \sin I \ \sin i'$,

$\delta T_{xz}(x, 0) = \Delta X(x, 0) \ \cos i' + \Delta Z(x, 0) \ \sin i'$

$\quad$ = anomalous magnetic field projected to x-z plane,

$\Delta X(x, 0) = (R \ \cos \varphi - 2 \ \sin \varphi) \ M' - 2\Omega N'$,

$\Delta Z(x, 0) = (-R \ \sin \varphi \ - 2 \ \cos \varphi) M' - RN'$,

$M' = -(\sin i' \ \cos \varphi \ + \ \cos i' \ \sin \varphi)$,

$N' = \cos i'$,

$R = \log \ (R_2/R_1)^2$

$\quad = \angle LxR$ (angle between Lx and Rx),

J_{xz} = magnetization intensity projected to $x-z$ plane,

i = angle of inclination of δT_{xz},

I = angle of inclination of the earth's main field T_0,

B = angle between the horizontal projection of T_0 and the positive x axis,

φ = angle of dip of the surface of dike measured from the positive x axis (-90 degrees to 90 degrees).

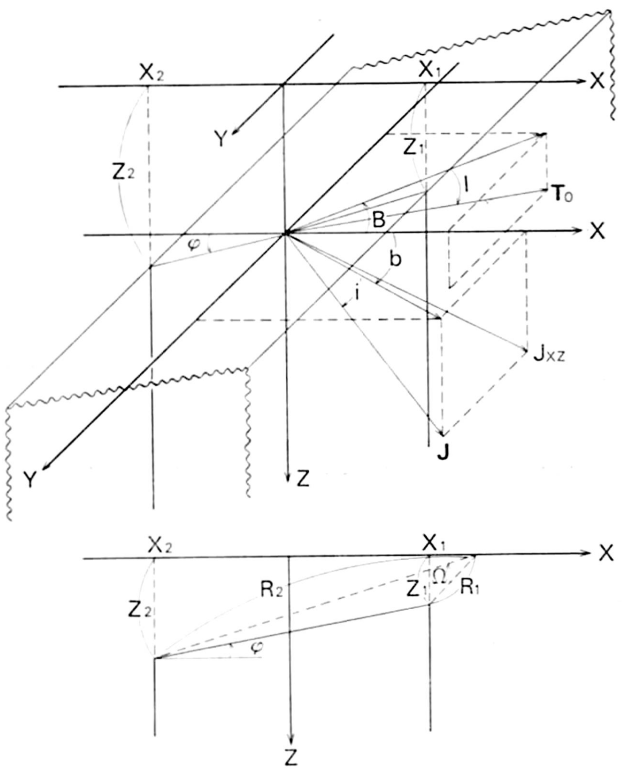

Figure 3. Oblique view of the two-dimensional dike with an arbitrary magnetization vector in the earth's magnetic field.

AUTOMATIC ADJUSTMENT

In order to reduce the interactive operation time, we introduced an automatic adjustment technique to find a better model. An interpreter can use automatic interpretation at any step of the iteration process by detecting on the word AUTOMATIC FITTING provided that the initial model has been given.

We define the error squares by

$$S(\Theta)=\sum_{u=1}^{N}(F_u-\Delta T(\xi_u\,;\Theta))^2 \tag{3}$$

where F_u and ΔT are the observed and theoretical magnetic profile values obtained at N points (ξ_1, ξ_2, ξ_3, ..., ξ_N) in a horizontal plane and Θ is the vector expression of the parameters to be computed, such as depth (H), length (L_y), width (L_x) or magnetization vector ($\boldsymbol{J}$) of the body. The solution of the vector may be obtained by letting

$$S(\Theta)\rightarrow\text{minimum},$$

or by

$$S(\Theta)=\frac{\partial S(\Theta)}{\partial\theta_r}=0 \quad (r=1,\,2,\,3,\ldots,\,P) \tag{4}$$

where P is the number of parameters.
Equation (4) becomes

$$\sum_{u=1}^{N}(F_u-\Delta T(\xi_u\,;\Theta))\cdot\frac{\partial\Delta T(\xi_u\,;\Theta)}{\partial\theta_r}=0 \quad (r=1,\,2,\,3,\ldots,\,P) \tag{5}$$

The simultaneous equation (5) is generally non-linear in vector as long as Θ represent the parameters of magnetic body. One of the usual methods to solve the equation (5) is to use the Gauss's iteration process, which replaces the non-linear equation by a linear equation

$$\sum_{u=1}^{N}\left(F_u-g_u{}^i-\sum_{l=1}^{P}\theta_l{}^{i+1}\cdot Z^i{}_{lu}\right)\cdot Z^i{}_{ru}=0 \quad (r=1,\,2,\,3,\ldots,\,P) \tag{6}$$

where

$$g^i{}_u=\Delta T(\xi_u\,;\Theta)$$

$$Z^i{}_{lu}\frac{\partial\Delta T(\xi_u\,;\Theta)}{\partial\theta_l}$$

and i means the i-th step of the iteration. Supposing that all values denoted by i have been given by the i-th iteration, we can get a new solution at the $i+1$-th iteration by solving a linear simultaneous equation (6). By this process the error squares $S\Theta$ may converge to a reasonable minimum.

Marquardt (1963) proposed a conventional method which reduces the number of iterations, and later Tsu and Ogawa (1973) modified it to make the process faster. The modified Marquardt's method is given by

$$\sum_{u=1}^{N}\sum_{l=1}^{P}\left(Z^{i}_{lu}Z^{i}_{ru}+\delta_{lr}\bar{\lambda}\right)\theta_{l}^{i+1}=\sum_{u=1}^{N}(F_{u}-g^{i}_{u})Z^{i}_{ru} \quad (7)$$

$$(r-1,\ 2,\ 3,\dots,\ P)$$

where

$$\delta_{lr}=\begin{cases}1 & l=r,\\ 0 & l\neq r.\end{cases}$$

A constant value added to the orthogonal component of the matrix is given by

$$\bar{\lambda}=q\sum_{u=1}^{N}\sum_{l=1}^{P}(Z^{i}_{lu})^{2}/P \quad (8)$$

where q is an arbitrary constant.

Generally speaking, judging whether the process has converged to a minimum is difficult, because the error squares is often caught in a relative minimum above the obsolute minimum in the course of the interation process. However, this may be easily done in the present system, because an interpreter can visually make judgement by observing the solutions which are displayed on the screen after each interation. In the common case where the solutions have converged but a reasonable visual fit between the observed and the theoretical magnetic profile has not been achieved, we may change the parameters manually. Further automatic adjustment may be done if necessary.

From equation (1) or (2), we can see that the intensity of magnetization (J) does not affect the solution of the shape of magnetic model as long as a uniform magnetization is assumed. As a result, we can get J by comparing the amplitude of the theoretical anomaly with that of the observed anomaly, i.e.,

$$J=(F_{\max}-F_{\min})/(T_{\max}-T_{\min}) \quad (9)$$

where the subscripts max and min mean maximum and minimum value, respectively. Thus, we can eliminate J from the non-linear parameters.

NORMALIZATION

In order to display the magnetic profile within a designed area on the screen, the profile values are normalized by

$$\bar{F}(\xi)=(F(\xi_{u})-F_{\min})/(F_{\max}-F_{\min})\times 100\,, \quad (10)$$

$$\Delta\bar{T}(\xi)=(\Delta T(\xi_{u})-\Delta T_{\min})/(\Delta T_{\max}-\Delta T_{\min})\times 100\,. \quad (11)$$

To express the degree of fit between $\bar{F}$ and $\Delta\bar{T}$, we introduced a value

$$d=\sqrt{\sum_{u=1}^{N}(\bar{F}(\xi_u)-\Delta\bar{T}(\xi_u))^2/N} \tag{12}$$

where $100\geq d>0$.

EFFECTIVE SUSCEPTIBILITY

The magnetization vector ($\boldsymbol{J}$) is the vector sum of the induced and the remanent magnetization vectors. And hence, the effective susceptibility defined here by

$$K_e=J/T_0 \tag{13}$$

is different from the susceptibility (K) of rock specimens unless the remanent magnetization is negligible or is aligned in the direction of the earth's magnetic field. The effective magnetization should be compared with the value (k_e) of a rock specimen defined by

$$k_e=C|\boldsymbol{J}_T|/T_0 \tag{14}$$

where

$$\boldsymbol{J}_T=K\boldsymbol{T}_0+\boldsymbol{J}_R \tag{15}$$

$$C=1+\cos^2 i(\cos^2\beta-1) \tag{16}$$

$\boldsymbol{T}_0$ = vector of the earth's magnetic field,
T_0 = intensity of $\boldsymbol{T}_0$,
$\boldsymbol{J}_R$ = vector of remanent magnetization of a rock specimen,
i = inclination of $\boldsymbol{J}_T$,
β = angle between the horizontal projection of $\boldsymbol{J}_T$ and the positive axis of the profile line used for interpretation.

OPERATION

Figure 4 shows the IMIS operation procedure. The procedure is divided into a) data preparation, and b) interpretation.

a) data preparation

When the input data are prepared in the form of a G. D. F, we start the operation from Panel 1. We key in both the number of contours and the area of the contour map to be displayed on the screen through the keyboard. *Figure 5* shows the relation between the G. D. F and the area thus chosen. After this, the grid data are read from the G. D. F; then the contour map is displayed on the screen (Panel 2). Next, we go into the selection of the profile position. This well be done by detecting a start point and an end point of the profile line using the Light Pen. The chosen profile line is superimposed on the contour map (Panel 3). The magnetic values along this profile line are computed from the G. D. F at equally spaced points by means of the spline interpolation method. *Figure 6* illustrates the grid points and the interpolated points along the profile line. When the input data are in the form of a P. D. C, data cards will be

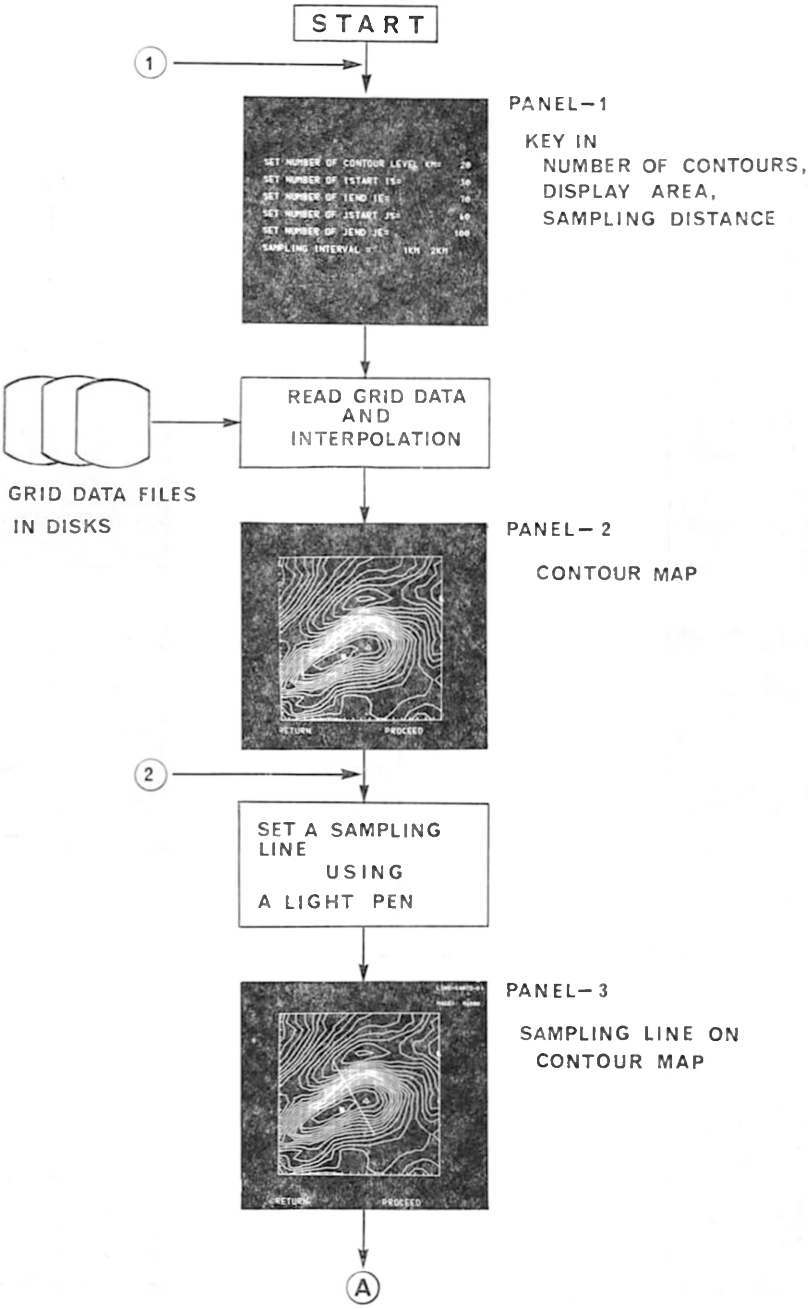

Figure 4(1). Outline of the "IMIS" operation shown with CRT images.

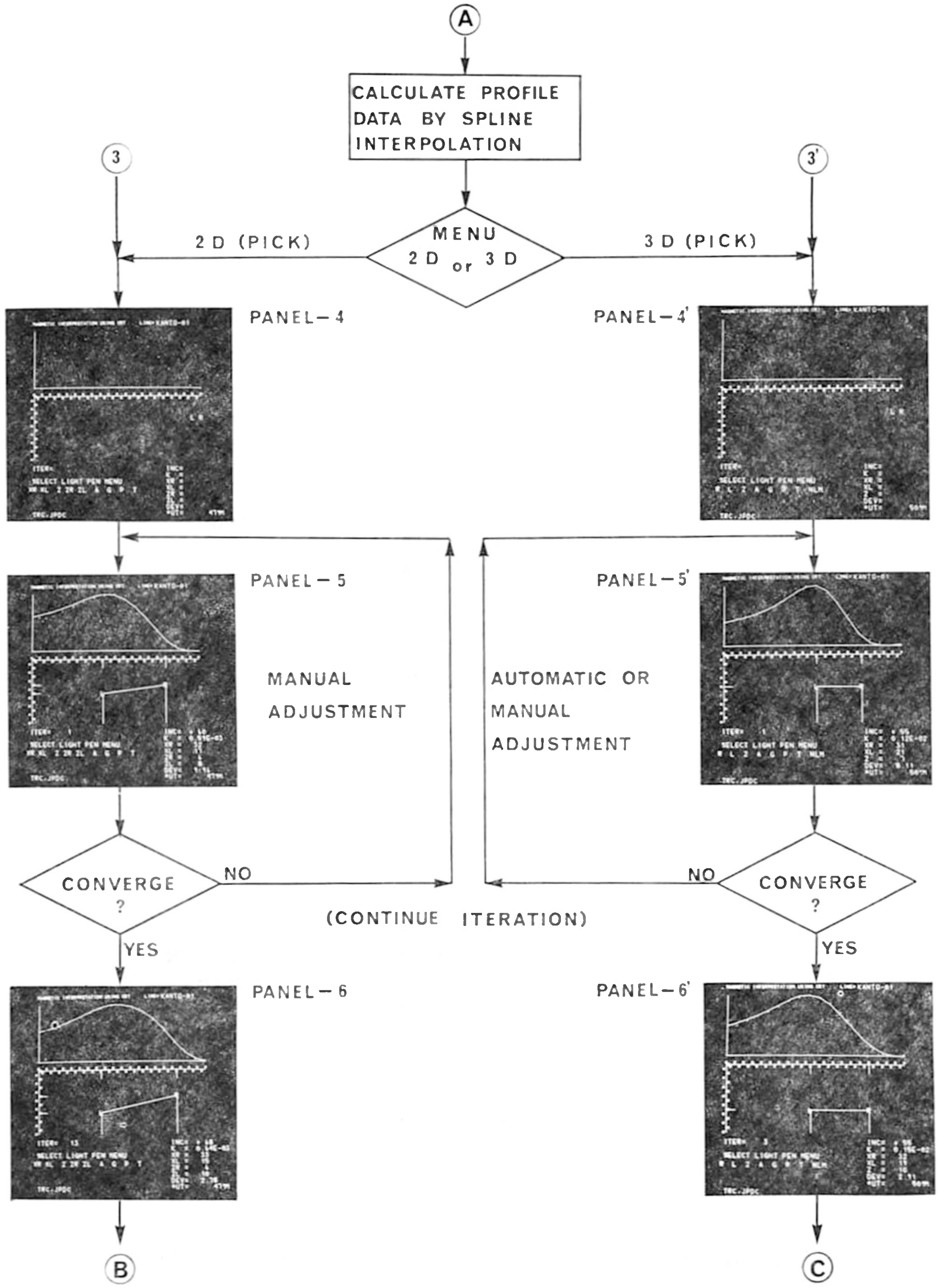

Figure 4(2). Outline of the "IMIS" operation shown with CRT images.

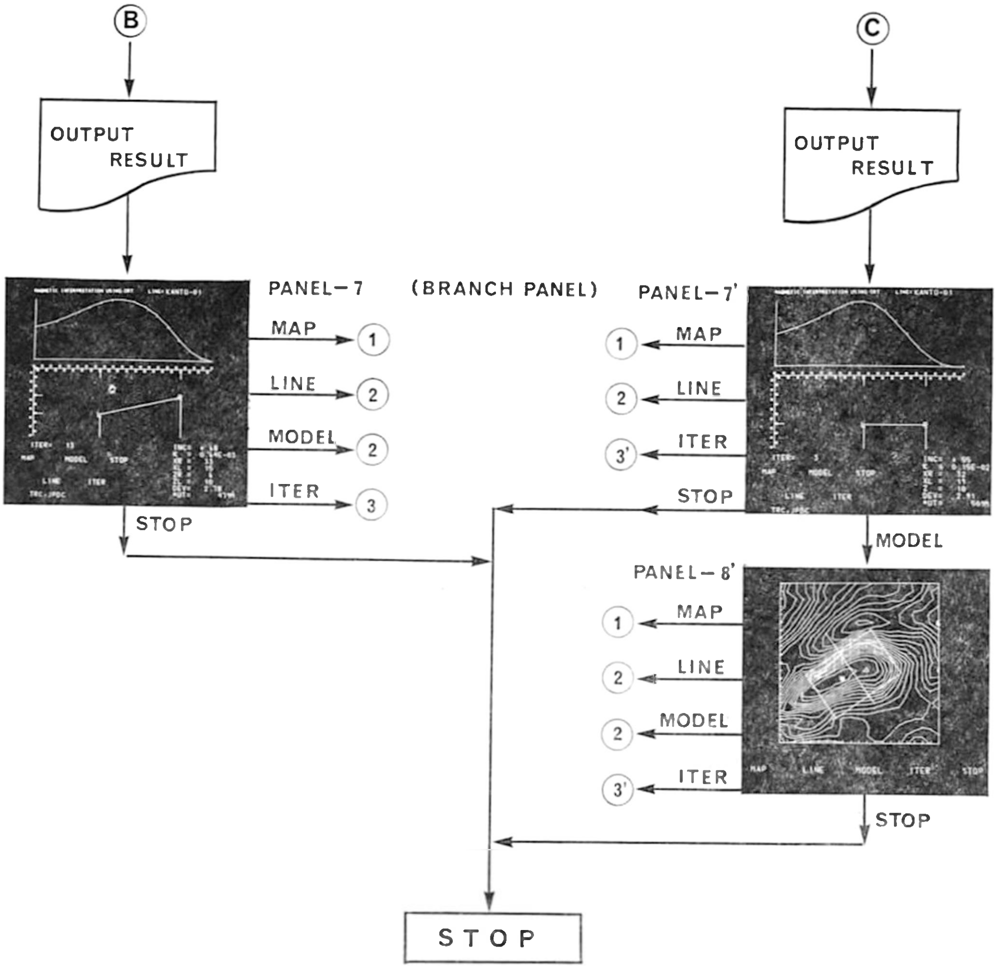

Figure 4(3). Outline of the "IMIS" operation shown with CRT images.

read at this stage.

What follows is the selection of the model type, i. e., two-dimensional dike model or three-dimensional prism model. Next, the normalized input profile values will be displayed (Panel 4 or Panel 4′) by dotted points. The next step is to set up an initial model as shown at the middle part of Panel 5 or Panel 5′. This is easily done by detecting on a word MENU shown at the lower part of the panel, and detecting horizontal and vertical coordinates shown at the middle by the Light Pen. The theoretical profile values due to the model thus given are computed by equation (10) or (11) together with equation (1) or (2).

The computed normalized values are displayed by a solid line at the upper part of the same panel. The computed d value (DEV), degree of fit, is also displayed at the bottom right of the panel.

Now, we go into the interpretation. An interpreter controls the iterative process

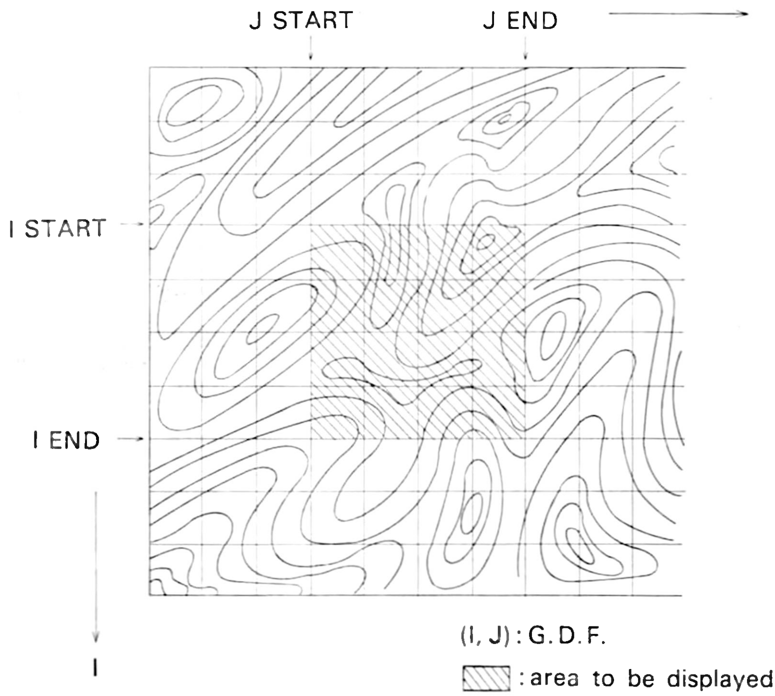

Figure 5. Relation between the G. D. F and the area to be displayed on the CRT unit.

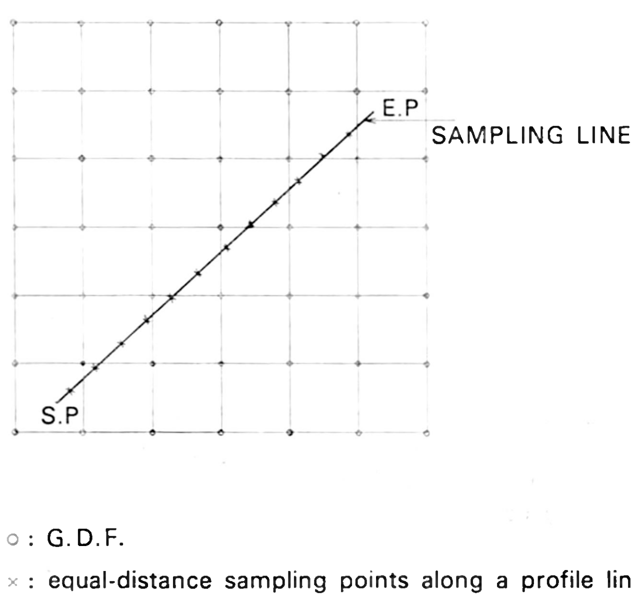

Figure 6. Relation between the G. D. F and the equal-distance sampling points along a profile line.

by means of interactive operation employing manual adjustment or automatic adjustment until he thinks that the best fit model has been obtained (*Fig. 7*). Panel 7 or Panel 7′ shows an example of the best fit model, its theoretical profile, the observed profile, and the d value. An image of this panel can be output in several forms, such as line printer, curve plotter, or film image.

Now, the interpreter can select any of the following steps 1) define a new area on the G. D. F (go back to Panel 1), 2) re-locate a profile position (go back to Panel 2), 3) try interpretation again for the same profile (go back to Panel 4 or Panel 4′), or 4) terminate the operation. In the case of the three-dimensional model, a plane view of the best fit model can be displayed (Panel 8) prior to the above operation.

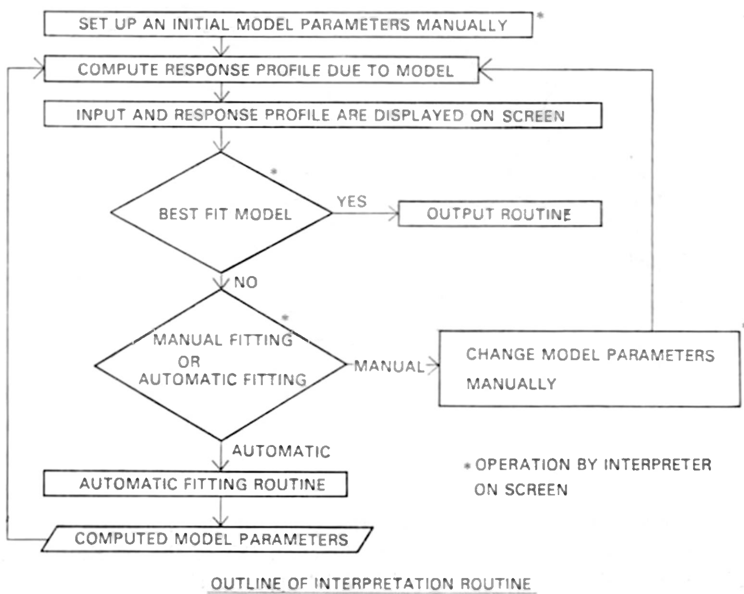

Figure 7. Operation flow chart of interpretation by "IMIS".

APPLICATIONS

IMIS has been applied to several aeromagnetic anomalies measured in Japan. The followings are some of the results.

Kashima Offshore Anomaly

Figure 8 shows a part of the total intensity isogam map (residuals of the International Geomagnetic Reference Field) off the coast of the Hitachi-Kamogawa area (Geological Survey of Japan, 1973). The large offshore anomaly located at the center of the map is the target of the present interpretation. The interpretation was performed by employing a two-dimensional dike model along a profile line denoted by the x-axis chosen perpendicular to the assumed strike direction of the body. The upper section of *Figure 9* shows the observed and the theoretical magnetic profiles. The lower

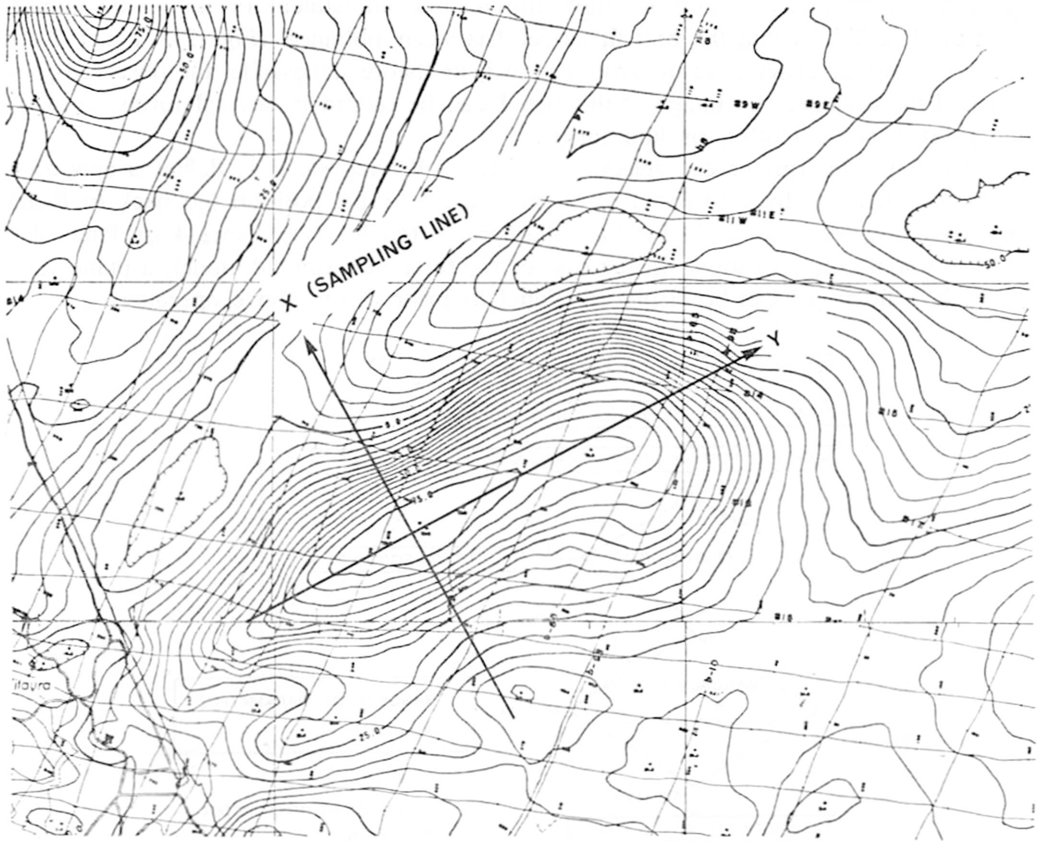

Figure 8. Part of GSJ aeromagnetic map off the coast of the Hitachi-Kamogawa area, Sampling line (X) and assumed strike direction (Y) of the off-Kashima anomaly which was used for a test study of "IMIS" are also shown.

section illustrates the resulting magnetic body together with the dike-like body inferred by the reflection seismic survey conducted by Japan Petroleum Development Corporation (1971). *Figure 10* shows the plane view of the magnetic body as well as the location of the faults obtained from the seismic interpretation.

Ishii (1962) discussed the basement of the Kanto Plain which occupies the broad area west of the present anomaly. This study showed that the east-trending metamorphic belt, the so-called Sambagawa belt, is crossing the Kanto Plain beneath the thick sediments of the Miocene to Recent.

Several east-trending magnetic anomalies located along the estimated metamorphic belt are apparent on the aeromagnetic map. These anomalies including the present anomaly may be produced by ultra-basic rocks (mainly serpentine) within the Sambagawa belt. Although the eastern extension of the belt to the Pacific Ocean where the anomaly studied is located was not discussed in the paper, it may be possible to consider this anomaly as a member of the ultra-basic group of the belt because of the similar magnetic pattern and trend. The resulting parameters obtained are as follows:

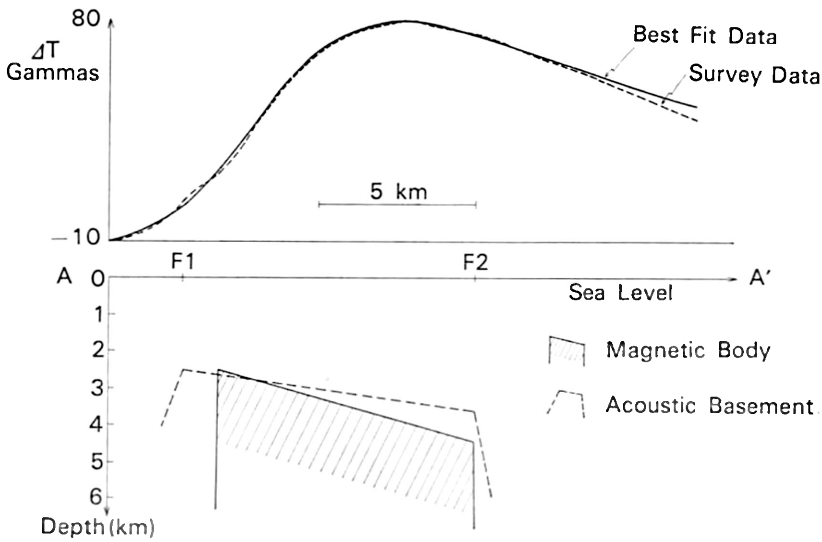

Figure 9. Aeromagnetic profile and the computed best fit profile along A-A′ in Figure 10 (upper part), and the cross section of the best fit body together with the acoustic basement derived from seismic interpretation (lower part).

K_e (effective susceptibility) $= 2{,}000 \times 10^{-6}$ emu/cc,
I_e (effective inclination of the magnetization vector) $= 72°$,
Depth to the top of the body below sea level $= \begin{cases} 4.5 \text{ km (eastern edge)} \\ 2.5 \text{ km (western edge)}, \end{cases}$
Width of the body $= 10$ km,
d (degree of fit) $= 2.78\%$ $(= 3$ gammas).

Sendai Offshore Anomalies

Figure 11 shows an application of the IMIS to a determination of magnetic basement configuration. The resulting location, depth, and width of magnetic bodies and basement depth contours are superimposed on the isogam map off the coast of the Kesennuma-Hitachi area (Geological Survey of Japan, 1970).

Geologically, the area of study includes two Mesozoic metamorphic belts, i. e., the Kitakami belt and the Abukuma belt both of which trend north. A series of anomalies with strong amplitudes and short wavelengths extending to the central part of the map from the extreme northern part of the map may represent the southern extension of the Kitakami belt whose main part is located north of the map. The western border of this anomalous zone is very clear, which indicates a fault system trending north. On the other hand, the eastern border is not so distinct. This may be due to the gradual increase of depth of the basement which is expressed by the basement contours. The reflection data, which indicate that the monoclinal east dipping sedimentary formations start at the margin of this anomalous zone, supports this interpretation.

Figure 12 shows the distribution of the computed effective susceptibilities. It may

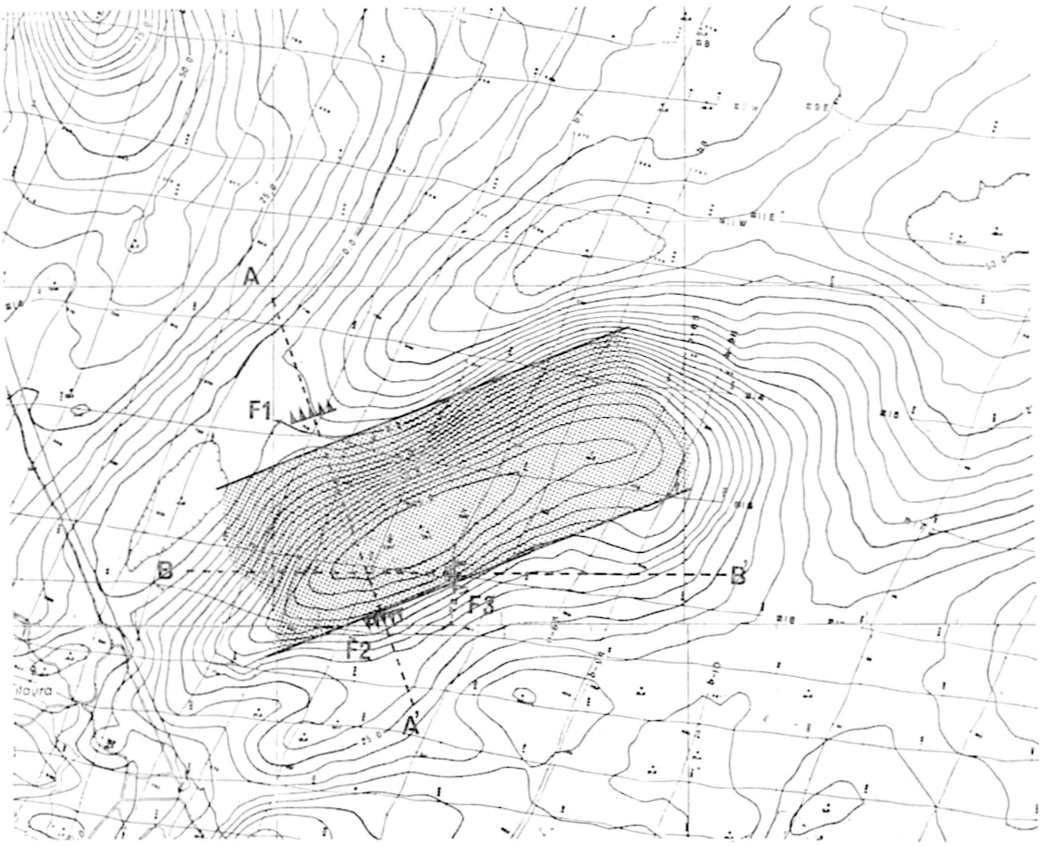

Figure 10. Plane view of the computed best fit body for the off-Kashima anomaly. A-A′ and B-B′ are the seismic lines crossing this anomaly, and F1, F2, F3 are the faults derived from seismic interpretation.

Table 1 Induced, remanent and effective magnetization of rock specimens sampled at P, Q, R, and S showing a difference in magnetic properties between zone A and zone B in Figure 12.

ZONE	SAMPLING POINT	ROCK	J_i 10^{-6}emu/cc	J_r 10^{-6}emu/cc	DEC of J	INC of J	J 10^{-6}emu/cc	k_e 10^{-6}emu/cc
A	P	basalt	2280	1580	335°	40°	2850	4420
A	Q	tuff	2130	495	348°	48°	2580	3970
B	R	quartz-diorite	450	153	352°	58°	520	800
B	S	grano-diorite	410	131	353°	54°	415	650

J_i : induced magnetization
J_r : remanent magnetization
J : effective magnetization $= |J_i + J_r|$
k_e : effective susceptibility obtained by Equation (14)
DEC: declination
INC : inclination

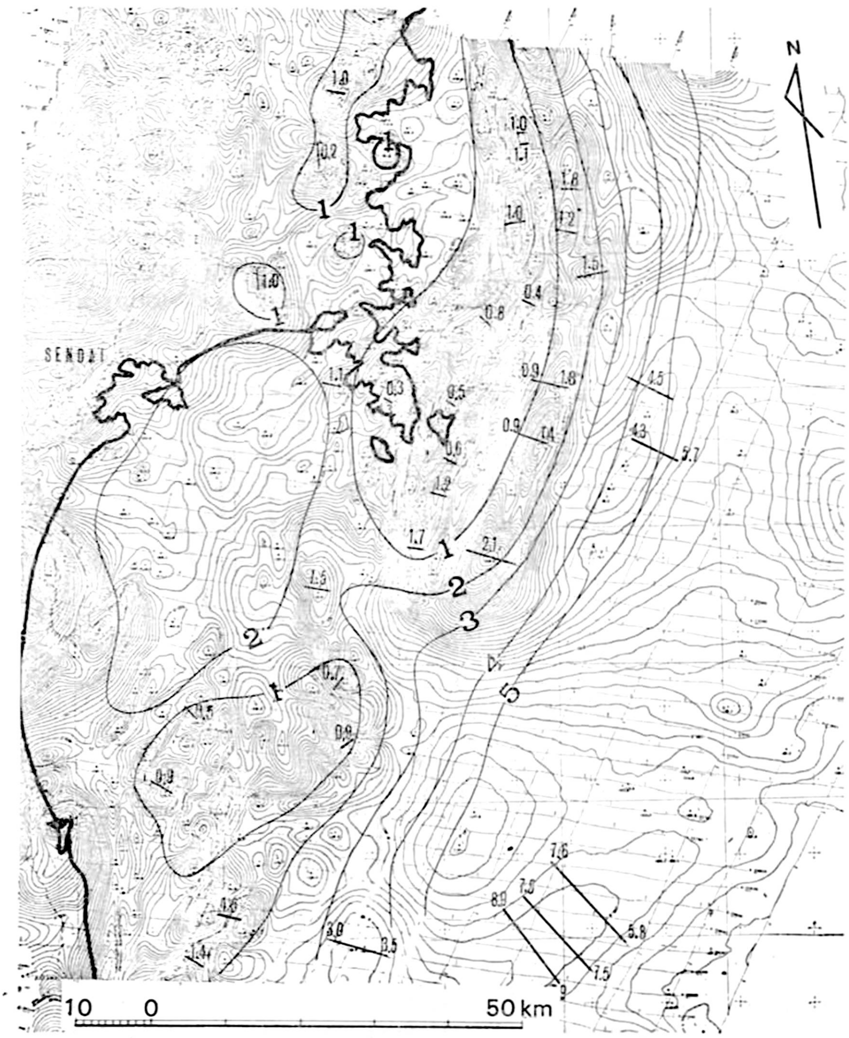

Figure 11. Part of GSJ aeromagnetic map off the coast of Kesennuma–Hitachi area. Contours are generalized magnetic basement depths obtained by "IMIS" interpretation. The computed depth, width, and location are also shown.
~3—: depth to the top of magnetic basement in km below sea level
7.5 5.8: position, width, and depth of the magnetic body

be easily seen that this anomalous zone can be divided into two sub-zones by their susceptibility contrasts. The western group (Zone A) has generaly higher susceptibilities than the eastern group (Zone B). Study on rock properties (Saito, personal communication) showed that the rocks sampled in the zone A (P and Q in *Fig. 12*) tend to have susceptibilities several-times higher than those in the zone B (R and S in *Fig. 12*). The effective susceptibilities of the rock specimens are listed on *Table 1*.

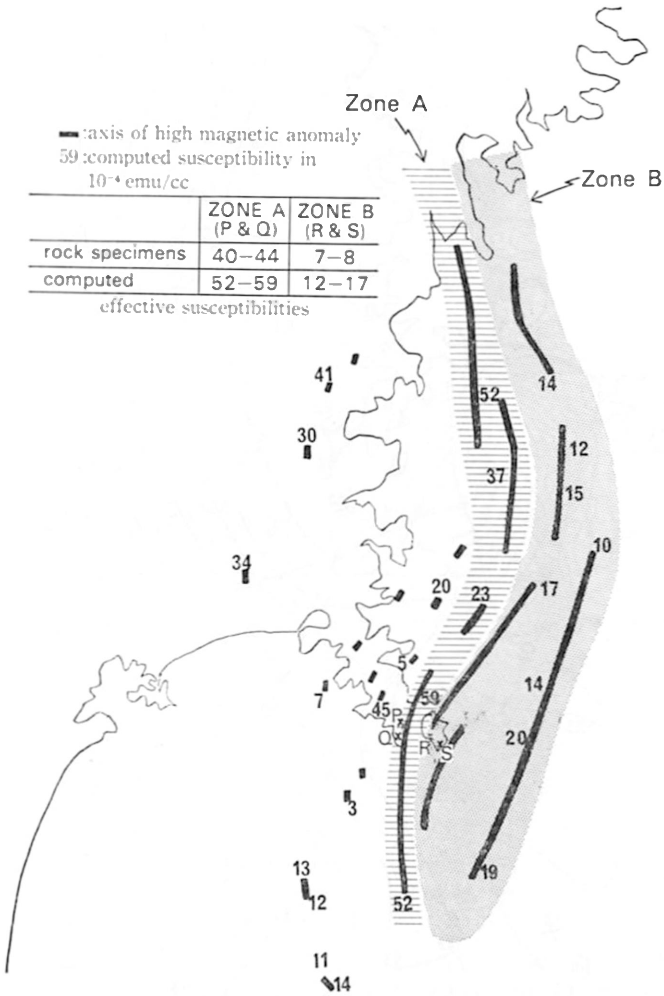

Figure 12. Zonning of igneous rocks based on the effective susceptibilities (Ke) obtained from "IMIS" interpretation. The computed effective susceptibilities are also shown. P, Q, R, and S show the locations of the rock specimens listed on *Table 1*.

The comparison shown in *Figure 12* suggests that the effective susceptibilities derived from the present interpretation may approximately represent the actual rock susceptibilities and, hence, may be helpful for the offshore geologic mapping of the area studied.

CONCLUSION

An interactive approach to geophysical interpretation may have a great possibility of future development because:

1) Trial-and-error adjustment is an essential technique for many geophysical interpretation problems. However, it usually requires a time-consuming computational process and often fails to produce acceptable solutions if the whole process is done automatically by the computer.
2) The interactive approach opens the possibility of bringing the following abilities of the interpreter to the computational process:
   i) visual ability to judge correctly the degree of fit in a least squares sense, and
   ii) ability to judge whether resulting models are geologically as well as physically realistic based on experience in geophysical interpretation.

And hence, the process may lead quickly to acceptable solutions.

ACKNOWLEDGMENT

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A REVIEW OF OIL EXPLORATION AND STRATIGRAPHY OF SEDIMENTARY BASINS OF THE PHILIPPINES[1]

By

Mineral Fuels Division, Bureau of Mines[2]
Manila, The Philippines

FOREWORD

This paper is a supplement to, and an outgrowth of the 1966 edition of "Review and Assessment of Oil Exploration in the Philippines". It attempts to update the geology and stratigraphy of the sedimentary basins in the Philippines and also gives attention to the contemporary development of hydrocarbon prospecting in each depositional area. While it carries a more detailed discussion about particular localities which have not been touched or only partially treated in the previous work, parts of the original text are summarily recast to make more effective and orderly presentation of the subject in review. The write-up preserves the same general organization of the original work. A brief description of the geographic setting and evolution of the archipelago, and of the major structures threat, serve as an introduction to subsequent discussion on the geology, exploration and hydrocarbon prospects in the different basin areas.

A location map of the different sedimentary basins in the Philippines and generalized table of stratigraphy with accompanying composite section for the different depositional areas are the principal illustrations attached. The table on wells drilled in the Philippines has been updated to the end of 1974.

INTRODUCTION

Geographic Setting and Evolution

The Philippine Archipelago is part of the southern segment of the Circum-Pacific Mobile Belt. It forms a roughly triangular area bounded by Formosa (Taiwan) on the north; the North-Luzon-Manila-Palawan trench and ridge systems on the west; the Palawan-Sulu Archipelago ridges, with the intervening Sulu Sea in the south; and the Philippine Deep and Pacific Ocean on the east.

Divergent views as to the origin of the Archipelago have been advanced by various workers, foremost of which was the theory of Smith (1924) that the region was once a part of the Asiatic continent and that the islands represent fragments of the ancient margins of that vast landmass. This postulation was deduced mainly on the

1) *Figure 2* to *Figure 12* in pocket on back cover.

2) Compiled and written by Salvador Martin with the collaboration of the technical staff of the Mineral Fuels Division, including a review of the manuscript by Benjamin Gonzales and some editing and revisions by Felipe U. Francisco.

basis of close similarities between the faunal and floral characteristics, both living and fossil, in both land masses.

Gervasio (1964) considers the Philippines as a product of the evolutionary transformation of a least three principal Mesozoic geosynclinal basins which were respectively superimposed on a deeply truncated basement and over which the Tertiary platforms subsequently developed. At least five stages of devolpment; the early, middle and late structural stages and the early and late post-platform stages, have been defined. At the peak of their development during the early structural stage, the principal geosynclines covered: a) almost the entire area of Luzon, b) the Bicol Peninsula and the entire Visayas and Mindanao; and c) the southern half of Palawan Island. The Palawan geosyncline, unlike the Luzon and the Bicol-Visayas-Mindanao basins, was assymetrical, there being no borderland to the west, and was surmised to have extended south to the northwest Borneo Geosyncline (Leichti, 1960). The archipelagic conditions that developed during the middle structural stage (Paleocene to Oligocene) persisted through middle Miocene (upper structural stage) and made possible the deposition of thick and extensive reefal limestone under shallow conditions and the development of paralic coal measures in several areas where slow subsidence were taking place. Extensive inundations acompanied by large-scale batholithic intrusions transformed the once negative regions into vast platforms. Mollasse deposition along intermontane troughs and foredeeps followed by widespread eruptions and diastrophic movements persisted from late Miocene through Pliocene (early post-platform stage). This was followed by the last stage of development which extended from Pliocene through Recent. The activities were essentially the continuation of the sedimentation processess of the previous stage with the principal troughs filled-up first, by shallow marine, and, later, by terrestrial deposits.

Current research on the tectonic framework of Eastern Asia locates the Philippine Archipelago along the southwest margin of an entirely oceanic crustal unit known as the Philippine Sea Plate. It considers the archipelago as a complex structural unit formed by at least four arc systems which had coalesced by late Oligocene, since tectonically mixed pre-Oligocene basement formations associated with large ultra-basic masses are spread in the islands. Intermediate to acidic plutionism and late Cenezoic sedimentary basins, affected by Miocene tectonic activity, have combined to produce a proto-continental crustal unit from materials which appear to have been originally part of an oceanic crust. The Manila Trench, a narrow sea-floor feature west of Luzon appears to be the site of a subduction zone dipping eastwards beneath the island, in an opposite direction of the east-Mindanao subduction zone. Accordingly, the Manila Trench zone swings round southeastwards near Mindoro and apparently terminates there. The Mindanao Trench subduction zone, swings to a roughly northeast alignment on the opposite side of the archipelago, converting into a left-lateral transcurent fault and adjoining another short subduction zone in the north-south trench of the Sierra Madre coast of Northern Luzon.

Major structures

Corby, et al (1951) distinguished four tectonic provinces in the Philippines based on geological history, structures, physiography and seismicity, consisting of: 1) the relatively stable Sundaland which embraces Palawan and Mindoro; 2) a belt of disconnected basins south and east of Sundaland which subsided during the Tertiary until the close of Pliocene and includes Panay Island; 3) the orogenically active area which engulfs the major parts of Luzon, central Visayas and Mindanao; and 4) a belt with undisturbed Tertiary sequence which includes Samar and perhaps northeastern Luzon. Gervasio (1964) reclassified Corby's four tectonic provinces into two structural units, namely, the Mobile belt and the Stable region. The Mobile belt runs longitudinally throughout the entire length of the archipelago and is characterized by a concentration of earthquake epicenters, numerous volcanoes, prevalence of Mesozoic to Tertiary igneous rocks and by sedimentary rocks that are rich in volcanic debris, clay matrix and iron oxides with very little quartz. The mobile belt includes four major blocks, each separated by steeply dipping shear zones.

The North Luzon Block extends from Batanes in the north to the vicinities of the Lingayen and Dingalan Bays southward and includes two intermontane troughs, the Ilocos Lowland and Cagayan Basin. The South Luzon Block is separated from the North Luzon Block by the Lingayen-Dingalan Lineament and extends south to Mindoro, Marinduque and the neck of the Bicol Peninsula. The principal geanticlinal elements within the block, the Zambales Range and southern Sierra Madre, are separated by a large intermontane trough, the Luzon Central Valley Basin. Northwest trending structures parallel to the Philippine Fault Zone are also manifested in the block. The region covering the Bicol Peninsula, Visayas and Mindanao, except southern Zamboanga and the Cotabato highland is called the Visayan Block. The most prominent structural feature within the block is the Philippine trench which runs along its eastern border. Included are several large and small northwest trending synclinal basins and linear depressions with thrustfaulted fold structures along their mobile fringe belts. The Zamboanga Block covers the Zamboanga Peninsula and Cotabato highland. Its greater part is submerged under the Celebes Sea. Thrust structures within the block assume a folded aspect that dip either to the northwest or southeast.

The stable region embraces Palawan mainland, Cuyo Island group, the Sulu Sea and possibly southern Mindoro. Structures within the region are comparatively less known since a greater part of the region lie under water. In northern Palawan, the structures generally trend northwest-southeast and except for minor overlapping of Tertiary rocks along the east coast, the formations are essentialy progressively younger to the west. The Sulu Sea is considered as a former platform mass consisting of gneiss, schists and granitic intrusives which collapsed during the final stage of mountain building during the Mesozoic while the adjacent mobile belt was being transformed into a platform, and subsequently readjusted.

GEOLOGY, EXPLORATION AND HYDROCARBON PROSPECTS IN THE BASIN AREAS

The Philippines contains at least eight defined Tertiary basins and several structural remnants of small and large basins that are superimposed on Mesozoic to early Tertiary metasediments, ultrabasic to intermediate plutonics and volcanic rocks usually referred to as the "Basement Complex" and commonly assumed as the economic petroleum basement; pre-Tertiary sedimentary rocks also are generally of complex structure and origin, are limited in occurrence and are generally considered of secondary significance from the standpoint of petroleum possibility. Exceptions could occur in some areas like southern Mindoro.

The archipelago was active throughout much of the Tertiary. Volcanism was extensive and formed ridges and troughs with broad shelves which acted as ledges for reef build-ups and/or areas for continued sedimentation. Eight such areas of persistent deposition have been defined by surface geological and geophysical works. These area: the Cagayan Valley Basin, Luzon Central Valley Basin, Southeast Luzon Basin which embraces the Bondoc and Bicol Peninsulas, Iloilo Basin, Visayan Sea Basin, Davao-Agusan Trough, Cotabato Basin and the Palawan-Sulu Sea Basin. Most of these are essentialy onshore basins, however, offshore extensions have been delineated in certain instances. The Cagayan, Luzon Central Valley, Iloilo and Davao-Agusan Basins are well defined gravity lows. The Visayan Sea Basin includes at least two northwest-trending linear lows separated by a gravity high conforming approximately with the island of Cebu. The Southeast Luzon Basin is considered a closed gravity low whereas the Cotabato and Palawan-Sulu Sea Basins are regarded as broad magnetic lows.

Most of the eastern Philippine region developed in an unstable or mobile zone. The area is characterized by vulcanicity, intrusive activity and localized rapid subsidence hence, a great portion of the sedimentary sections contain large amounts of basic igneous and metamorphic detritus deficient in quartz. Unlike the above, the southwestern side covering the Palawan-Sulu Sea area formed in a stable or aseismic zone characterized by prolonged marine deposition, lack of igneous activity and reduction of the land areas by slow marine transgression. The sedimentary sequences therefore, are essentially quartzose, i. e., rich in quarts with very little clay matrix.

Geologic affinities, including relationships or similarities in structures, geologic histories, ages and characteristics of sediments and basement suite occurrences, between the Philippines and the neighboring islands of Taiwan and the Indonesian Archipelago have been recognized. All these neighboring island groups have established commercial production of oil and/or gas. In all the sedimentary basins of the Philippines, great thickness of potential hydrocarbon source rocks in the form of deep-water shales and carbonate rocks rich in organic materials are known to exist. Oil bearing sands of sufficient thicknesses with adequate porosity and permeability are present while impervious clays and silts which can supply the necessary cap rocks are verified to exist in several sedimentary sections. Several structural and stratigraphic conditions capable of large-scale petroleum trapping have been mapped from the surface and confirmed by subsurface studies. Surface oil and gas seepages have been verified in several areas; notably in Cagayan, Bondoc Peninsula, Mindoro, Cebu and in Mindanao. Asphalt-impregnated vesicular basalt occurs in Camarines Sur. Several of the wells that have been drilled in various areas have encountered oil and/or gas shows at varied depths and lithologic intervals; some oil and/or gas freely flowed to sub-commercial levels.

Onshore drilling for petroleum started in 1896, and has continued intermittently to the present. Extensive geological and geophysical works in the onshore areas were

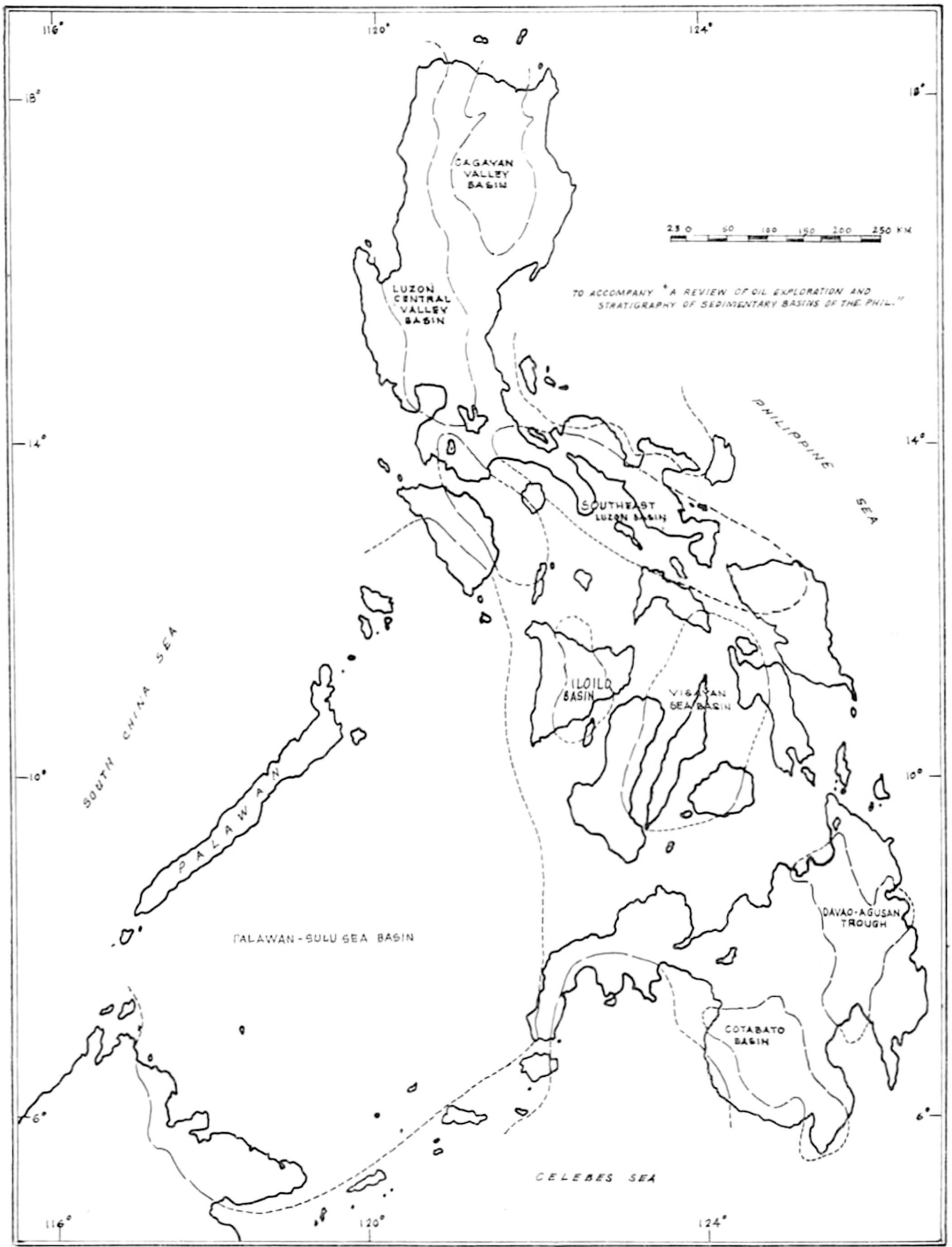

Figure 1. Location Map of Sedimentary Basins of the Philippines.

carried out between 1950 and 1963 and at the end of 1966 many prospectives areas were covered by detailed studies. Offshore exploration commenced in the middle 1950's and considerable work has been done before 1966. Offshore drilling started in 1971.

A total of 284 exploration wells with an aggregate footage of 806,980 have been drilled in the Philippines up to the end of 1974. Although the first well on record was spudded in 1896, wildcatting did not proceed extensively until 1950 after the passage of the 1949 Petroleum Law. Of the total wells completed, only 83 were drilled to depths over 3,000 ft. including the seven (7) offshore deep tests in the Palawan-Sulu Sea region. Sub-commercial oil discoveries were made in northern and central Cebu (Visayan Sea Basin) while gas deposit had been found in the Cagayan Valley Basin. On record however, there have been 18 wells with gas shows and 21 with oil and gas showings. Most of the drillnig have been directed to large anticlinal structures although lately, reef prospects and stratigraphic traps have been considered as equally potential targets.

Three onshire sedimentary basins have up to 1970 attracted the most attention from the wildcatters. Based on well density per unit area, the Visayan Sea Basin, particularly the island of Cebu, the Bondoc Peninsula of Southeast Luzon Basin and the Cagayan Valley Basin have received the brunt of exploratory drilling. Lately, however, the operation shifted and are focused on the offshore areas of Palawan and Sulu Sea.

Cagayan Valley Basin

The geology and stratigraphy of Cagayan Valley Basin presented in the 1966 edition of "Review and Assessment of Oil Exploration in the Philippines", are summarily reproduced in the following discussion. Additional information gathered from recent studies of the region are incorporated in the review.

a) Geology and Stratigraphy

The Cagayan Valley Basin is a north-south trending trough circumscribed by the Balintang Channel on the north, the Caraballo Mountains on the south, the Sierra Madre Range on the east and the central Cordillera on the west. The basin measures about 240 kms. long and 85 kms. wide covering an area approximately 20,000 sq. kms. The basin roughly coincides with the valley drained by the Cagayan River which flows along its central axis.

Several structural provinces are distinguished within the basin area. The Sierra Madre Range and the Cordillera Central are complex geanticlinal features consisting Tertiary volcanic rocks or their metamorphosed equivalents. They each appear as series of fault blocks that have been tilted either to the east or to the west. The general north-south trend of the basin margins is broken in the north by he north-east-oriented Cassigayan-Bajucan horst block. A similar positive feature exists in the south-west and these, plus another which may have existed in the mid-basin area during the early stage of basinal development, controlled sedimentation during early and middle Tertiary times. The basin gradually assumed its present shape commencing from late Miocene.

Several large anticlinal features which are separated by poorly-defined synclines occur along the flanks and central basin areas. The folds are sinuous, generally north-south trending and mostly strongly assymetrical to the east. They are believed to have originated late in the history of the basin and their existence appear to be due mainly to upwarping of the basin margins.

Economic basement is represented by a thick succession of pre-Tertiary metamorphic rocks and plutons which have been intruded and uplifted by igneous intrusives during the late Tertiary and Quaternary periods.

A thick marine clastic and carbonate section, ranging in age from Oligocene to Recent, occupies the main part of the basin. The section varies from 15,000 to 30,000 ft. thick along the flanks but attains a maximum thickness of over 40,000 ft. at the center.

Oligocene is represented by the Dumatata Formation consisting of an alternation of basic lava flows, partly metamorphosed agglomerate, tuff breccia and tuffaceous sandstones and siltstones. The formation is localized in the southwest portion of the basin where it unconformably overlies basement rocks and attains a maximum thickness of almost 2,000 feet.

The lowermost Miocene is represented by a massive biohermal limestone unit, the Ibulao Formation. In the southwest basin flank, the rock unit unconformably overlies the Dumatata. Here, the local term Sicalao has been adopted. The formation ranges from 500 to almost 2,000 ft. thick with the thickest section exposed in the vicinity of the type locality at Ibulao Gate in Ifugao. No well has so far penetrated the formation although it is believed to be present in the deeper part of the basin.

Conformably overlying the Ibulao are Lower to Middle Miocene sands, shales and silts comprising the Lubuagan Formation. The rock varies in thickness from 5,000 ft. in the east to approximately 20,000 ft. in the west where it has been subdivided into three members based on varying shale/sand ratio. The lower member called Asiga consists of shale and siltstone. The middle Balbalan is dominantly coarse sandstone and conglomerate whereas the upper member, the Buluan, is largely silty claystone with occasional gray-wacke beds. Recent structural drilling in the west-central basin area penetrated over 15,000 ft. of the formation without reaching the next underlying unit.

In the northeast basin area, the Middle Miocene Callao Formation unconformably overlies the Lubuagan. The rock is basically a reef complex which grades into a calcareous clastic facies basinward. Significant gas shows were obtained from the limestone during drilling; a sub-commercial reserve of 2.5 billion cubic feet having been computed in Ipil Well No. 1 in the southeast. The formation is significantly not represented in the west, hence, the next overlying unit, the Cabagan, unconformably overlies the Lubuagan in that area. The Cabagan which has been dated Lubuagan in that area. The Cabagan which has been dated late Miocene to Pliocene consists essentially of shale with limy sandstone, siltstone and conglomerate intercalations. The unit is widespread, attaining a maximum thickness of over 9,000 ft. in the west. In the east, the section is much thinner with a maximum measured exposed thickness of only about 2,400 feet. Here the Cabagan confirmably overlies or interfingers with the Callao.

The most widespread rock unit in the basin, the Pliocene to Pliestocene Ilagan Formation, consists of a lower marine shale and sandstone section and an upper marine sandstone and continental siltstone-conglomerate unit. The formation conformably overlies the Cabagan on both sides of the basin. A thicker development, however, is noted in the west where a thickness of over 7,000 ft. has been measured.

Late Pleistocene to Recent sands, silts, gravel and pyroclastic deposits belonging to the Awiden Mesa Formation are found in the central part of the basin. The section is entirely non-marine and attains a maximum thickness of over 2,000 feet.

b) Exploration Works

Extensive geological studies, including detailed section measurement, have been conducted in the entire basin area between 1955 and 1962. Reconnaissance airbone magnetometer and limited ground seismic and gravity surveys were undertaken mostly in the southern half of the basin between 1956 and 1960. Among the salient features brought out by the gravity surveys are: a) gravity gradients along the eastern and western fringes are generally steeper than in the central basin area; b) the denser Callao and Ibulao formations and basement rocks that are exposed along the basin flanks are either deep-seated or not present in the mid-basin area; and c) the gravity contours along the basin fringes trend generally north-south and that most of the surface-delineated structures are reflected either as closed highs or noses.

In general, the seismic results could be interpreted with fair accuracy and some features of interest, such as, the existence of sub-surface reefal build-ups which were not mapped on the surface were discovered. The over-all interpreted results revealed the following: a) sub-surface structural traps delineated by surface geological and gravity surveys were not confirmed by seismic reflections; b) the existence of several stratigraphic traps, including pinchouts, were uncovered particularly near and along the basin margins; and c) buried reefs were delineated in the south where gravity data indicated nose structures.

Drilling in the basin started in late 1956 and to-date a total of 15 structural and 4 stratigraphic holes with an aggregate footage of 138,496 have been completed. Significant indications of oil and/or gas were encountered at different levels in most of the deep tests. Ipil No. 1 well which was drilled in 1958 over a seismic structure reached a total depth of 7,260 ft. and made the biggest gas discovery in any well drilled in the country. The flow was measured at about 7 MMCFD with a conservative recoverable reserve of about 2.5 billion cubic feet from the reefal Callao limestone. Partial re-interpretation of previous results augmented by additional surface mapping particularly in the west-central part indicate a probable eastward migration of the basement block during particular stages in the over-all period of basinal development. Several additional prospective structures were properly drilled. On this basis two (2) shallow and three (3) structural deep tests were drilled from December, 1970 to January, 1975: Topac Strat. No. 1 (TD–726 ft), Pinto Strat. No. 1 (TD–1,278 ft.), Topac No. 1 (TD–15,708 ft.), Allangigan No. 1 (TD–8,545 ft.) and Allangigan No. 2 (TD–5,171 ft.). The wells were spudded in the Lubuagan Formation and were abandoned without reaching the next underlying unit. The holes are technically dry but they proved the presence of oil and gas in the Lubuagan. High pressure gas was encountered during drilling of Topac No. 1 however, it did not prove commercial on drill stem test.

On the whole, the wells so far drilled encountered sub-surface structural complexities and largely did not penetrate adequate reservoirs. All previous drilling in the basin were oriented towards the structural geological approach. Unfortunately, the mapped structures, although exhibiting strong appearance on the surface are often attentuated at depth or proved to be considerably more complex or non-coincident relative to their surface expressions.

c) Hydrocarbon Prospects

Prolific oil and gas seepages from the Lower Miocene section occurs in different parts of the basin, particularly in the northwest flank. Shows in most of the wells that have been drilled and source rock analysis indicated that suitable source rocks capable of hydrocarbon production exist particularly in the Lubuagan and Cabagan formations. Both sequences are marine and include paralic fine-grained clastics and carbonate rocks. It has been postulated that the Cagayan Basin was a silled basin, at least, during the Miocene, thus enhancing the hydrocarbon source rock potential of the area.

The older Tertiary sandstones entirely lack or are deficient in quartz. They consist largely of lithic and volcanic fragments and are rich in feldspars, hence, they are dirty and tight and are not very good reservoirs. The Ilagan and Awiden Mesa formations contain better reservoir prospects however, they are generally separated by a wide stratigraphic interval biohermal facies of the Callao Formation is considered the best reservoir rock in the basin. Carbonates from the Lower Miocene section which likewise show reefal characteristics may also represent reservoir prospects but to-date these have not been adequately tested. Most of these limestone bodies are enclosed, both laterally and vertically, by marine shales and silts regarded as both source and cap rocks.

The marginal areas of the basin that were not exposed much by subsequent uplift afford good areas to search for porous reef limestone. The fact that buried reefs could contain oil or gas generated from adjacent clastic sediments is demonstrated in the Ipil area. The advent of digital seismic methods together with computerized processing, should enable more reef traps to be located in many parts of the basin. Such useful and sophisticated tools were not available at the time when extensive exploration works were being carried out in the region. A re-study of the exploration effort following new trends of thought and approach to better understand the basin geometry or depositional history may revitalize the belief that commercial quantities if hydrocarbons exist in the Cagayan Valley Basin.

Luzon Central Valley Basin

In the 1966 edition of "Review and Assessment of Oil Exploration in the Philippines", detailed descriptions of the stratigraphic sequences in five major exposure areas in the Central Valley were presented. The presentation is hereunder condensed to include a discussion on the mid-west basin area which did not appear in the original text. Additional information are likewise incorporated in particular sections.

a) Geology and Stratigraphy

The Central Valley is one of the prominent structural features in Luzon. It is a north-northeast trending elongate trough which opens in the north into Lingayen Gulf and in the south into Manila Bay. It is bounded along the east by the Sierra Madre Mountains and the Cordillera Central and along the west by the Zambales Range. The basin measures roughly 190 kms. at its widest part, covering an area about 12,500 sq. kilometers.

The Zambales Range along the west is a volcanic belt consisting chiefly of ultrabasic to basic plutonic intrusives and andesitic to basaltic flows. The Central Cordillera and Sierra Madre Mountains which bound the eastern side of the geosyncline is composed of faulted, folded and locally intruded metavolcanic and metasedimentary rocks including tuff breccias, agglomerates and andesite flows. The Philippine Rift, a zone of left-lateral strike slip faults, cuts across and separates the geosyncline from the two eastern mountain ranges. Isolated volcanic plugs occur generally near the basin margins, but one extinct volcano, Mt. Arayat, is present near the center. The basin is believed to have undergone two major cycles of inundation since the beginning of the Miocene. The first commenced during early Miocene with shelf carbonate and clastic deposition that gave way to deep water clastic sedimentation throughout most of the remainder of the Miocene. A second shelf-type carbonate deposition developed within the marginal areas during middle Miocene and simultaneously, the mid-basin area received deeper water detrital carbonates and clastics. Late Miocene diastrophism interrupted the deposition of deep water clastics and this resulted in the differential erosional truncation of Miocene strata. The second cycle of marine inundation occurred during the Pliocene with subsequent rapid sedimentation and subsidence producing shallow water and even non-marine deposits that blanketed the truncated Miocene strata in the basin. Five major anticlinal folds have been mapped. They generally follow the north-northeast regional structural trend and are all assymetrical with the steeper limbs to the east. Several other gravity highs and magnetometer anomalies which includes prospective fault structures have been delineated.

Lithofacies within the basin is so markedly pronounced that no standardized stratigraphic column could be devised to show clearly the relations of the marginal areas with each other and with the basin as a whole. Five principal areas of exposures have been distinguished.

In the east central margin, the section ranges from Miocene to Pleistocene and exceeds 12,000 ft. in total thickness. The Angat Formation of early to middle Miocene age consists of a basal clastic and an upper biohermal limestone facies. The formation unconformably overlies basement metavolcanic and metasedimentary rocks and is in turn conformably overlain by the clastic member of the Middle Miocene Madlum Formation. Together with the middle Alagao Volcanics and the upper Buenacop Limestone Members, the Madlum attains a minimum exposed thickness of 3,000 feet. The clastic member is essentially a thin to medium bedded sandstone and silty shale sequence with minor limy sandstone intercalations and conglomerate at the base. The Alagao Volcanics Member consists of agglomerate, tuffs, graywackes and andesite flows whereas the Buenacop is a typical reef complex limestone which either overlies the Alagao or forms a wedge within the clastic member.

The Upper Miocene Makapilapil Formation consisting of tuffaceous sandstone and silty shale with conglomerate lenses is unconformable over the uppermost clastic section of the Madlum. The formation is localized in the northern sector of the mid-eastern Central Valley region where a maximum exposed thickness of 3,200 feet has been estimated. Further south in the same general area, the age-equivalent Lambak Shale disconformably overlies the Madlum. The Plio-Pleistocene Tartaro Formation consisting of claystone and siltstone locally unconformably overlies either the Madlum clastics or the Buenacop Limestone and is in turn overlapped by the Pleistocene Guadalupe Formation. The latter formation which is the youngest in the basin consists of a lower marine to continental tuffaceous siltstone and tuff sequence the Diliman Tuff Member.

The sedimentary sequence in the southeast flank of the basin is broken by major faults and the older strata are locally intruded by plutonic rocks. The section ranges from Cretaceous to Pleistocene and reaches over 10,000 ft. in aggregate thickness. The oldest unit, the Kinabuan Formation of Cretaceous to probably Early Paleocene age consists of tuffaceous sandy shale and limy sandstone unconformably overlying or in fault contact with older metavolcanic and metasedimentary rocks. The formation is about 2,000 ft. thick and contains a rich *Globotruncana* fauna indicating upper bathyal deposition. Conformable over the Kinabuan is a thick (over 6,000 ft.) succession of siliceous argilites, graywacke, shales and sandy limestone designated the Maybangain Formation. The unit is dated probably Paleocene-early Oligocene based on large foraminiferal species found in the limestone beds. The Angat Formation conformably overlies the Maybangain and is in turn directly overlain by the Madlum Formation. These two units have an aggregate thickness of over 6,000 ft. Small and large foraminifera species present indicate deposition in shallow to moderate depths during early to middle Miocene time. The Pleistocene Laguna Formation consisting of tuffs, agglomerates and volcanic flows generally unconfrmably overlies the Madilum. The formation is barren of fossils however, lithologic similarities and stratigraphic position suggest correlation with the Diliman Tuff Member of the Guadalupe Formation in the mid-basin area.

The western flank of the basin contains about 15,000 ft. of predominantly clastic Tertiary deposits. The section consists of a basal, Eocene to Oligocene, detrital limestone designated the Aksitero Formation. The unit unconformably overlies pre-Tertiary meta-volcanic and metasedimentary rocks (basement) and is unconformably overlain by a thick succession of Lower to Middle Miocene sandstone, shale and pebble conglomerate—the Moriones Formation. Late Miocene tuffaceous sandstone and shale and vitric tuffs (Malinta Formation), over 4,000 ft. thick, unconformably overlie the Moriones and is in turn unconformably overlain by a 3,000 ft. thick sequence of Upper Miocene shales and sandstones referred to as the Tarlac Formation. Plio-Pleistone tuffs and gravels of marine and continental origin form a blanket over the central part of the basin.

In the northern Luzon area, the total sedimentary sequence exceeds 19,000 ft. thick and is transected by several faults associated with the Philippine Rift. The basal Benguet Limestone of early middle Miocene age unconformably overlies older metal volcanics and intrusives. The rock is massive, grading upward into coarse sandstone with localized volcanic conglomerate and agglomerate development at the base. The Middle Miocene Labayog Limestone found in the western north Luzon area is probably a facies equivalent of the Benguet. The unit is a typical shelf deposit consisting of coralline sandy limestone interbedded with marly sandstone with minor conglomerate at the base. Unconformably overlying is the Bued Canyon Formation consisting of dark-gray, well-consolidated conglomerates alternating with graywacke and sandy shale. The formation is at least 7,000 ft. thick in the type locality along Bued Canyon and is considered of late middle Miocene age. The Amlang Formation consists of an interbedded sequence of tuffaceous sandstone and sandy shale in beds reaching over one meter thick. Faunal associations indicate a late Miocene age for the unit; deposition evidently having taken place within outer neritic to upper bathyal depths. The Pliocene Aringay Formation unconformably overlies the Amlang. The unit is over 8,000 ft. thick and includes both marine and non-marine sandstones, siltstones and shales.

Though not directly above the Aringay, the Bacnotan Limestone or its faces equivalent, the Mirador Limestone, occupies the next higher position in the reginoal stratigraphic succession. The Bacnotan crops out along the coastal areas particularly in Bacnotan, La Union where the type section was designated. The rock is massive to poorly bedded, detrital, coralline and crystalline. The onshore section was observed to extend offshore and to merge with reefs growing under shallow water in the shores of Lingayen Gulf. The age-equivalent Mirador Limestone which occurs in the highland areas particularly in the Baguio district is lithologically very similar. The unit is generally unconformable over the Bued Canyon Formation and is estimated not to exceed 400 ft. in thicknes. Both carbonates are Pliocene to Pleistocene in age.

b) Exploration Works

Surface geological studies aided by air-photo geology have been carried out by several private organizations and the Philippine Bureau of Mines. Work started in 1955 and by 1962, the entire basin area was almost wholly covered by semi-detailed or detailed studies including stratigraphic section measurement of type sections and detailed sampling for biostratigraphic correlation. Exploration geophysics was initiated by a reconnaissance airborne magnetometer survey in 1956. Between 1958 and 1959, land gravity and magnetometer surveys were simultaneously undertaken over selected areas. These were supplemented by reflection seismograph surveys starting in 1960 primarily to check interesting gravity anomalies and surface defined structures. Among the salient features delineated by the gravity were: a) gravity contours generally trend north-south to northwest-southeast following the regional trend of the structures; b) the valley area is reflected as a gravity minimum, the gradient becoming steeper near the basin edges; c) surface defined anticlinal features are reflected on the Bouguer or residual maps as closed highs or as slight nosing of the contours. Seismic results generally confirmed the existence of surface geological and gravity defined structures and their subsurface closures. In the northern half of the basin, at least 4 broad and well defined anticlinal features were defined, however, they all appear to be faulted in the west or southeast flanks. No interesting features were revealed in the southern half of the valley basin.

So far, only nine wells (aggregate footage=51,913 feet) have been drilled in the basin area. Most of the wells were drilled in the western part of the basin hence, very little is known about the subsurface geology of the eastern side. The more significant work was carried out by Union Oil which drilled a series of 5 deep structural tests between 1963 and 1964 over 3 promising structures. Camiling No. 1, the deepest in the five well series at TD 11,229, encountered fairly good gas shows at several intervals however, as in the other four, it did not prove commercial on testing.

Except for limited geological review and re-evaluation studies, no significant additional work has been conducted in the basin area since about the end of 1964.

c) Hydrocarbon Prospect

No oil seeps are known to exist in the basin area, although a number of gas emanations have been reported.

The basin contains a large volume of marine clastics and carbonates some of which are considered good hydrocarbon source rocks. The sandstones are lithic, containing abundant feldspars and volcanic detritus with little quartz. The decomposition of the feldspars has resulted in the formation of abundant clay interstitial materials hence, porosity and permeability of the sandstone has been much reduced. Reefal developments along the margins of the basin could provide favorable reservoir condition and are mostly adequately capped by impervious clays or shales. Exploration for reef type anomalies has practically been unatempted therefore, an approach towards them may prove rewarding.

At least three known major anticlines have been deeptested and proven by drilling. Several other large structures which were delineated from the surface and confirmed by gravity and magnetometer surveys have remained untested. The Bamban Prospect in the southwestern basin region is a large anticline delineated by magnetometer. Residual gravity indicates a closed north-south anomaly whose axis closely coincide with the surface axial trace. Depth to basement as indicated by the gravity is approximately 14,800 feet. The Baluñgao Prospect in the central basin area consists of four gravity and/or magnetic-delineated anomalies which are interpreted to represent closed folds or fault traps which involved the Middle Tertiary clastic formation. Magnetometer data indicate probable depths to basement as ranging from 5,000 to 6,000 feet. The Manila Bay Prospect includes five north-south trending gravity highs extending from Manila Bay to the southern tip of Bataan Peninsula. The gravity anomalies were interpreted as structural folds with depth to basement at approximately 6,500 feet.

Southeast Luzon Basin

This basin covers the Bondoc Peninsula and the southern extension of Luzon, possibly stretching southeast into the island of Samar.

The better studied areas are the Bondoc and Bicol Region, and little is known about the geology and petroleum prospect of Sammar. This part of the review includes a correlation of the stratigraphy of north and south Bondoc Peninsula based on the results of the more recent surveys in the area. The stratigraphy of the Bicol Region was condensed from the original text of "Review and Assessment of Oil Exploration in the Philippines."

A. Bondoc Peninsula

a) Geology and Stratigraphy

Structurally, the peninsula is a sohutheast plunging anticlinroium extending approximately 2,500 sq. kms. and lying on the northeast limb of a synclinal basement. The region is transected by branches of the Philippine Rift and the sediments are mildly and locally metamorphosed. Tight northwest trending folds and major longitudinal type faults running parallel to the trend of the peninsula characterize the region.

The composite stratigraphic column established by the Bureau of Mines indicates a total thickness of 15,000 to 20,000 ft. The section which ranges from Miocene to Pleistocene includes a basal Lower to Middle Miocene bathyal to neritic sandstone/shale sequence with carbonaceous layers (Vigo Fm.) reaching over 8,000 ft. thick in the north where it is given a facies name Gumaca Formation. Oil and gas seepages are known to emanate from this unit particularly in the south. Unconformably overlying is the Canguinsa Formation of late Miocene age and consisting of clayey sandstone and shale with minor limy sandstone interbeds. The Upper Miocene Pitogo Conglomerate which includes thin detrital limestone beds unconformably overlies the Gumaca in the northwest but is conspicuously absent in the south. The unit is probably the equivalent of the Lower Canguinsa in the north. Unconformable over the Pitogo in the same area is the Hondagua Formation of Pliocene age and comprising mostly of siltstone beds reaching approximately 3,300 ft. in thicknes. Locally, the Hondagua is conformably overlain by Pliocene interbeds of shale and sandstone with limestone base belonging to Viñas Formation. Maximum thickness exceeds 1,500 ft. east of Calauag in the north. The richly coralline Malumbang Limestone of Pleistocene age disconformably overlies the older formations and is widespread in the south-central region.

b) Exploration Works

The region, owing to the existence of several oil seepages, has long been recognized as an area of potentially important petroleum occurrence and therefore has been subjected to several intensive geological investigations. Detailed surface studies including some gravity and reflection seismic work were carried out by private companies between 1954 and 1962 whereas the Bureau of Mines conducted its own investigations which included measurements and stratigraphic correlation in 1967. Stratigraphic and structural drilling have been conducted as early as 1921, intensively pursued between 1947 and 1960 and resumed in 1971. A total of 21 wells with an overall footage of 93,058 have been drilled. Significant shows were encountered in several intervals with a small production attained from at least one well.

c) Hydrocarbon Prospect

At least 8 major and several minor anticlines extending from 10 to 40 kms. long arranged en echelon follow the northwest trend of the peninsula. The folds are tight and largely dissected by large fault structures from which hydrocarbons emanate. Drilling has been carried out on some of the structures, but, on the whole, the majority has so far been untested. The two test wells, Aurora No. 1 and No. 2 drilled by White Eagle in 1971 in west-central Bondoc penetrated hydrocarbon bearing sandstone beds in the Canguinsa and Vigo sections, however, subsequent tests proved them non-commercial.

B. Bicol Peninsula

a) Geology and Stratigraphy

The Bicol region in southern Luzon covers an area approximately 3,640 sq. kms. The composite sedimentary section which aggregates over 15,000 ft. in thickness is exposed in the central plain area and bordered by northwest aligned rows of volcanoes in the northeast, a block of igneous rocks on the west central part and a blanket of Quaternary tuffs in the south.

The stratigraphic column includes a thin, basal fractured Eocene limestone unit (Pantao Limestone) unconformably overlain by a very thick bathyal to neritic clastic and carbonate sequence (Bicol Fm.) of Miocene age. Resting unconformably over the Bicol Formation is the upper Miocene Albay Group consisting of a carbonate/siltstone/sandstone siute reaching over 8,600 ft. in thickness. The Pliocene-Pleistocene Ligao Formation and its facies equivalents, the Sorsogon and Nabua formations are varied assemblages of limestone, sandstone, marl and pyroclastic rocks. These units either unconformably or conformably overlie the Miocene section and are in turn blanketed by Pliocene-Pleistocene marls, tuffs and basalt flows (San Roque Tuff).

b) Exploration Works & Hydrocarbon Prospects

Reconnaissance and semi-detailed surface geological work puls limited gravity survey were conducted by private organizations between 1954 and 1959. The Bureau of Mines conducted its own geological and gravity surveys in the region between 1961 and 1964. A total of 23 shallow stratigraphic holes with a total footage of 20,280 were drilled. Only 6 wells were drilled more than 1,000 feet with the deepest at 3,000 feet total depth. Minor gas shows were encountered in some although, in most cases, drilling was not carried out deep enough to penetrate the probable reservoir beds.

A more extensive exploration work, to include detailed section measurement and additional geoyhysical surveys and deep tests should be carried out to make a more factual assessment of the hydrocarbon potential of the region.

C. Visayan Sea Basin

The present review presents in brief, the regional stratigraphy of the Visayan Sea Basin as a sequence to an earlier review of the onshore stratigraphy of the different provinces composing the basin. Also included is a summary of the more recent exploratory drilling activities in the region.

a) Geology and Stratigraphy

The Visayan Sea Basin is a major structural depression in Central Philippines cosnidered a feature superimposed on the main Philippine archipelagic basin. It is roughly ovoid in shape, oriented north-south and measures aproximately 275 kms. long and about 160 kms. at its widest part. The basin covers in part, the islands of Negros, Masbate, Cebu, western Leyte, northeastern Panay, northern Bohol, and the Camotes Islands but the major portion of the area occupied by sedimentary rocks lies beneath the Visayan Sea, Tañon Strait and Camotes Sea. The southwestern margin is covered by extensive Quaternary volcanic flows whereas the eastern margin is interrupted by a Pleistocene volcanic belt in Leyte.

The composite sedimentary column which reaches up to 25,000 ft. thick in exposure but possibly attains a maximum thickness of 35,000 ft. in the offshore areas is distributed into five nomenclatural groups separated by regional unconformities in most parts of the area. At least 10 lithologic formational units above the basement complex are distinguished.

The basement which is exposed in Central Cebu, northeastern Panay, Masbate and Bohol includes a complex suite of ultra-basic rocks and basic igneous intrusives closely associated with shattered fossiliferous limestone and metamorphosed shales. Unconformably overlying the basement is the Mindanao Group which includes the Lutak Limestone, Dumatata Formation and an unnamed Orbitolina limestone unit all of Paleocene to early Oligocene age. The Dumatata consists of silicified mudstones, limestones, welded tuffs and basaltic flows. The Oligocene to Lower Miocene Argao Group with a maximum exposed thickness of more than 9,000 ft. unconformably rests on beds equivalent to the Dumatata. Included in the Group are three distinctly mappable clastic and limestone units, the Calagasan Formation, Cebu Limestone and Malubog Formation. Overlying is the Middle to Upper Miocene Talavera Group consisting of two largely bathyal clastic formations (Maingit and Toledo) with a maximum exposed thickness of 3,000 ft. in northwestern Leyte. The Barili Group which includes a lower limestone (Barili Limestone) and an upper marl section (Bolok Formation) rests with a distinct angular unconformity over the Talavera. The two units attain a maximum exposed thickness of 4,290 ft. and a possible maximum thickness of 5,000 ft. in the offshore as shown by subsurface isopachs. The age is late Miocene to early Pliocene. The Hubay Group of Pliocene to Pleistocene age unconformably rests on the Barili. The section consists of a basal limestone (Carcar), a middle sandstone/shale sequence (Ilagan), and an upper tuffaceous clastic and tuff section (Awiden Mesa) with an estimated aggregate thickness of 1,500 ft.

It is believed that the basinal depressions within the structural trough are presently being filled up with detrital sedimnts. The Plio-Pleistocene Carcar Limestone is observed to extend seaward and merge with coral reefs that fringe most of the shoreline areas in the different islands.

b) Exploration Works

Extensive field geological mapping, land gravity, magnetic and seismic surveys, aeromagnetic and, lately, offshore reflection seismic and magnetometer surveys have been carried out in the region. The basin, in particular the island of Cebu, is considered the most extensively drilled area in the Philippines. A total of 179 shallow and deep wells with an aggregate footage of 407,040 have been drilled in the region. Several of these, more specifically those drilled in Cebu have given very good indications of oil and/or gas while a few actually produced limited amounts of very good quality oil.

After a lull of more than five years, exploratory drilling in Visayan Sea Basin was renewed with feverish tempo in late 1970.

In August 1970, Cletom and Associates, a California-based group spudded Cletom Well No. 102A-16, the first exploratory well for oil since 1964. The well is the 18th of a series drilled since 1960 over the Alegria Anticline in PEC-6 in southern Cebu, owned jointly by REDECO and PODCO. The well was at a total depth of 1,750 ft. Oil shows were reported at two intervals, 1,222–1,280 ft. and 1,473–1,520 ft. within the Middle Miocene Maingit Formation. Drill stem tests conducted on the two horizons however, were both unsuccessful as the tool failed to open in both instances. The second of the first to a total depth of 1,883 ft. A 22 ft. vugular limestone horizon within the upper Maingit section which showed slight oil fluorescence during drilling was drill stem tested. No oil was produced during the test however, approximately 420 lb/sq. inch of formation pressure was recorded. The third hole, Cletom 102A-20, has a total depth of 1,534 ft. The site is 400 m. west of the 102A-21 location and 800 m. directly south of the discovery well, Lumpan #1, drilled in 1964. The well was reported to have encountered 44 ft. of hydrocarbonbearing sand at bottom that flowed approximately 13 bbls. of light oil in eight minutes with pressures exceeding 650 lb. per square-inch. A 24-hours regulated flow test produced no oil with significant pressure drops registered in both the tubing and caisng head valves. The fourth well, Cletom 102A-29 was drilled as an offset well, 1,320 ft. south of Cletom 102A-20. The well reached TD 2,350 ft. Two gas horizons were encountered at 1,820 to 1,935 ft. and 2,065 to 2,110 ft. which appear to be structurally higher than in 192A-20. The pay zones when subsequently drill stem tested produced gas to surface with oil flowing intermittently with gas from the lower zone. Production test flowed gas and oil cut mud and filtrate at varying rates. To-date, work over job is planned to develop the promising gas prospect. The fifth well Cletom 102A-33 was drilled on May 22, 1972. It reached a total depth of 3,153 ft. with oil and gas shows from the same Maingt sandstone reservoir.

On the same Alegria structure, REDECO Well NR-1 was spudded on June 6, 1973 and was drilled to total depth of 1,007 ft. bottoming on the Maingit formation. Two possible pay zones, the 944–977 ft. and 985–1,005 ft. intevals were drill stem tested resulting in recovery of some amount of oil and gas.

In Badian Island, southwestern Cebu, Pacifica, Inc. spudded on February 19, 1971 Badian No. 1. The well was drilled to a total depth of 3,974 ft. in Upper Miocene limestone of the Maingit Formation. Core and log analyses did not indicate any significant zone.

On June 7, 1974 Chinese Petroleum Corporation spudded CPR No. 1 on the southern extension of the Alegria-Malabuyoc structure and proceeded to drill to TD-5,210 ft. into Maingit Formation. Gas cut in mud and oil shows were encountered while drilling the Maingit clastics. Drill stem tests were conducted on seven (7) prospective zones containing an aggregate thickness of 136 ft. of Maingit sandstone however, all the tested intervals were found saturated with fresh water with some amount of gas cuts and paraffin-base crude oil similar to the type produced from nearby REDECO wells.

In northern Cebu, following a joint venture agreement with Pioneer Natural Resources in the operation of AAOC concessions, Taiwan-base CPC completed eight (8) wells from April, 1971 to July, 1973: Sta Fe No. 1 (TD-7,563 ft.), BTY-1 (TD-7,686 ft.), CMB No. 1 (TD-3,340 ft.), CMB No. 2 (TD-3,173 ft.), CMB No. 3 (TD-3,740 ft.), CMB No. 4 (TD-2,580 ft.), DAB No. 1 (TD-7,888 ft.) and TLS No. 1 (TD-6,122 ft.), Sta. Fe No. 1 was drilled over a seismic high and BTY-1 was spudded on top of the Bito culmination of the Bantayan Bito fault in Bantayan Island. The wells penetrated Pleistocene to Lower section without encountering any significant oil and/or gas bearing zone. All succeeding wells were drilled on the seismic-defined Maya Anticline on the northern tip of Cebu to test the reservoir possibilities of the sandstones of Middle-Upper Miocene Maingit Formation and the sandstone and limestone lenses within the Lower Miocene Malubog Formation. Oil and gas cut were recognized from drill cuttings and core samples at various intervals, however, subsequent tests found the prospective zones saturated with water with only some amount of oil and gas.

In Borbon, Cebu, two test wells were programmed and subsequently drilled by South Seas for Acoje Oil in their concession area, PEC-32. The first well, Sagay M-2 was spudded on November 2, 1973 and abandoned as dry at 2,768 ft. after encountering severe lost circulation problems while attempting to drill thru the Barili Limestone. The second well, Sagay M-1 was spudded about 1.8 kms. southwest of Sagay M-1 and was drilled to 4,648 ft. when formation sloughing became persistent at depth. Oil cut was observed both in the mud and washed and unwashed cuttings consisting of dirty sand probably belonging to Malubog formation.

c) Hydrocarbon Prospects

Several anticlines have been mapped and/or delineated by geophysical methods in the region. At least 11 are welldefined and are on land, 26 are considered fair to good prospects while others are either defined only by surface geological studies and have been partially tested or are in deep waters. Fault prospects, stratigraphic pinch-outs and reef possibilities are also present in the area. The Philippine Rift is probably a key to the regional tectonics of the area and among the results are folds and faults in the region.

Surface hydrocarbon indications from the sedimentary groups in outcrops, shows in various exploratory holes, and oil and gas discoveries all indicate that there are probably several parts in the stratigraphic section which are probable sources for oil and gas. Generation of hydrocarbons are known particularly from the Middle and Upper Miocene groups.

Iloilo Basin

A comprehensive review of the stratigraphy and hydrocarbon prospects of Iloilo Basin is made in as much as these have not been part of the original text. Supplementary information on drilling activities in the region are included in the following discussion.

a) Geology and Stratigraphy

The region known as the Iloilo Basin constitutes a roughly rectangular area, approximately 5,500 square kilometers covering parts of Aklan and Antique provinces and a major portions of Capiz and Iloilo provinces in the island of Panay. It lies between the two principal mountain ranges of Panay, the western Cordillera and the eastern Cordillera. Its northern end opens to the Sibuyan Sea while its southern end opens to the Guimaras Strait.

The "Basement Complex" in Iloilo Basin is composed of complex suite of igneous and metamorphic rocks whose collective shape and surface distribution define the basin area. In the southwestern end of the Basin, the Basement constitutes a varied assortment of green-colored serpentinized rocks, basalt flows, slates and metavolcanic rocks and, in places, agglomerates and metamorphosed fined grained mafic volcanics. At the eastern rim of the basin are extensive outcrops of pre-Miocene diorite bodies. In the northcentral part, approximately along the basin axis is a dikelike igneous body consisting mainly of basaltic agglomerate.

The oldest formation, unconformably overlying or in fault contact with the basement in the west side of the Basin is a sequence of Upper Oligocene to Miocene sandstone, shale and reefal limestone designated as the Singit Formation. The formation derived its name from Mount Singit, a prominent peak in the west central part of the basin.

Regionally, the Singit Formation is made up of three lithologic sequences. A limestone facies to the Sewaragan Complex in the southwestern part of the basin is considered a fourth member of the formation.

The Sewaragan Complex Member was named after its type locality along the Sewaragan River in the southwest. Three lithologic types compose the Sawaragan, namely: 1) Metasandstone—the rock is massive, partly re-crystallized, hard, dense and brownish gray to dark gray; 2) Argillites and slates—these two rock types are either interbedded with the meta-sandstone or occur as thin to medium bedded sequences of considerable thickness. The argillites are gray, well indurated, brittle and fossiliferous while the slates are characteristically hard, dark colored and exhibit excellent fissility; 3) Basalt flows, sills and dikes are associated with the above two sedimentary rock types. Massive flow-layered basalt which, in places, appears agglomeratic are typical of the dikes. Reference measured sections in the south and west-central basin areas show maximum exposed thicknessess of 3,990 ft. and 7,350 ft.

The Tanian Limestone Member includes a downslope facies which is interlayered with the above metasandstone and argillites and an upslope facies which makes up the bulk of the rock unit and directly caps the Basement Complex. The downslope facies consists of hard and thick bedded, fragmental to detrital limestone with thin, friable sandstone partings, and pure, buff colored dense limestone honeycombed with solution cavities. The sequence is 90 ft. thick in the type locality along the Tanian River headwater in the southwest. The upslope facies is hard, dense, buff to light cream and composed essentially of microcrystalline calcite. It occurs as discontinuous isolated bodies as much as 450 ft. thick. Both facies yield Middle Miocene large Foraminifera.

The Igtalongon Shale Member is a shale-siltstone unit. In the type section along Tanian River the unit is generally dark gray to brownish gray, largely calcareous, fossiliferous and carbonaceous. The sandstone beds are light gray to buff, coarse to fine grained, tightly consolidated, calcareous and fossiliferous. Unusually thick-layers of calcareous graywacke and conglomerate occur in the sequence. Zonation studies on fossil collections from the Igtalongon sections indicate a Teritary for middle to late Miocene age. Measured thicknesses vary from approximately 2,470 ft. in the north to as much as 4,635 ft. in the south.

The uppermost member, Barasan Sandstone, conformably overlies the Igtalongon and consists of thick bedded, coarse grained sandstone and massive cobble conglomerate with occasional shale partings. Towards the mid-basin area the sandstone grades from lithic to quartz type. From fossil assemblages identified mostly from the silty shale partings, the unit was determined to be of Tertiary f_3 or late Miocene age. Reference sections measured in the north-central and north-western portions of the basin gave aggregate thicknesses of 5,500 ft. (1,678 meters) and 6,670 ft. (2,034 meters) respectively.

Generally conformable on the Singit is the Tarao Formation. The lithologic characters of the formation allow its sub-division into two distinct members, the Tubungan Siltstone and the Guimbal Mudstone.

The Tubungan Siltstone Member was named after the town of Tubungan in the southwest where it is best exposed along the Har-ao River. It consists chiefly of a rhythmic alteration of thin bedded siltstone (or fine sandstone) and claystone (or shale) with occasional thick bedded mudstone and sandstone. It is slightly carbonaceous with the organic matters occurring as streaks, patches or irregular lumps. A thick conglomerate bed, at places, marks the top of the member. The unit was observed to conformably overlie the Barasan Sandstone. The type section along the Har-ao River measures 3,960 ft. (1,206 meters) thick however, farther north the thickness was determined to be 7,260 ft. (2,214 meters). The Tubungan was determined by paleontology to be Tertiary f_3 (late Miocene) age.

The Guimbal Mudstone Member is composed essentially of soft, thick bedded, homogenous, highly calcareous and foraminiferal mudstone. It is greenish gray when wet and light gray to pale cream when dry. Clay minerals and silty materials are the chief constituents. Locally however, non-persistent sandy beds are interlayered. The unit is best exposed in the Har-ao River section wherein it attains an exposed thickness of approximately 3,830 ft. (1,166 meters). Downsection the rock grades into rhythmic alteration of siltstone, claystone and sandstone typical of the underlying Tubungan. The lithologic boundary between the two corresponds with a time boundary. Fossil examination revealed its age to be Tertiary g (early Pliocene).

Overlying the Tarao is the Iday Formation, a sequence of carbonaceous conglomerates, fine sands and clay. The formation was named after Iday Hill, a conglomerate hogback in the west-central part of the basin. The different lithologic types occur as layers and lenses of various thicknesses intergrading with each other. Constituent pebbles and cobbles are commonly volcanics and occasionally, limestone and diorite. The interbedded sandstone and mudstone are generally fossiliferous and calcareous and contain randomly scattered diorite and volcanic pebbles.

The contact of the Iday Formation with the overlying Ulian Formation is gradational and conformable. The lower contact with the Tarao Formation is also gradational but locally the surface appears irregular. Paleontological studies indicate the Iday Formation to have been deposited under both shallow water and deep marine conditions. The measured reference section of the Iday along Ulian River in the mid-basin area is 2,230 ft. (681 meters) thick.

The Ulian Formation represents the last deep water deposit in the Iloilo Basin. The major portion of the formation consists of greenish gray, massive-bedded, homogeneous, highly calcareous and fossiliferous claystone or mudstone with occasional sandy or silty partings. In the northeastern flank of the basin where the Ulian grades into the Dingle Formation, the lower part of the section contains impure limestone with silty mudstone interbeds. In the western margin of the basin, pebbles and granules of volcanic rocks randomly occur in the lower bed of the Ulian. At least 400 ft. (123 meters) thick of Ulian sediments were measured in the reference section along Ulian River. The section however, is not complete. In the other portions of the basin, the unit was determined to be as much as 1,700 ft. thick. Paleontological determinations indicate Pliocene (Tertiary h_1) age for the Ulian.

The youngest formational unit is the Pliocene-Pleistocene Cabatuan Formation named after the town of Cabatuan in the south-central portion of the basin. The formation is subdivided into three members based on lithology, stratigraphic relations and faunal evidence.

The lowermost Balic Clay Member is lithologically similar to the Ulian. The unit is essentially dark gray, homogenous, soft, highly fossiliferous, thick bedded mudstones. In the designated type section along Cabatuan River the sequence is dominantly silty claystone with interbeds of fine grained sandstone. Cobbles of volcanic rocks are randomly scattered in both lithologic types. The unit contains excellently preserved megafossils. Directly overlying with gradational contact are the cobbly sandstones of the Maraget Member. Locally a slight disconformity was observed to separate the two units. Although the unit is presumed to occur extensively in the subsurface, exposures were observed to be confined in the south central part of the basin.

The Sta. Barbara Silt Member consists of poorly bedded gray sandstone with occasional siltstone and minor claystone layers. The sandstone is generally massive, gray to brown and coarse grained to silty with tuffaceous constituents. Lithologic differences and stratigraphic relations are poorly defined hence, the rock locally appears as a lateral facies of the overlying Maraget Sandstone Member.

Type section of the Maraget is at Barrio Maraget located four (4) kilometers northwest of Cabatuan town proper in the south-central basin area. Here, the unit consists of brown, medium to fine grained, fossiliferous and well bedded calcareous sandstone. At places, the upper beds are ferruginous and cross-bedded with white tuffaceous claystone partings. The sandstones are generally loosely consolidated, very porous and friable, permeable and light. Fossil content is limited to the siltstone interbeds and the fine grained sandstone. The lower beds are largely siltstone with occasional mudstone and coarse grained layers. A representative section in the vicinity of the type locality shows the unit to be at least 1,290 ft. (392 meters) thick. The unit is the only member of the Cabatuan which is represented in the east side of the basin.

In the east, the stratigraphic section is comparatively thinner than in the west. The Oligocene unit exposed in the west is concealed or not represented hence, the Lower Miocene Passi Formation directly overlaps the basement metavolcanics and intrusives. The formation, named after the town of the same name situated at the junction of the Jalaur and Lamunan Rivers in the north central part of Iloilo province is composed essentially of dark colored, very coarse to fine grained sedimentary rocks. Two members; the Salngan and Assisig, have been distinguished. The formational contact with the overlying Dingle Formation is a distinct lithologic break marked by faunal discontinuity. Both lithology and fossils indicate shallow, if not fluviatile environment.

The Salngan Member is a uniformly interlaminated sequence of mudstone, indurated sandstone and shale. The unit was defined after exposures in Barrio Salngan about 10 kilometers north-northeast of Passi town where it rims the volcanic rocks prevalent in the eastern border of the basin. In comparison with the overlying Assisig Member, the Salngan is metamorphosed and altered thus, making lithologic differentiation easier. In the type section along Ginayan River the Salngan is about 1,220 ft. (373 meters) thick. Along Assisig River, where a reference section was measured the sequence is at least 1,130 ft. (345 meters).

The Assisig Member is essentially a suite of uniformly stratified, thin bedded, light greenish brown, fine grained sandstone and shale. Locally, massive conglomerate or pebbly sandstone is present at the base and thickning of beds is manifested midway along the sequence. The type section along Assisig River is about 1,780 ft. (543 meters) thick whereas along Lamunan River, the reference section as measured is 1,540 ft. (470 meters) thick.

Directly overlying the Passi Formation along the east and north margins of Iloilo Basin is a belt of Upper Miocene reefs called the Dingle Formation. The formation was named after "Dingle", a town about 45 kms. north of Iloilo City. The unit is believed equivalent to the Tanian Limestone of the Iloilo Basin. Three distinct members were mapped, namely: the Aglalana Limestone Member, the Summit Clastic Member and the Sto. Thomas Limetsone Member.

The Aglalana consists of well stratified limestone with minor mudstone and sandstone beds near the base. It was defined from its type section in Aglalana, a barrio of Passi on the eastern bank of Lamunan River.

The Aglalana Limestone is represented by both the massive, structureless core facies and the coarse grained, fragmental, outward dipping reef flank strata. Lithology and fossils imply deposition under very shallow to intermediate waters within a well-aerated zone. The section as measured by plane table along the Lamunan River is 1,940 ft. (590 meters) thick.

The name "Summit" was adapted after Barrio Summit, a settlement along the railroad tract about 13 kms. north of Passi, Iloilo. The member unit is a sequence of massive, medium to coarse grained, gray sandstone, fossiliferous mudstone and thin limestone lenses which progressively become predominant downsection. The type section measured along Lamunan River is 1,585 ft. (483 meters) thick.

The Sto. Thomas Limestone is an argillaceous carbonate sequence which, together with the Summit Clastics, represent the coarse grained fragmental, outward dipping reef flank facies and the fine grained reef and deeper water facies that composed most mature organic reefs. The type section is located along Bitaogan Creek in Barrio Sto. Tomas, about 10 kms. north of Passi. Here, the limestone is thinly bedded, hard, dense and fragmental. Thin layers of highly calcareous, coarse grained sandstone and fossiliferous mudstone are occasionally interbedded with the limestone. Section measurements indicate varied thicknesses for the unit as; 2,460 ft. (750 meters) at the type section in Sto. Thomas and 3,690 ft. (1,125 meters) in the reference section at Dumaran.

The Dingle is unconformably overlain by the same bathyal mudstone and shale of the Ulian is in turn gradationally overlain by shallow water deposits of the Maraget sandstone member of the Cabatuan Formation.

Correlation of Miocene and Pliocene units across the basin is complicated by the occurrence of radically different lithologies with dissimilar faunal assemblages but of the same age cropping out on opposite flanks.

b) Exploration Works

The Iloilo Basin had been the subject of extensive surface geological work both by private exploration groups and the government. Reconnaissance aeromagnetic, gravity and patchy seismic surveys were involved in later studies. The Bureau of Mines conducted its own stratigraphic study covering the entire basin area in 1963–1964 which included plane table section measurements. Several prospective structures were delineated during these surveys, some of which were confirmed by gravity and seismic survey and lately tested by the drill.

Eight (8) wildcat wells with a total footage of 51,147 have so far been drilled. Drilling in the basin started as early as 1953 but it was not intensively pursued until 1973. From January, 1973 to October 1974 PODCO successively drilled 5 well to test the sandstones and reefal limestones of the Pliocene Ulian and Miocene Dingle and Passi formations. The wells Lucena No. 1 (TD-6,640 ft.), Sta. Barbara No. 1 (TD-5,150 ft.), Manduriao No. 1 (TD-6,153 ft.), Manduriao No. 2 (TD-6,118 ft.) and

Leganes No. 1 (TD-5,975 ft.) were drilled deep enough into metamorphic rocks considered part of the economic basement. Significant gas blows and minor oil indications were encountered in Middle Miocene porous limestone considered the basinward extension of reefs however, none proved commercial. Nevertheless, the test wells are considered successful in that it proved the existence of thick carbonate prospects in the Iloilo Basin. Drilling has so far been carried out only in the south central part of the basin and prospects elsewhere have not been explored by the drill.

c) Hydrocarbon Prospects

The Passi and Singit formations and the reefal facies of the Tanian and Dingle formations which constitute the seaward portions of the miogeosynclinal area of Iloilo Basin provide fair to excellent possibilities for hydrocarbon occurrence. Nevertheless, there exist specific areas wherein interest and investigation could be preferably directed.

In the eastern flank, the Kapasigan Anticline, a symmetrical fold was mapped along the Lamunan River. Both flanks of the structure dip approximately 15° and involved porous sandstone beds of the Passi Formation. About two kilometers farther upstream along the Ginayan River, a much broader anticline than the Kapasigan structure was defined. In the western flank, plane table survey along Tigum River delineated a northwest trending anticline in the lower member of the Tarao Formation. The structure, called the Daba Anticline, is a doubly plunging assymetrical fold. Potential reservoirs are the sandstones within the Tubungan siltstone Member of the Tarao with a total thickness of 1,510 ft. (460 meters). The claystones and mudstones overlying the sandstone horizons could provide good cap rock while the thick sequence of shale and mudstone below could furnish the necessary source rock. A lower horizon of interest would be the massive sandstone of the Singit Formation. Another established structure is the Igbaras Anticline, however, its potential depends on whether good reservoir rocks, as represented by the Barasan Sandstone of the Singit exposed eight kilometers to the west, extend below the anticline. The Tarao could provide the necessary cap rock. The south plunge could provide the southern closure. Faults running transverse to the axis were mapped so that, in effect, the anticline is a closed structure. In the Tubungan-Alimodian-Maasin area, several tight folds usually oriented to the northwest are present. Numerous gas seeps have been reported and thick sandstone beds of the Tubungan Siltstone Member of Tarao Formation are persistent in the area. Various other fold prospects occur in other parts of the basin which to the present, have remained untested.

Potential structural traps in the Iloilo Basin include faulted ancient shorelines where shallow-facies reservoir horizons between finer layers are present. In the western flank of the basin, the Iday Formation which would make an ideal reservoir, overlaps the elongated igneous mass northwest of Calinog and is in turn overlain by the Ulian Formation which is a less pervious formation. Nine kilometers northwest of Calinog, a fault cuts parallel to the igneous body and the subsequently uplifted portion of the igneous mass may have effectively sealed the homoclinal Iday beds to form a potential fault trap. Similar kind of traps were noted north of Tapaz, Capiz. Here, the clastic and/or limestone facies of the Dingle Formation overlie unconformably igneous bodies and are in turn overlain by the Ulian that would serve as cap rocks.

Faults in both areas are present and can provide the necessary seal and closure.

Cotabato Basin

While the basin, for the past several years has been the subject of extensive geological studies, most of the literatures on the subject have been kept confidential. In the 1966 edition of Review and Assessment of Oil Exploration in the Philippines discussion was limited on an earlier gravity survey conducted in the region.

a) **Geology and Stratigraphy**

The Cotabato Basin in the island of Mindanao is a NW-SE trending trough containing late Oligocene to Pleistocene sedimentary fills totalling approximately 28,000 ft. thick. The basin is bounded in the west and southwest by the Tiruray Uplands and the Southwest Coastal Range. Both mountain masses consist of uplifted pre-Miocene and Miocene intrustives and some sedimentary and metamorphic rocks. To the southeast and north, the basin is bounded by the Cotabato highlands composed of the basement rocks and some sediments occasionally masked by Plio-Pleistocene intrusives, flows and pyroclastics. The eastern margin of the basin is formed by the Central Cordillera, a complex suite of uplifted pre-Miocene and younger rocks. This cordillera separates the basin from the Davao-Agusan trough.

Basement rocks in the basin consist of numerous rock types, but are predominantly porphyritic andesite, basalt, agglomerate, several varieties of schist and other metasediments. The complex, as a whole, served as the initial depositional interface for subsequent Tertiary sedimentation. Outcrops of basement are most extensive in the Dagama Range, in the southwestern core of Quezon Mountain Range in the vicinity of Mount Matutum and in Mt. Akir-Akir in the north. Highly altered metavolcanics locally associated with altered graywacke sandstone are intruded by basic and intermediate igneous rocks.

The oldest dated formation which directly and unconformably overlie the Maganoy Formation. The unit represents late Oligocene to early Miocene sedimentation. Its occurrence is limited to the western margin of the Cotabato Basin. The type section along the Maganoy River in west-central Cotabato is principally of marine origin and consists of dark gray to black, highly indurated, fossiliferous, partly recrystallized and well bedded limestone; hard, pebble and cobble conglomerate and serpentine-bearing, orbitoidal, greenish gray, conglomeratic sandstone. The sequence measures at least 1,640 ft. (500 meters) thick.

Conformably overlying the Maganoy is the Lower Miocene Nakal Formation consisting predominatly of indurated graywacke sandstone and conglomerate with thin interbeds of shale or argillite. Two lithologically similar and age-equivalent limestone members which appear as white to buff, dense, massive, lenticular and fossiliferous occur locally at or near the base of the formation. The Head Allah Limestone in the south central part of the basin attains a maximum thickness of at least 1,640 ft. (500 meters) whereas its counterpart in the northern part, the Tigbuan Limestone, was observed to be no more than 328 ft. (100 meters thick. Total thickness of the Nakal is approkimately 4,920 ft. (1,500 meters).

A thick succession of Middle Miocene limestone and clastic beds, belonging to the Patut Formation conformably overlies the Nakal Formation. The Patut is subdivided into two distinct facies: the nearshore marine and continental deposits in the north and the offshore marine Saul Creek facies in the south central portion of the basin. At its type locality along Patut Creek in the northern part of the basin, the formation consists of a sequence of cobble conglomerate and thick bedded, coarse to medium grained graywacke sandstone with occasional interbeds of bluishgray carbonaceous mudstone. Massive conglomeratic limestone, 940 to 1,640 ft. (30 to 50 meters) thick, are often found in the lower part of the section. In the south central area of the basin, the Saul Creek facies is composed of interbeds of siltstone, mudstone and medium grained, well bedded sandstone with basal dull white to gray, porous lenticular reefal limestone. Thiskness of the formation varies from a maximum of 3,770 ft. (1,150 meters) in the north to 2,950 ft. (900 meters) in the south.

The Lower and Middle Miocene strata are intruded by Miocene intrusives consiting of basic plutonic rocks distributed in elongated belts in various mountain ranges that fringe the Cotabato Basin and the Kulaman-Masiag Plateau. The intrusives are subdivided into seven units on the basis of their lithology and areal distribution as follows: 1) the Balogo Gabbro; 2) the Babuy Andesite-Agglomerate; 3) the Kitubod Granodiorite; 4) the Quezon Porphyritic Andesite; 5) the Sinolan Porphyritic Dacite; 6) the Salatan Diorite; and 7) the Southern Cotabato volcanics and plutonics composed of altered, pyritized porphyritic andesite and basalt.

A thick marine section which increasingly becomes non-marine towards the south marked the beginning of late Miocene sedimentation in the basin. The Dingayen Formation is dominantly mudstone and claystone section in the north. In the south-central and southern Cotabato, the sandstone components become conglomeratic while lenses of boulder conglomerate become frequent interbeds in mudstone and siltstone. The thickest development of the Dingayen in north Cotabato measures about 6,560 ft. (2,000 meters).

Paleontological studies indicate continuous late Miocene to early Pliocene deposition of the Nicaan Formation above the Dingayen Formation. The Nicaan consists of an upper coarse clastic member and a lower finer clastic member. The lower member partly interfingers with the upper member and is dominantly shallow marine deposits consisting of blue-gray to black, thin bedded, locally tuffaceous sandstone, siltstone and thin to massive pebble conglomerate and agglomerate with occasional intercalations of marl and impure limestone. At its type locality in the north along Nicaan River, it has a computed thickness of 3,940 ft. (1,200 meters) whereas in the south it is between 960 to 1,300 ft. (300 to 400 meters) thick. The upper clastic member varies from locally conglomeratic, cross-bedded sandstone to marine mudstone and siltstone. This includes the Nicaan-Pulangi clastics of northern Cotabato and its equivalent strata in the south, the Maibu Mudstone and Sandstone and Dimuluk Conglomerate. The upper Nicaan in both the northern and southern part of the basin has been observed to be from 960 to 1,640 ft. (300–500 meters) thick.

A sequence of white to pink to gray, soft, fossiliferous, porous, biohermal limestone and associated interbeds of marl, mudstone, sandstone and local beds of coarse volcanic conglomerate belonging to the Marbel Formation occurs stratigraphically above the Nicaan Formation with unconformable relationship as seen in south-central Cotabato. The formation has a maximum thickness of over 3,940 ft. (1,200 meters) in the area south of Mt. Matutum. In the north, the Marbel is represented by at least two distinct lithologic entities, the San Mateo clastics consisting predominantly of tuffaceous mudstone with marl, limestone, tuffaceous sandstone and pebble conglomerate beds having an aggregate thickness of 1,149 ft. (350 meters) and the Awang-Table Limestone described as thick, white to pink, fossiliferous, porous, lenticular, biohermal limestone partly intertonguing with and/or conformably below the San Mateo clastics. The limestone has a maximum thickness of approximately 980 ft. (300 meters). The formation is assigned to Pliocene with the possibility that the lowermost beds extend down to uppermost Miocene.

Resting with unconformable relationship on the Marbel Formation is a relatively thin section of fluviatile to shallow lacustrine deposits consisting of buff to gray, fine grained, poorly consolidated, ferruginous sandstone; calcareous siltstone and cross-bedded, porous pebble conglomerate beds designated the Kilada Formation. The formation as herein defined, includes the Simuay and Libungan conglomerates in the northwestern and north-central Cotabato, respectively. The formation is barren of fossils, however, on the basis of its stratigraphic relationship with adjoining units, it is thought to be Plio-Pleistocene in age.

Interbedded sequence of clastic and pyroclastic rocks; and volcanic flows comprising the Carmen Formation appears as lenticular outcrop belt showing unconformable relationship with any of the underlying formations and overlying alluvium. The sediments consist chiefly of fluviatile deposits of fine to coarse grained poorly consolidated, tuffaceous sandstone and clay; soft, porous and crumbly, lenticular conglomeratic and agglomeratic channel deposits of volcanic origin while the igneous rocks consist primarily of amygdaloidel basalt and andesite. Basalt dikes and sills occur in the margins of volcanic areas. Estimated thickness of the formation varies from feather edge to at most 1,640 ft. (500 meters). Law of superposition implies Plio-Pleistocene age for the formation.

The Omanay Marl represents the final marine cycle of deposition in the Cotabato basin. The formation contains perfectly preserved oyster beds and plenty of small foraminifera in matrix of soft, greenish cream colored marl implying probable Plio-Pleistocene time of deposition. The formation is relatively thin with only a maximum estimated thickness of 115 ft. (35 meters). The unit appears to grade conformably into, and in some localities possibly laterally equivalent with a portion of the Carment Formation.

Recent deposits of unconsolidated stream and valley gravels, low-level terrace deposits along present rivers, natural levees and unconsolidated swamp muds occur throughout the basin. These deposits attain as much as 820 ft. (250 meters) in thickness as evidenced by recent water well drilling in some areas.

b) Exploration Works

Extensive geological mapping, reconnaissance aeromagnetic and ground seismograph surveys have been conducted in the basin. Ground gravity work has revealed strong features parallel to surface-mapped structures with maximum reliefs amounting to 70 milligals. Two phantom horizons with reflections ranging from 340 to 660 miliseconds and 820 to 1,600 miliseconds two-way time were delineated by seismic. A thinning of the section in the southwest, suggestive of possible stratigraphic plays, was determined.

Nine (9) wildcat locations with a total footage of 52,187 have so far been drilled. After the last drilling in 1962, six test wells were drilled from 1971 to 1974.

South Seas Oil spudded Roxas No. 1 on June 20, 1971 on the southeastern flank of Roxas Anticline in south-central Cotabato within PEC-33 with the Lower Miocene Head Allah Limestone and the Middle Miocene limestone and sandstone beds of Hakal Formation as objectives. The well was abandoned as a dry hole at 5,303 ft. without reaching the principal objective after constant sloughing and bridging made further drilling impossible.

The second well drilled during the period was spudded on June 30, 1971 by Fil-Am Resources in PEC-62 of Maremco. The well, Lagao No. 1 was spudded on Pleistocene formation in Sultan de Barongis, north Cotabato. Drilling stopped at 3,657 ft. after drill pipes got stuck in the core hole. The well was finally abandoned as a dry hole and plugged on September 17, 1971.

In South Cotabato, SESMAR spudded Kalian No. 1 to probe the potential of the Sarangani Peninsula. Drilling was at 8,018 feet in Oligocene-Upper Eocene limestone and claystone section when operation was suspended pending delivery of 3 1/2″ pipe to the drill site.

The second well drilled on the Roxas Range in SANJOCO's PEC-33 by South Seas Oil was spudded on October 15, 1971. After drilling to 8,425 feet into Lower Miocene formation, the well was abandoned as dry. DST was conducted on a shale and sandstone zone at 6,215 feet which showed a very slight cut in CCL 4 in the core sample but the test subsequently resulted in negative findings.

In Buluan, North Cotabato within PEC-62, Fil-Am spudded its second well in the basin. Pedtobo No. 1 was drilled to a total depth of 5,200 feet after penerating Pleistocene to Lower Miocene clastic and limestone formations and more than 100 feet of metavolcanic basement rocks. The well was abandoned without encountering any significant shows.

The third of the deep tests conducted by South Seas on Roxas anticline was commenced on April 5, 1972 atop Pliocene limestone. Roxes No. 3 well was abandoned at 7,765 feet as a dry hole after it hit the Lower Miocene section. Electric logs did not record any interesting petroliferous zones.

c) Hydrocarbon Prospects

Two prominent prospects or structural trends delineated within the basin are the Roxas-Matulas Anticlines and the Quezon Mountain Range.

The Matulas Anticline is an assymetrical doubly plunging anticline occurring in the southern end of south-central Cotabato basin. The west flank is vertical to overturned with regional N25°W trend. Lower Miocene sediments belonging to the Nakal Formation are exposed in the core of the structure. Several faults out the axis and produced downthrown east side.

The Roxas anticline is a close structure trending N28°W approximately 15 miles long en echelon with the Matulas anticline to the northwest. The fold is less affected by faulting than the Matulas structure. Patut Formation is exposed in the core.

The Quezon Mountain Range is actually a deeply eroded, faulted and intruded anticline in the south-central part of the basin which plunges northward into the Liguasan Marsh. It trends northwest across the basin, finally emerging at the Pikit-Gonotan Ridge in the north and in the Mount Akir-Akir area in the west.

Agusan-Davao Basin

The bulk of information contained in the following discussion, particularly on stratigraphy, was taken from the original text of "Review and Assessment of Oil Exploration in the Philippines".

a) **Geology and Stratigraphy**

The Agusan-Davao Basin is a north-south trending elongate trough occupying the intermontane lowland of eastern Mindanao Sea in the north and into the Davao Gulf in the south. It is bounded in the east by the Pacific Cordillera consisting of a faulted and folded sequence of ultra-basic rocks and metamorphosed volcanic and sedimentary rocks and in the west by the Central Cordillera of essentially similar association of basement complex lithilogic suite.

Field evidence suggest that the trough is a half graben, the sedimentary section regionally tilted into a homocline dipping eastward at about 15–20°. The Philippine Rift is adjacent to and is roughly parallel to the east of the main axis of subsidence of the basin. It is believed that regional structures are controlled by, or associated with, this major zone of movement.

Generally, the older Tertiary rocks are exposed along the margins of the valley; the coarser clastics are found on the west and the deeper-water, finer counterparts on the east. The younger rocks, mostly Pliocene and Pleistocene, are exposed in the central part.

The sedimentary sequence ranges from Eocene to Pleistocene and attains a maximum thickness of more than 13,000 ft.

The Eocene (Umayan Limestone in Western Agusan, Baggao Limestone in Eastern Agusan) on both flanks consists of massive reef limestone and associated bedded carbonate deposits unconformably overlying the basement and reaching as much as 2,000 ft. in total thickness. Although locally overlapped by Pleistocene sediments, the Eocene in the overall succession is unconformably overlain by Lower to Middle Miocene marine sandstone, shale, conglomerate and limestone associated with coal beds (Saugan Formation, Wawa Formation) and reaching over 3,000 ft. in thickness. A thick sequence of marine Upper Miocene-Pliocene (Adgaoan Formation) crops out along the flanks of the Pacific Cordillera in the Agusan and Surigao regions and blankets most of the low areas extending across the central part of the range. The Upper Miocene in northeastern Agusan consists of about 300 ft. of clastic limestone overlain by more than 3,000 ft. of alternating shale and sandstone locally intruded by basalt and diorite. Isolated exposures of Upper Miocene reefel limestone less than 300 ft. thick unconformably overlie the clastic series.

Mio-Pliocene to Pleistocene sedimentary rocks (Adgaoan Formation, Nasipit Formation, Diwata Limestone, Liuanan Sandstone) generally overlap the Middle Miocene section. In west-central Agusan, shale/sandstone with intertongues of massive reef limestone attain a maximum thickness of more than 1,000 ft. In central Agusan and western Davao, the Mio-Pliocene to Pleistocene section is thickest (over 8,000 ft.) and consists of poorly consolidated mudstone, shale, sandstone and conglomerate. Massive, reef type limestone, some exceeding 500 ft. thick, are locally interbedded with the sandstone and shale.

b) Exploration Works

A great deal of geological mapping has been carried out by private workers. Reconnaissance aeromagnetic survey and limited seismic and gravity works were carried out principally to determine depths to magnetic basement. The Bureau of Mines conducted reconnaissance field study in certain portions. To-date, only 2 locations (total footage 6,377) have been drilled. The only significant test, Matina #1, was drilled to 6,002 ft. on a seismic/gravity location in southern Davao. No significant reservoir was encountered but the well did not penetrate the entire sedimentary sequence to basement.

c) Hydrocarbon Prospects

Gas seeps are known in this basin although no significant shows were encountered in the wildcat drilled. The basin contains a large number if untested anticilinal structures with developed local closures. In addition, a number of fault controlled stratigraphic prospects including pronounced angular unconformities and abrupt fancies changes exist in the area. It is held that the marine fossiliferius dark shales and muds of the Miocene and Pliocene formations represent good hydrocarbon source and cap rocks. The fact that the basin was a silled trough during the Miocene further enhances the potential of these sediments as hydrocarbon source rocks.

Palawan-Sulu Area

The following discussion presents particular information on the subject area which have not been presented in the original text of "Review and Assessment of Oil Exploration in the Philippines". Materials for the discussion come from the more recent available reports and reviews from the industry and the Bureau of Mines.

A) Geology and Stratigraphy

a. Palawan and Associated Islands

The island of Palawan and associated groups form the southwestern margin of the Philippine Archipelago. These islands are considered the protruding portions of a major northeast-trending Paleozoic to Mesozoic basement ridge, the Palawan Arch, which trend in almost the same direction as the submarine ridge off the northwest coast of Borneo. It is held likely that the Arch may be related to extend on a northwesterly direction from the Dent Peninsula, swinging in a northerly direction through the Kudat Peninsula to join the Balabac Islands and thence into southern Palawan mainland.

The onshore areas, including the Calamian Group, Dumaran Island and Balabac Island can be divided on the basis of common structural and petrological features into two regions — a northern one, consisting of highly folded and faulted Late Paleozoic metamorphic and sedimentary rocks, acidic plutons and limited exposures of Tertiary rocks; and a southern one comprising largely of a suite of Cretaceous-Paleogene ophiolites and associated siliceous sediments onlapped by Paleogene to Neogene sedimentary rocks.

The marine Tertiary sediments are generally well exposed in the southern end of the mainland where they wrap around the southwest plunging nose of the island and in the southeastern coast where they occur as structural embayments with pronounced sea-ward plunges. Sedimentary rocks in the north are represented by erosional outliers of a Middle Miocene Limestone on the late Paleozoic sequence and an Eocene Limestone on the northeastern coast.

The structurally more complex northern region is underlain by a basal sequence of metamorphic rocks consisting of quartzo-feldsphatic and mica schists, phyllites, slates, and quartzites. Further north, this sequence is overlain by a succession of progressive-ly younger rocks dominated by cherts, siliceous clastics, wackes, and an uppermost carbonate unit if probable middle Permian age. These rocks display a wide variety of folding styles and orientation reflective of different phases of folding. Although the regional strikes of the mainland and surrounding shelves is northeast, fold trends on the mainland are north and northwest. On the islands of Busuanga and Culion, north-west trends predominate.

There is local evidence of tight folding and intricate faulting in the southern part of Palawan, but the area as a whole is less tectonically deformed. When the sedimen-tary sections involved are of Tertiary age, the axes of the major foldings are parallel to the northeast-northwest trend of Palawan.

Palawan mainland appears to be cut by several north-trending strike slip faults, one if which (Ulugan Bay Fault) conspicuously cuts the island into two structural and petrologic regions. A strong component of dip-slip is also suspected along this fault to account for the contrasting stratigraphy.

The geology of the onshore areas is rather different from that of the surrounding shelves. As interpreted from the marine seismic and aeromagnetic occur sporadically onshore whereas a more or less continuous and widespread deposition of the same sediments occur in the surrounding shelf. This is explained by the fact that mainland Palawan has been exposed to erosion since probable Paleozoic time thus causing the debasement of the landmass and consequent transport and deposition of the products on the shelf areas.

The stratigraphic section onshore consists of a Paleozoic basement suite including plutonic, igneous and highly metamorphosed sedimentary-volcanic rocks which have been intruded by basic and intermediate igneous bodies. The basement outcrops which are widely distributed in the north and central portions of the island are generally uncon-formably overlain by a thick sedimentary sequence estimated to exceed over 58,000 ft. in the offshore. The lower part of the section is made up of interbedded arkose, shale and thinly bedded chert and limestone which have been differentially metamorphosed into schists, phyllites and quartzites. The upper portion includes biohermal limestone, mudstones, siltstones and conglomerates which apparently, were laid down under flctuat-ing environmental conditions. Noteworthy is the fact that most of the rocks in the lower part if the Tertiary sequence bear no relationship to the sediments in the other basin areas in the Philippines.

a. 1 Southern Palawan

Unconformably overlying the basement complex in southern Palawan is the Bacuit Formation consisting of a thick series of highly indurated, folded and overturned, lenti-cular arkose, shales and conglomerates interbedded with bituminous siltstone and marbolized limestone. The section which is tentatively dated pre-Eocene is considered correlative to the Crocker Formation of north Borneo. The rocks are believed to have been derived from a southern or western source area either in Borneo or South China Sea. In outcrop, the rocks may be considered economic basement although the section is considered prospective offshore, away from the deformed zone of the Palawan Plutonic Uplift.

Overlying the Bacuit with a marked unconformity is an Oligocene to Lower Miocene section composed of arkose, mudstone, siltstone and minor limestone referred to by different workers as Sumbiling, Coron, Panas or Tabon formations. The arkose are generally gray to light brown, fine to medium grained and contain occasional conglomerate and limestone lenses. The mudstones are greenish gray, compacted and contain bituminous layers. The section does not exceed a few hundred feet in outcrop however, offshore it is estimated to be over 5,000 ft. in thickness.

A Lower to Middle Miocene transgressive sequence (Tabon Formation) generally conformably overlies the above sequence. The sediments consist predominantly of sandstones, mudstones, siltstones and inner shelf limestone aggregating over 5,000 ft. thick. Local units such as the St. Paul Limestone and Coron Limestone are included in the unit.

The Upper Miocene Pandian Formation consisting of massive quartz-rich sandstones with few thin beds of shale and the Pliocene or younger Iwahig Formation consisting of conglomerates, sandstones and limestone locally overlie the Tabon. The formation which is extensively developed in the southern tip of Palawan including Balabac and nearby islands is over 3,000 ft. in thickness. Locally the upper portions of the section consisting of unconsolidated silts and conglomerates merge with terrace gravels making separation rather difficult.

In Balabac Island, massive, yellow to buff sandstone consisting largely or subangular quartz grains, feldspars with scattered dark gray shale stringers and bituminous siltstones unconformably overlie a volcanic chert association. It has been postutlated that the quartz-rich sandstones were derived from a siliceous source to the west in the South China Sea. If this is the case, the paleo-geography of the area at the time if deposition was vastly different from the present. Another theory is that the sediments were derived from the quartz-rich regions of Borneo which has been postulated as being situated as that time immediately west of Palawan and subsequently displaced by transcurrent movement of the south.

a. 2 Central Palawan

The sedimentary section in central Palawan ranges from Eocene to Miocene with approximately 85% of the known strata belonging to Eocene and Oligocene. Considerable portions of the column are missing hence the true thickness of the section onshire can not be estimated. Offshore however, the composite section is comparatively much thicker and may exceed 25,000 ft. in the western side and 10,000 to 15,000 ft. on the eastern as shown by seismic profiles.

East of Mt. Aborlan in the central part of Palawan mainland is a thick, primarily clastic unit similar to the Bacuit Formation in the south. The section appears to be of outer shelf of slope fore-deep, partly turbidite origin and consists of mudstone, arkose and siltstone with minor inner-shelf limestone beds and turbidites. Over 5,000 ft. of the formation is exposed however, no less than 15,000 ft. of the section is estimated to be present in the shelf. The age has been tentatively regarded as Eocene to Early Oligocene based on scanty fossil Foraminifera.

Unconformably overlying the Bacuit is the Bongaya Formation consisting largely of poorly sorted conglomerates, sub-arkose, to graywackes and few mudstone interbeds. The formation is approximately 3,000 ft. thick and is considered differentiated Miocene in age.

Very young, Pleistocene to Recent, sediments grouped with the Iwahig Formation unconformably overlie the Bongaya. The section consists of poorly bedded, non-consolidated conglomerates intercalated with thin beds of siltstone and sandstones. The upper part of the section generally contains more carbonate and locally grades into limestone. The unit is estimated to be 1,500 to 3,000 ft. thick.

a. 3 Northern Palawan

Sadimentary outcrops in northern Palawan are very limited in extent. The section ranges from Eocene to Recent with the bulk of the section (approximately 80%) consisting of Eocene rocks.

The Bacuit Formation consisting of cherts and metamorphosed clastic rocks and limestone unconformably overlies the pre-Eocene basement. The section is generally highly contorted and forms a shield over the igneous basement, thus indicating on the magnetometer map the apparent absence of magnetic igneous bodies in the region. The section is locally unconformably overlain by the St. Paul Limestone or Iwahig formation. These younger units are sparsely distributed and probably represent erosional remnants.

The total section onshore amounts to only a few hundred feet in thickness however, thick and extensive continuations in the offshore are believed present.

a. 4 Offshore Western Palawan

The continental shelf off west Palawan covers approximately 7,000 square miles measuring 220 miles long and about 30 miles wide. Seismic work in the area shows a thick west dipping sequence of clastic and carbonate rocks resting unconformably on basement.

Based on onshore geology and the section penetrated by two offshore wells, the following generalized stratigraphic sequence may be expected.

Unconformably resting on the basement is the Lower Miocene St. Paul Limestone which, in turn, is conformably overlain by Lower to Middle Miocene shale, silts and sandstones of deep marine deposition. The sequence is folded, faulted and possibly uplifted and eroded. Resting on a possible unconformity surface are Upper Miocene deltaic-sands, shales and silts with occasional detrital limestone lenses probably belonging to the Pandian Formation.

Pliocene shelf clastics and reefal limestone belonging to the Iwahig Formation conformably overlie the Upper Miocene deltaic sequence. These rocks are in turn unconformably overlain by Pleistocene reefs.

Further south, adjacent to the southwest Palawan mainland, seismic surveys have revealed a northeast-southwest regional trend. Major faulting runs parallel to the regional trend. At least two large anticlinal closures have been delineated; a) the northeast trending Regeant Shoal west of Banbaran Point whose areal extent is 4.9 kms. by

1.4 kms. and shows a vertical closure of .702 seconds, two-way time, and b) the northeast trending structure just north of Balabac Island whose area under closure measures 8.7 by 3.4 kms. and shows a vertical closure of .880 seconds two-way time.

a. 5 Offshore Eastern Palawan

The offshore area immediately east of Palawan covers the western depositional and erosional edge of the North Sulu Sea Basin. The depth to magnetic basement on the area ranges from 5 to 8 kms. as indicated by aeromagnetic survey data. Large structural features have been interpreted and are considered associated with the nonmagnetic area.

Offshore reconnaissance seismic surveys have shown at least 2.000 seconds (8,000 ft.) of acoustic section may be present. Deeper sections may exist but are probably obliterated by the diffractions emanating from the diaphiric shale zone.

The east region of the Sulu Sea basin appears to be represented by a number of northeast trending sub-basins and basement ridges running parallel to the trend of Palawan mainland.

b. Sulu Archipelago

The Sulu Archipelago comprises approximately 200 valcanic islands forming a chain about 450 kms. long and 100 kms. wide trending northeast from Borneo and extending to the Zamboanga Peninsula in the southwestern part of the Philippines. The largest, northernmost island is Basilan which is about 1,200 sq. kms. in area. Most of the islands are less than a few sq. kms. in area and range to mere rocks or coral banks exposed only during low tide.

The region can be divided into four geologic areas based on outcrop lithologies, namely, the Basilan-Jolo-Siasi Island group, the Northern half of Tawi-Tawi and nearby islands, the Southern half of Tawi-Tawi, Sañga-Sañga and Bongao, and the Sibutu Island group.

b. 1 Basilan-Jolo-Siasi Area

These groups of islands comprise the northern part of the archipelago and extend over more than half of the distance from the Zamboanga Peninsula to the Borneo Coast. The islands are volcanic in origin, generally conical in profile and more or less circular in map view. Presumably they are young (Plio-Pleistocene) based on their rugged geomorphic appearance. The volcanoes are all dormant or inactive.

The sea floor surrounding the islands is shallow to very shallow, and somewhat topographically irregular, presumably representing various sub-sea side vents and flows. The islands are in part fringed by recent coral build-ups and some coastal areas and upland valleys contain poorly sorted gravels and sandstone derived from the surrounding volcanic highlands. The total thickness of these clastics is probably less than a few hundred meters and have little if any significant hydrocarbon potential.

Conceiveable later Tertiary sediments which could have been deposited in this area of the archipelago, are now submerged and are overlain by volcanic rocks.

b. 2 Northern Half of Tawi-tawi Island and Nearby Islands

This island group has varied lithologies in outcrop and is structurally, based on topography, complex.

The northern half of Tawi-tawi Island proper is composed of probable basement rocks, primarily serpentinized basalts and associated meta-volcanic intrusives with massive quartz veins.

The area is in part composed of relatively high (200–300 meters), rugged hills and ridges, running sub-parallel to the northwestern coast. The highlands appear to be formed by differential faulting. The northeastern coast is flat and tends to ramp seaward to the southeast. The metavolcanic ridges of Baliungan Island trends perpendicular to that of Tawi-tawi proper.

The island group is probably presently rising on the northwest side as indicated by elevated coral and sinking on the southeast as manifested by drowned river valleys.

b. 3 Southern Tawi-tawi, Sañga-Sañga, and Bongao

These three islands are separated by narrow, shallow structurally controlled channels and can be considered as one unit. Southern Tawi-tawi is underlain by a sandstone-conglomerate sequence of unknown thickness and probably of Miocene age.

This formation was named the Bongao Conglomerate by Taylor (1951) after Bongao Island where excellent outcrops are present. The sequence is predominantly a pebble to boulder conglomerate with associated sandstone units averaging less than 20%. The sandstones generally occur as poor to moderately developed graded channel deposits that have cut through older units.

No significant porosity was observed, but this may be related to outcrop weathering. The conglomerate is generally light to medium gray on fresh surface and weathers to dark brown or black. Sorting is always extremely poor and rock fragments are subrounded to subangular and consist primarily of fine to medium crystalline, light to medium gray igneous and metamorphic rocks.

The relationship, if any, between the "basement rocks" on the northern Tawi-tawi Island and the conglomerate is not apparent. Conceivably the source of the Bongao Conglomerate could have come from paleo-highs anywhere surrounding the present Tawi-tawi Island group.

Structurally the Bongao and southern Tawi-tawi areas appear to be a series of fault blocks with well developed fault slopes forming near vertical cliffs and more gentle dip slopes.

The general strike of the inferred faulting is parallel to the trend of the archipelago, i.e., northeast-southwest.

Possibly the Bongao Conglomerate, or a facies equivalent, extends across the Sibutu Channel and is present in the subsurface of the Sibutu Island area to the southwest.

b. 4 Sibatu Island Group

The Sibutu group of islands is separated from Bongao Island by the relatively deep Sibutu Passage. The passage is interpreted as structurally controlled but this is entirely conjectural.

The trend of Sibutu Island, Timindao Island, Meridian Reef, plus the various channels and shoals is north-south, whereas the trend of the remainder of the archipelago, as a whole, is predominantly northeast-southwest.

The islands are extremely flat and are covered with Pleistocene (?) to Recent carbonates with the exception of Sibutu Hill. This hill is 150 meters high and is composed of medium-grained, crystalline diorite. Field evidence show that the diorite did not metamorphose the surrounding limestone. The diorite is mineralogically distinct from the basic volcanies of Jolo-Basilan-Siasi area. Possibly it is an old "basement" high or related to the Miocene diorite vents of Borneo or Zamboanga.

c. Southwest Palawan-Sulu Sea Basin

The Southwest Palawan-Sulu Sea Basin or West Sulu Basin refers to the predominantly upper Tertiary sedimentary basin along the western part of Sulu Sea bordered in the north-northwest and south-southeast by the tectonic are extending from Palawan, through central Sabah, the Semporna Peninsula and the Sulu archipelago to the Zamboanga Peninsula. During Cretaceous to Oligocene times, the basin was part of the Northwest Borneo Geosyncline which extended from western Borneo northeastwards to Sulu Sea.

The crystalline basement in the area consists of Jurassic or older metamorphics complicated by mid-Jurassic intrusives. During late Cretaceous eugeosynclinal sediments consisting of flysch-type sandstone and shale, pelagic limestone and spilitic volcanic rocks (the Chert-Spilite Formation) were deposited unconformably on the basement over much of the former basin area. Geosynclinal subsidence continued through the Eocene with contemporaneous deposition of up to 30,000 ft. of flysch-type sandstone-shale alterations (the Crocker and Kulapis Formations). Oligocene to Lower Miocene miogeosynclinal deltaic to shallow to deep marine sediments (the Kudat, Balabac and Labang Formations) were deposited locally in northern and eastern Sabah. Formation of synclinal basin in late Miocene were accompanied with the deposition of tuff, slump breccia and interbedded mudstone (the Garinono and Ayer Formations) under shallow to deep water conditions. Uplift before the end of Miocene caused extensive folding of underlying sedimentary sequence and led to a regressive period when Upper Miocene deltaic to neritic sediments (the Bongaya and Sandakan Formations) were deposited over much of the present West Sulu Basin area. In other areas sandstones were deposited with pyroclastic materials (Labong, Tabanak and Tungku Formations). An orogeny towards the close of Miocene caused differential movement and erosion of the Upper Miocene in some area. Uplift along the present basin margin was initiated at this time. Down-warping in the northeast within the present limits of the Sulu Sea also occurred and provided for the deposition of Upper Miocene to Pliocene neritic to deltaic sediments (Lower Dent Group). Volcanism continued along the southern margin. A major orogeny towards the close of Pliocene resulted in the uplift of mainland Sabah and establishment of the Cordillera zone in southwestern Philippines.

B) Exploration Works

Surface geological mapping covering most of Palawan mainland and surrounding island areas and the Sulu Archipelago have been carried out by private companies. The Bureau of Mines conducted reconnaissance geological studies covering portions of the east-central and southern Palawan.

A regional aeromagnetic survey covering the entire offshore areas and extending to Southern Sulu was undertaken under the sponsorship of ECAFE. The survey indicated at least two magnetic horizons, ranging from 1 to 3 kms. depth in the northwestern part and 5 to 11 kms. deep in the south. A number of offshore seismic and magnetometer surveys have been conducted in waters surrounding the islands.

Marine seismic and magnetometer surveys, plus the drilling of two offshore wells on the northwestern shelf have yielded valuable information on the late Tertiary geologic history of the region. These exploration activities have shown that since the deposition of several thousand meters of deep-sea marine clastic sediments on a Lower Miocene Limestone depositional base in early Miocene time, the region has undergone two major periods of regression and marine transgression. These events are recorded as two prominent unconformities recognized on seismic profiles which subsequently have been identified from well information as intervening between the Middle Miocene and Upper Miocene, and between Upper Miocene and Pliocene strata. Thus far, structures suggesting late Tertiary intrusive or extrusive igneous activity have not been recognized on any of the seismic profiles. To a large extent, the geophysical surveys have led to the recognition of several prominent reflecting horizons whose lithologies and ages have been determined from the results of the first two offshore wells drilled in the northwestern part of the region. At least two of these reflectors are distinct enough and continuous throughout the region to define the structural features of the underlying shelf. The deeper and more continuous of the two reflecting horizons has subsequently been identified as a basal Lower Miocene Limestone formation. It is easily recognized by its strong double bank character and was considered the "acoustic basement" for the area. Deeper primary reflectors have been recognized below the deepest continuous reflector but they are irregular and discontinuous.

The shallower, continuous reflecting horizon on the other hand, corresponds to the base of the Pliocene carbonate unit which is lithologically very similar to the Pliocene limestone formation of southeastern Luzon and the Visayan area. The Pliocene sequence, and parts of the Upper Miocene, are generally undeformed, while the Middle and Lower Miocene sections show evidence of folding and faulting.

To-date seven offshore wells with a total footage of 66,435 have been drilled in the Palawan-Sulu Sea offshore region. All seven wells have shown indications of the presence of oil and/or gas at varied depths however, attempts at commercial production were unsucessful.

Based on seismic surveys conducted in 1970 and early 1971, Oriental Petroleum and Minerals Corporation spudded Pag-asa 1-A on March 16, 1971 some 50 miles offshore off northwest Palawan on the upthrown block of a faulted monocline overlain unconformably by a thick wedge of sediments. It was believed that the existence of a fault in combination with the onlapping of younger strata on a bevelled or eroded surface of younger strata provided the necessary elements for hydrocarbon trapping. Aside from the purely structural aspects of the play, it was also felt that the selected drill site would furnish maximum stratigraphic data, considering drilling capabilities of the available equipment. The well was originally programmed to 7,500 ft. in the expectation that the acoustic basement at that depth constituted the true metamorphic basement for the region. Subseqquent events however, proved this to be wrong.

The well penetrated 7,238 ft. of Tertiary sedimentary rocks ranging from Pliocene to Lower Miocene. From the Pleistocene coralline limestone (171–330 ft.), the lithology persists to the Pliocene (330–1,720 ft.) without any apparent change. The Upper Miocene (1,720–3,700 ft.) is marked at the top by a thin calcareous claystone bed which grades into an intergrading sequence of claystone, siltstone sandstone and limestone down to 3,700 ft. The Middle Miocene (3,700–4,600 ft.) is characterized chiefly by carbonaceous claystone, siltstone and shale. The Lower Miocene from 4,600 to total depth, consists of a monotonous sequence of shale and siltstone with sparsely distributed thinly bedded sandstone.

Eight foraminiferal assemblage zones were recognized, the boundaries of which closely correspond with lithologic and faunal breaks.

A total of seven cores and 112 sidewall cores were taken for prosity and permeability determinations. Recovery was generally good however, porosity and permeability data were not very conclusive inasmuch as the cores were, in most cases, too friable to give accurate results. The tests indicate that permeability at different levels range from 0 to 348 MD whereas porosity ranges from 25 to 45%. Two drill stem tests were attempted at two levels where water saturation were less than 100%. No oil or gas shows were detected however, the tests were considered valid inasmuch as formation fluids were recovered after the tests.

As a wildcat, the drilling of Pag-asa I-A was considered a success in that it has proven the existence of extensive and prospective section of Tertiary rocks. Although no significant oil or gas shows were encountered, thick sequences of marine source rocks capable of generating oil and suitably emplaced reservoir rocks are present in the shelf. The well was abandoned as a dry hole on May 24, 1971 because of technical difficulties.

Calamian No. 1, the second of Oriental's deep test in the same general area, was spudded on 26 May 1971 and abandoned as a dry hole on 18 July 1971 due to severe weather conditions.

The well was programmed to test the possible accumulation of hydrocarbons on an anticlinal fold involving possible prospective zones of Middle to Lower Miocene sands and a Lower Miocene limestone objective. The location is a combination type trap on the up-dip of a nose on a north on a northwest plunging anticline as defined by seismic profiles.

As in Pag-asa I-A, Calamian No. 1 penetrated a sedimentary section ranging in age from Pleistocene to Lower Miocene. Basement was not reached.

The Plio-Pleistocene section, from sea floor to 1,300 ft. consists of white coralline, chalky, porous limestone grading to calcareous siltstone. No definite dating was made however, the section from 1,142 to 1,300 is probably representative of the Lower Pliocene.

A distinct faunal break was observed between 1,270 and 1,300 ft. and this zone is believed to approximate the top of the Upper Miocene. The interval 1,300 to 1,900 ft. (Upper Miocene) consists of an upper calcareous siltstone and a lower conglomerate section.

The interval 1,900–2,980 ft. which is considered Middle Miocene consists primarily of friable siltstone with quartz granules. The section grades to sandy and shaly facies within the interval and to claystone at the bottom. The Lower Miocene (2,980–6,904 ft.) consists of siltstone, sandstones and shale with noticeable chert pebbles found towards the lower part.

Six faunal zones, generally indicative of deep water deposition, were determined. As in Pag-asa I-A, the well section represents three geologic series from the Pleistocene to the Miocene.

In south Sulu Sea, two offshore deep tests, Sulu Sea A-1 and Sulu Sea B-1, were drilled between December 1972 and March 1973 by a consortium of local companies composed of Triton Philippines, Pioneer Natural Resources and Philippine Oil Development Company. Sulu Sea A-1, the first in a three-well program, was spudded over a seismic location on December 22, 1972 at a point approximately 75 miles southeast of Balabac Island and 35 miles southwest of Cagayan de Sulu. The well was originally programmed to 5,600 ft. to test two important intervals, the Oligo-Miocene Sugut beds and the Mio-Pliocene sands of the Bongaya Gandaman Formation (nomenclatures follow the north Borneo geology). The section penetrated consists of limestone, conglomerate and sandstone from 0 to 2,500 ft. and an almost monotonous sequence of claystone with minor sandstone and limestone from 2,500 to total depth. Coal beds were encountered at various intervals from 1,000 ft. down.

A 22 feet thick porous limestone section (5,356–5,377 ft.) which gave a good "kick" in the E-long was tested but proved non-commercial. The hole was finally abandoned at 8,586 ft. when a high pressure low volume zone was reached and caused the drill pipe to become stuck in the hole.

Subsequently, the second well, Sulu Sea B–1 was spudded on another seismic location approximately 18 miles northeast of the A–1 site. The second well was programmed to 7,500 ft. to test the same objectives in the first well. An essentially similar section encountered in the first location was penetrated. No significant hydrocarbon bearing zones were tested although shows were encountered at various intervals during the drilling. The well was finally abandoned as a dry hole at 7,287 on March 26, 1973.

On September 7, 1973, SW Palawan No. A–1 was spudded approximately 25 miles southwest of the southern tip of Palawan in 351 feet of water. It was operated by Chevron Oil Company of the Philippines for Chevron Texaco Overseas Petroleum Co., Astro Mineral and Oil Corp., and JINICO. The well was drilled to test a seismically defined low relief southward plunging anticline and to investigate the section below the structure for stratigraphic traps. Drilling reached a total depth of 7,540 ft. bottoming in the Lower Miocene and encountering only moderately abnormal pressure. The primary objective Carcar limestone was topped at 2,876 ft. and was found very porous in part, but with corresponding low hydrocarbons. Some of the secondary objective sands in the pre-Carcar section were found well sorted and exhibited good porosity, however, they were evaluated as only being water wet. Two sizeable gas kicks were recorded during drilling at 6,500 and 7,080 ft. but chromatograph analysis showed that the gas is almost totally methane. The well is considered a dry hole when abandoned.

Further south in Sulu Sea, two exploratory wells were drilled and operated by Superior Oil for a consortium of domestic companies composed of Fil-Am, Pacifica and the Philodrill Group. The first well, Sulu Sea 333–1 was drilled on a seismic high previously defined by seismic survey at a location about 19 miles south of Cagayan de Sulu. Principal objectives were the reef development at approximately 2,800–3,200 ft. and the Pliocene-Upper Miocene sandstone correlative with the oil and gas bearing zone of Acquitane well Nymph Nord I in offshore Sabah waters. Drilling reached a total depth of 13,456 ft. without penetrating the basement and confirmed the presence of thick sedimentary section ranging in age from probable late Oligocene to Quaternary. Some beds exhibit excellent reservoir characteristics and capability of generating hydrocarbons. Two Lower to Middle Miocene zones, at 11,715—11,794 and 10,560—10,576 ft. which had oil shows from core and/or fluorescence from ditch cuttings were tested and these were found to be highly saturated with brackish water but associated with some amount of oil.

After completion of its first well, Superior Oil proceeded to drill exploratory well Sulu Sea 409–1 on the property of Pacifica at a point 30 kms. southeast of Sulu Sea 333–1 well. The well is located on a NW-SE trending faulted anticlinal structure which had been defined by seismic to cover more than 18,000 acres. Objective in drilling were the sandstone beds of Lower Pliocene and Upper Miocene. The well was drilled to a total depth of 15,095 feet making it to-date, the deepest offshore well in the country. The drilled section consists of vuggy, reefal Carcar limestone and alternating sequence of older clastic formations of probable early Miocene to Pleistocene age. Some intervals contain significant percentage of quartz sandstone with reservoir potential. Sandstone interbeds totalling 60 feet in thickness within the 12,848–12,981 ft. depth interval were tested but were found to contain formation water with only small amount of gas.

C) Hydrocarbon Prospects

Oil and gas seeps have been recorded in the Tertiary sediments in southern Palawan. In the offshore fields of northeast Borneo, quartz sandstones associated with shale diaphirism are productive. It is a possibility that similar geologic conditions exist offshore along the southeast coast of southern Palawan and in the Sulu Sea Basin.

Marine shales and bituminous silts presumably developed in great thicknessess offshore should represent good hydrocarbon source rocks. The presence of thick quartz sandstones and arkose which could act as suitable reservoirs are interpreted to have developed east of south Palawan and Balabac Island and in Sulu Sea area. It would be reasonable to assume that sufficient Upper Miocene and Pliocene shales and silts are developed offshore to form an effective seal to any hydrocarbon that may be trapped in sandstone reservoirs. Plio-Pleistocene and Upper Miocene reef development may also be considered as possible reservoir particularly where they have developed secondary porosity and fracturing.

Table 1. STRATIGRAPHIC WELLS AND WILDCATS DRILLED IN THE PHILIPPINES (1970-1974)
(Last well drilled before 1970 was abandoned in November 1964.)

Name of Well	PEC NO.	PET. REGION NO.	Location	Concessionaire (Operator)	Spud and Abandoned Dates	Depth in Feet	Latitude Longitude	Results and Remarks
Cletom 102A-16	6	IV	Alegria, Cebu	REDECO/PODCO (CLETOM)	Aug. 15/70	1750	N9°42′52.93″ E123°21′55.86″	Gas shows Drilling suspended.
Cletom 102A-21	6	IV	Alegria, Cebu	REDECO/PODCO (CLETOM)	Nov. 3/70 Jan. 14/71	1883	N9°42′39.91″ E123°21′55.875″	Oil & gas shows Drilling suspended.
Topac Strat #1	292	I	Tabuk, Apayao Kalinga	PHILODRILL	Dec. 9/70 Mar. 25/71	726	N17°19′40.0″ E121°26′47.0″	Slight gas/oil shows and abandoned in Lower Mio.
Badian #1	174	IV	Badian, Cebu	PACIFICA	Feb. 19/71 July 31/71	3974	N9°52′56.4″ E123°22′19.2″	Gas shows from Maingit Ss. Abandoned dry hole. Maingit Ss.
Pag-asa #1	322	III	NW Palawan, (Offshore)	FOJAS (ORIENTAL)	Mar. 14/71 May 24/71	7568	N11°00′42.16″ E118°51.02.30″	Abandoned dry, Lower Miocene.
Cletom 102A-20	6	IV	Alegria, Cebu	REDECO/PODCO (CLETOM)	Apr. 1/71 June 1/71	1530	N9°42′39.91″ E123°21′42.76″	Suspended oil & gas shows. Bottom. Mid. Mio.
Sta Fe #1	118	IV	Sta. Fe Bantayan Is. Cebu	AAOC/PIONEER (CPC)	Apr. 5/71 July 7/71	7563	N11°10′13.2″ E123°47′36.35″	Gas shows, abandoned dry Oligocene.

Pinto Strat 1#	291 / I	Potia, Ifugao	PHILODRILL	May 10/71 May 31/71	1278	N16°58'94.5" E121°26'13.0	Abandoned dry Lower Mio.
Calamian #1	324 / III	Culion, Palawan (Offshore)	FOJAS (Oriental)	May 26/71 July 18/71	6904	N11°53'10.39" E119°21'31.83"	Abandoned dry in Lower Mio.
Topac #1	292 / I	Tabuk, Apayao Kalinga	PHILODRILL	May 8/71 Sept. 28/72	15,708	N17°19'27.9 E121°26'40.2"	Gas shows. Abandoned as dry hole in Lower Miocene.
Aurora #1	198 / V	Aurora Bondoc Peninsula	WHITE EAGLE (Hercules)	May 28/71 Aug. 19/71	6852	N13°23'45.00" E122°30'50.00"	Strong gas shows. Upper Mio.
Roxas #1	33 / VI	Roxas, Koronadal Southern Cotabato	SANJOCO (South Seas)	June 21/71 Sept. 25/71	5303	N6°30'12.58" E124°45'33.68"	Gas shows. Abandoned Middle Mio.
Lagao #1	62 / VI	Sultan sa Barongis, Catabato	MAREMCO/ANGLO (Fil-Am Res.)	June 30/71 Sept. 17/71	3657	N6°24'57.52" E124°30'26"	Gas shows. Abandoned Pliocene.
Kalian #1 (Sarangani #1	342 / VI	Gen. Santos South Cotabato	SESMAR	July 25/71	8018	N6°07.00" E125°28'30"	Gas shows, suspended in oligo.
BTY #1	118 / IV	Bantayan Island	AAOC/PIONEER (CPC)	Aug. 14/71 Nov. 3/71	7686	N11°12'46" E123°44'43"	Abandoned dry Lower Oligocene
Aurora #2	198 / V	San Francisco (Aurora, Quezon)	WHITE EAGLE (Hercules)	Sept. 11/71 Oct. 26/71	3622	N70°00W, 1.28 kms. from Aurora #1	Gas shows, suspended Mid. Miocene, Vigo formation.
Roxas #2	33-A / VI	Koronadal Southern Cotabato	SANJOCO (South Seas)	Oct. 15/71 Jan. 15/72	8425	N6°29'54.315" E124°45'35.759	Abandoned dry hole Lower Mio.

Pedtobo #1	62 VI	Buluan, North Cotabato	ANGLO/MAREMCO (Fil-Am)	Oct. 27/71 Nov. 19/71	5200	N6°43'08.43" E124°46'27.6"	Abandoned dry hole Basement Complex.
Cletom 102A-29	6 IV	Alegria, Cebu	REDECO/PODCO (Cletom)	Dec. 4/71	2350	N9°42'26.89" E123°21'42.76"	Gas shows at 1815-1953 suspended Toledo formation
CMB #1	213 IV	Daanbantayan Cebu	AAOC/PIONEER (CPC)	Dec. 20/71 Jan. 15/72	3340	N11°16'37.7" E124°03'30.5"	Oil & gas shows. abandoned dry Cret. Pandan Fm.
CMB #2	213 IV	Daanbantayan Cebu	AAOC/PIONEER (CPC)	Mar. 17/72	3171	N11°16'22" E124°03'06"	Gas-70,000-100,000 cu. ft./day; Oil-40-50 bbl/day fr. 1564-1580' Malubog Fm.
Roxas #3	33 VI	Koronadal Cotabato	SANJOCO (South Seas)	Apr. 5/72 Sept. 21/72	7765	N6°28'28.777" E124°46'36.996	Abandoned dry. Lower Mio.
CMB #3	213 IV	Daanbantayan Cebu	AAOC/PIONEER (CPC)	July 3/72 July 29/72	3740	N11°16'09.7" E124°02'483"	Abandoned dry Up. Oligo. Cebu Ls.
Cletom 102A-33	6 IV	Alegria, Cebu	REDECO/PODCO (CLETOM)	May 22/72 Aug. 25/72	3153	N9°42'13.870" E123°21'55.857"	Oil & gas shows. Suspended in Maingit Fm.
CMB #4	213 IV	Dannbantayan Cebu	AAOC/PIONEER (CPC)	Sept. 8/72 Nov. 18/72	2580	N11°16'25" E124°03'11"	Oil shows, abandoned in Upper Oligo. Cebu Ls.
DAB #1	213 IV	Daanbantayan Cebu Island	AAOC/PIONEER (CPC)	Dec. 29/72 Mar. 5/73	7888	N11°15'20" E124°00'11"	Gas cut- 890m. & 1465m. 1400 psi. 2800 psi. abandoned dry Cebu Ls.
Lucena #1	2 IV	New Lucena Iloilo	PODCO	Jan. 3/73 Feb. 6/73	6640	N10°52'50.2" E122°34'50.4"	Gas shows. Abandoned dry hole Basement.

Sulu Sea A-1	382 IV	Cagayan de Sulu	PODCC/PIONEER (Triton)	Dec. 22/72 Feb. 22/73	8586	N7°17′10″ E117°56′49″	Gas shows. Abandoned dry hole in Oligo-Mio.
Sulu Sea B-1 (Offshore)	381 IV	Cagayan de Sulu	PODCC/PIONEER (Triton)	Feb. 28/73 Mar. 26/73	7287	N7°27′30″ E118°07′37″	Gas shows. Abandoned dry. Oligo-Mio.
Sta. Barbara #1	2 IV	Sta. Barbara Iloilo	PODCC	Mar. 21/73 Apr. 6/73	5150	N10°49′10.7″ E122°33′41.0″	Abandoned as dry hole in Basement.
TLS #1	213 IV	Talisay, Daanbantayan Cebu	AAOC/PIONEER (CPC)	May 23/73 July 12/73	6122	N11°15′28″ E124°03′05″	Gas shows Maingit Fm. Abandoned dry Malubog Fm.
Manduriao #1	2 IV	Mandurriao, Iloilo	PODCO	Apr. 30/73 May 31/73	6153	N10°43′26″ E122°32′38″	Gas shows. Abandoned dry. Basement.
NR #1	6 IV	Alegria, Cebu	PODCC/REDECO	June 6/73 Sept. 7/73	1007	N9°43′12.63″ E123°21′44.52″	Oil & gas shows. Abandoned dry. Maingit Fm.
SWP-1	444 III	Southern Palawan Offshore	JINICO ASTRO AMOSEAS (Chevron Texaco)	Sept. 7/73 Oct. 24/73	7540	N8°17′20″ E116°48′36″	Abandoned dry. Lower Mio.
Sulu Sea 333-1	333 VI	Sulu Sea	BAGUIO GOLD (Superior Oil)	Oct. 30/73 Mar. 20/74	13,456	N6°40′07″ E118°33′04″	Oil & gas shows. Abandoned dry. Lower Mid. Mio.
Sagay M-2	32 IV	Borbon, Cebu	ACOJE (South Seas)	Nov. 2/73 Dec. 13/73	2768	N10°52′26.72″ E123°57′34″	Abandoned dry. Barili Ls. due to lost circulation
Sagay M-1	32 IV	Borbon, Cebu	ACOJE (South Seas)	Feb. 8/74 May 1974	4648	N10°52′1.46″ E123°56′51″	Oil shows. Abandoned dry in Malubog Fm.

Sulu Sea 409-1	409 VI	Sulu Sea	PACIFICA (Superior Oil)	Mar. 23/74 July 1974	15,095	N6°03′15.074″ E118°53′18.288″	Oil & gas shows. Abandoned dry. Lower Mio.
CPR #1	6 IV	Malabuyok, Cebu	REDECO (CPC-PIONEER)	June 7/74 Sept. 10/74	5210	N9°40′40″ E123°21′12″	Oil & gas shows. Abandoned Maingit Sandstone.
Mandurriao #2	2 IV	Mandurriao, Cebu	PODCO	June 23/74 July 20/74	6118	N10°42′55″ E122°31′41″	Gas shows. Abandoned dry. Basement
Allangian #1	291 I	Parasilis, Mt. Province	PHILODRILL	Sept. 1/74 Nov. 10/74	8545	N17°06′18″ E121°30′34″	Oil & gas shows. Abandoned dry. Lubuagan Fm.
Leganes #1	Serv. Contract IV	Iloilo City	PODCO	Sept. 15/74 Sept. 29/74	5975	N10°46′33″ E122°35′50″	Abandoned dry in Basement.
Trend Well #1	Serv. Contract V	Lamon Bay	TREND OIL CORP.	Dec. 7/74		N14°24′00″ E123°34′00″	
Allangigan #2	291 I	Parasilis, Mt. Prov.	PHILODRILL	Dec. 14/74 Jan. 1975	5171	N17°05′49″ E121°30′06″	Gas shows. Abandoned as dry Lubuagan Fm.

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APPENDIX: EXPLORATION WORKS IN THE PALAWAN-SULU AREA

Surface geological mapping covering most of Palawan mainland and surrounding island areas and the Sulu archipelago have been carried out by the Bureau of Mines and private companies.

A regional aeromagnetic survey covering the entire offshore areas was undertaken under the sponsorship of ECAFE. Offshore seismic and magnetometer surveys have been conducted in waters surrounding the islands resulting to delineation of a number of potential structures and stratigraphic prospects, some of which have been recognized from seismic profiles whose lithologies and ages have been determined from the results of offshore drilling in the region.

Geophysical surveys and offshore drilling on the northwestern shelf have yielded valuable information on the late Tertiary geologic history of the region. These exploration activities have shown that since the deposition of several thousand feet of deep-sea marine clastic sediments on a Lower Miocene limestone depositional base, the region has undergo two major periods of regression and marine transgression. These events are recorded as two prominent unconformities intervening between the Middle Miocene and Upper Miocene, and between the Middle Miocene and Pliocene strata. In addition, eight foraminiferal assemblage zones were recognized, the boundaries of which closely correspond with lithologic and faunal breaks.

To-date fifteen offshore wells with an aggregate footage exceeding 121,200 have been drilled in the region. All wells have proven the existence of extensive and prospective section of Tertiary rocks. The shelf has been confirmed to contain thick sequences of marine source rocks capable of generating oil and suitably emplaced reservoir rocks consisting of clastic sediments and carbonate facies with appreciable porocity. Several of the wells have been given very good indications of oil and/or gas at varied depths and the latest, Nido Well No. 1 which was drilled northwest of Palawan actually produced considerable amount of very good oil. As a result of this latest development, more detailed offshore seismic surveys and extensive drilling activities are programmed in the region.

(6 May 1976)

Table 2. WILLS DRILLED IN THE PHILIPPINES (1975-EARLY 1976)

Name of Well	PEC NO.	REGION NO.	Location	Concessionaire (Operator)	Spud and Abnndoned Dates	Depth in Feet	Latitute Longitude	Remarks
Trend No. 2	Free Area	V	Bicol Shelf	(Filon Expl.) (Trend Corp.)	Jan. 2 1975 Jan. 18	2,905	14°39′49″N 123°08′44″E	Recovered salt water during DST.
Trend No. 3	Free Area	V	Bicol Shelf	(Filon Expl.) (Trend Corp.)	Jan. 23 1975 Mar. 7	5,393	14°31′00″N 123°40′00″E	Recovered salt water during DST.
CPR #2	6	IV	Malabuyoc, Cebu	REDECO (CPC-PIONEER)	Jan. 30 1975	6,719	09°39′42″N 123°20,29″E	Oil & gas recovery during production test.
Sun Oil 389 #1	389	IV	Sulu Sea (Offshore)	Basic Petroleum (Sun Oil)	Apr. 4 1975 June 7	12,029	06°28′39.113N 118°24′53.974E	Oil & gas show.
PEC 296-1X	269	III	Northwest Palawan (Offshore)	PHILODRILL (Amoco, Husky, Mosbacher)	Apr. 8 1975 June 10	9,926	10°25′56″N 118°27′48″E	No shows.
Coral #1	361	III	Southeast Palawan (Offshore)	PHIL-AUST. (Husky)	Aug. 13 1975 Sept. 21	1,050	8°15′49″N 117°59′15″E	No shows.
Champlin Penascosa #1	P-591*	III	West Central Palawan (Offshore)	ASTRO (Champlin Phils.)	June 19 1975 Nov. 20	14,000	9°55′22″N 118°03′49″E	Oil shows.
Albion Head No. 1—X	NRA 272**	III	Southwest Palawan (Offshore)	(Philips Petroleum)	June 28 1975 Sept. 9	12,390	9°31′03″N 117°42′12″E	Oil & gas show.

Boayan No. 1	369 III	Northwest Palawan (Offshore)	BASIC PETROLEUM (Champlin-Tricentral-Landoil)	Nov. 22 1975 Dec. 27	7,616	10°40′25″N 118°33′48″E	
Lamon Bay No. 1	Free Area I	Lamon Bay NE of Alabat Island	(Texas Oil-Pacific)	Dec. 3 1975	2,600	14°36′20″N 122°05′11″E (Approx.)	
Paragua #1	Free Area III	Southwest Palawan (Offshore)	Phillips	Sept. 18 1975 Oct. 14	9,020	8°51′15″N 117°09′05″E	
Nido 1	322 III	Northwest Palawan (Offshore)	FOJAS (Cities Service-Husky)	Jan. 25 1976	9,500 Susp.	11°3′19″N 118°52′32″E	Oil discovery

* P–591—Published Petroleum Exploration Concession Application.
** NRA–272—National Reserve Area.

Total No. of wells drilled in the Philippines up to early 1976 .... 298 wells
Total No. of onshore wells drilled in the Phil. up to early 1976 .... 279 wells
Total No. of offshore wells drilled to the Phil. up to early 1976 .... 19 wells
Total No. of wells drilled over 3,000 ft. up to early 1976 .... 92 wells
Total No. of wells with gas shows .... 18 wells
Total No. of wells with oil & gas showings .... 26 wells
Aggregate footage of wells drilled in the Philippines .... Approx. 885,000

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PETROLEUM GEOLOGY AND INDUSTRY OF THE PEOPLE'S REPUBLIC OF CHINA

By

A. A. MEYERHOFF[1)]
and
J.-O. WILLUMS[2)]

ABSTRACT

Since 1949, the annual oil production of the People's Republic of China (PRC) has risen from a rate of 2,420 bbl/d (883,000 bbl = 121,000 mt) to a rate of about 1,534,000 b/d (559.91 million bbl = 76.7 million mt) at the end of 1975 (these figures include shale oil). Gas production in 1974 is estimated to have been 2,100 Bcf (= 60 Bcm). The annual rate of oil-production increase was 61 per cent from 1949 to 1950, with an average of 27.6 per cent between 1949 and 1968. The average rate of increase remained almost constant at 20.6 per cent from 1969 through 1975. However, because of the steadily growing volumes of economic resources required to increase production, future rates of increase will decline, although PRC production can be expected to increase for approximately the next two decades. A level of approximately 6,640,000 bbl/d (2.42 billion bbl = 332 million mt) can be predicted for 1985. These figures are based on known geological and geophysical data, and are far below figures predicted from unscientific and unfounded claims that the PRC offshore alone contains reserves equal to, or even 10 times greater than, those of the Middle East. The most realistic estimates for produced, proved, probable, and potential onshore oil recovery are 5,398 billion mt (39.51 billion bbl); and for the equivalent categories of offshore reserves, 4.11 billion mt (30.0 billion bbl), a total of 9,507 billion mt (69.51 billion bbl). These estimates do not include shale oil. Ultimate gas recovery is estimated at 5,714 Bcm (209,000 Bcf) onshore and 2,857 Bcm (100,-000 Bcf) offshore.

The growth of the PRC's petroleum industry is related directly to the adoption by PRC geologists of unorthodox hypotheses concerning the origin of petroleum. Most petroleum-prospective basins in the PRC contain only non-marine strata, whereas most petroleum geochemists and geologists long have argued that petroleum, especially oil, is of marine origin, despite convincing evidence to the contrary in parts of (a) Argentina, (b) the USSR, and (c) the western USA. Indeed, of the estimated 424,185,500 mt (3,096,554,150 bbl) produced by the end of 1975 in the PRC, at least 94 per cent came from non-marine Triassic, Jurassic, Cretaceous, and Tertiary reservoirs and source materials.

A total of 30 prospective petroleum basins (Taiwan is excluded) is known from the PRC. All produce or are capable of producing from Triassic and/or younger strata, with only tiny amounts of production from Carboniferous and Permian beds. Six have sizable commercial production; seven have marginally

1) Tulsa, Oklahoma 74104, USA.
2) 1322 Høvik, Norway.

commercial or noncommercial production (six of the latter have possibilities for larger scale commercial production); and the rest are untested or tested only in very small areas. Twenty-three basins are onshore with only three known to contain marine reservoirs and/or source materials. Production ranges in age from Carboniferous through Pliocene; one basin is partly onshore and offshore, with production from both marine and nonmarine Tertiary beds; six basins are wholly to mainly offshore, with potential production from both marine and nonmarine Tertiary beds.

A substantial part of the future development of the PRC petroleum industry is committed to the development of the offshore, although major emphasis will continue in the onshore basins for many years. Soviet onshore technology gradually has been replaced by Chinese-built technology and lesser amounts of imported Rumanian, Western, and Japanese equipment. Offshore technology, begun with Soviet techniques, now is becoming increasingly based on Western and Japanese models and equipment. Processing and transportation, both serious bottlenecks in the PRC's attempts to increase production, are being improved steadily by the expanded use of Chinese and foreign technologies. However, present trends in the PRC indicate that the government intends to continue—at least for the time being—its post-1960 policy of self-reliance, with minimum dependency on non-PRC sources of technology.

INTRODUCTION

Until 1961, the PRC's petroleum industry was fairly well known to those who were interested, largely because of papers and books published in the Soviet Union (Antropov, 1958; Chang Keng *et al.*, 1958; P'ang and Ryabukhin, 1961; Kravchenko, 1965, *in* Brod, 1965; and 1968, *in* Vasil'yev, 1968). More up-to-date, non-geological reviews were published by Kudo (1966) and Ho K'o-jen (1968). Geology-based papers by Meyerhoff (1970, 1975), Bakirov *et al.* (1971), and Li (1971) appeared subsequently. Li's paper has numerous errors, particularly with respect to productive zones, their ages, and depths. More recent economic and geologic reviews were published by Shabad (1972), Connell (1974), Kambara (1974), the Central Intelligence Agency (1975), and Williams (1975). Probably the best geological data published by non-PRC sources are by Kravchenko (*in* Brod, 1965; Vasil'yev, 1968; Bakirov *et al.*, 1971). Translations of critical PRC policy statements were published by Ling (1975), although Ling made almost no use of the other publications cited in this paper. Extremely helpful reviews of offshore potential were published by Emery and Niino (1968), Wageman *et al.* (1970), Parke *et al.* (1971), Willums (1974a, 1974b), Leyden *et al.* (1973), Salmanov (1974), and many others. A comprehensive study of the PRC offshore potential was prepared by Willums (1975). The popular press, particularly in Japan and the United States, published many unsubstantiated statements about the "gigantic" potential of offshore China, and the thereby contributed nothing to what actually is known of the Chinese offshore. A paper published by the Shantong Seismo-Geologic Group (1975) for the first time provided basic data on the Shengli fields along the Gulf of Pohai, and demonstrated scientifically the errors of many sensationl press stories. Meyerhoff (1973) published a paper on the geopolitical implications of onshore petroleum in the PRC. Harrison (1975) speculated on the geopolitical implications of offshore petroleum in the PRC.

Although much has been written concerning the history of the PRC petroleum industry, the interrelations between internal policies and politics, relations with the USSR, and progress in PRC exploration and development have not been emphasized strongly enough. Consequently, we present a brief political history to provide the reader with an understanding of what the effects of internal and external (mainly USSR) politics have been in relation to the PRC petroleum industry. We also take this opportunity to update our previous papers (Meyerhoff, 1970, 1973, 1975) and Willums (1974a, 1974b), to expand the data given in these papers, and to correct some minor errors published by Meyerhoff (1970).

PRE-1949

China's petroleum industry is one of the oldest in the world (Owen, 1975), with records of petroleum usage dating to 3000 B.C. or before. Confucius, about 600 B.C., mentioned the deliberate drilling of bamboo wells for salt deposits in the Szechwan basin (*Fig. 1*). Gas deposits were found during the drilling of these early salt wells. In 211 B.C., a bamboo well was drilled deliberately for gas on the Chi-liu-ching anticline, west of modern Chung-king (*Fig. 1*). The gas, found in the Triassic Chia-ling-chiang Limestone, was flared to evaporate the salt that is interbeded with the lime-

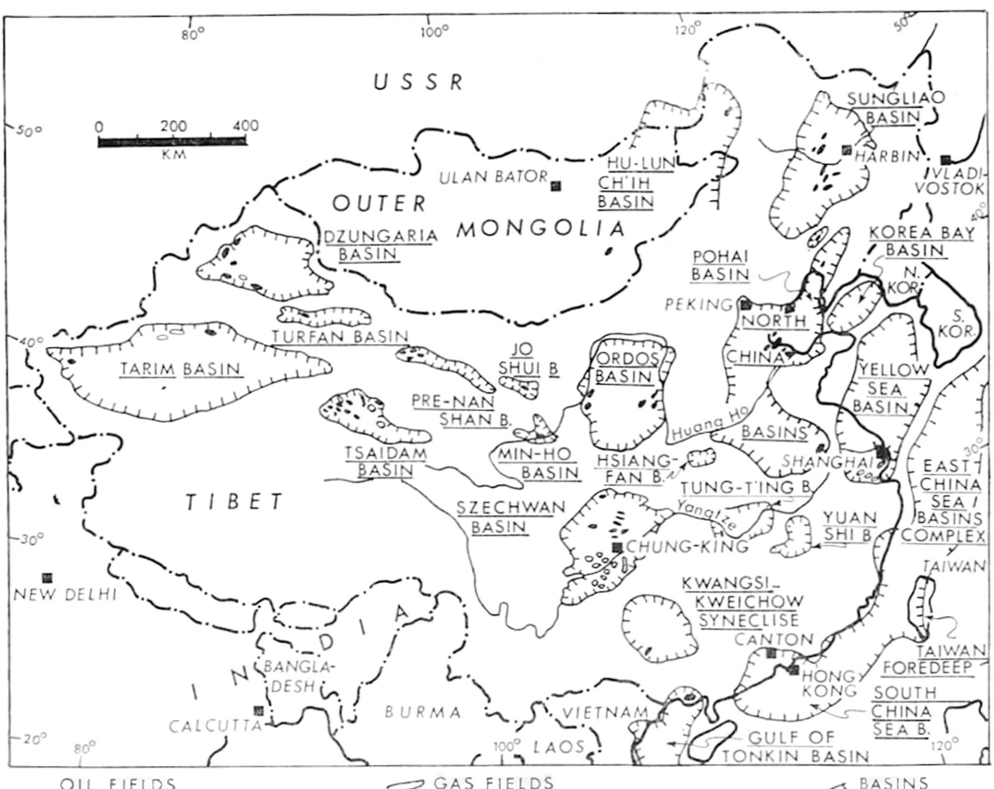


Figure 1. Index map of principal basins of the PRC; oil and gas fields are shown.

stone. Eventually, wells were drilled to depths of 1,000 m or more, and more than 1,100 wells had been drilled by 1900 (Strubell, 1968).

Between 1100 and 1200 A.D., numerous shallow gas wells were dug by hand and drilled with bamboo at Yung-p'ing (Ordos basin) and south of Shang-hai (southern end of Yellow Sea basin). Hand-dug tar pits and wells were dug in and along many anticlines and faults along the southern margin of the Dzungaria basin, along the southern flank of the Pre-Nan Shan basins, and along the southern, western, and eastern margins of the Tarim basin (Huang *et al.*, 1947; *Fig. 1*). Strubell (1968) reported that oil and tar from shallow wells were used widely by Chinese and Mongol soliders in the construction of fire bombs.

The first modern commercial field was discovered in 1897 by Chinese and Russian drillers at Tu-shan-tze in the southwestern part of the Dzungaria basin (*Fig. 1*). Remoteness, lack of markets, and the more immediate need for the drilling equipment in the Caspian Sea region brought the Russian drilling efforts to a halt in World War I. Interest in the area was not renewed until World War II (Huang *et al.*, 1947), and the post-1949 discovery of much larger fields in the northwestern part of the Dzungaria basin (*Fig. 1*) renewed interest in the Tu-shan-tze structural trend, which consists principally of strongly deformed Tertiary, Cretaceous, and Jurassic continental strata adjacent to the Tien Shan along the basin's southern flank.

In 1907, Yu-ch'ang field was discovered in the Ordos basin (*Fig. 1*). Poor reservoir quality in the productive Triassic section caused abandonment of the field in 1931. The field was reopened in 1951.

In 1928, Shih-you-kou field was discovered in the Pre-Nan Shan basin complex (*Fig. 1*) of the Kansu (Ho-hsi) Corridor. Several years later—in 1938—the original Yü-men (Lao-chün-miao) field was discovered close to Shih-you-kou. In 1938, the Japanese discovered the only other pre-1949 commercial field in China, the T'ung-an field of the Fou-hsin area, just southeast of the Sungliao basin (*Fig. 1*). The Fou-hsin area is a graben between the Sungliao graben complex on the northwest and north, and the North China basin (graben) complex on the south and southeast.

1949–1960

General—Failure to discover substantial petroleum reserves in China before 1949 generally is attributed to the conscious, or subconscious, notion among geologists that, because petroleum—especially oil—is of marine origin, commercial accumulation could not be expected in China, with the sole exception of the Szechwan basin (Weller, 1944). Other reasons for failing to develop commercial petroleum resources during the pre-1949 period include (1) a lack of market and transport facilities in a relatively backward, war-torn country, (2) plentiful petroleum supplies elsewhere in the world, (3) the presence in China of large deposits of oil shale for which economic refining techniques were being sought, (4) uneconomic logistics in remote regions of formidable topography, and (5) unsettled local conditions—not just the Japanese invasion, but also the conflicts among local war lords, the central government, and the Communist forces which were establishing themselves in northern China.

The principal reasons for the great progress in the PRC's petroleum development since 1949 are (1) the government's determination that the PRC would be independent of foreign petroleum imports, (2) the early recognition by Soviet and PRC geologists that petroleum is generated in the nonmarine environment, (3) the determination by PRC officials to make their country into a great world power, and (4) the lack of large petroleum deposits in the Soviet Far East and Maritime Provinces. The Soviets wanted very much to build a substantial petroleum base in China for import to the USSR, particularly to the growing industrial regions of the Amur-Ussuri Valleys, centered on the city of Khabarovsk. The Soviet reserve situation on Sakhalin Island, their only Pacific petroleum-productive region, had deteriorated badly, a situation which continues today. Large tank-car petroleum shipments are necessary from the Soviet Union's pipeline terminus at Irkutsk; no pipeline extends to the Pacific coast. Thus, the concept of a close-by, friendly source of imported oil was paramount in the minds of many Soviet planners.

As a result, large influxes of Soviet aid took place during the period 1949–1952, which was a period of regrouping—an interval of national economic and political revitalization which was followed by the First Five Year Plan. During the 1949–1952 period, a complete inventory of economic resources was undertaken; plans were made to fill in the greatest gaps (one of which was a petroleum industry); and exploration for drillable structures was begun on a broad scale. In fact, between 1949 and 1958 (when the "Great Leap Forward" began), Soviet and Chinese geologists and geophysicists discovered (and rediscovered) not less than 600 undrilled structures (Antropov, 1958) within the onshore area of the PRC. By 1960, when the last Soviet technician left, 41 of these structures had become commercial oil and/or gas fields (Kudo, 1966; Meyerhoff, 1970).

First Five Year Plan—This includes the period 1953–1957 and, as a result of massive transfer of Soviet know-how to China, was the most important period in the history of modern Chinese industrialization (Willums, 1975). Large-scale exploration was conducted in most of the major onshore basins of the country, particularly in the Dzungaria, Tsaidam, Turfan, Pre-Nan Shan, Ordos, Sungliao, and Ordos basins (*Fig. 1*). The annual production target was 1.4 million mt (14.6 million bbl), but reached only 1.4 million mt (16.2 million bbl), about 36 percent short of the goal (*Table 1*). Nevertheless, 27 moderate-sized to giant[1] fields were discovered, most of them in the Tsaidam and Szechwán basins (*Fig. 1*). Karamai, a giant which produced about 147,500 bbl/d in 1973 (possibly 162,000 bbl/d in 1975) (Connell, 1974; National Council, 1976) and with an ultimate recovery of 730 million bbl (100 million mt; Meyerhoff, 1970), was discovered in the Dzungaria basin (*Fig. 1*). About 387,000,000 bbl = 53,000,000 mt had been produced through 1975, according to the National Council [1976] report.[2]) Successes during the period of this plan appear to have awakened Chinese awareness in their own abilities, an effect possibly unforseen by the Soviet advisors who had left the PRC "to teach it a lesson."

Second Five Year Plan and "The Great Leap Forward"—This plan was created for

1) A giant field is defined here according to Holmgren *et al.* (1975)—an oil field with recoverable reserves of 500,000,000 bbl (68 million mt) or more of oil, or a gas field of 3.0 Tcf or more (86 billion cu^3) of natural gas.

2) Williams' (1975) figures (extrapolated) are much lower—a total of 69 million bbl (9.46 million mt). Williams' figures seem far too low.

the years 1958–1962. An official slogan of the plan was "The Great Leap Forward," the aim of which was to accelerate economic expansion, especially in agriculture. New-field development was emphasized strongly, and the 1962 annual production goal was set at 5–6 million mt (36.5–44 million bbl). This goal was accomplished 12–18 months ahead of schedule (*Table 1*). However, depression in most industries followed "The

Table 1. Estimated Oil Production, PRC, 1949–1975.

Year	Metric Tons	Barrels	Bbl/d
Pre-1949	2,780,000[1]	20,294,000	—
1949	121,000[2]	883,300	2,420
1950	200,000[2]	1,460,000	4,000
1951	305,000[2]	2,226,500	6,100
1952	435,500[2]	3,179,150	8,710
1953	622,000[2]	4,540,600	12,440
1954	789,000[2]	5,759,700	15,780
1955	966,000[2]	7,051,800	19,320
1956	1,163,000	8,489,900	23,260
1957	1,410,000[2]	10,293,000	28,200
1958	2,264,000	16,527,200	45,280
1959	3,700,000[2]	27,010,000	74,000
1960	5,500,000	40,150,000	110,000
1961	5,300,000	38,690,000	106,000
1962	5,830,000	42,559,000	116,000
1963	6,400,000	46,720,000	128,000
1964	8,700,000	63,510,000	174,000
1965	10,800,000	78,840,000	216,000
1966	13,500,000	98,550,000	270,000
1967	13,000,000	94,900,000	260,000
1968	15,200,000	110,960,000	304,000
1969	20,300,000	148,190,000	406,000
1970	28,500,000	208,050,000	570,000
1971	36,700,000	267,910,000	734,000
1972	43,000,000	313,900,000	860,000
1973	54,700,000[3]	399,310,000	1,094,000
1974	65,300,000	476,690,000	1,306,000
1975	76,700,000	559,910,000	1,534,000
TOTAL	424,185,500	3,096,554,150	—

1 From Kudo (1968, p. 1) and Kambara (1974, p. 700). This figure includes shale oil, as do all subsequent figures.

2 These figures are official ones. All others are extrapolations, mainly from Williams (1975) and the National Council (1976).

3 We use the Williams and National Council figure despite the fact that Chou En-lai stated only that PRC production had surpassed 50 million mt/d for the first time in 1973—and in the second half of the year at that!

Great Leap," and the Second Five Year Plan was cancelled (Shabad, *in* Meyerhoff, 1970).

Near the beginning of "The Great Leap Forward," Sino-Soviet relations were in a poor state of repair because, during the First Plan, the Chinese began to realize that the Soviet (Stalinist) development model, based on industrialization at the expense of agriculture, was not applicable directly to conditions in the PRC. At the same time, the PRC leadership saw that the Soviets themselves were deviating from the prescribed Communist path toward what Mao regarded as a "revisionist road." In face of the growing imbalance between agriculture and industry and the consequent disillusionment with the USSR model, the PRC tried to pioneer its own road—hence the slogan, "The Great Leap Forward." The deliberate change in emphasis from the Stalinist industrialization model to a more balanced approach, emphasizing agriculture as much as industry, created strains in relations between the PRC and the USSR. Despite the disruption produced by "The Great Leap," the Chinese approach did bring about a rebirth of China's innovative capabilities, nearly dead since the days of the Old China. As a part of "The Great Leap" the petroleum industry began to build many small- and medium-sized refineries (0.3 to 60 bbl/d) to supply fuel to local farm machinery over the entire country. Such policies disturbed Soviet leaders, who then decided to leave China to its own devices until the PRC leadership "came to its senses."

The effect of the Soviet decision was precisely the opposite (Willums, 1975). Departure of the technicians drastically altered the political and economic direction of the PRC. The natural Chinese innovative spirit was rekindled. The many peoples of China grew closer together. Although numerous industries were hurt seriously by the withdrawal of Soviet technicians, the petroleum industry went forward into its own. The Soviet punitive measure produced a bitterness among the Chinese which drew them together into an all-out effort for survival. Present Chinese attitudes toward the USSR undoubtedly were produced by the Soviet withdrawal and were the principal factors that led to the present PRC policy of self-reliance. Significantly, it was during the height of "The Great Leap Forward" that the PRC's greatest oil field, Ta-ch'ing, was discovered on September 10, 1959, in the Sungliao basin (*Fig. 1*). Ultimately recoverable reserves, estimated by Meyerhoff (1970) at 624–1,200 million bbl, are closer to 3,000 million bbl. Nevertheless, and despite the success in exploration—many of which are attributable to the time lag between exploratory mapping and drilling—the Soviet withdrawal did deliver one severe blow to the PRC petroleum industry; this blow was in refining. Soviet refinery blueprints went back to the USSR with their creators, and the PRC turned extensively to Rumania, Italy, West Germany, France, and Japan. Because of the delays resulting from the refinery bottlenecks, the PRC only now is beginning to recover noticeably and to develop sufficient refining capacity of her own.

POST–1960

"Period of Consolidation," the Third Five Year Plan, and "The Great Proletarian Cultural Revolution"—A period of readjustment ("Period of Consolidation") followed "The Great Leap Forward" and the cancellation of the Second Five Year Plan. During this period, several major oil fields were discovered. A Third Five Year Plan was prepared for 1966–1970. However, the "Great Proletarian Cultural Revolution" of 1966–

1969 caused suspension of the Third Plan. Priority was put on political motivations of the youth "to educate the masses in new techniques and knowledge" (Shabad, *in* Meyerhoff, 1970). Mao suspected that the country was skidding toward counterrevolution and wished to attack his opponents by injecting more revolutionary fervor into the Party and government—thereby to regain clear political leadership. In August 1966, millions of teenaged Red Guards were mobilized, armed with Mao's Red Book, and sent to the countryside to carry the revolutionary message. Anti-USSR feelings reached unparalleled heights, even to the point of attacking and beating Soviet diplomats.

Despite the disruptions caused during "The Cultural Revolution," the petroleum industry seems to have suffered hardly at all, and almost certainly not to the extent suggested by Meyerhoff (1970, p. 1569). Offshore studies were begun in 1969 with seismic equipment in the Gulf of Po Hai, the Bay of Korea, and the Yellow Sea. By 1970, political and industrial activities had normalized again. Imports of advanced machinery from Japan, and to a lesser extent from Western Europe, were bringing China into the age of petrochemicals. Consequently a new long-range plan seemed to be necessary (Willums, 1975, p. 337).

Fourth Five Year Plan (1971–1975)—At the eve of the Fourth Five Year Plan, the PRC could be regarded as having reached a generally balanced level of economic development. Emphasis in 1971 was on basic industries, especially iron and steel. A rapidly developing chemical industry registered large increases, and the demand for petroleum raw material for the chemical industry increased rapidly. Self-sufficiency—a national policy which was a direct outgrowth of the Soviet abandonment of the PRC in 1959–1961—was emphasized even more strongly. High-technology enterprise became increasingly important. Rapproachment with the United States was deemed necessary for the PRC to advance its plans for great technological advance. Imports of U.S. products and technology to China showed a dramatic upswing by 1972. A similar change in attitude took place between the PRC and Western Europe. Numerous scientific and technical exchanges were begun with Western countries, as well as with Japan. The net result in the petroleum industry has been the exploration and exploitation of areas closer to the PRC's industrial and population centers. Before 1960, most of the PRC petroleum development took place in the northern tier of provinces adjacent to the Soviet Union, a situation which the Chinese leadership regarded as dangerous to its national interests. Discoveries of the Ta-ch'ing fields in the Sungliao basin (1959) and of the Shengli fields near the mouth of the Huang Ho (1962–1964) led increasingly to a southward shift of the centers of PRC petroleum production. The successes of the Shengli fields encouraged offshore development, and the first of the Takang fields was discovered in 1964 (Williams, 1975). Crude output from Takang has increased enormously since 1967, and the field complex is said to be as large as or larger than Ta-ch'ing. Offshore drilling no longer is conducted only from artificial platforms and earthen fills built outward from the shoreline. Beginning in 1969, the PRC began to operate one home-built platform rig 16 km offshore in the Gulf of Po Hai, 40 km southeast of Ta-ku. In 1972, the Japanese-built offshore rig, *Fuji*, was purchased, and began operating in the Gulf of Po Hai during 1973. In 1975, a deepwater catamaran, the *Kantan No. 1*, built in the PRC, drilled a stratigraphic test in the Yellow Sea. Numerous contacts between foreign companies and countries (United

States, Mexico, Canada, Western Europe, Japan, Australia) were made between 1968 and 1976, and purchase of a few selected foreign rigs already has begun. In addition, the Chinese continue to construct offshore rigs of their own. The Chinese are limiting the number of purchases in order to build up an offshore drilling industry of its own, in keeping with its national policy of self-reliance.

PETROLEUM GEOLOGY

GENERAL

Thirty basins or basin complexes are known from the onshore and offshore regions of the PRC. The total number of distinct basins may increase as offshore exploration is carried out.

The geology of each onshore basin has been described extensively in both the Chinese and Soviet literature. The principal sources for onshore data presented here are Chang Keng *et al.* (1958), China Academy of Sciences (1958), Ch'ang Ta (1963), Kravchenko (1965) *in* Brod (1965), Kravchenko (1968) *in* Vasil'yev (1968), Meyerhoff (1970), Bakirov *et al.* (1971), and the Shantong Seismo-Geologic Group (1975). Some offshore data were obtained from the above sources, as well as from Emery and Niino (1968), Emery *et al.* (1969), Wageman *et al.* (1970), Parke *et al.* (1971), Emery and Ben-Avraham (1972), and others.

The interior basins west of the Gulf of Po Hai and the Sungliao basin (*Fig. 1*) are large intermontane deeps which consist generally of a central stable massif bordered by strongly folded foredeeps. The foredeeps may surround the central massif, or may be present only along one side of it. In contrast, the coastal basins, onshore and offshore, contain numerous complex grabens associated in many areas with Mesozoic and/or Cenozoic volcanic rocks. The graben systems generally strike north-northeast-south-southwest to northeast-southwest.

All of the interior basins produce from nonmarine strata. Only in the Szechwan basin is some production found in marine beds. The nonmarine production in mainly from Triassic through Pliocene sandstones. Some small production has been found in Carboniferous and Permian beds of the Pre-Nan Shan basin. The only marine production onshore is from Triassic carbonates in the Szechwan basin. The nonmarine oil and gas are indigenous, and did not migrate from marine source materials.

Production from the coastal grabens also is largely nonmarine, as in the Sungliao basin, site of the giant Ta-ch'ing field complex. The Tertiary production at the mouth of the Huang Ho is reported to be nonmarine, but production at Takang is from Tertiary deltaic sandstones and marine carbonates.

Future offshore discoveries presumably will be from mixed paralic and marine formations, as on Taiwan where all reserves discovered to date are in Pliocene and Miocene marine to paralic sandstones. M. J. Terman of the U.S. Geological Survey (oral commun., Sept. 16, 1976) disagrees with this view, and believes that most future production from the continental shelf will come principally from nonmarine Tertiary strata.

Regardless, the petroleum geology of China is unusual because of the huge amounts of nonmarine oil and gas. Therefore, a study of the individual basins is instructive.

Figure 2. Index map of Dzungaria and Turfan basins, Sinkiang-Uighur Autonomous Region. Locations of fields and untested structures are shown, together with principal tectonic elements. Locations of *Figures 3, 4, 13* are shown. Political boundaries are from the 1975 edition of the *Times Atlas of the World*. **Fields:** 1=Tu-shan-tze; 2=Yan-chi-hai; 3=Chiigu; 4=Karamai; 5=Urho; 6=Chuung-kuai; 7=Sheng-ting-k'ou.

DZUNGARIA BASIN

General

This, the northwesternmost of the PRC basins, occupies a triangular area of 130,000 sq km (*Figs, 1, 2*) in the Sinkiang-Uighur Autonomous Region. It is an area of interior drainage with an average elevation between 500 and 1,000 m. The basin is bordered on the south by various ranges of the Tien Shan (P'o-lo-k'o-nu Shan, Po-

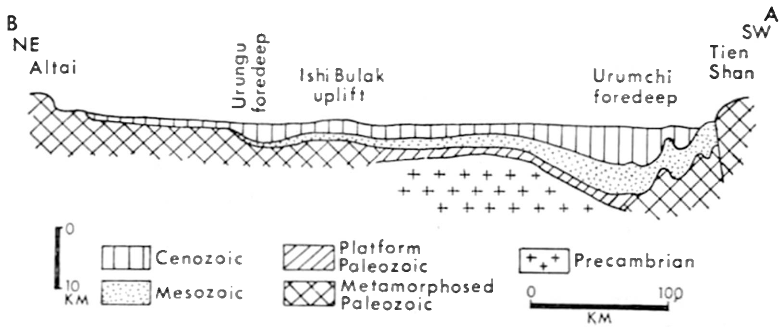


Figure 3. NE-SW generalized structural cross section of Dzungaria basin. From Brod (1965). Location shown on *Figure 2*.

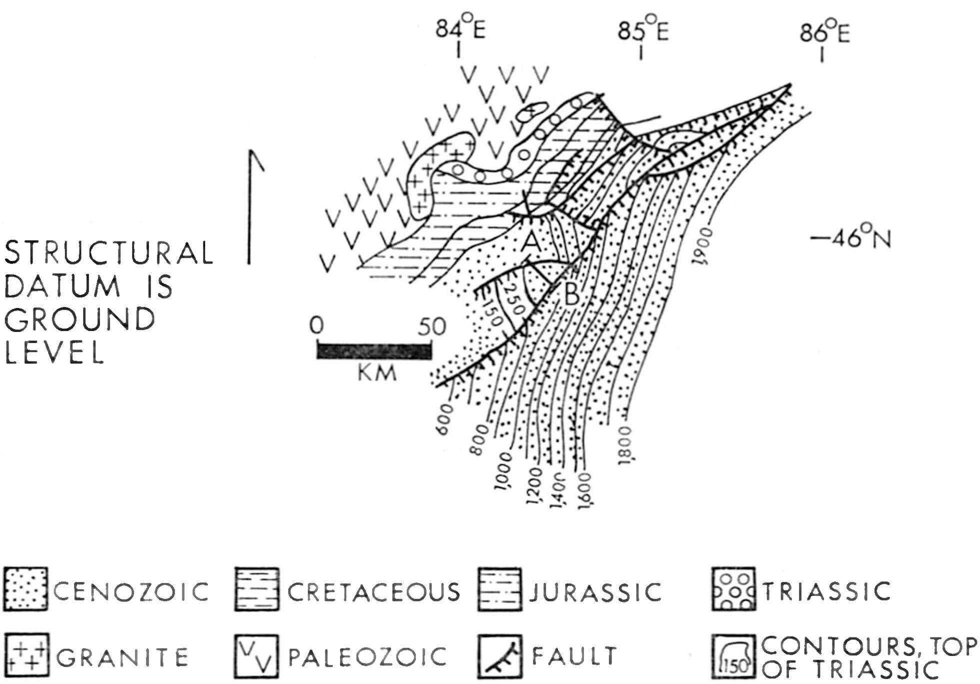


Figure 4. Geologic and structural contour map of Urho-Karamai monocline, western Dzungaria basin. Structural datum is the top of the Triassic Karamai Series. From Bakirov *et al.* (1971). Location is on *Figure 2*. Shows location of *Figure 8*, which is parallel with and close to the cross section of *Figure 9*.

ko-to Shan), on the northwest by several ranges of the Ma-li Shan and Chierh Shan, and on the northeast by the Altai Ranges.

Figure 2 shows the principal tectonic subdivisions: (1) the Urumchi Meso-Cenozoic molasse foredeep on the south (the thickness is 10–12 km, *Fig. 3*); (2) the Ebi Nor molasse basin on the west; (3) the Borten Gobi molasse basin on the east; (4) the Urungu molasse foredeep and Ishi Bulak uplift on the north; and (5) the Dzungaria median massif (Zwischengebirge), underlain by Paleozoic and older rocks, in the center, rising toward (6) the Urho-Karamai monocline on the northwest (*Fig. 4*). The Altai is thrust southward along the northwest and the Tien Shan is thrust northward along the southern margin. The latest episode of thrusting and folding around the basin margins took place in Pliocene and Pleistocene times.

Producing fields have been discovered in three anticlines of the Urumchi foredeep on the south and in several fault blocks within the Urho-Karamai monocline (*Fig. 4*) along the northwestern margin of the Dzungaria median massif, close to the USSR border. Exploratory work and drilling have been restricted to a very few areas. Only six fields have been reported and three appear now to be in exploitation.

Urumchi Foredeep Stratigraphy

The Urumchi foredeep is a nonmarine Triassic through Pliocene trough separating the Tien Shan on the south from the Dzungaria median massif on the north. The basin is 200–250 km long and 40–50 km wide.

The Triassic overlies strongly deformed Paleozoic beds and consists of 750 to 1,500 m of conglomerate, sandstone, and shale (Saidov, 1956; Chang Keng *et al.*, 1958; Brod, 1965). The shales typically are brownish red, red, violet red, and greenish gray, of lacustrine origin, interbedded with green-gray beds of sandstone and fine-grained conglomerate. A few 1.5–m–thick limestone beds are present locally. Lateral facies changes are numerous.

The Early to Middle Jurassic consists of lagoonal to lacustrine, nonmarine, coal-bearing shale and sandstone; the thickness generally is 1,700–2,400 m, but locally is 3,200–4,000. Conglomerate beds are present locally, including a basal conglomerate. The shales are gray to dark gray, greenish gray, and brown. The sandstones are light gray, green gray, yellow, reddish, and greenish, with some rose-colored zones. Locally the metamorphosed Paleozoic rocks of the Tien Shan area are overthrust on the Early to Middle Jurassic. Lateral facies changes are marked.

The Late Jurassic, about 500 to 680 m thick, consists of reddish and brown sandstone and shale. In most places it grades transitionally into the Middle Jurassic. Locally the unit thins to 25–60 m, and in places is eroded.

The Early Cretaceous consists of 60 to 1,270 m of conglomerate, sandstone, siltstone, and shale with some tuff beds. Most of the section is conglomerate (basal) and sandstone. Colors are gray, red gray, brown gray, gray brown, and yellow gray. The section lies with angular unconformity on Late and Middle Jurassic strata. Lateral facies changes are numerous and abrupt. At Tu-shan-tze field, minor production has been found in Early Cretaceous reservoirs.

The Late Cretaceous ranges in thickness from 40 to 1,800 m, locally reaching 3,000 m. The unit is mainly silty shale, with lesser amounts of sandstone and minor beds of conglomerate. Greenish-gray to dark-gray colors predominate in the lower part, and reddish-brown, brown-red, red, and brown colors predominate in the upper part.

The Tertiary (Tu-shan-tze Series) consists of a Pliocene "upper variegated" or "conglomerate zone" overlying the Miocene "upper brown zone," "upper green zone," "variegated zone," "second or middle green zone," and "lower brown zone." These units overlie the Oligocene "lower green zone," and the Paleocene-Eocene "red zone." Average total Tertiary thickness is 2,135–3,000 m, although lateral thickness changes are pronounced. The Tertiary is uncomformable on older units, and in some areas the lower units are absent, with Miocene directly above the Cretaceous. Conglomerate, sandstone, siltstone, and shale are the predominant lithologic types.

Oil and Gas Fields

Tu-shan-tze field (Figs. 5, 6, 7)—In both Russian- and English-language literature, this field name has been transliterated as Tu-shan-tze and Tu-shan-tzu. Because the joint Russian-Chinese publications (pre-1960) uniformly use the Tu-shan-tze transliteration, we use this spelling in this paper.

Tu-shan-tze is a small (3–4 × 8 km) asymmetrical anticline pierced by a small clay diapir (*Fig. 5*). Flank dips are 20°–40°S and 60–80°N. A 65°, south-dipping reverse fault cuts the northern flank of the structure (*Figs. 6, 7*). Tu-shan-tze is one of many frontal folds along the northern flank of the Tien Shan and within the Urumchi basin (*Fig. 3*).

Tu-shan-tze is the oldest commercial field in Sinkiang (*Figs.5–7*), and was discovered in 1897 by the Sinkiang Commerce Bureau (Kudo, 1966, p. 32). Small production was maintained for nearly two decades. New Tsarist Russian drilling equipment was introduced in 1907, but the field eventually became noncommercial and was abandoned about 1917. Exploitation did not begin until 1935 when the Sinkiang government began an active exploration program (Huang *et al.*, 1947, p. 19). A small well was drilled and opened to production in 1936 (Chang Keng *et al.*, p. 51, 55). Soviet technicians and machinery were introduced in 1938, and a small topping plant was

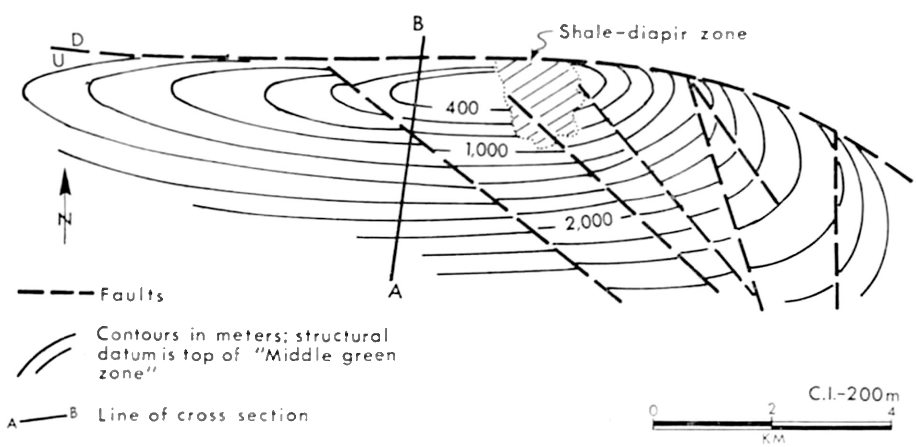


Figure 5. Structural contour map of Tu-shan-tze field, Dzungaria basin. Structural datum is the top of the "middle green zone" (Miocene). Field location is on *Figure 2*; line of cross section is *Figure 7*. From Chang Keng *et al.* (1958).

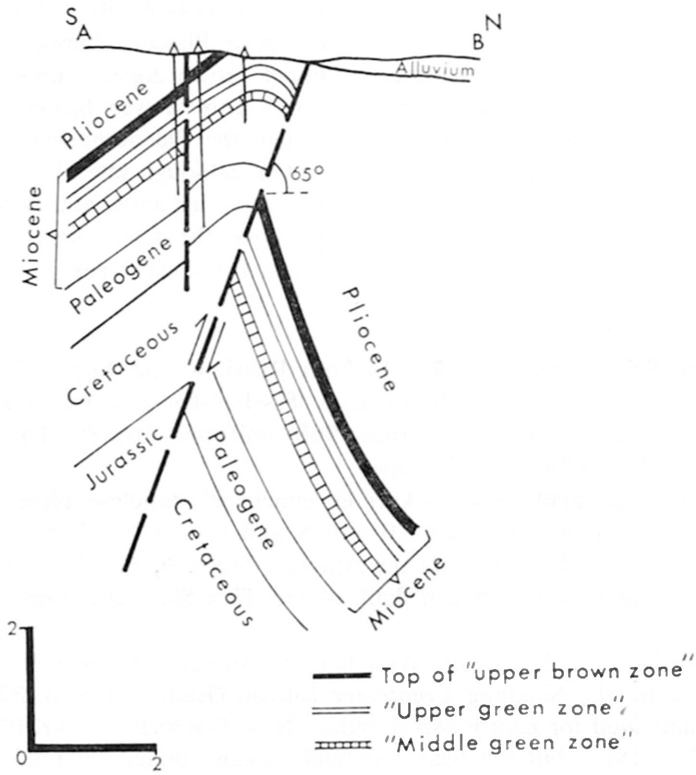


Figure 6. Generalized south-north structural cross section of Tu-shan-tze field, Dzungaria basin. From Chang Keng *et al.* (1958). Location shown on *Figure 5.*

constructed (219 mt/d = 1,600 bbl/d capacity). Fifteen wells were drilled in 1938 at the eastern end of the Tu-shan-tze anticline; average depth was 200–300 m; the deepest well was 360 m. The results were disappointing in that the wells were depleted rapidly —in 1 or 2 years. Six wells were drilled farther west in 1939 and 1940—all of them reaching 800 m or more. Mainly gas was found, and there was little use for it. Therefore, in 1941 and 1942, eight wells were drilled south of the crest of the anticline; depths ranged from 560 to 1,017 m. Oil and gas were discovered, and IPs ranged up to 27 to 37 mt/d (200–270 bbl/d). Two dry holes were drilled in 1942—one to a depth of 1,453 m. Two additional wells were drilling in early 1943, but in May 1943 the Russian government withdrew the technicians and the machinery for utilization west of the Urals. In January 1943 total daily production was between 63 and 71 mt/d (460–520 bbl/d) mainly from four wells. Decline was rapid, and the field soon was abandoned except for local use. In 1950, the mainland government began efforts to revive the field (Kaufmann, 1958), and the topping plant was expanded into a refiinery to handle Tu-shan-tze, Karamai, and Urho crude.

In April 1954, a decision was made to rebuild and enlarge the Tu-shan-tze refinery, and Kudo (1966, p. 8) reported that the capacity in 1962 was 500,000 mt/year (3,350,000 bbl/yr = 9,450 bbl/d). Drilling was begun, but apparently without much

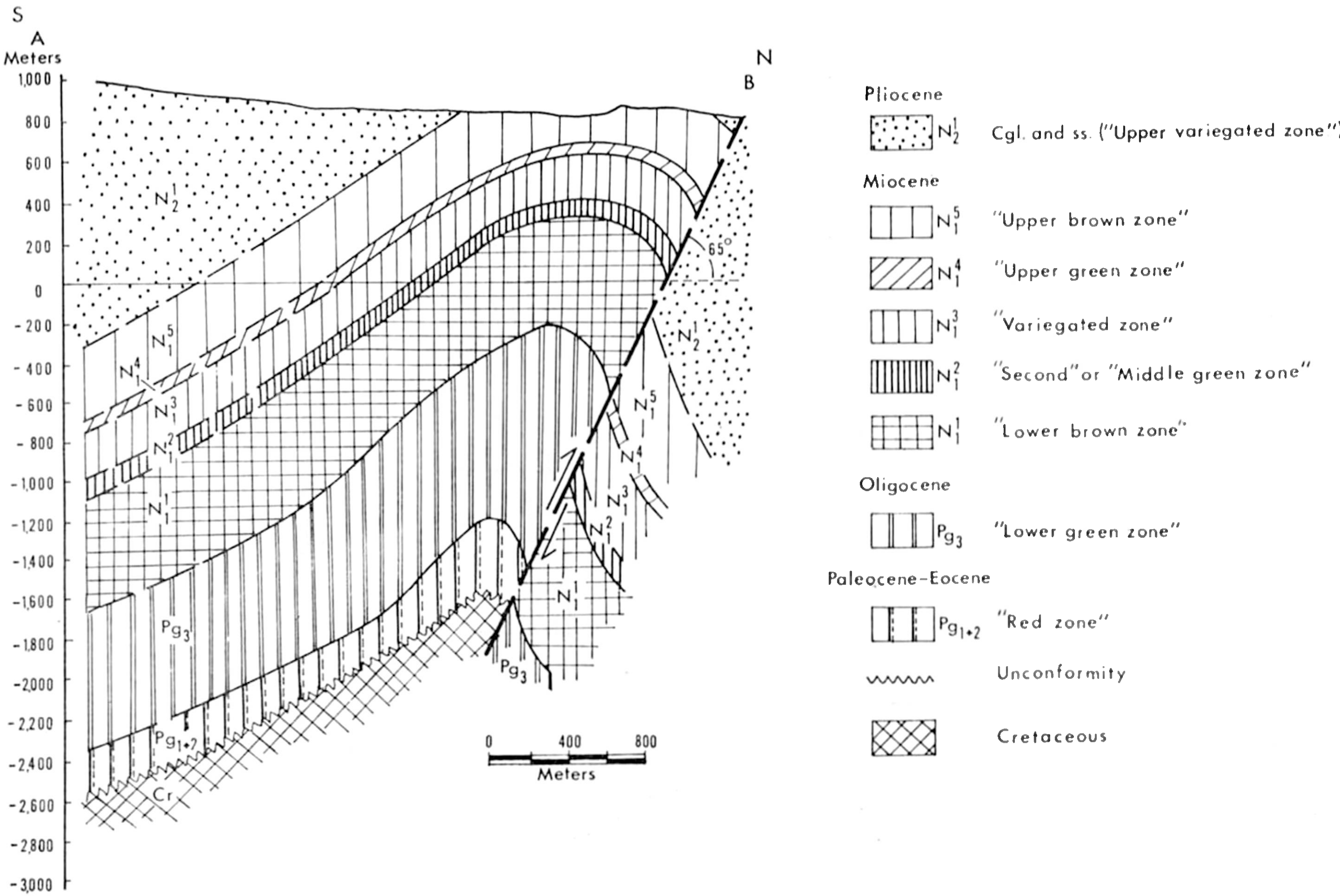


Figure 7. Detailed south-north cross section of Tu-shan-tze field, Dzungaria basin. From Bakirov *et al.* (1971). Location is the same as *Figure 6*.

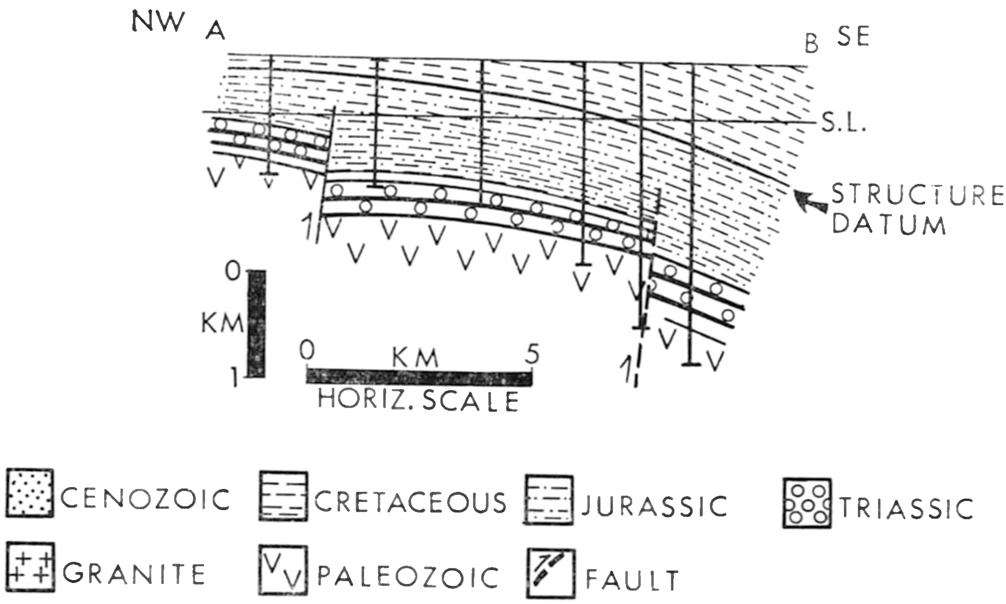


Figure 8. NW-SE cross section of part of Karamai field, Dzungaria basin. From Bakirov *et al.* (1971). Location shown on *Figures 2* and *4*.

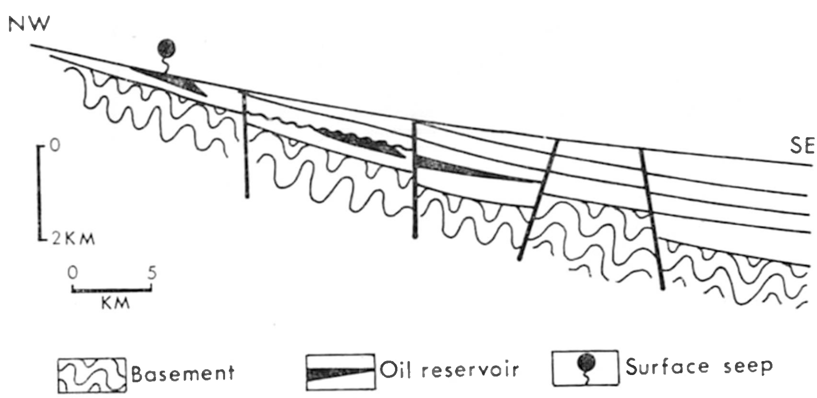


Figure 9. NW-SE cross section of several fault blocks in Karamai field, Dzungaria basin. From Vasil'yev (1968). Location shown on *Figure 4*.

success—to judge from the general lack of published information (Antropov, 1958).

In 1959, five wells were drilled to 3,000 m—four of them were abandoned (Kudo, 1966, p. 32). The fifth reportedly produced from the Lower Cretaceous. The 1959 deep tests found noncommercial oil in Triassic and Permian strata.

Producing depths range from 200 to more than 3,000 m below the surface (*Figs. 6, 7*). Except for one Cretaceous zone, all production is from the Tertiary Tu-shan-tze Series. Ten oil-productive sandstones are present in the Miocene—six in the "lower brown zone" and four in the "upper green zone." Three oil-productive sandstones are in the Oligocene "lower green zone"; one is known from the Lower Cretaceous. In addition, several gas-bearing reservoirs are present. The gas has been used only as fuel for drilling.

Initial daily production of each well ranged from 50 mt/d to 70 mt/d (365–511 bbl/d). The initial rates decreased within short time periods (a few weeks to a few months) to a few tons per day. Oil density is 0.86 g/cm^3. Some characteristics of Tu-shan-tze oil are shown on *Table 2*.

Table 2. Some Characteristics of Tu-shan-tze Oil
(from Kudo, 1966, p. 32)

S.G.	0.86
API Gravity	38°
Pour T. °C	40
Sulfur Content Wt. %	0.16
Paraffin Coutent Wt. %	6.00
Vol. % Gasoline after Distillation	36.5

Total recoverable reserves probably are less than the 7,000,000 mt (50,000,000 bbl) originally estimated by Meyerhoff (1970). The field, even with secondary recovery, probably will produce less than 5,500,000 mt (40,000,000 bbl). By the end of 1966, 82 wells had been drilled since 1935 (34 of them were depleted or dry) and production reached 300,000 mt/yr (2,200,000 bbl; Ho K'o-jen, 1968). By March 1976, only 29 wells were producing from an area of 3.5 sq. km.

Yan-chi-hai field—The Yan-chi-hai anticline is 50–60 km east of Tu-shan-tze (*Fig. 2*) in the Urumchi foredeep (Chang Keng *et al.*, 1958, p. 56). This is the Andihai gas field mentioned by Perrodon (1966, his Fig. 69). The structure is associated with seeps (Huang *et al.*, 1947, pl. 2) and is approximately 10 km long and strikes east-west. The structure is very similar to that of Tu-shan-tze. In 1952, gas was discovered in the Miocene Tu-shan-tze Series. Additional drilling was conducted from 1953 through 1955 to delineate the field and explore for oil. Only gas found. The field is shut in. Total proved reserves are 280,000–560,000 cu m (10–20 Bcf).

Chiigu field—The Chiigu anticline is about 100 km west of Urumchi (*Fig. 2*) in the Urumchi foredeep. The fold, being closer to the mountain front, is more deeply eroded and Cretaceous is exposed along the axis. Small oil pools were found in Early and Middle Jurassic sandstone during 1958, the year of discovery (Vasil'yev, 1968). Producing depths range from 860 to 1,000 m. IP's range from 10–16 mt (73-110 bbl/d) on 7-mm chokes. The trap is a shale seal above the unconformity surface between the Jurassic and Lower Cretaceous strata. Ultimate recovery will be less than 1,000,000 mt (7,300,000 bbl).

Other structures—The Wu-su structure, 20 km west-northwest of Tu-shan-tze and 5 km west of Wu-su (*Fig. 2*), is 12 km long and 5 km wide, and is north of the Tu-shan-tze trend of faulted anticlines. Hand-dug shafts and a few wells have been drilled on this structure. Production, from the Tu-shan-tze Series, is noncommercial (Kudo, 1966, p. 31).

The Urumchi structure, east of Urumchi town and just north of the western end of the Po-ko-to Shan, is a folded and faulted structure with numerous seeps that have been exploited for centuries.

Kudo (1966, p. 29) mentioned a Manass structure on the right bank of the Manass River. Kudo showed the structure at 45°N and 88°E. No other details are available.

Kudo also mentioned a structure called "Ichikuriku"; this appears to be the Chiigu field. A field, labelled "Tchiktei" by Perrodon and shown in the Turfan basin (Perrodon, 1966, p. 370), actually is an area of seeps near Ch'i't'ai in the southeastern part of the Dzungaria basin.

Urho-Karamai Monocline Stratigraphy

Figure 4 shows the basic structure of the Urho-Karamai monocline at the western margin of the Dzungaria median mass (*Fig.2*). Location of the Karamai field is shown.

The Mesozoic stratigraphy is similar to that of the Urumchi basin. The principal difference is the widespread unconformity at the top of the Middle Jurassic. Late Cretaceous directly overlies the Jurassic. Tertiary is absent, and a Quaternary cover overlies the lower (eastern) part of the monocline, as well as the Dzungaria central massif. Total thickness ranges from 500 m on the west to more than 3,000 m on the east.

Oil Fields

Karamai field group (Figures 4, 8, 9)—The Karamai field is a complex of several productive but separate fault blocks on an east-plunging structural nose, 25 to 50 km wide (Brod. 1965, p. 300), on the 120-km-wide Urho-Karamai monocline (*Fig.4*). *Figure 8* shows the generalized stratigraphy and productive block (the location of *Figure 8* is on *Figure 4*). *Figure 9* is a longer cross section parallel with that *Figure 8*. Production is from the Early to Middle Jurassic and from the Triassic Karamai Series. The traps are of several types—(1) unconformity traps in the Early and Middle Jurassic below the Late Cretaceous; (2) fault seals between fault blocks bounded by growth faults; (3) lithologic traps caused by (a) pinchouts, (b) lateral facies changes, and (c) lateral changes in cement; (4) tar seals; and (5) local flexures and noses (P'ang and Ryabukhin, 1961).

Karamai (which means "black oil" in the Uighur language) has been known for its numerous oil seeps and asphalt hills for many centuries. The asphalt hills have diameters of 450×500 m, and attain elevations up to 50 m (P'ang and Ryabukhin, 1961). Most seem to be aligned with surface faults. Cretaceous terrestrial sandstone beds at the surface are cemented with asphalt, and form a stark badlands topography characterized by striking and unusual shapes—spires, fortresses, castles, and even the outlines of many kinds of animals. Although known for centuries, this asphalt-badlands area was not described until the famous naturalist, V. A. Obruchev, travelled during 1907–1909 through Dzungaria (P'ang and Ryabukhin, 1961).

Several noncommercial wells were drilled at Karamai by the Sinkiang government beginning in 1937. A concentrated exploration effort was begun by the Russian and Chinese in 1950. The first joint Russian-Chinese well (Soviet-Chinese Oil Co., Ltd.)

was drilled in 1955, and was completed as a flowing well on October 29, 1955. In 1956, 10 additional flowing wells were drilled, and in 1957 and 1958, 22 more flowing wells were completed. Kaufmann (1958, p. 1723) rated the wells at 7 to 14 mt/d (50–100 bbl/d) each. Average daily production per well in 1968 was approximately 8.4 mt (61 bbl/d). By March 1976, 1,540 wells had been drilled, but many of these had been abandoned. Fourteen rigs were active, and 427 new locations had been staked. Production currently is from only 177 sq km of a once much larger area.

Depths to the top of production in the Middle and Early Jurassic range from 200 to 2,300 m or more; in the Triassic, from 600 to 3,000 m or more. Dips range from 1 to 3°, locally 4–7°. Basement is a metamorphosed and intruded Paleozoic sequence.

IP's for each well ranged from 70 to 130 mt/d (511–949 bbl/d; Vasil'yev, 1968; Bakirov *et al.*, 1971). Oil density is 0.86 g/cm^3, but ranges from 0.848 to 0.918. The best production is from Triassic reservoirs of the Karamai Series. The source of the oil is mainly organic nonmarine shale in Early to Middle Jurassic and Triassic lake beds.

Updip, production is mainly from five sandstone zones of the Karamai Series (Late Jurassic). In the downdip fault blocks, several Early Triassic and eight Late Triassic sandstone zones of the Karamai Series are productive. In addition, Early to Middle Jurassic sandstones (at least two zones) are productive from downdip fault blocks.

Total recoverable reserves were estimated by Meyerhoff (1970) to be 100,000,000 mt (730,000,000 bbl). This estimate may be optimistic, because individual well performances are erratic owing to the large clay matrix in parts of the productive sandstones and conglomerates. Water injection began in 1959.

Estimates of cumulative production at Karamai differ by nearly six times. If PRC statements regarding production (always expressed in percentage increases, generally with reference to a specific year) can be taken at face value, the production figures given by the National Council (1976) are probably reasonably accurate.

According to the National Council (1976), total production through 1975 was about 53,000,000 mt (387,000,000 bbl). In contrast, Williams' (1975) figures—extrapolated by us where no estimate of production was given for certain years—amount to about 9,500,000 mt (69,000,000 bbl) through 1974. To illustrate even more dramatically the wide divergence, Williams' 1973 figure is 725,000 mt (5,292,000 bbl = 14,500 bbl/d); Kambara's (1974) and the National Council's figure is 5,000,000 mt (36,500,000 bbl = 100,000 bbl/d; Connell's (1974) figure for the same year is 7,400,000 mt (54,000,000 bbl = 147,000 bbl/d). (Even Ho K'o-jen [1968] reported total Karamai production through 1966 as 17,760,000 mt = 130,000,000 bbl.) Our own review of the data suggests that Williams' figure is the most realistic, largely because 1975 production was 1,070,000 mt (7,811,000 bbl).

Williams (1975, p. 252) observed that the development of Karamai has been erratic. He expressed the opinion that the field's "disappointing performance can be explained in terms of Great Leap Forward policies and new, more attractive, discoveries in the Sung-Liao Basin." The latter reason undoubtedly slowed Karamai's development, but Williams did not mention two very important points: (1) reservoir quality at Karamai is erratic, and secondary recovery requires large volumes of water, which Karamai does not have; and (2) a fact that is paramount in planning by the PRC leadership is that the Soviet military presence is only a few hours from Karamai; hence, quick capture of the field would be certain were a war to break out. The water problem was solved partly by construction of a water line from the Manass River farther east. This was built in 1957 (Williams, 1975). The military problem is one which is not so easily resolved and, until the Ta-ch'ing area well under development, the PRC officialdom gave a low priority to Karamai. Even today, the Urumchi railhead has not been extended to the Tu-shan-tze refinery, and much of the Karamai oil is trucked to the railhead, a distance of 400 km. The remainder of the oil is piped to Tu-shan-tze in two parallel lines—one 16 inches in diameter and the other, 24 inches in diameter (National Council, 1976, p. 43).

Some characteristics of Karamai oil (from Kudo, 1966) are given on *Table 3*.

Urho field—Discovered in July 1968, Urho (Wu-erh-ho) is 100 km northeast of Karamai, close to the shore of the lake of the same name (Chang Keng *et al.*, 1958; Kudo, 1966; *Fig. 1*). The field is very similar in structure and stratigraphy to Karamai,

Table 3. Some Characteristics of Karamai Oil
(from Kudo, 1966, p. 31)

S.G.	0.86	
API Gravity	31.5	
Pour T. °C	44	
Sulfur Content Wt. %	0.19	
Paraffin Content Wt. %	0.1	
Product Yield, °C and Vol. %		
	200	14.87
	200-350	21.80
	350-400	7.40
	400	56.00

and also is on the Urho-Karamai monocline. A single 14-inch pipeline joins Urho with the Karamai pipelines. Urho's production is from the Triassic, Early to Middle Jurassic, and from one 20-m-thick sandstone reservoir in the Late Cretaceous (Chang Keng *et al.*, 1958, p. 55). The oil in the Cretaceous appears to be of Jurassic origin and reached its position in the Upper Cretaceous by migration along fractures and faults. Recoverable reserves are believed to be in the 6.85–13.0 mt (50–100 million bbl) range. The field is fairly large or a pipeline would not have been constructed to it. (However, we should note that no trace of a pipeline can be seen on aerial photographs.)

Chung-kuai field—This field was reported by both Kudo (1966, p. 30) and Williams (1975, p. 252). It is 60 km southeast of Karamai (*Fig. 2*), and contains oil in structures and stratigraphy similar to those at Karamai. The field may be small and of little importance; it receives almost no attention in PRC press reports. Recoverable reserves are unknown.

Other areas—Numerous folds are present in the Urumchi foredeep fold belt, and seeps within the folds have been exploited for 1,000 years or more. Several hand-dug pits and shafts are present near Urumchi, along the Manass River, Wu-su, and elsewhere. Northwest of the Dzungaria basin at T'a-ch'eng, oil was produced in small quantities for many years from pits and shallow wells. Production ultimately may be established in many parts of the Dzungaria basin, including the Urungu foredeep along the northeastern margin of the basin. Seismic data show that the Urungu sedimentary fill is at least 3 km thick, which is much less than the sediment cover of the Urumchi basin but is the same as the cover of the Urho-Karamai monocline.

Conclusions

The Dzungaria basin has one of the greatest potentials of the PRC onshore basins. Its development will continue to play a major role in the future of the PRC, despite the fact that only 2 percent of 1975 PRC production came from this basin.

TARIM BASIN

General

The Tarim basin (Sinkiang-Uighur Autonomous Region) is one of the largest intermontane basins on earth, with a surface area of 500,000 sq km (*Figs. 1, 10, 11*). The basin—a vast desert rimmed by oases at the base of the mountains—is bordered on the north by the Tien Shan, on the east by the Kuruk Tagh and the Turfan basin, on the south by the Kunlun Shan and the Tibetan Plateau, and on the west by the Pamir Range. The average elevation of the basin floor is about 1,200 m.

Figure 10 shows the principal tectonic subdivisions: a central stable platform, the Tarim (Oyhart) median massif (Zwischengebirge) of K. N. Kravchenko (1968, *in* Vasil'yev, 1968), underlain by Paleozoic strata; and a ring of Meso-Cenozoic molasse basins around the Tarim massif: (1) Kucha (K'u-ch'e) foredeep on the north, bounded on the south by (2) the Shayer (Shi-ya) syneclise; (3) Kashgar (Su-fu)) foredeep on the southeast; and (6) Lop Nor syneclise. The Tien Shan was thrust southward against the Kucha and Kashgar foredeeps; the Kunlun Shan was thrust northward toward the Kashgar, Pre-Kunlun Shan, and Charchan foredeeps. The latest episode of thrusting and folding around the basin margins took place in Pliocene and Pleistocene times.

Four fields have been found, although two of them—gas fields—appear to be shut in. One oil field and two gas fields are in the Kucha foredeep; one oil and gas field is in the Kashgar foredeep. Exploratory work and drilling have been restricted to a very small number of structures, and the potential of the Tarim has scarcely been tapped.

Kucha Foredeep Stratigraphy

As in the Urumchi foredeep of the Dzungaria basin, Triassic through Pliocene continental deposits overlie Paleozoic and Precambrian with a marked angular unconformity. The Mesozoic-Cenozoic section was derived from the rising Kunlun Shan and Tien Shan geosynclines on the south and north respectively.

The Triassic consists of 700–1,000 m of conglomerate and breccia layers, with interbedded layers of sandstone and lacustrine marl (Chang Keng *et al.*, 1958; Ch'ang Ta, 1963). The flora indicates a Late Triassic age. Metamorphosed Permian and older

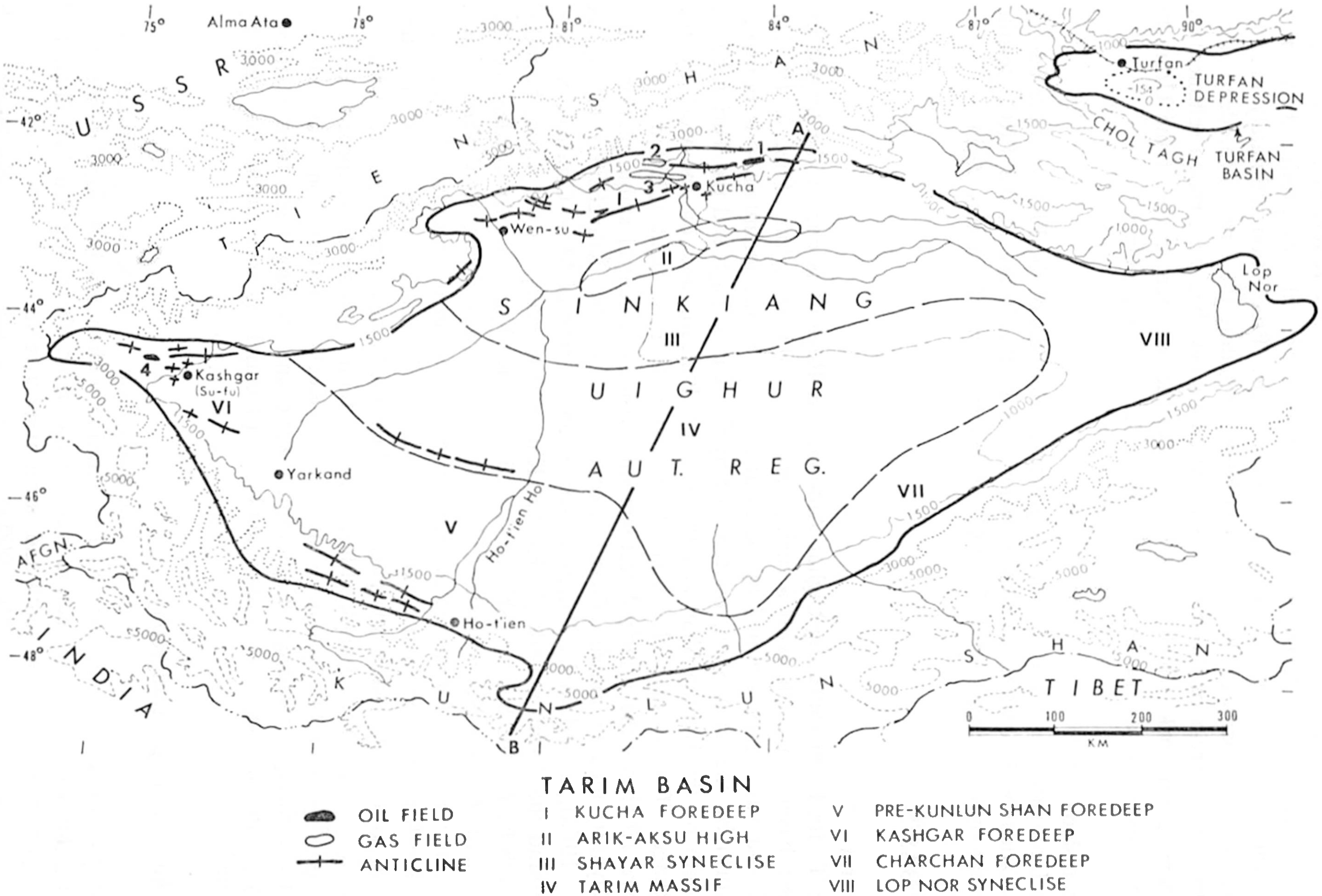


Figure 10. Index map of Tarim basin, Sinkiang-Uighur Autonomous Region. Locations of fields and structures are shown, together with principal tectonic elements, and location of *Figure 11*. Political boundaries are from the 1975 edition of the *Times Atlas of the World*. **Fields:** 1=Ichkelik; 2=Kumger; 3=Kosartok; 4=Karato.

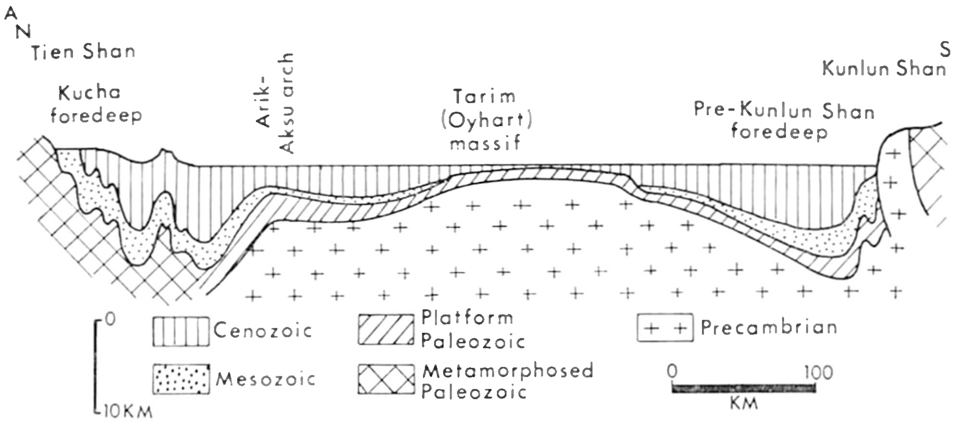


Figure 11. North-south generalized structural cross section of Tarim basin. Location of cross section is on *Figure 10*. From Brod (1965).

rocks underlie the Triassic (Chang Keng *et al.*, 1958).

The Jurassic is conformable on the Triassic, and ranges in thickness from 1,900 to 2,300 m. The "lower division" consists of 500–600 m of sandstone, conglomerate, shale, coal, and coaly shale overlain by 100–300 m of thin-bedded, gray sandstone with streaks of conglomerate. The "middle division" consists of 1,100–1,250 m of alternate beds of poorly sorted sandstone, shale, and fissile shale with a Middle Jurassic freshwater fauna, including microfauna. Coal beds are present. The "upper division," 200–300 m thick, contains beds of brown and maroon shale alternating with poorly sorted sandstone.

The Lower Cretaceous is unconformable on all divisions of the Jurassic. It is 800–1,400 m thick, and is composed of red-brown shale and fine-grained sandstone. A basal conglomerate is present. Upward the section becomes increasingly conglomeratic with angular clasts and red colors. The upper part—possibly Upper Cretaceous—is 200 m thick.

The Paleogene—600 to 1,950 m thick—has a lower gypsum-bearing unit and an upper "brown zone" of brown-yellow shale and conglomerate layers. The upper part may be Neogene.

The Neogene consists of a lower "dark-brown zone" and an upper "conglomerate zone." The "dark-brown zone," 1,630–3,700 m thick, consists of dark-brown shaly sandstone, sand, calcareous sandstone, and conglomerate with numerous shale layers. The "dark-brown zone" ranges in thickness from 500 to 1,600 m. The "conglomerate zone" reaches a thickness of up to 1,100 m.

Oil and Gas Fields

General—Drilling in the area began in 1913 (Kudo, 1966), and was restricted to a few shallow cable-tool wells, plus some hand-dug shafts. Seeps have been known for many centuries. Pits and a few wells were dug around Kucha and Wen-su for local use.

Ichkelik field—This field, discovered in 1958, is a surface anticline 25 km long and 5 km wide (*Figs. 10, 12*). Flank dips are up to 40–50° (*Fig. 12*). Oil production is from Middle Jurassic sandstones at a depth of 1,100 m. Miocene gas also is present. IP's range from 30 to 100 mt/d (219–730 bbl/d), but average 30–40 mt/d. This field is not fully developed. Potential recoverable reserves are 3,000,000–

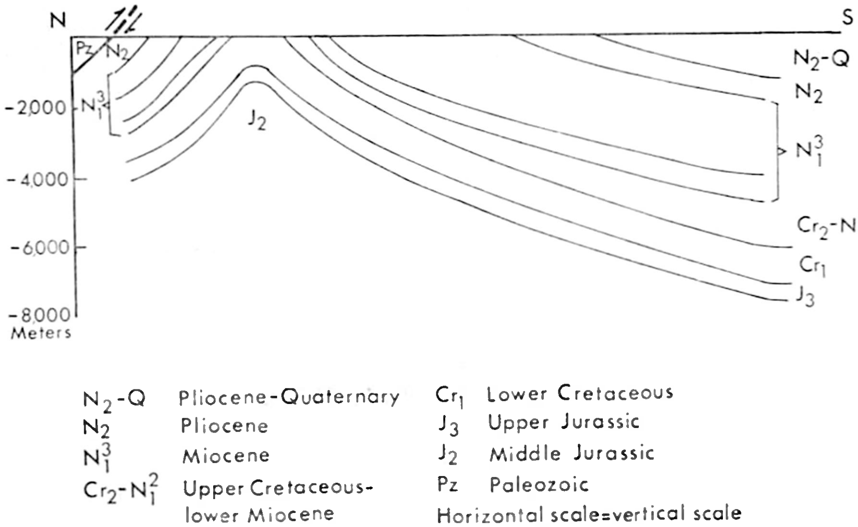


Figure 12. North-south cross section of Icheiik field, Tarim basin. From Vasil'yev (1968).

6,850,000 mt (23,000,000–50,000,000 bbl). There are no railways or pipelines, and the few productive wells are exploited for local use.

Kumger and Kosaptok fiields—Kumger and Kosaptok fields also are anticlinal structures (*Fig. 10*). The exact dates of discovery are not known, except that they appear to have been found between 1951 and 1955 when the PRC and Soviet Union jointly did most of the exploratory drilling in the basin (Petrov, 1967). Gas was discovered in Miocene and Jurassic sandstones, and both fields were shut in because of the absence of a market. Potential reserves are estimated to be about 1–2 billion m^3 (35–70 Bcf).

Kashgar Foredeep Stratigraphy

The stratigraphic section of this foredeep at the western end of the Tarim basin (*Fig. 10*) is somewhat similar to that of the Kucha foredeep (Chang Keng *et al.*, 1958). The Triassic consists of 80–230 m of conglomerate (overlying basement), that grades upward into sandstone alternating with siltstone and argillaceous limestone. Conformably above is 2,250–3,400 m of Jurassic.

The "lower division" of the Jurassic is 800–1,000 m of conglomerate. The "middle division" is 1,100–1,400 m of sandstone and lacustrine shale. The "upper division" is 350–1,000 m of sandstone, sandy shale, and shale.

Unconformably overlying the Jurassic, the basal Cretaceous includes 250–350 m of red conglomerate. This is overlain by 650–850 m of paralic Cenomanian sandstone of red-brown color. The Cenomanian grades upward into 200 m of Turonian marine marl, fissile shale, and limestone. Turonian is overlain by 100–200 m of Senonian brickred marl and sandstone with gypsum and limestone layers. The Cenomanian-early Senonian is the only marine Cretaceous established in this part of China.

Early Tertiary (Paleogene and earliest Miocene[?]) strata are generally conformable with the Cretaceous. They include 1,500–2,200 m of nonmarine shale, sandstone, limestone, and gypsum with a well-developed fauna and flora. Yellow and red colors characterize the shale.

The Neogene consists of four units: (1) streaks of variegated and mottled yellow to brown lignitic shale; (2) dark-brown layers of siltstone alternating with some shale, 1,000–1,100 m thick; (3) a gray sandstone-shale unit 1,200–1,500 m thick; and (4) a late Neogene conglomerate unit, 300–1,100 m thick. Units 1–3 range in thickness from 1,500–5,000 m.

Oil Field

Karato field—The Karato anticline, near the town of Kashgar, was first drilled in 1918 (Kudo, 1966, p. 33). The structure is 6 km by 3 km in size. Production was found in a Miocene sandstone at a depth of about 1,000 m. The oil flows with water, and was retested during the period 1951–1955 (Petrov, 1967). The field is shut in except as a source of local fuel (Vasil'yev, 1968).

Conclusions

The Tarim basin—nearly the size of the state of Texas—is one of the largest and least explored onshore basins in the world. Ultimately production should be found in many areas of the basin margins and interior. A major obstacle will be the water supply for drilling. However, Soviet explorationists have solved a similar water problem in the vast desert region of Soviet Central Asia, from the eastern shore of the Caspian to the boundary with Afghanistan. Therefore, as the need for development of the Tarim basin becomes more acute, it most assuredly will be developed.

TURFAN BASIN

General

The Turfan intermontane basin (Sinkiang-Uighur Autonomous Region) is bounded on the north by the Po-ko-to Shan (Bogdo Ula), the Barköl Tagh, and the Karlik Tagh; on the east by the Ma-tsung Shan and Kansu (Ho-hsi) Corridor, or Pre-Nan Shan basin; on the south by the Chol Tagh, Altin Tagh, and Tsaidam basin, and on the west by the Tien Shan K'u-lu-k'o Shan(Kuruk Tagh), and the Tarim basin (*Figs. 1, 2*). The basin is rectangular, east-west, and is 500 km long and 80 km wide, with an area of 30,000 sq km. The lowest point in China is in the Turfan oasis, at a subsea depth of –154 m. Average depth of the basin floor is 200–600 m above sea level.

Figure 2 shows the principal tectonic subdivisions. *Figure 13* shows two structural cross sections of the basin (Kravchenko, 1965, *in* Brod, 1965). Like the Dzungaria and Tarim basins, the Turfan basin is filled by Triassic through Quaternary molasse 5–7 km thick in the west and 2.5–4 km thick in the east. The molasse fill overlies a Paleozoic basement containing many volcanic rocks.

The structure of the basin is asymmetrical, with the northern ranges over-thrust

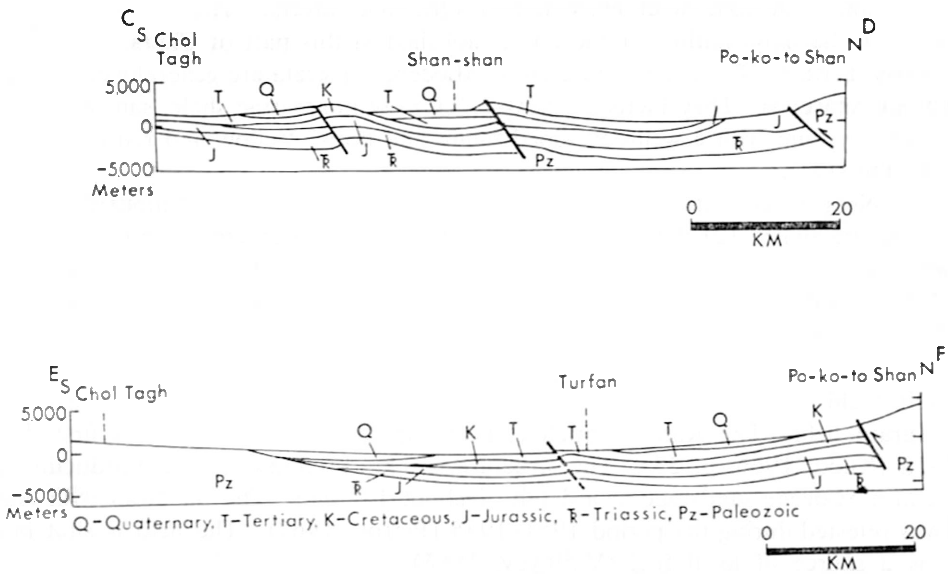


Figure 13. Two south-north cross sections of the Turfan basin, Sinkiang-Uighur Autonomous Region. Locations of the cross sections are shown on *Figure 2*. From Brod (1965).

southward toward the basin. A platform rises from the basin center towards the southern margin. The Central Turfan arch strikes through the basin; the thickest sections and most prospective areas to date are along this arch and in the basins south of it (Lukchun depression, Ha-mi depression).

One oil field has been found along the northern flank of the Lukchun depression. Exploratory drilling has been very limited because other areas of the PRC have larger structures with greater volumes of readily exploitable reserves.

Lukchun Depression Stratigraphy

The entire Turfan basin is post-Paleozoic, like most interior PRC basins. The Lukchun depression is the deepest part. The nonmarine molasse section ranges in age from Triassic through Cenozoic.

The Triassic "lower division" has a basal conglomerate that grades upward with alternate beds of sandstone and shale. In places, porphyry sills are present. Total thickness is up to 765 m. The "middle division" is 420–560 m of conglomerate, sandy shale, and sandstone. The "upper division" is 500–550 m of sandstone with streaks of fissile shale. Locally the "upper division" is 1,300 m thick.

The Jurassic, averaging 2,000 m in thickness, is more widespread than the Triassic. The Lower to Middle Jurassic consists of four units. The lowest is 200–360 m of sandy shale and coal with a basal conglomerate. The second unit is 110–120 m of shaly, lacustrine conglomerate, grading upward into sandy shale with coal seams. The third unit is sandstone with thick coal beds, up to 10 m thick. The unit is 100 m thick. The highest unit is 200–426 m of fissile shale and sandstone with a basal conglomerate. This unit is oil-bearing. The Middle and Upper Jurassic is about 1,200 m of conglomerate with sandstone and sandy shale.

The Cretaceous exhibits marked lateral thickness changes, from 140 to 1,900 m. The lower part is 140–510 m thick and consists of brown-red and gray-green fissile shale and shaly sandstone. One clean sandstone is an oil reservoir. The middle part is 0–800 m of sandstone with some conglomerate. This unit also is oil bearing. Average thickness in wells is 218 m. The upper part is 0–365 m of shaly sandstone and sandy shale.

The lowest Tertiary unit, 370–510 m thick, is Paleogene, and consists of shallow-water, lacustrine sandstone which is unconformable on the Cretaceous. Locally, red conglomerate and shale are present. The second Tertiary unit (basal Miocene) is 120–520 m of red-brown shale and sandstone with bedded anhydrite and halite. The third

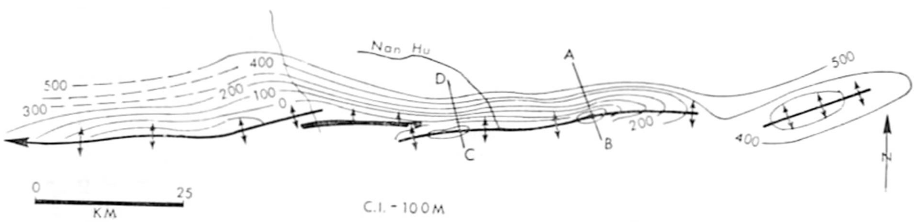


Figure 14. West-east-striking Yanmuss sector of the Central Turfan arch (see *Fig. 3* for location). Locations of the cross sections of *Figure 15* are shown. From Chang Keng *et al.* (1958).

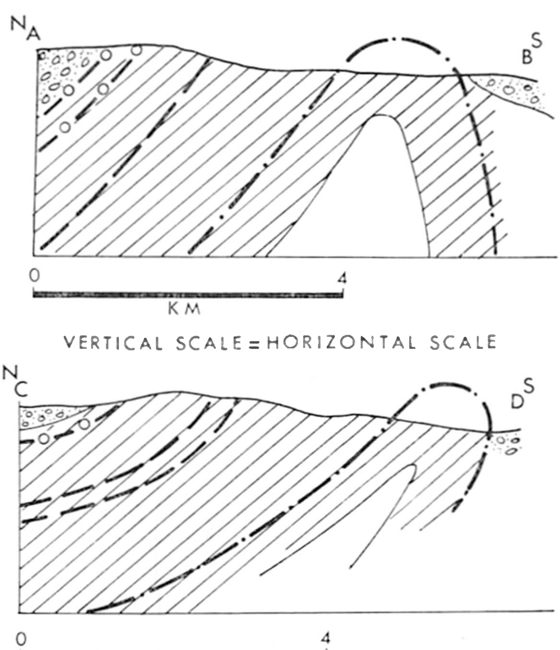


Figure 15. Two south-north structural cross sections of the Yanmuss sector of the Central Turfan arch. Locations are shown on *Figure 14*. From Chang Keng *et al.* (1958).

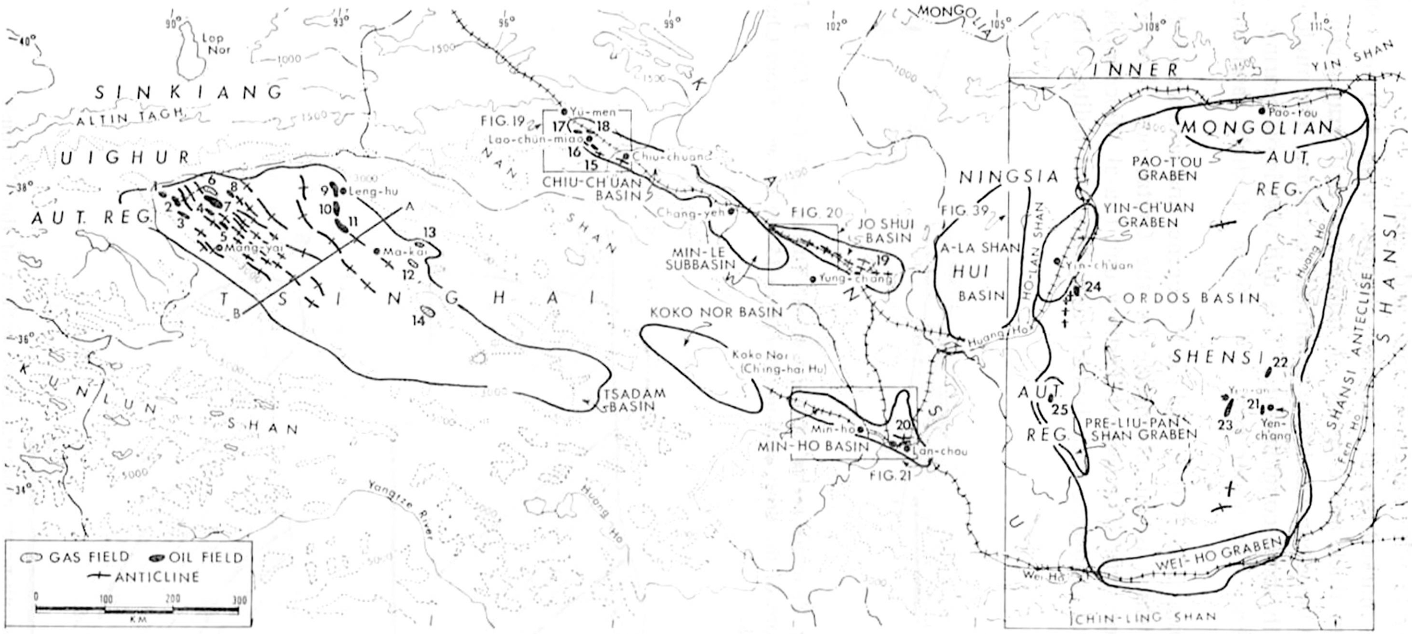


Figure 16 Index map of the Tsaidam and Pre-Nan Shan basins (Tsinghai and Kansu Provinces and Inner Mongolian Autonomous Region) and of the Ordos Basin (Inner Mongolian and Ningsia Hui Autonomous Regions and Shensi and Kansu Provinces). Locations of fields and other structures are shown, together with the principal tectonic elements. Locations of *Figures 17, 19, 20, 21,* and 39 are shown. Political boundaries are from the 1975 edition of the *Times Atlas of the World.* **Fields:** 1=Ch'i-kuo-ch'üan; 2=Shih-tze-kou; 3=You-sha-shan; 4=You-ch'üan-tze; 5=Kaitmilik; 6=Hsaio-lien-shan; 7=Nan-shan; 8=Tsen-tin-shan; 9=Leng-hu 3; 10=Leng-hu 4; 11=Leng-hu 5; 12=Ma-hai; 13=Yü-k'a; and 14=Yen-hu; **note:** the location of Min-ho-hsien field is unknown; 15=Shih-you-kou; 16=Lao-chün-miao; 17=Ya-erh-hsia; 18=Pai-yang Ho; 19=Ch'ing-t'u-ching; 20=Hu-t'uai; 21=Yen-ch'ang; 22=Yung-p'ing; 23=Yen-an; 24=Ma-chia-t'an; 25=Sha-t'ing-tze.

Tertiary unit is a Miocene sandstone with calcareous concretions, layers of conglomerate, and some shale. Thickness ranges from 116 to 330 m. The fourth unit is 20 to 400 m of Pliocene sandy shale with limestone concretions and poorly cemented conglomerate. The highest Tertiary unit is up to 250 m of conglomerate of limited distribution. Sand dunes and alluvium up to 40 m thick complete the section.

Oil Developments

Sheng-ting-k'ou field—This field is on the Central Turfan arch. *Figure 14* is a structural contour map of this arch (Yamuss sector) east of the Sheng-ting-k'ou field. *Figure 15* shows two structural cross sections of the arch. The structures are asymmetrical toward the south. Sheng-ting-k'ou is an asymmetrical anticline (flank dips 10–20°) in which commercial oil was found in the Middle Jurassic and two oil-bearing reservoirs were found in the Lower Cretaceous. The most favorable reservoir is the Middle Jurassic sandstone at a depth of 610 m. IP's range from 25 to 30 mt/d (183–219 bbl/d). The field was discovered in 1958. Wells drilled on neighboring structures also have found probable commercial volumes of oil. Except for local use, most of the production is shut in for lack of a market and because other basins have greater potential. Ultimate recovery is estimated to be 6,850,000 mt (50,000,000 bbl).

TSAIDAM BASIN

General

This intermontane molasse basin in Tsinghai Province has a ground elevation ranging from 2,600 to 3,000 m between the Altin Tagh and Nan Shan on the north (with elevations up to 5,400 m) and the Kunlun Shan on the south and west (with elevations more than 6,000 m). The basin is triangle shaped, having a 100-km width in the east, a 200-km width in the west, and a length of about 650 km. The minimum area is 100,000 km²; because some marginal parts of the basin are now known to be prospective, the total area for future development is not less than 120,000 km².

Figure 16 shows the principal tectonic elements. The basin is very similar struc-

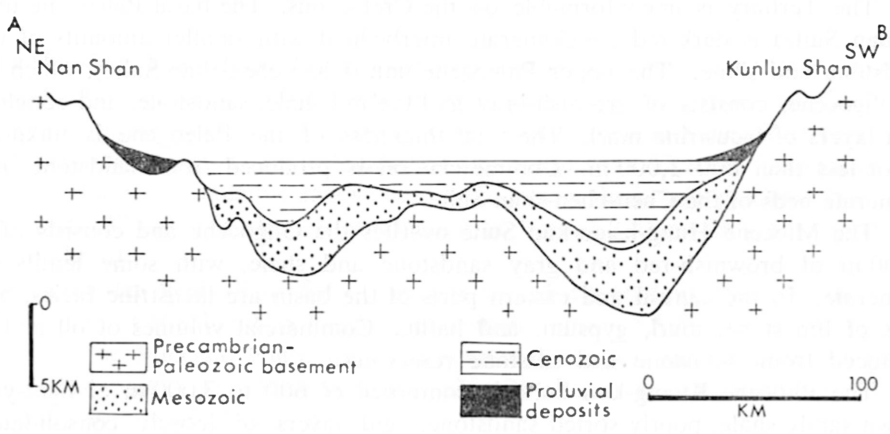


Figure 17. SW-NE generalized structural cross section of the Tsaidam basin. Location shown on *Fiure 16*. From Petrov (1967).

turally to the Tarim basin, with a central median mass (*Fig. 17*), and bordering foredeeps. However the median mass is buried more deeply—by at least 5 km of Meso-Cenozoic continental strata. The thickest Meso-Cenozoic sections are 10–12 km thick. The entire basin was folded during Plio-Pleistocene time, and is now characterized by several subparallel rows of northwest-southeast-striking anticlines. In the eastern part of the basin, intensely deformed Paleozoic eugeosynclinal rocks are exposed in the anticlinal cores.

At least 11 oil fields and 4 gas fields, some of giant to very large size, have been found (Bakirov *et al.*, 1971; Williams, 1975) since exploratory drilling commenced during 1954. Several additional discoveries—each a potential field—probably have been made but not developed. The basin is one of the most promising of the onshore PRC. A total of 24 oil-productive zones—with an average total effective thickness of 60 m—has been discovered from depths of 150 to 3,000 m. Oil IP's range from 0.2 to 800 mt/d (1.5–5,840 bbl/d). Gas IP's range from 280,000 m^3 (9,800 Mcf/d) or less up to 2.8 million m^3/d (98,000 Mcf/d).

Tsaidam Basin Stratigraphy

In general, the Meso-Cenozoic section becomes finer grained toward the basin center. Triassic continental molasse is known only from outcrops along the northeastern border of the basin. The section is uncomformable on strongly deformed Permian and older rocks. It consists of an unknown thickness of violet-red sandstone, variegated and mottled shale and sandstone, and some layers of limestone.

The Early Jurassic overlies the Triassic unconformably and is composed of 1,000–2,000 m of greenish-gray conglomerate, sandstone, black coaly shale, and coal. Oil seeps are associated with several sandstone beds of this age. The Late Jurassic, 300–500 m thick, is violet-red shale and sandstone.

The Cretaceous is unconformable on the Jurassic, and is composed of 1,000–2,000 m of red and greenish-gray conglomerate and sandstone. In the middle part, the sandstone and conglomerate alternate with siltstone. In the outcrop, oil seeps are found in some of the sandstone and conglomerate layers.

The Tertiary is unconformable on the Cretaceous. The basal Paleogene unit (Mati Shan Suite) is dark-red conglomerate interbedded with smaller amounts of dark-red sandstone and shale. The upper Paleogene unit (Chen-chen-shan Suite), which is largely Oligocene, consists of greenish-gray and the red shale, sandstone, and conglomerate, with layers of lacustrine marl. The total thickness of the Paleogene is unknown but is not less than 800–1,000 m. Commercial oil is produced from sandstone and conglomerate beds of the Chen-chen-shan Suite.

The Miocene Hung-hsiao-kao Suite overlies the Oligocene and consists of 1,200–2,000 m of brownish-red and gray sandstone and shale, with some lentils of conglomerate. In the central and eastern parts of the basin are lacustrine facies, including beds of limestone, marl, gypsum, and halite. Commercial volumes of oil and gas are produced from sandstone and siltstone reservoirs.

The Pliocene Kuang-kou Suite is composed of 600 to 3,000 m of light-yellow to brown sandy shale, poorly sorted sandstone, and layers of loosely consolidated conglomerate. Near the basin center, hematitic shale is present. Commercial gas and some oil are present.

The Pleistocene Siao-pei Shan Suite consists of 300–1,200 m of conglomerate and associated rocks. Gypsiferous shale is in the central part of the basin.

Oil and Gas Fields

Ch'i-kuo-ch'üan field—This field (*Fig. 16*) was discovered in the 1956–1958 period, and has oil in the early Pliocene Kuang-kou Suite (7,000,000 mt = 50,000,000 bbl), the Miocene Hung-hsiao-kao Suite 5,500,000 mt = 40,000,000 bbl), and the Oligocene Chen-chen-shan Suite (1,370,000 mt = 10,000,000 bbl). Like all productive structures discovered in the Tsaidam basin, Ch'i-kuo-ch'üan is a surface anticline. This structure is about 12 km long. Total effective thickness of the different oil-bearing zones is 50 m, with local buildups of individual reservoirs up to 10–35 m. IP's from the wells range from 10–100 mt/d (73–730 bbl/d).

Shih-tze-kou field—The field (*Fig. 16*) was discovered in 1958. About 6,200,000 mt (45,000,000 bbl) was discovered in the Miocene Hung-hsiao-kao Suite; approximately 5,000,000 tons of oil (36,500,000 bbl) was discovered in the Oligocene Chen-chen-shan Suite. The structure is 10–12 km long; IP's range up to 100 mt/d (730 bbl/d).

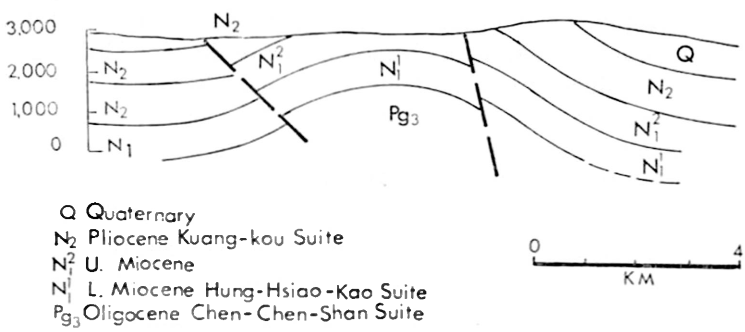


Figure 18. SW-NE structural cross section of You-sha-shan field, Tsaidam basin. Field location appears on *Figure 16*. From Vasil'yev (1968).

You-sha-shan field (Figs. 16, 18)—You-sha-shan, discovered in 1958, contains about 9,000,000 mt (65,000,000 bbl) in the Miocene Hung-hsiao-kao Suite and 7,000,000 mt (50,000,000 bbl) in the Oligocene Chen-chen-shan Suite. The field structure is 26 km long and 6 km wide. Southwest dips range from 12 to 80°; northeast dips are 30–36°. Twelve productive sandstones, each 1–4 m thick, are present. Net effective pay totals 27 m. The deepest production is from 1,200 m. IP's are up to 100 mt/d (730 bbl/d).

You-ch'üan-tze field—This field (*Fig. 16*) was discovered in 1955, is the oldest commercial field of the Tsaidam basin, and contains about 5,500,000 mt (40,000,000 bbl) of oil in the Miocene Hung-hsiao-kao Suite and an equal amount in the Oligocene Chen-chen-shan Suite. The Miocene oil is 32°API. There are approximately 12 productive sandstones, each 1–5 m thick.

Kaitmilik field—This appears to be the second discovery (1956) in the Tsaidam basin (*Fig. 16*). The field contains about 4,000,000 mt (30,000,000 bbl) in the Miocene Hung-hsiao-kao Suite. There are 12 productive sandstones, each 1–5 m thick. Net effective thickness is 40 m. Depths to productive zones range from 150 to 700 m. IP's range from 0.5 to 120 mt/d (3.6–876 bbl/d).

Hsiao-lien-shan field—Hsiao-lien-shan (*Fig. 16*) was discovered in the late 1950's. Reserves, estimated at 24.3 billion m^3 (850 Bcf), are in the early Pliocene Kuang-kou Suite. Only gas has been reported from this structure.

Nan-shan field—Nan-shan (*Fig. 16*) was discovered in the 1956–1958 period, and may have an ultimate recovery of 27,500,000 mt (200,000,000 bbl) in the Miocene Hung-hsiao-kao Suite. The structure is symmetrical with 30–40° flank dips. Individual productive zones are 1–5 m, and at least 12 sandstones are productive.

Tsen-tin-shan field—Also discovered in the 1956–1958 period, Tsen-tin-shan (*Fig. 16*) is similar in every respect to Nan-shan field, except for the size. Miocene recoverable reserves are estimated to be 6,850,000 mt (50,000,000 bbl).

Leng-hu 3, 4, and 5 fields—The Leng-hu fields, discovered in 1958, are three separate closures on a single anticline and include 67 sq km. A total of 114 wells were producing in 1976, accounting for 95 per cent of the basin's production. Only three other fields are producing. Flank dips on the southwest are up to 80°; on the northeast, 25–40°. At depth, Leng-hu may be a single field. The Leng-hu 4 and 5 closures produce oil from the middle and upper Miocene part of the Hung-hsiao-kao Suite. Leng-hu 3, in addition, produces from the Oligocene Chen-chen-shan Suite. Individual reservoirs generally are 1–5 m thick and total 100–120 m of net effective pay. Traps are both structural and stratigraphic. IP's in the Leng-hu 3 and 4 closures are in the 50–150 mt/d (365–1,095 bbl/d) range. IP's in Leng-hu 5 are similar but commonly are in the 150–200 mt/d (1,096–1,460 bbl/d) range. Two wells have produced 200 mt/d (1,460 bbl/d) for extended periods. One well had an IP of 250 mt/d (1,825 bbl/d) and another, 800 mt/d (5,840 bbl/d). Because almost all reservoirs at Leng-hu have a fairly large clay matrix, such IP's decline rather rapidly. Ultimate recoverable reserves of Leng-hu 3, 4, and 5 were estimated by Meyerhoff (1970) as 150,000,000 mt (1.1 billion bbl), and subsequent developments of the structures corroborate this calculation. Specific gravity of the Miocene oil is 0.86, and of the Oligocene oil, 0.83 Radchenko, 1965).

Ma-hai field—This gas field (*Fig. 16*), discovered in 1958, contains an ultimate recoverable reserve of 43 billion m^3 (1.5 Tcf) in the Miocene Chun-siao Suite (equivalent to the Hung-hsiao-kao Suite). IP's up to 280,000 m^3/d (9,800 Mcf/d) have been recorded. The structure is symmetrical, with flank dips of 4–9°. At least one oil reservoir is present. The field is shut in.

Yü-k'a field—Discovered about 1958, this is primarily a gas field in the Miocene Hung-hisao-kao Suite. Oil was found in the Cretaceous Hsai-chi-lin Suite, the oldest commercial production reported to date in the Tsaidam basin. The field is shut in. Reserves are estimated to be 10 billion m^3 (350 Bcf). Oil reserves are less than 1,000,000 mt (7.3 million bbl).

Yen-hu field—Yen-hu was discovered in 1958. The structure is 12 km long and 8 km wide. Northeast dips are 12–30°; southwest dips are 4–14°. Depth to the shallowest production is 65–120 m. The maximum recorded IP is 2.8 million m^3/d (98,000 Mcf/d). Reserves are estimated to be 40 billion m^3 (1.4 Tcf). All reserves are in the early Pliocene Kuang-kou Suite. The field is shut in.

Min-ho-hsien field—Discovered about 1970 (Williams, 1975), the field produces from the Miocene Hung-hsiao-kao Suite. Production from eight wells averaged 75 mt/d apiece (416 bbl/d). Reserves are not less than 6,850,000 mt (50,000,000 bbl).

Concluding Remarks

The Tsaidam basin is one of China's most important productive basins, where more than 100 closures had been mapped by 1960 (P'ang and Ryabukin, 1961). The greatest difficulties are poor highways, lack of a railroad and/or pipeline, isolation in high, mountainous country, and great distance from markets. Future development will be mainly in the central and northwestern sections of the basin, because strongly deformed Paleozoic rocks crop out in the center of many anticlines in the eastern part of the basin. The area provided 0.9 per cent of the PRC's 1975 production (*Table 4*).

Table 4. Production of Major PRC Productive Areas, 1975.

Basin	Group of Fields	1975 Production			% of PRC Production
		mt × 10⁶	bbl × 10⁶	bbl/d	
Sungliao	Ta-ch'ing (Ta-t'ung-chen)	40.26	293.9	805,180	52.5
Po Hai	Shengli	14.90	108.8	298,000	19.4
Po Hai	Takang	4.34	31.7	86,650	5.6
Tung-t'ing	Ch'ien-chang	4.10	29.9	82,000	5.3
Po Hai	P'an-shan	4.05	29.6	81,000	5.2
Sungliao	Fu-yü	3.00	21.9	60,000	3.9
Dzungaria	Karamai	1.07	7.8	21,400	1.4
Chiu-ch'üan	Yumen	0.79	5.8	15,800	1.0
Tsaidam	Leng-hu	0.70	5.1	14,000	0.9
Others	—	3.49	25.4	69,800	4.8
Total	—	76.70	559.9	—	100.0

PRE-NAN SHAN BASINS

General

The Pre-Nan Shan basins (*Figs. 1, 16*) are peripheral to the main Nan Shan complex of ranges. Three are north of and adjacent to the frontal thrust zone of the Nan Shan (*Fig. 16*) in Kansu Province and the Inner Mongolian Autonomous Region. These basins straddle the famous 900-km-long Kansu (Ho-hsi) Corridor or trade route between eastern China and Central Asia. From west to east the three basins are: (1) the Pre-Nan Shan basin proper of Chang Keng *et al.* (1958), or the Chiu-ch'üan basin (*Figs. 16, 19*); the eastern end of the Chiu-ch'üan basin includes the Min-le subbasin of Chinese literature; (2) the Jo Shui (Chao Shui) basin (*Fig. 20*); and (3) the A-la Shan basin. At the eastern and southeastern margin of the Nan Shan, mainly south of the To Lai Shan, is the Min-ho basin (*Fig. 21*). South of the Nan Shan and

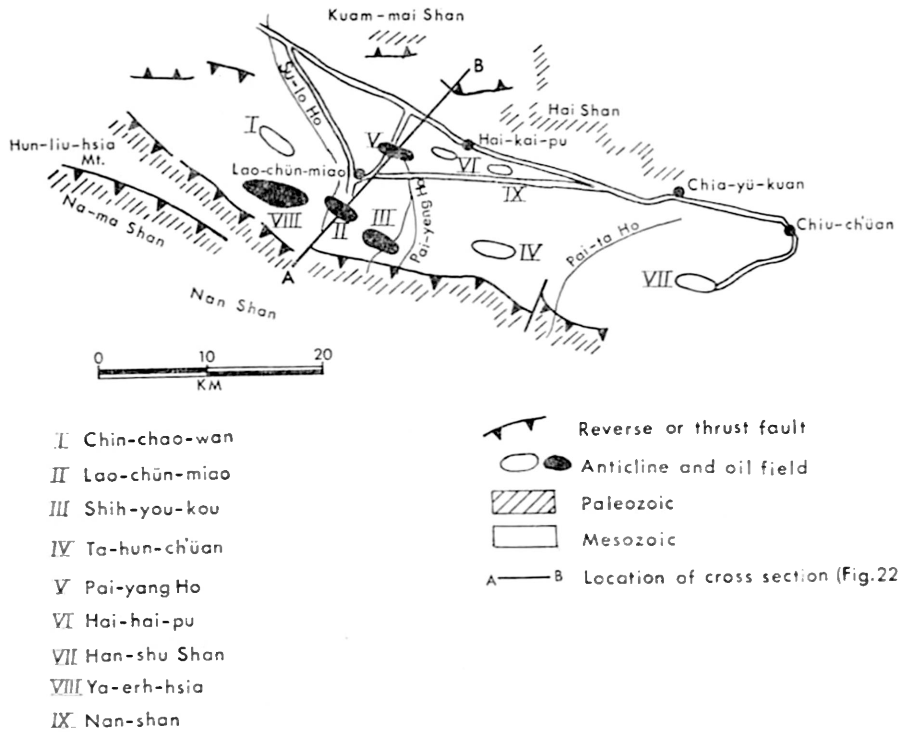


Figure 19. Index map to fields and structures of Chiu-ch'üan basin area, Pre-Nan Shan basins. Location of the figure is shown on *Figure 16*. Location of *Figure 22* also is shown. From Chang Keng *et al.* (1958).

north of the Kunlun Shan (i.e., between the Tsaidam and Min-ho basins) is the Koko Nor basin. The Min-ho basin straddles the Kansu-Tsinghai provincial boundary. The Koko Nor basin is in Tsinghai Province.

The Chiu-ch'üan, Jo Shui, and A-la Shan basins, therefore, are molasse downwarps or foredeeps which formed as the Nan Shan geosynclinal sequence was thrust northward onto the Precambrian Gobi massif (Sino-Korean platform). In contrast, the Min-ho and Koko Nor basins are intermontane molasse troughs on folded Paleozoic and older rocks of the Nan Shan and Kunlun Shan geosynclines.

Petroleum exploration and drilling have been concentrated in the Chiu-ch'üan, Jo Shui, and Min-ho basins. The Chiu-ch'üan basin is the site of numerous oil seeps which have been exploited for more than 2,000 years and is the Yü-men oil district which first was drilled in 1928 by Nationalist Chinese geologists and engineers. To date, eight fields have been discovered in the area—six in the Chiu-ch'üan basin and one each in the Jo Shui and Min-ho basins. During 1976, nine rigs were active. A total of 1,207 wells had been drilled in the Chiu-ch'üan basin, and 38 new locations had been prepared. The Chiu-ch'üan fields produced 52 per cent of the PRC's oil in 1955; today it produces 1 per cent (*Table 4*).

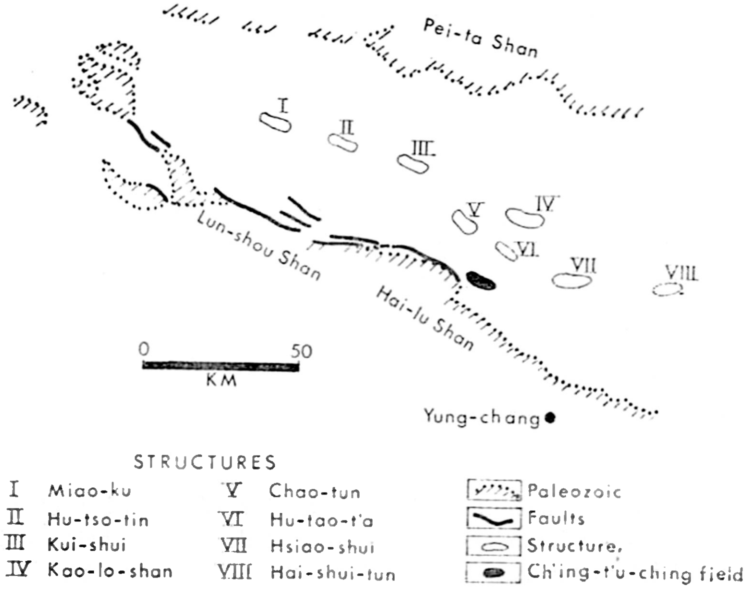


Figure 20. Index map to field and structures of Jo Shui basin area, Pre-Nan Shan basins. Location of the figure is shown on *Figure 16*. From Chang Keng *et al.* (1958). Scale is approximate.

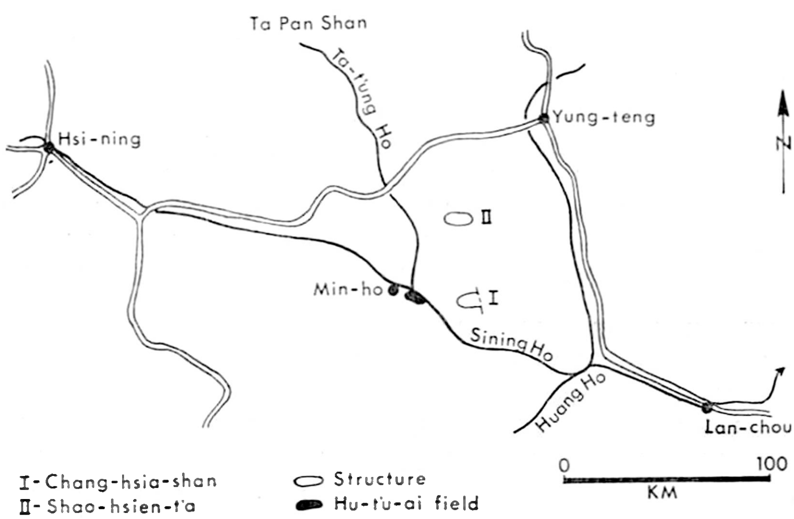


Figure 21. Index map to field and structures of Min-ho basin area, Pre-Nan Shan basins. Location of the figure is shown on *Figure 16*. From Chang Keng *et al.* (1958).

Chiu-ch'üan Basin

The Chiu-ch'üan basin of Kansu Province is 400 km long and 35–60 km wide, with an area of about 16,000 sq km. Oil seeps and hand-dug pits have been exploited commercially since the beginning of the Ch'ing dynasty. The first deliberately drilled commercial well was completed in 1928 at the site of what is now the Shin-you-kou oil field. The basin consists of a southern frontal thrust zone, a central zone or depression, and a northern platform zone (*Fig. 22*).

As in all northwestern China, the pre-Mesozoic rocks are strongly deformed. Marine early and middle Paleozoic grade upward into mixed marine (sandstone, shale, limestone) and continental (conglomerate, sandstone, coal) Carboniferous and Permian formations. The Permian with some oil—is overlain unconformably by continental Triassic. The Triassic is 0–1,060 m thick and consists of gray and yellow-green sandstone with oil shows) with minor shale and sandy shale. Conformably above is 570–1,440 m of Early Jurassic coal-bearing gray shale and sandstone, with conglomerate, and Middle to Late Jurassic, violet-red to bluish-gray shale grading upward into sandstone and conglomerate.

The Early Cretaceous, unconformable on the Jurassic, consists of 300–1,400 m of dark-gray to black bituminous and coal-bearing shale, green shale, and red shale which pass upward into sandstone and conglomerate. Oil shows are in the Lower Cretaceous. The Late Cretaceous is 0–500 m thick and consists of sandstone, conglomerate (with oil shows), and minor greenish shale. The Late Cretaceous strata grade upward into the early Tertiary Ho-sha-kou (-fire) Suite—0 to 960 m of light-gray sandstone and shale. This unit commonly is absent by erosion.

The Pai-yang (=white poplar) Ho Suite above—late Paleogene-Miocene—overlies the Ho-sha-kou with angular unconformity. In fact, the Pai-yang Ho transgresses strata of all ages, Permian through early Paleogene, and is the principal oil-productive unit of the basin. The section is alternate layers of dark-brown shale and light-brown sandstone. Three sandstone zones produce: from top to bottom, these are K, L, and M sandstone zones. Each zone consists of several separate sandstone beds. For example, at Lao-chün-miao field, the L sandstone is divided into 11 sandstones beds which form 5 groups—L_1, L_2, L_3, L_4, and L_5.

The Pai-yang Ho is overlain unconformably by the middle to late Miocene Su-lo Ho Suite, 300–1,940 m thick, consisting of red sandstone which grades upward into red conglomerate. Oil shows are found in the Su-lo Ho. The Yü-men Suite—10–900 m of gravel and sand, overlies the Su-lo Ho unconformably and in turn is overlain unconformably by 10–200 m of the Pleistocene to recent Chiu-ch'üan Suite.

Chiu-ch'üan Basin Oil Fields and Structures

General—The so-called Yü-men field of Kansu province actually is a complex of four, and possibly six, separate fields. They are discussed below.

Shih-you-kou field (**Figs. 16, 19, 23, 24**)—This field, a surface anticline about 2×2 km, was drilled in 1928 by Nationalist Chinese geologists and engineers to provide a local source of fuel for operations against Communist and other hostile groups in the area (Kudo, 1966, p. 21–22). The structure, although small, is very sharp and has a large closure—nearly 3,000 m on three sides at the depth of the Permian. The northeastern closure is a major reverse fault.

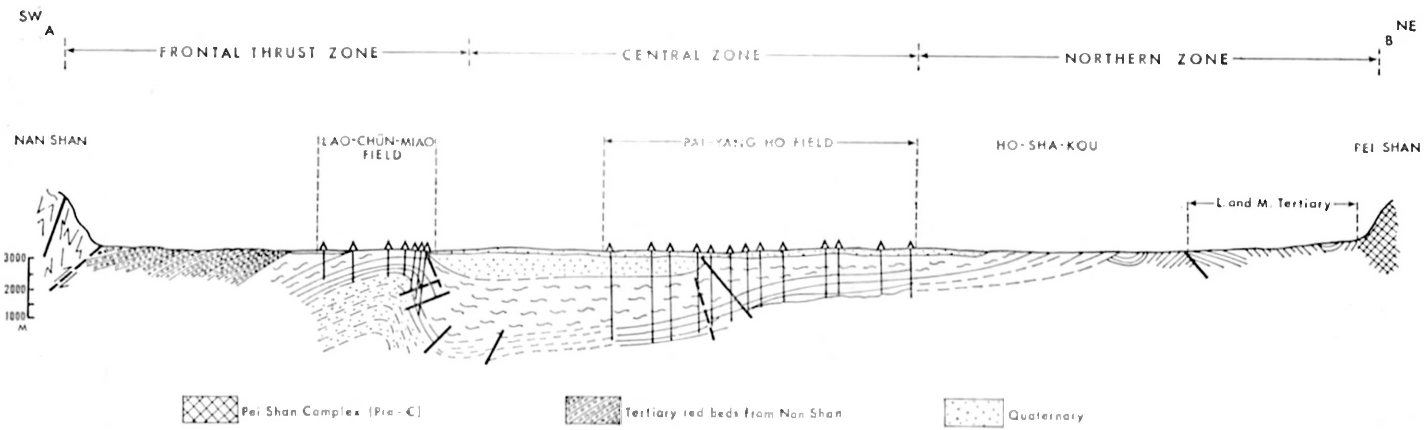


Figure 22. SW-NE cross section of Chiu-ch'üan basin. Location is shown on *Figure 19.* Section passes through Lao-chün-miao and Pai-yang Ho fields. From Chang Keng *et al.* (1958), as modified by Brod (1965) and Petrov (1967).

The original drilling in 1928, and subsequent drilling in 1938, was mainly to develop the reserves in the M sandstone of the Pai-yang Ho Suite (Miocene). The productive sandstones range in depth from 350 to 500 m. IP's were 2–3 mt/d (15–22 bbl/d). A smal refinery was built. Lateral pinchouts and tar seals, in addition to

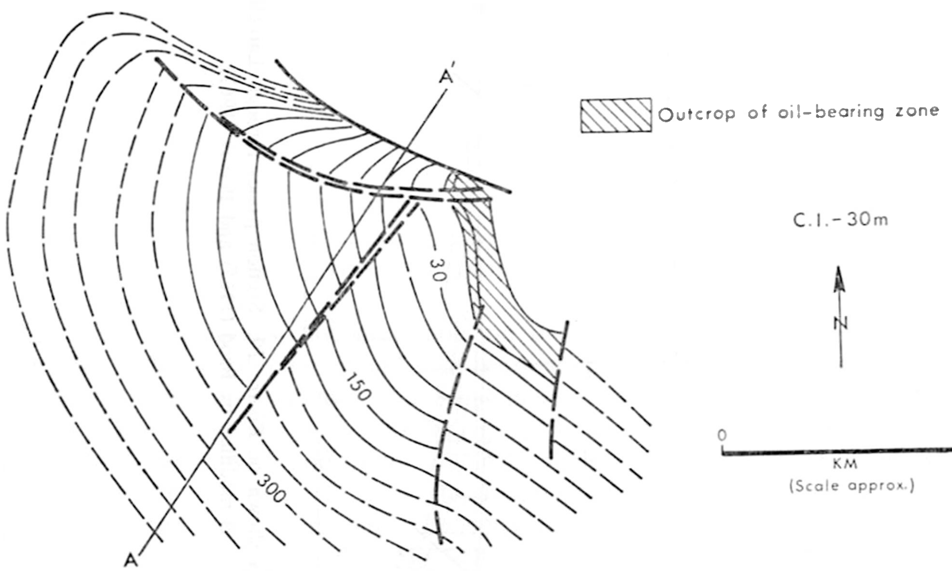


Figure 23. Structural contour map of Shih-you-kou field, Chiu-ch'üan basin. Structural datum is an oil-bearing layer (bed M) of the Pai-yang Ho Suite which crops out in the northeastern part of the structure. Location of the field is shown on *Figure 19*. Line of cross section of *Figure 24* is shown. From Chang Keng *et al.* (1958).

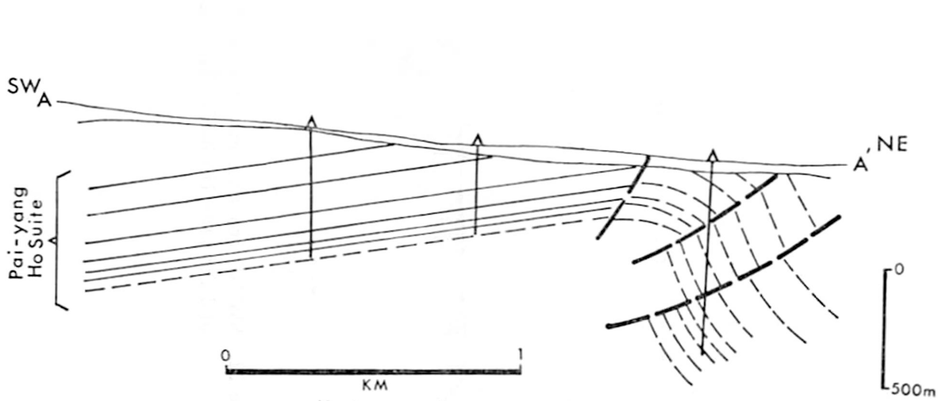


Figure 24. SW-NE cross section of Shih-you-kou field, Chiu-ch'üan basin. Location is shown on *Figure 23*. From Chang Keng *et al.* (1958).

structure, were the trapping mechanisms. When the Communist armies overran the area in 1949, interest in the structure was rekindled. Drilling began in 1951 and oil was discovered in Permian sandstoned during 1953. IP's ranged up to 10 mt/d (73 bbl/d). Oil subsequently was found in Carboniferous sandstones overlying a metamorphosed Devonian basement. However, Carboniferous production has been negligible, with IP's of only 0.3 mt/d (2.2 bbl/d).

Total recovery from the field is not expected to exceed 550,000 mt (4,000,000 bbl), and may be less.

Lao-chün-miao field (Figs. 16, 19, 25, 26)—This field was discovered in 1938, although the 1938 well was not completed until 1939 (Pratt and Good, 1950). Large-scale development commenced in 1955 (Chang Keng *et al.,* 1958).

The Lao-chün-miao anticline is 8 km long and 5 km wide. Closure is 400 m. The average south dip is 20° and the north dip is 70–90°. Three productive zones, K, L, and M, have been found in the Miocene Pai-yang Ho Suite (*Fig. 26*). Production from K and M is negligible with IP's rarely exceeding 2–3 mt/d (15–22 bbl/d). IP's from the L zone, 265–1,400 m below the surface, range from 40 to 200 mt/d (292–1,460 bbl/d). The decline rate, however, is fairly rapid. Oil density is 0.863, API gravity is 32–33°, and paraffin content is 16 percent. There are 11 productive sandstone bodies in the L sandstone zone. Sandstone-body thickness ranges from 0.5 to 14.0 m. Total effective thickness in the L zone ranges from 20 to 30 m. Several

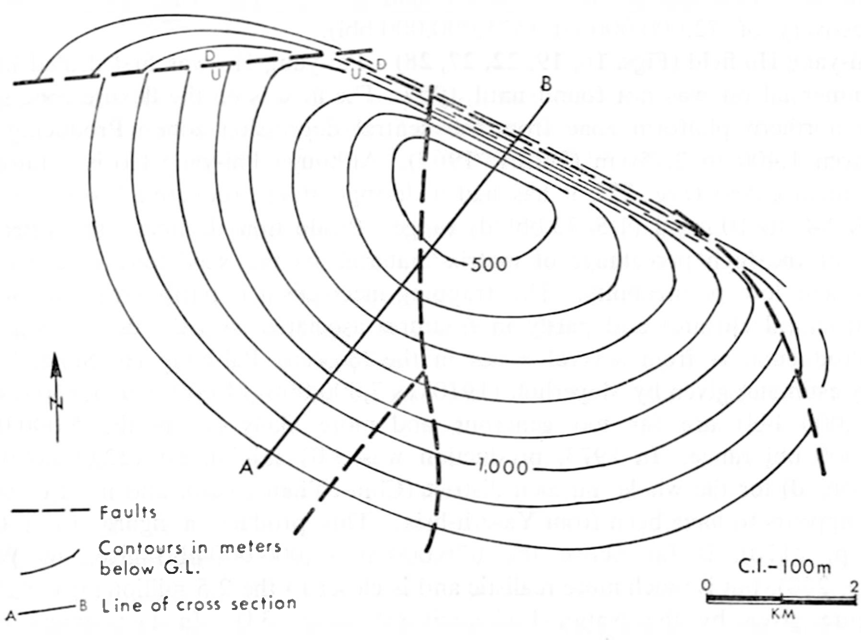


Figure 25. Structural contour map of Lao-chün-miao field, Chiu-ch'üan basin. Structural datum is the top of the L zone, Pai-yang Ho Suite. Location of the field is shown on *Figure 19*. Line of cross section of *Figure 26* is shown. From Chang Keng *et al.* (1958).

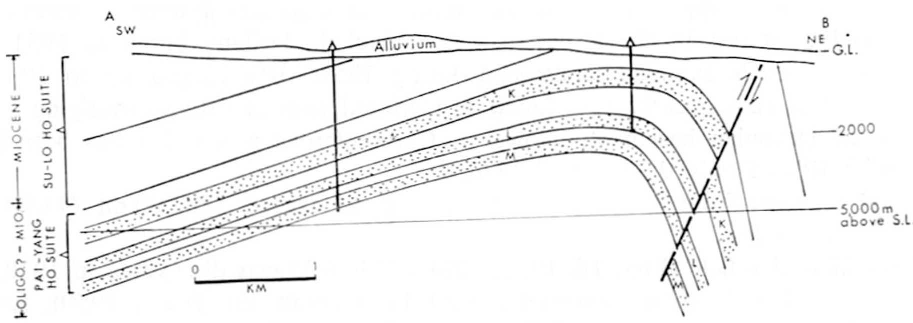


Figure 26. South-north cross section of Lao-chün-miao field, Chiu-ch'üan basin. Location is shown on *Figure 25*. From Chang Keng *et al.* (1958).

Miocene productive sandstones occur only on the flanks. One Late Cretaceous sandstone is productive.

Lao-chün-miao is one of the two largest fields of the Chiu-ch'üan basin. Ultimate recovery is estimated to be not less than 5,000,000 mt (36,500,000 bbl), and probably will be 7,000,000 mt (50,000,000 bbl).

Ya-erh-hsia field (Figs. 16, 19)—The field was discovered in 1958. Drilling depths range from 2,000 to 2,700 m. The principal production is from the Miocene Pai-yang Ho Suite, specifiically, the L zone. IP's range from 40 to 1,000 mt/d (292–7,300 bbl/d). This appears to be largest field in the basin, with an estimated ultimate recovery of 72,000,000 mt (525,000,000 bbl).

Pai-yang Ho field (Figs. 16, 19, 22, 27, 28)—Pai-yang Ho was first drilled in 1954, but commercial oil was not found until 1957. The field is on the flexure zone separating the northern platform zone from the central depression zone. Producing depths range from 1,400 to 2,750 m (Petrov, 1967). Although Pai-yang Ho is a fairly large field in areal extent (*Fig. 27*), it has had a disappointing productive history, with IP's in the 0.2–8 to 10 mt/d (1.5–73 bbl/d) range. Production declines are rather rapid, because of the high percetnage of matrix material in the sandstone reservoirs—low porosity and low permeability. The trapping mechanism is partly stratigraphic (there is no structural closure) and partly in fractures asociated with the flexure zone in the field. Production is from several zones in the Miocene Pai-hang Ho Suite. Ultimate recovery estimates given by Meyerhoff (1970) as 7,000,000–14,000,000 mt (50,000,000–100,000,000 bbl) are far too generous and more likely are in the 5,000,000 mt 36,500,000 bbl range. In 1973, production was 3.01 million mt (22,000,000 bbl = 60,300 bbl/d) for the whole Yü-men district (Chiu-ch'üan basin), and most of the production appears to have been from Ya-erh-hsia. This production figure, from Connell (1974, p. 2170), is far above the 676,000 mt (5,000,000 bbl) given by Williams (1975, p. 260), but is much more realistic and is closer to the 2.5 million mt (18,250,000 bbl) figure given by the National Council (1976, p. 34). In fact, many of Williams' figures—including discovery dates, basin areas, and production—are far too conservative and some are wrong (e.g., Williams, p. 251 and 253, wrote that the Chiu-ch'üan basin has an area of 100,000 sq km, 5 times too large, and that the Tsaidam basin's area is 20,700 sq km, 6 times too small).

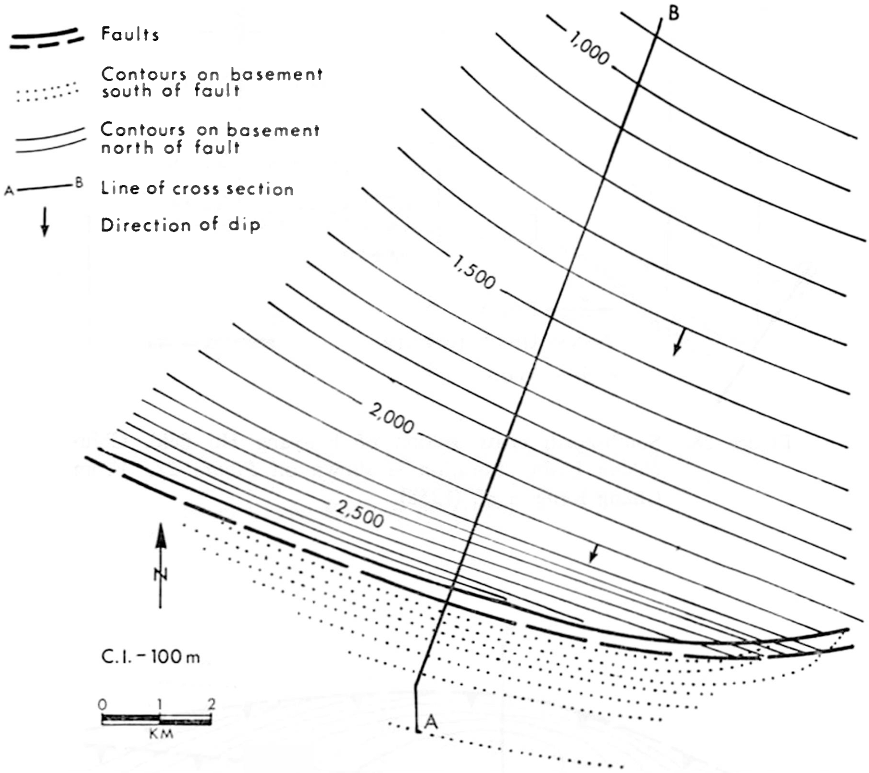


Figure 27. Structural contour map of Pai-yang Ho field, Chiu-ch'üan basin. Structural datum is top of Pai-yang Ho Suite. Location of the field is shown on *Figure 19*. Line of cross section of *Figure 28* is shown. From Chang Keng *et al.* (1958).

Other fields—PRC press reports, summarized by Williams (p. 251), indicate that, by 1973, two new fields were about to be put on stream in the Chiu-ch'üan basin. The names and locations of these structures are unknown to us.

Chin-chao-wan structure (Figs. 19, 29, 30)—This anticline was first drilled about 1953. The structure is an asymmetircal anticline thrust toward the north in the southern frontal thrust zone (*Fig. 22*; see also *Figs. 29, 30*). The overthrust block shows gentle (7–8°) south dips with only a small amount of structural reversal. Steeper, monoclinal north dips are everywhere present beneath the thrust plane. Effective seals are absent in the overthrust block and along the thrust plane. All wells were dry in the Pai-yang Ho Suite. The overlying Su-lo-Ho Suite is 1,770 m thick.

Ta-hun-ch'üan structure (Fig. 19)—This is another northwest-southeast- striking asymmetrical (toward the north) anticline in the southern frontal thrust zone (*Fig. 22*). It is associated with surface seeps. Wells penetrated 1,150 m of the Su-lo Ho Suite above the Pai-yang Ho Suite. A thrust plane dips 20–40° southwest. All wells—drilled beginning in 1953—were dry because of the absence of many of the reservoir beds found in Lao-chün-miao field; the absence of these beds is the result of faulting.

Han-shu Shan structure (Figs. 19, 31, 32)—This structure is in the central de-

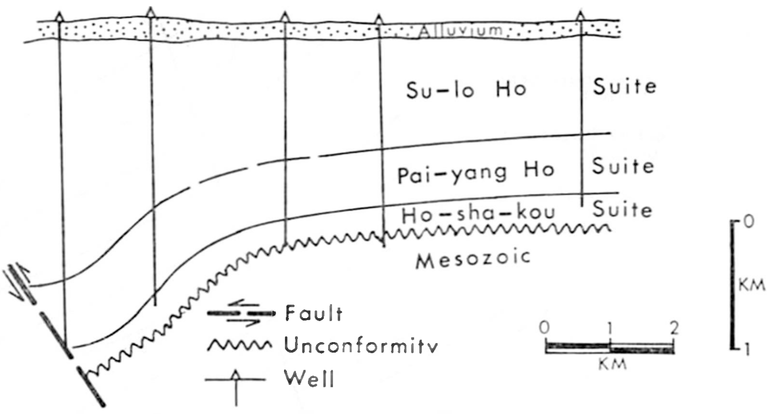


Figure 28. South-north cross section of Pai-yang Ho field, Chiu-ch'üan basin. Location is shown on *Figure 27.* From Chang Keng *et al.* (1958).

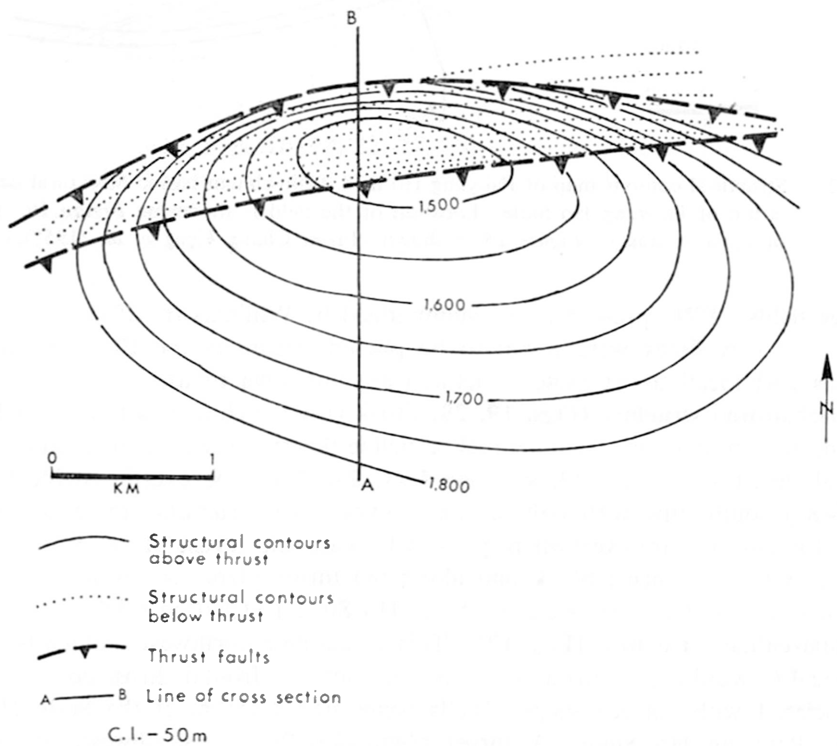


Figure 29. Structural contour map of Chin-chao-wan structure, Chiu-ch'üan basin. Structural datum is top of lower Su-lo Ho Suite. Line of cross section of *Figure 30* is shown. Location of the structure is given on *Figure 19.* From Chang Keng *et al.* (1958).

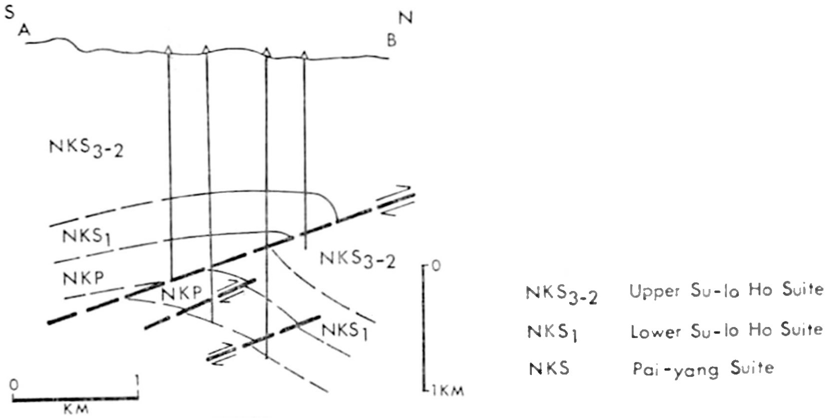


Figure 30. South-north cross section of Chiu-chao-wan structure, Chiu-ch'üan basin. Location is shown on *Figure 29*. From Chang Keng *et al.* (1958).

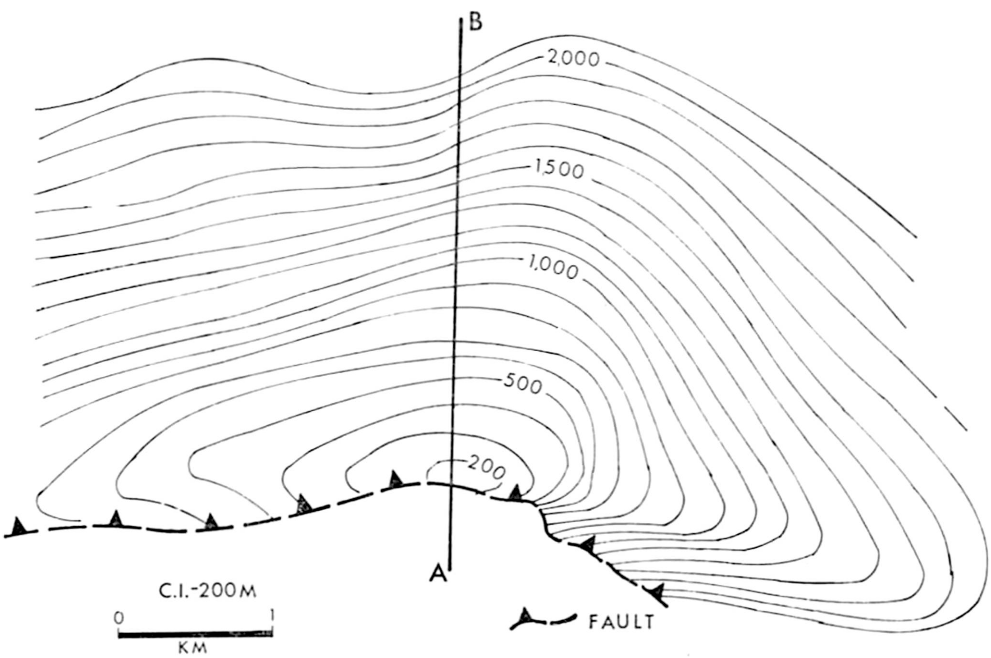


Figure 31. Structural contour map of Han-shu Shan structure, Chiu-ch'üan basin. Structural datum is top of the lower Su-lo Ho Suite. Line of cross section of *Figure 32* is shown. Location of the structure is given on *Figure 19*. From Chang Keng *et al.* (1958).

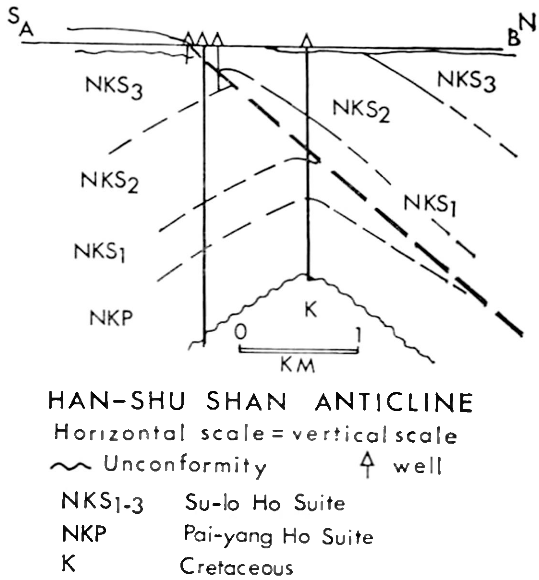


Figure 32. South-north cross section of Han-shu Shan structure, Chiu-ch'üan basin. Location is shown on *Figure 31*. From Chang Keng *et al.* (1958).

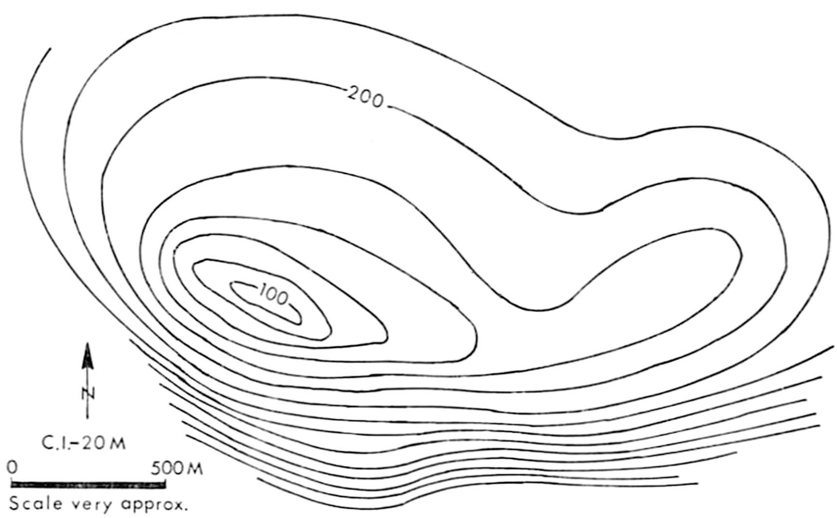


Figure 33. Structural contour form map of Hai-hai-pu structure, Chui-ch'üan basin. Location is shown on *Figure 19*. From Chang Keng *et al.* (1958).

pression zone (*Fig. 22*). It was first drilled in 1950 on the basis of surface seeps. The Pai-yang Ho Suite, however, was not tested until 1953. The structure is dry. As can be seen on *Figure 32*, the anticline is different from the structures farther south in that thrusting was from north to south. Two anticlinal structures are present —one above the thrust (*Figs. 31, 32*), and one below the thrust (*Fig. 32*). Flank dips are 10–30°, with some drag (60–90°) near the thrust. Thrusting has removed the reservoirs present at Lao-chün-miao field.

Hai-hai-pu structure (Figs. 19, 33)—This structure was mapped by corehole drilling in 1954. It is in the central depression zone (*Fig. 22*). South dips are 4–7°; north dips are 2–4°.

Nan-shan structure (Figs. 19, 34)—This anticline, with 5–8° south dips and 46–84° north dips, is just east of the Hai-hai-pu structure.

Other structures—Chang Keng *et al.* (1958) described and illustrated several other anticlines east and west of those shown on *Figure 19*. Although the Chin-chao-wan, Ta-hun-ch'üan, and Han-shu Shan structures were dry, the Hai-hai-pu and Nan-shan structures were untested as of July 1, 1958. These and other structures described by Chang Keng *et al.* may be the sites of the two new fields mentioned by Williams (1975, p. 251), as well as others west of the area of *Figure 19*—the Fo-tam-yao, Yuan-shan-

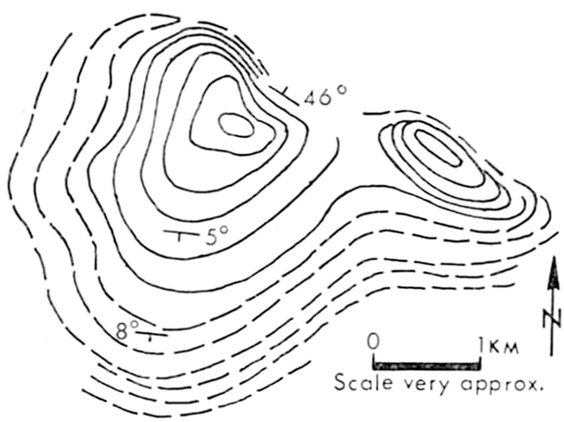


Figure 34. Structural contour form map of Nan-shan structure, just east of Hai-hai-pu structure. Location is shown on *Figure 19*. From Chang Keng *et al.* (1958).

tze, and other anticlines. They listed (p. 35–36), as objectives in addition to the Miocene-Oligocene (?) Pai-yang Ho Suite, the late Miocene Su-lo Ho Suite, the Cretaceous Hai-hai-pu Suite, the Permian, and the Carboniferous. They also mentioned (p. 36) possibilities in the Jurassic and Triassic. The most favorable untested structures are in the southern frontal thrust zone and the central depresion zone.

Jo Shui Basin

The location of the Jo Shui basin is shown in *Figure 16*. *Figure 20* is an index map to the one field and the several structures studied in the basin. Attention was first focused on the basin in 1939 when oil seeps were reported from the Ch'ing-t'u-ching anticline. Drilling comenced on the Hsiao-shui structure in 1951. Area of the basin is 5,000 sq km.

Basement is metamorphosed pre-Carboniferous rocks deformed during the middle Paleozoic. Although severely deformed, Carboniferous and Permian strata do have some potential, especialy in the southern part of the region.

Jurassic continental rocks (Liassic age) directly overlie Permian and Carboniferous with angular unconformity. The lower and middle parts consist of 500–1,760 m (average is 1,100 m) of gray continental sandstone, shale, and conglomerate which grade upward into coal-bearing strata. Oil seeps and oil production originate in this part of the section. The upper part of the Jurassic consists of 300–500 m of red and gray-green sandstone and shale, with lentils of conglomerate.

The Cretaceous is divided into three parts. The lowest, K_1, is a basal conglomerate, unconformable on the Jurassic, 6–250 m thick. K_2 is red to pale-red conglomerate, sandstone, and shale in the lower part and red to gray shale with limestone concretions above. The thickness is 400 m. K_3, the highest unit, is 450 m of red and gray conglomerate, pink sandstone, and red to gray-green shale. All beds are of continental origin.

The Tertiary overlies the Cretaceous unconformably. Average thickness is about 1,000–1,100 m. The basal unit, NK_1, is red conglomerate grading upward into sandstone. The thickness is 340 m. NK_2 is sand, sandstone, conglomerate, and shale, 390 m thick. NK_3 is red and gray sandstone and shale with some conglomerate. NK_4, the highest unit, is sandstone with pebble beds—up to 115 m thick.

Jo Shui Basin Field and Structures

Ch'ing-t'u-ching field (Figs. 20, 35, 36)—The field, discovered in 1956 or 1957, was first drilled in 1952. The structure is a severely thrust-faulted anticline with 60° south dips and 60–80° north dips (*Figs. 35, 36*). Small noncommercial volumes (200–300 kg/d) of oil were recovered from basal Jurassic (Liassic) coal-bearing sand-

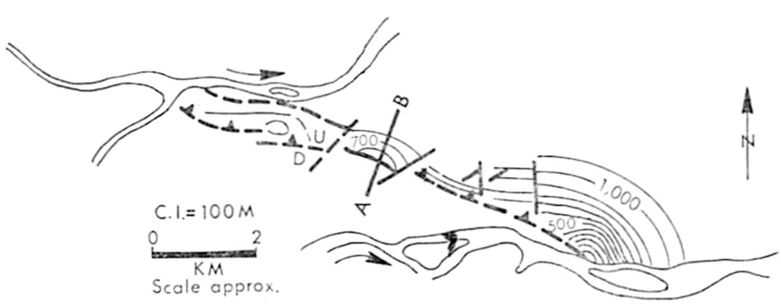


Figure 35. Structural contour map of the Ch'ing-t'u-ching oil field, Jo Shui basin. Structural datum is top of the Lower Jurassic. Line of cross section is *Figure 36*. Location of the field is given on *Figure 20*. From Chang Keng *et al.* (1958).

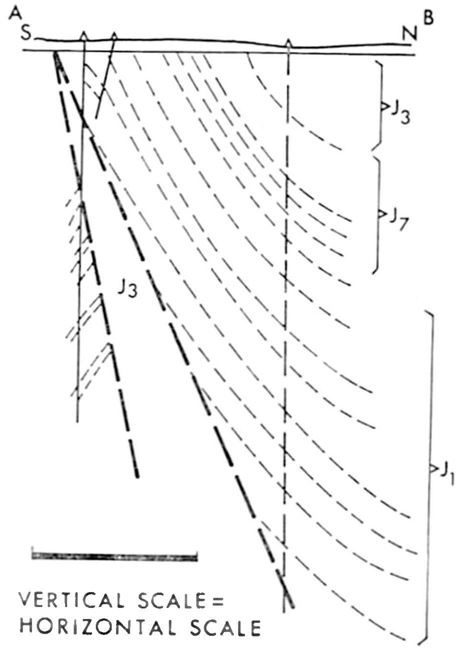


Figure 36. South-north cross section of Ch'ing-t'u-ching oil field, Jo Shui basin. Location is shown on *Figure 35*. From Chang Keng *et al.* (1958).

stones. Ultimate recovery will be less than 70,000 mt (500,000 bbl).

Other structures—Several other anticlinal features have been mapped in the basin, and are shown on *Figure 20*. Several of these structures have been drilled, including the following: Miao-kou, Hu-tso-tin, Kui-shui, Kao-lo-shan, Chao-tun, Hu-tao-t'a, Hsiao-shui (Tiao-shui), and Hai-shui-tun.

Hsiao-shui was drilled in 1951. It is an asymmetrical anticline covered by Tertiary and Cretaceous sediments (K_1, K_2, K_3), which directly overlie metamorphosed Paleozoic rocks. North dips are 10–30°; south dips are 60°. The Jurasic is absent in this structure and no shows were found. In the opinion of Chang Keng *et al.* (1958, p. 42), the Liassic strata are the source of the oil here and, therefore, oil will be found only in structures which are underlain by the Liassic coal-bearing section found at Ch'ing-t'u-ching.

Min-ho Basin

The Min-ho basin, not to be confused with the Min-le subbasin of the Chiu-Ch'üan basin, is just west of Lang-chou. It is small (5,000 sq km) and geologically complex (*Fig. 21*). Basement is a metamorphosed sequence of Paleozoic eugeosynclinal and platform-facies strata. Early and Middle Jurassic overlies the Paleozoic directly. It consists of 148 to 450 m of nonmarine basal conglomerate and sandstone grading upward into coal-bearing shale and sandstone. The Late Jurassic-Cretaceous overlies older rocks with angular unconformity. The Late Jurassic is 150–1,800 m of transgressive nonmarine conglomeratc, sandstone, and shale with oil seeps. Above is 2,700 m of nonmarine Cretaceous fissile shale with minor amounts of sandstone. The Tertiary, up to 1,800 m thick, is unconformable on all older rocks. It consists of nonmarine conglomerate, sandstone, and shale with some coal near the base. The Tertiary resembles closely the equivalent section of the Chiu-ch'üan basin. Oil seeps are present in the section.

Min-ho Basin Field and Structures

Hu-t'uai field (Figs. 16, 21, 37, 38)—This field was discovered in the 1956–1957 period. It is a faulted anticline (*Figs. 37, 38*), 1 sq km, with flank dips ranging

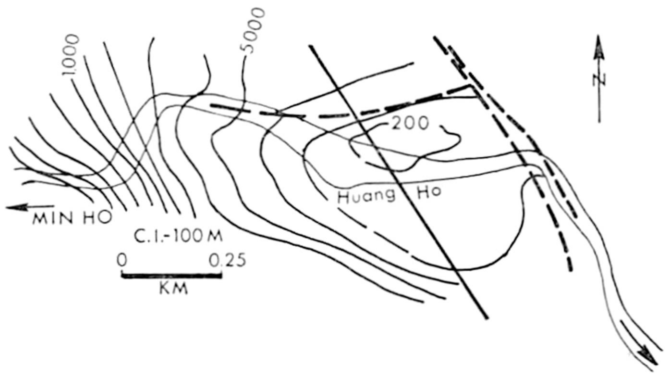
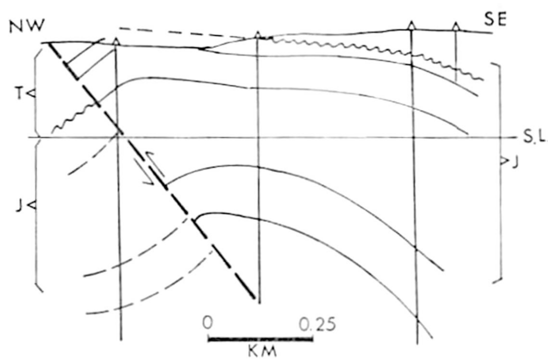


Figure 37. Structural contour map of the Hu-t'uai field, Min-ho basin, Kansu and Tsinghai Provinces. Structural datum is the top of the Lower Jurassic. Cross section line is the location of *Figure 38*. Location of the field is given on *Figure 21*. From Chang Keng *et al.* (1958).



VERTICAL SCALE=HORIZONTAL SCALE

Figure 38. NW-SE cross section of Hu-t'uai field, Min-ho basin. Location is shown on *Figure 37*. From Chang Keng *et al.* (1958).

from 20 to 60°. Ten productive sandstones have been found in the basal Tertiary and in the Upper Jurassic. IP's range from 0.5 to 3 mt/d (3.7–22 bbl/d). Ultimate recovery will be no more than 137,000 mt (1,000,000 bbl).

Chang-hsia-shan structure (Fig. 21)—This structure, 10 km long, was drilled first in 1954. Flank dips range from 7–90° to 21–26°. A north-south fault delimits the eastern side of the structure. Drilling results were negative.

A-la Shan Basin

This basin, northeast of the Nan Shan, contains about 17,000 sq km and is on the southern side of the Gobi desert. The basin is a massif or Zwischengebirge within the Sino-Korean platform. Gray and violet nonmarine sandstone and conglomerate (Permo-Triassic), 400 m thick, directly overlie a Precambrian basement. The Lower Jurassic is unconformable above and consists of about 500 m of coal-bearing asndstone and shale. The Late Jurasic-Cretaceous, up to 200 m thick, is unconformable on the Lower Jurassic and is composed of predominantly nonmarine shale with some sandstone. The Tertiary, about 300 m thick, is unconformable on the Cretaceous, and includes conglomerate, sandstone, marl, and shale. Gas seeps are known in the basin, but the region is essentialy unexplored.

Koko Nor (Ch'ing-hai Hu) Basin

This small intermontane basin (about 4,000 sq km) is a superimposed or successor-type basin of Jurassic and younger nonmarine strata on a strongly deformed Paleozoic fold complex. It has an elevation of about 3,200 m, and is in Tsinghai Province. Little exploration has been done in this area.

ORDOS BASIN

General

The Ordos basin (*Figs. 39, 40*), or platform, is a Precambrian platform, 180,000 sq km in area, surrounded by folded mountain ranges. The latest folding is post-Pliocene. The platform is 1,000–2,000 m above sea level and forms a classic example of a Zwischengebirge—part of the Sino-Korean platform. The basin is covered by 4–7 km of late Paleozoic through Tertiary nonmarine rocks except on the east, where the basement is only 2 km deep. Politically, the basin is in the Inner Mongolian Autonomous Region, the Ninghsia Hui Autonomous Region, and parts of Kansu and Shensi Provinces.

The northern and eastern flanks are paralleled by the Huang Ho. On the east is the Shansi anteclise; on the north is the Yang Shan and the Pao-t'ou graben; on the west is the Ho-lan Shan, the Yin-ch'uan graben, and the Pre-Liu-pan Shan graben; the southern border is formed by the Ch'in-ling Shan and the Wei Ho graben.

Anticlinal structures are present in the various graben-foredeeps adjacent to the mountains which rim the basin. These anticlines are strongly folded. Structures also are present on the interior platform, but are only mildly deformed.

Numerous seeps have been exploited since the time of the Sung Dynasty (960–1368 A.D.). A formal oil administration was established at Yen-ch'ang in 1901 when

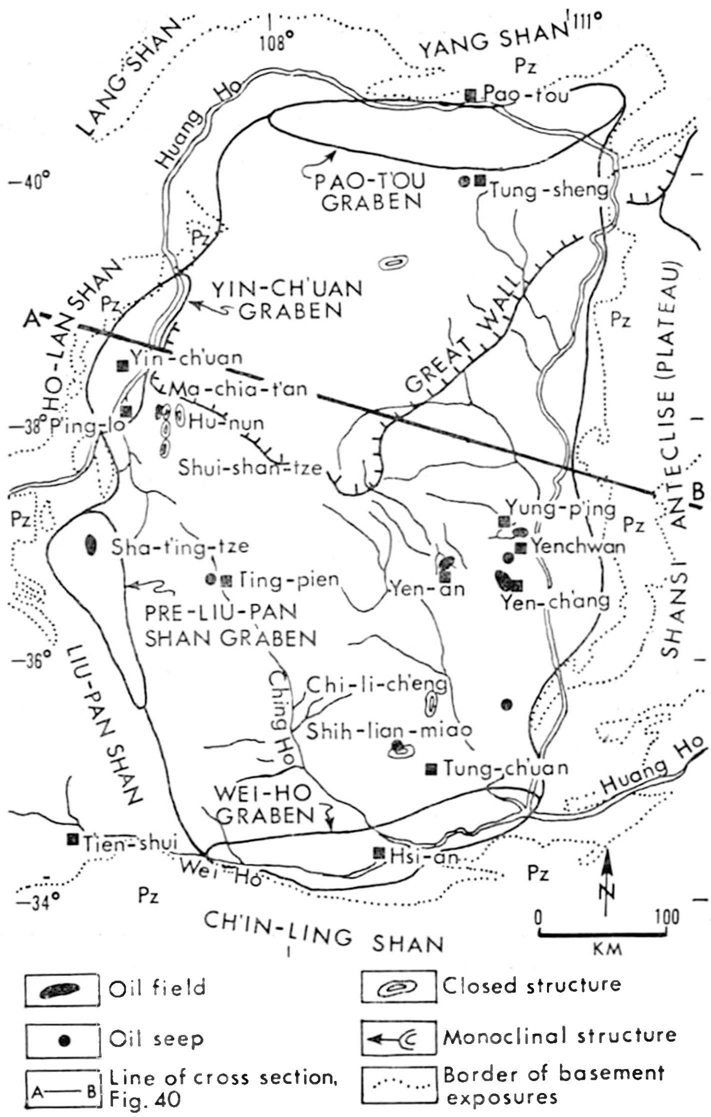


Figure 39. Index map of Ordos basin, Inner Mongolian and Ninghsia Hui Autonomous Regions; Shensi and Kansu Provinces. Locations of fields and other structures are shown. Location of figure is given on *Figure 16.* Figure shows location of *Figure 40.*

production from hand-dug wells was begun under government auspices. Deeper drilling at Yen-ch'ang commenced in 1907 and led to the discovery of new reservoirs. Four additional fields have been discovered in the basin. None of the discoveries is important, and prospects within this platform-basin are not good, manly because of the poor quality of the reservoirs.

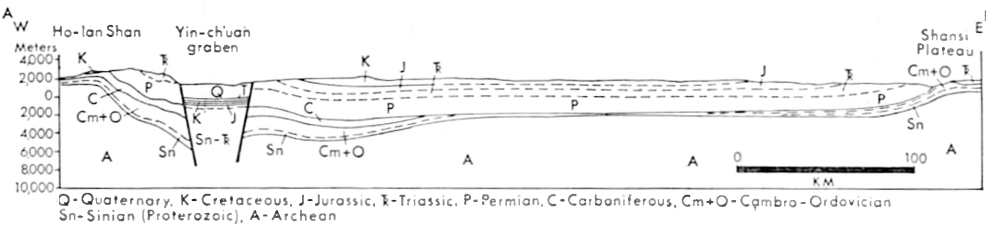


Figure 40. West-east cross section of Ordos basin. From Brod (1965). Location of figure is given on *Figure 39.*

Ordos Basin Stratigraphy

The platform is underlain by Archean igneous and metamorphic rocks and by Paleozoic—Cambrian, Ordovician, Upper Carboniferous, and Permian. Nonmarine Late Triassic overlies the Permian and older formations unconformably. Most of the Late Triassic is referred to as the Yen-ch'ang Suite, and consists of 1,000 to 1,400 m of gray sandstone and sandy shale. Black bituminous shale, (source of the oil) is present in the middle of the Yen-ch'ang. At least seven oil-bearing zones are present in the midle and upper parts of the Yen-ch'ang.

The Yen-ch'ang is overlain by 100–380 m of the latest Triassic Wai-pu Suite which consists of sandstone, sandy shale, and shale with some coal seams. The Wai-pu in turn is overlain by up to 550 m of Middle and Iate Jurassic—mainly coal-bearing shale. Both the Triassic and Jurassic are exposed in the cores of many anticlines.

Cretaceous lacustrine and continental-deltaic (nonmarine) beds are widespread and commonly are 1,000–1,200 m thick. The Cretaceous includes conglomerate, sandstone, and sandy shale with layers of shale and fissile shale.

The Tertiary, locally 2,000 m thick, consists of reddish conglomerate, sandstone, and sandy shale. The Tertiary is more lacustrine in the basin center, and is finer with calcareous concretions.

Ordos Basin Fields and Structures

Yen-ch'ang field (Figs. 16, 39, 41)—The field is a west-dipping monocline (0.5–1°) associated with numerous seeps (*Fig. 41*). Several structural noses and minor dip reversals are present. Numerous seeps are present at the surface in sandstones (arkoses) of the Late Triassic Yen-ch'ang Suite. Seeps and hand-dug wells had been exploited at Yen-ch'ang since the Sung Dynasty (960–1368 A.D.). In 1901, the Shensi government formally established an Oil Mining Bureau. Production during 1901 (from seeps and shafts) was 1,785 kg (1.785 mt = 13 bbl). In 1907, the first cable-tool hole was drilled, and produced 8.2 mt/d (60 bbl/d) at a depth of 76 m. The Shensi Oil Company was organized for further operations (Kudo, 1966, p. 34; Owen, 1975, p. 426). Two aditional wells were drilled in 1910–1911. One produced about one metric ton per day at 113 m; the other had only a show of heavy oil. A Japanese engineer was in charge.

Production during 1907 was 23.8 mt (174 bbl) and, after the Standard Oil Company of New York entered the scene in 1914, reached a peak of 378 mt in 1916

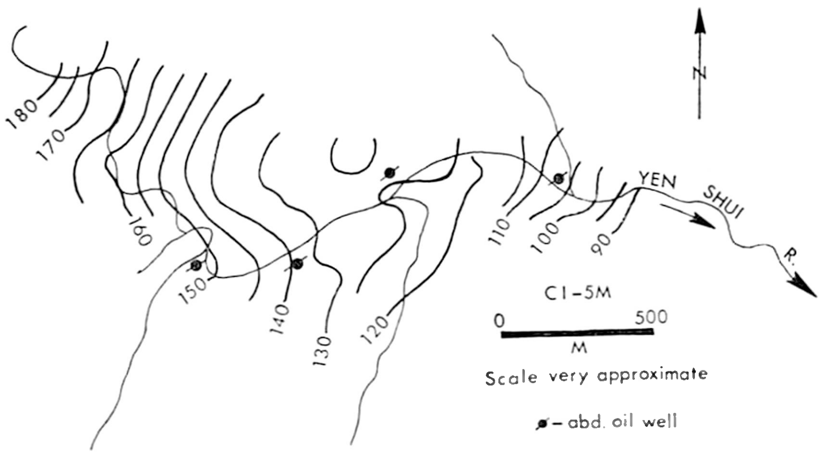


Figure 41. Structural contour map of Yen-ch'ang field, Ordos basin. Structural datum is on a Triassic sandstone. Location of the field is shown on *Figures 16* and *39*. From Chang Keng *et al.* (1958).

(2,759 bbl). Standard of New York's first well was drilled in 1914 to 692 m; it was dry. Two wells drilled in 1915 and 1916 had IP's of 3 and 0.7–1.3 mt (25 and 5–10 bbl) respectively. Standard abandoned operations in 1916. The field was produced until 1931. Sporadic attempts were made to revitalize the field until 1936.

Drilling recommenced in 1951. Between 1952 and 1953, 142 wells were drilled at Yen-ch'ang (Cheng Keng *et al.*, 1958, p. 83). IP's ranged from a few kilograms per day per well to—in one case—100 mt/d (730 bbl/d). Wells having more than a few metric tons per day of production are very scarce (Vasil'yev, 1968, p. 341). Average IP's are 30–50 kg/d. Drilling depths range from 150 to 200 m.

The trapping mechanism is structural in only a few wells. Generally, the traps are the clay matrix (lack of permeability), lateral pinchouts, and even tar seals. Permeability values are a few millidarcys—0.2–5 md; porosity values locally are up to 10 percent. The arkose reservoirs of the Late Triassic Yen-ch'ang Suite have a very large clay content. Ultimate recovery may reach 2,000,000 mt (14,600,000 bbl). Total production in 1958 was only 11,000 mt (80,300 bbl; Vasil'yev, 1968).

This figure contrasts strongly with figures published by Ho K'o-jen (1968), who gave annual production in 1957 as 170,000 mt; in 1960, 152,000 mt; in 1964, 164,000 mt; and 1966, 170,000 mt. Ho K'o-jen's figures, even if they include the entire Ordos basin, seem to be far too high. Connell's (1974, p. 2170) figure of 920,000 mt for 1974 does include the entire Ordos basin output for that year, and it also seems too high.

Yung-p'ing field (Figs. 16, 39, 42)—Yung-p'ing also is a west-dipping monocline (*Fig. 42*) with production from the Late Triassic Yen-ch'ang Suite. Depth to production ranges from 70–900 m, with average production depth between 100 and 200 m. The field was discovered in 1930, although surface seeps had been exploited since 960 A.D. More than 100 wells had been drilled by 1959. IP's range up to 2–3 mt/d (15–22 bbl/d), but average 30–50 kg/d. Three zones—I, II, and III—are produc-

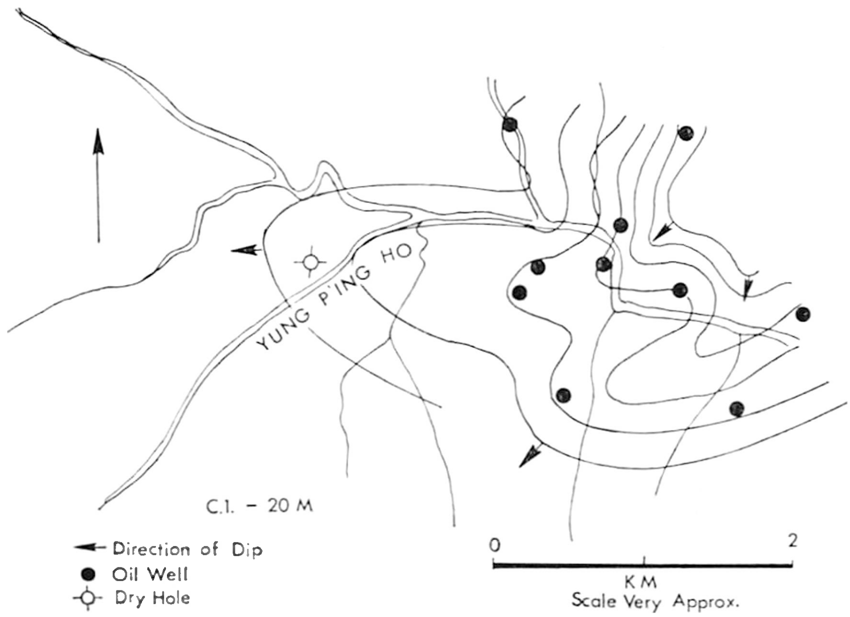


Figure 42. Structural contour map of Yung-p'ing field, Ordos basin. Structural datum is a Triassic oil-bearing sandstone. Location of the field is shown on *Figures 16* and *39*. From Chang Keng *et al.* (1958).

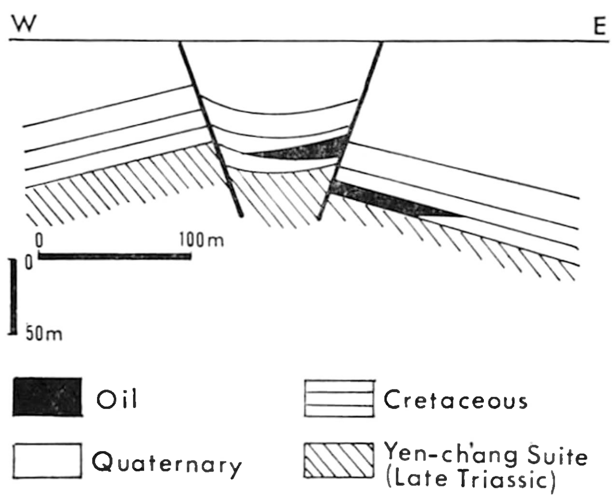


Figure 43. West-east cross section across the Sha-t'ing-tze field, Ordos basin. Location of the field is shown on *Figures 16* and *39*. From Vasil'yev (1968).

tive from the upper part of the Yen-ch'ang Suite (see *Fig. 45*). Ultimate recovery will be less than 1,000,000 mt (7,300,000 bbl).

Yen-an (Ts'ao-yüan) field (Figs. 16, 39)—The Yen-an or Ts'ao-yüan field is a monoclinal flexure west of Yen-ch'ang (*Fig.39*). The area appears to have been exploit-

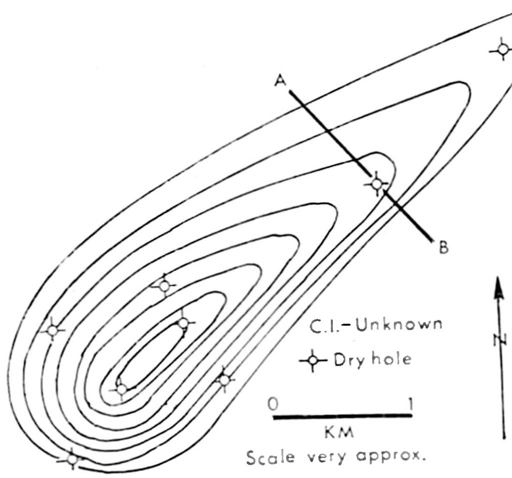


Figure 44. Structural contour map of Shih-lian-miao anticline, Ordos basin. Structural datum is near the top of Zone II, Triassic Yen-ch'ang Suite. Scales are only approximate. Location of the structure is on *Figure 39*. From Chang Keng *et al.* (1958). Location of *Figure 45* is given.

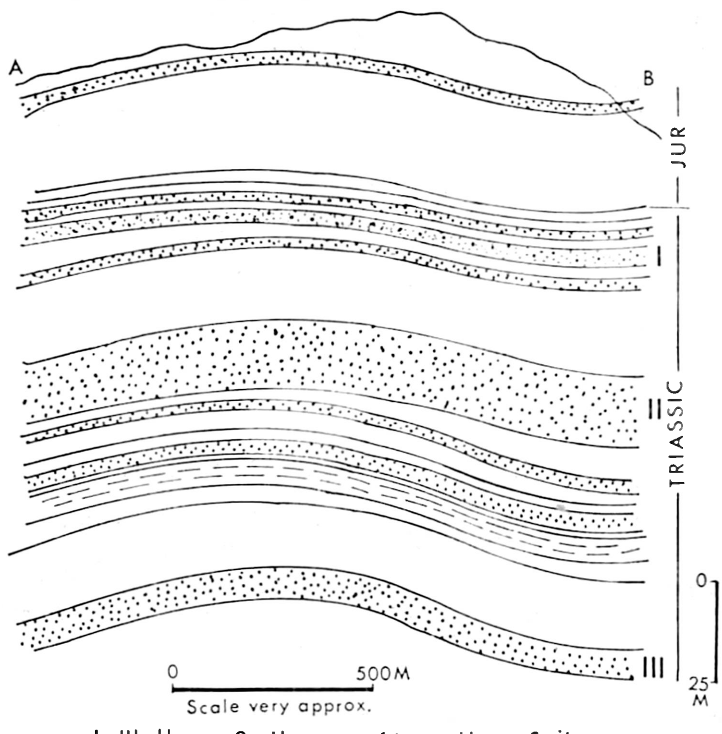


Figure 45. Northwest-southeast cross section of Shih-lian-miao anticline, Ordos basin. Location of the cross section is shown on *Figure 44*. From Chang Keng *et al.* (1958).

ed with shallow wells and hand-dug shafts during the early 1930's, but serious attempts to develop the area did not begin until 1957–1958. Productive zones are very shallow (100 m or less, on the average), and production is from the Early to Middle Jurassic Yen-an Suite. The largest IP reported is 1.5 mt/d (11 bbl/d); the average IP is only 10 liters/d (Brod, 1965, p. 312–313; Vasil'yev, 1968, p. 341). Ultimate recovery will be less than 1,000,000 mt (7,300,000 bbl).

Ma-chia-t'an field (Figs. 16, 39)—This is a faulted anticline just east of the Yin-ch'uan graben in the western part of the Ordos basin. The western flank is severely faulted. Paleogene is at the surface. The Late Triassic is 200 m deep and it, together with the overlying Early Jurassic, contains 40 productive sandstone bodies between the depths of 200 and 900 m. The average IP is 10–20 liters/d in each sandstone. Ultimate recovery will be less than 1,000,000 mt (7,300,000 bbl).

Sha-t'ing-tze field (Figs. 16, 39, 43)—This field is in the Pre-Liu-pan Shan graben in the northwestern part of the Ordos basin (*Fig. 39*). The structure is a faulted anticline

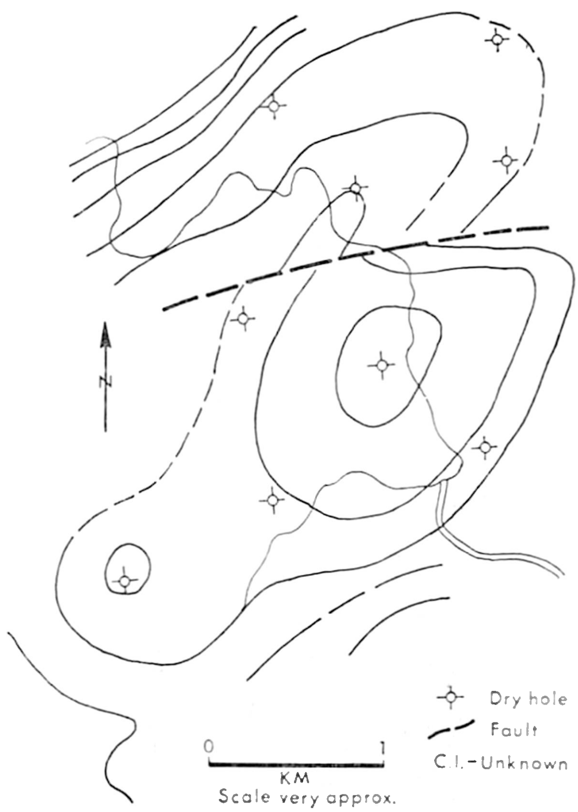


Figure 46. Structural contour map of Chi-li-ch'eng anticline, Ordos basin. Structural datum is approximately the top of the Triassic Zone II of the Yen-ch'ang Suite. Scales are only approximate. Location of the structure is on *Figure 39*. From Chang Keng *et al.* (1958).

with a graben at the top (*Fig. 43*). Dips are gentle—3–5°. The faults dip 70°. Production is from Cretaceous sandstones 3–4 m thick that directly overlie the Triassic. Depths to the productive zones range from 40 to 100 m. Ultimate recovery will be less than 1,000,000 mt (7,300,000 bbl).

Shih-lian-miao anticline (Figs. 30, 44, 45)—This is a northeast-southwest- striking anticline between the Yen-an field and the Wei-ho graben (*Figs. 44* 45). Middle Jurassic crops out at the surface. The drilling of the structure began in 1951; all wells were dry, although shows were present. The Permian and Carbiniferous also were tested with negative results. All sandstones tested were impermeable. Therefore, the structure was abandoned.

Chi-li-ch'eng anticline (Figs. 39, 46)—This structure is just northeast of the Shih-lian-miao anticline (*Fig. 39*). It has two closures, of which the southern was drilled by the Standard Oil Company of New York in 1914; Standard drilled five wells and six Late Triassic sandstone zones of the Yen-ch'ang Suite were tested. Shows were present in all zones, but the sandstones were too tight. In 1953, the northern closure was tested wih four wells. Shows were present in numerous zones, but porosity and permeability were absent.

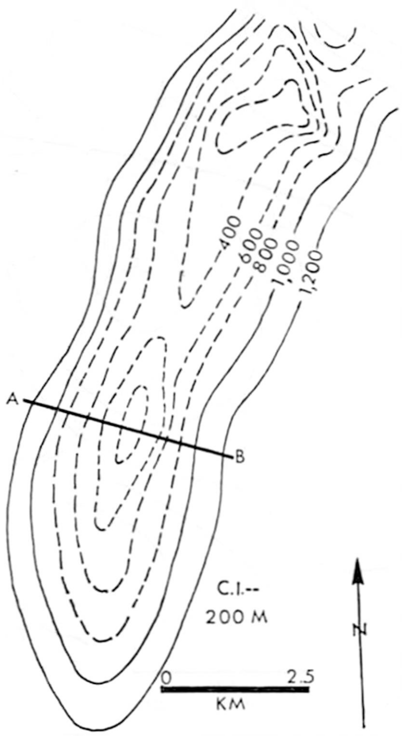


Figure 47. Structural contour map of Shui-shan-tze anticline, Ordos basin. Structural datum is near the top of the Late Triassic Yen-ch'ang Suite. Scales are at best approximate. Location of the structure is on *Figure 39*. From Chang Keng *et al.* (1958). Shows location of *Figure 48*.

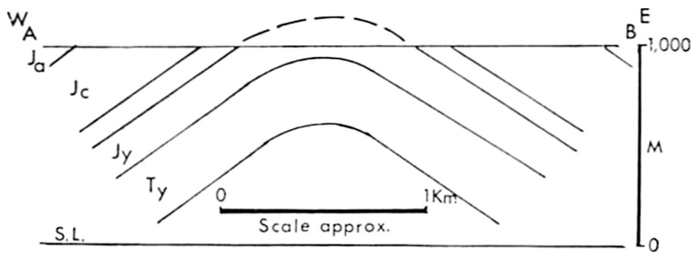


Figure 48. West-east structural cross section of Shui-shan-tze anticline, Ordos basin. Scale is only approximate. Location is given on *Figure 47*. From Chang Keng *et al.* (1958).

Shui-sha-tze anticline (Figs. 39, 47, 48)—This structure had not been drilled as of January 1, 1958, and a decision not to drill it had been made by 1955 because of the poor results of drilling other structures in the Ordos basin. Shui-shan-tze is a small north-south-striking symmetrical anticline delineated by surface geology, corehole drilling, and seismic work along the eastern margin of the Yin-ch'uan graben (*Fig. 16*). Flank dips range from 2 to 40°.

Conclusions

Unless the presence of permeable and porous reservoirs can be established in some part of the Ordos basin stratigraphic section, the basin must be disregarded as potentially commercial. This conclusion applies particularly to the Mesozoic and Cenozoic sections. The Carboniferous and Permian sections could have greater potential, but drilling to late Paleozoic formations has not been sufficiently extensive to support or refute this opinion.

SZECHWAN (RED[3]) BASIN

General

The Szechwan (Red[3]) basin, with an area of 160,000 km and an elevation generally between 200 and 700 m, is the oldest hydrocarbon-producing basin in the world (*Fig. 49, 50*). It is bounded on all sides by mountains—the Mi-ts'ang Shan and Ta-pa Shan on the northeast; the Tibetan Plateau ranges (Lun-min Shan) on the west; the Ta-liang Shan and Ta-lou Shan on the south; and the Fangtou Shan on the southeast. The Yangtze River flows through the southeastern side of the basin and leaves the basin on the east through the spectacular series of Yangtze gorges. Politically the basin occupies almost all of Szechwan Province whose capital city is Chung-king (Ch'ung-ch'ing).

The basin is divided into the following tectonic subdivisions (*Fig. 49*): (1) Pre-

3) The term "Red basin" is derived from the widespread outcrops of Cretaceous redbeds.

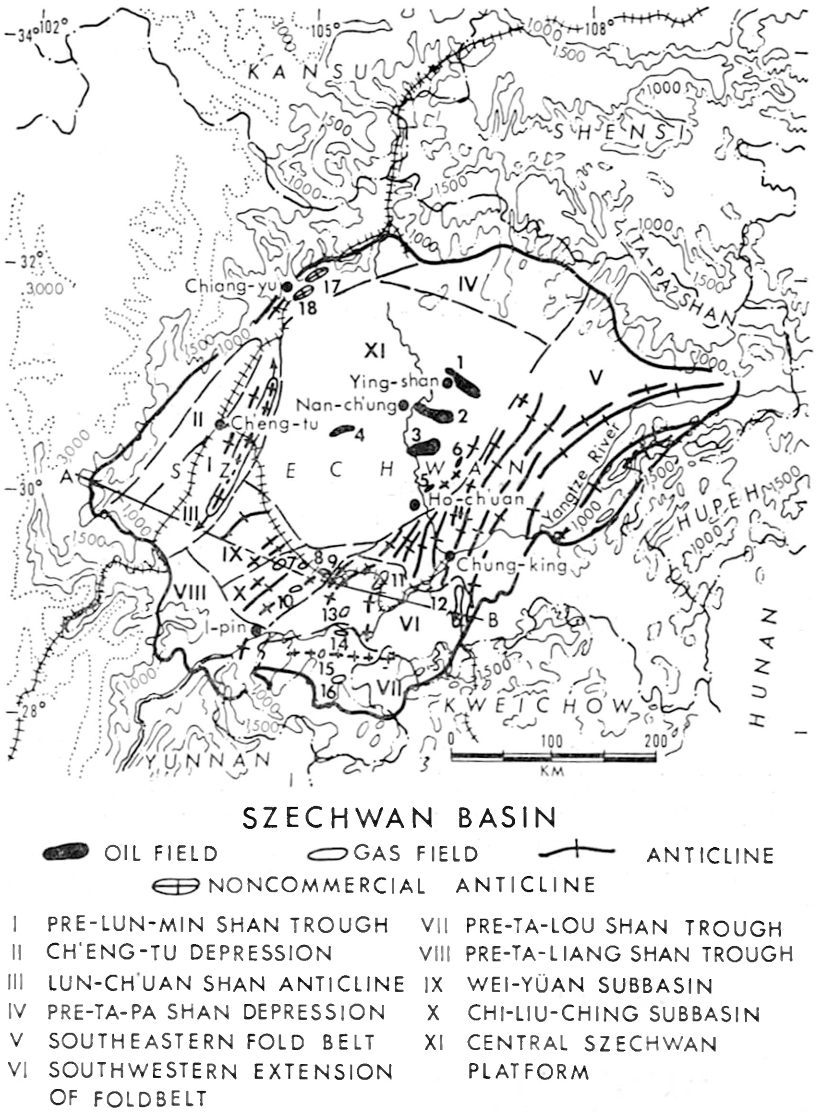


Figure 49. Index map of Szechwan (Red) basin, Szechwan Province. Locations of fields and untested structures are shown, together with principal tectonic elements. Location of *Figure 50* is shown. Political boundaries are from the 1975 edition of the *Times Atlas of the World.* **Fields:** 1=Ying-shan; 2=Nan-ch'ung; 3=Lung-nü-ssu; 4=Peng-lai-cheng; 5=Ho-ch'uan; 6=Lou-tu-hsi; 7=Chi-liu-ching; 8=Huan-chia-ch'an; 9=Sheng-teng-shan; 10=Teng-ching-kuan; 11=Huang-kuan-shan; 12=Shih-you-kou—Tung-ch'i; 13=Yen-kao-hsi; 14=Na-hsi; 15=Ch'an-yüan-pi; 16=Kao-mu-tin; 17=Chao-hua anticline; and 18=Ho-tai-p'o anticline.

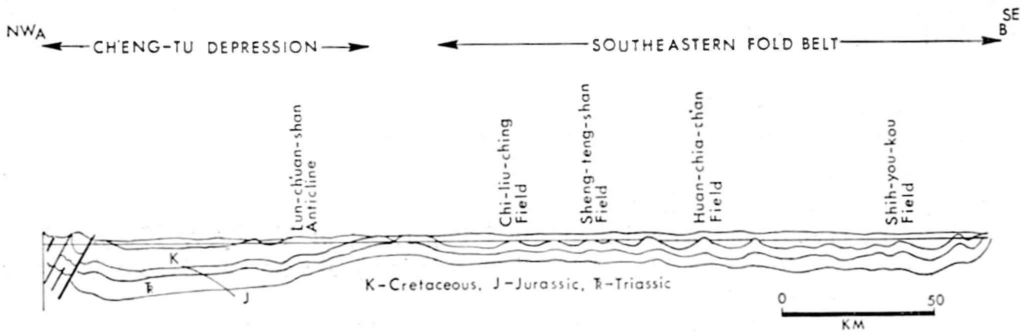


Figure 50. Northwest-southeast cross section, highly generalized, of the Szechwan basin, Szechwan Province. From Brod (1965). Location is given on *Figure 49*.

Lun-min Shan trough with the (2) Ch'eng-tu depression and the 3) Lun-ch'uan Shan anticlinal zone; (4) the Pre-Ta-pa Shan trough; (5) the Southeastern fold belt with its (6) Southwestern fold-belt extension; (7) the Pre-Ta-lou Shan trough; (8) the Pre-Ta-liang Shan trough; (9) the Wei-yüan and (10) Chi-liu-ching subbasins and (11) the Lung-nü-ssu or Central Szechwan platform. The mountain ranges around the basin have been thrust toward the Lung-nü-ssu platform.

The Southeastern fold belt and its Southwestern extension form a zone of spectacular northeast-striking anticlines and synclines, many of them more than 200 km long. Some are up to 400 km long. The folds include several types—the Jura or Appalachian "Valley-and-Ridge" type, Iranian-type box folds, and chevron folds. The area appears to be one of partial decollement within the Middle Triassic salt beds in the Chia-ling-chiang Suite. A total of 200 anticlinal closures has been mapped in this basin.

The remainder of the basin is underlain either by a median massif or platform of the Zwischengebirge type, or by troughs superimposed on the platform, particularly in the zones adjacent to the mountains.

In 1976, the PRC drilled the nation's deepest wildcat in the Szechwan basin—a hole to 6,011 m.

Early History

The history of the area is sufficiently unique that a brief summary is given. The ancient Chinese found oil and gas while drilling for salt with bamboo "drill pipe." The salt is in the Middle Triassic Chia-ling-chiang Suite. The date of the first drilling is unknown, but is at least as long ago as 211 B.C., and probably was earlier. Confucius, about 600 B.C., mentioned wells which were about 200 m deep or more (Owen, 1975, p. 2). Gas eventually was penetrated beneath the salt and was used for heating and lighting. In several salt works, salt brines were run via flumes into containers which were heated by the gas for evaporation. Small quantities of oil and condensate also were used for heating and for the manufacture of fire bombs. Chi-liu-ching field was discovered about 211 B.C. (Strubell, 1968). Some wells were drilled below 250 m by 347 A.D. and to 1,000–1,200 m by 1132 A.D. Thus, Chi-liu-ching appears to be the world's oldest hydrocarbon field—drilled deliberately for the discovery, production, and exploitation of gas and oil.

Szechwan Basin Stratigraphy

The Permian-Cretaceous cover ranges in thickness from 3,000–4,000 m on and adjacent to the Central Szechwan platform to more than 6,000–12,000 m in the surrounding troughs and mountain ranges. We have used the stratigraphic terminology of Ch'ang Ta (1963) and Kravchenko (*in* Brod, 1965; *in* Vasil'yev, 1968). Many stratigraphic names (representing local facies variations) are not used here in order to simplify the presentation.

The Szechwan basin is underlain by an unknown thickness of Proterozoic (Sinian) slate and up to 5,300 m of strongly deformed marine Cambrian, Ordovician, Devonian, and Carboniferous strata. Several unconformities are present in the section.

The least deformed and unmetamorphosed basin fill includes a Permian through Cretaceous sequence. The section is marine to paralic at the base, becomes increasingly marine in the Upper Permian-Upper Triassic, and abruptly changes to nonmarine in the Jurassic and Cretaceous. A thin nonmarine Cenozoic cover is present in the western part of the basin.

The Early Permian Chi-sia Suite is 70-200 m thick, averaging 150 m. It consists of black, coal-bearing shale and sandstone at the base that grade upward into light-gray marine limestone. Gas pools are present. The Chi-sia grades upward into the Mao-kou Suite, 100-300 m thick (average is 200 m). The Mao-kou, also Early Permian, consists of gray shale at the base and gray limestone at the top. Gas pools are present in the limestone beds.

The Late Permian includes two suites—the Lo-pin below and Chan-sin above. The Lo-pin is 100 m of black, coal-bearing shale with thin layers of interbedded sandstone and limestone. The Chan-sin is 150 m of gray siliceous limestone with good oil shows.

The Early Triassic is conformable on the Permian. The Fei-sian-kuan Suite is 300-500 m thick. It consists of violet-gray and black shale and marl with streaks of sandstone. Some gas pools are present, together with shows of oil. The gas is in fractured marl.

The Middle Triassic Chia-ling-chiang Suite is 430-1,000 m thick, averaging 600 m. It is composed of light-gray limestone, dolomitized limestone, and dolomite with lenses of shale, mudstone, halite, gypsum, and anhydrite. The halite forms an important seal for many of the gas pools, and served as a plane of decollement in the Southeastern fold belt. The fractured carbonate reservoirs are the principal gas-productive units of Szechwan.

The Late Triassic Lei-k'ou-p'o Suite is 200–500 m of light-gray limestone, dolomitized limestone, and dolomite. In the middle and lower parts of the section is gray-green shale. Small oil shows have been found in many wells.

Unconformably above the Triassic is the Early to Middle Jurassic Hsiang-ch'i Suite, 400-800 m thick on the Central Szechwan platform and the Southeatesrn fold belt, and up to 3,000 m thick in the western part of the basin. The sequence is alternate dark-gray shale, coal and light-gray sandstone. Some small oil pools are present.

Unconformably above the Early and Middle Jurassic is the Late Jurassic Tzu-liu-ching Suite. This suite is 400-700 m (average is 500 m) of alternate dark-gray shale, light-gray sandstone, and freshwater limestone, and light-colored lilac-red shale and sandstone. The sandstone bodies form the most important oil reservoirs in the Szechwan basin—particularly the Liang-ho-shan Sandstone Member at the base. The entire Jurassic through Cenozoic section is nonmarine.

The Tzu-liu-ching grade uspward into the Shahsi-miao (Lower Chung-king) Suite, 1,000-2,000 m thick (averages 1,500 m). This suite consists of dark lilac-red shale with streaks of sandstone; in the lower part are beds of yellow-green shale. The suite contains some small pools of oil. The Late Jurassic Upper Chung-king Suite also is 1,000-2,000 m thick (average is 1,500 m), and is composed of alternate light-red sandstone and shale.

The Createceous Chia-ting Suite consists of nonmarine red sandstone and shale with a basal conglomerate. It ranges in thickness from zero to 1,700 m. The red-beds of the Cretaceous crop out over most of the Szechwan basin, and are the reason why the basin is commonly called the "Red basin."

Cenozoic nonmarine strata crop out only along the western margin of the basin and consist of zero to 500 m of gravel, conglomerate, sandstone, and shale.

Szechwan Oil and Gas Fields

General—Production in the Szechwan basin is from paralic to marine Early Permian strata, from marine Early and Middle Triassic dolomitic limestone, and from nonmarine Early and Middle Jurassic sandstone. The shows of oil have been found in Ealry, Middle, and Late Trissic dolomitic limestone; shows of gas have been found in Late Permian limestone.

Permian and Triassic production is concentrated in the Southwestern extension of the Southeastern fold belt, in the Chi-liu-ching subbasin, and in the Pre-Ta-lou Shan trough—all in the southern and southeastern parts of the basin. Jurassic oil production is found on the Lung-nü-ssu or Central Szechwan platform. More than 20 oil and gas fields have been discovered, according to Bakirov *et al.* (1971). Seventeen fields (from Bakirov *et al.*) are shown on *Figure* 49.

Folds in the Pre-Ta-lou Shan trough and the Central Szechwan platform have widths of 3 to 7 km, and lengths of 15 to 50 km. Dips in the Pre-Ta-lou Shan folds are steep, like those of the Southwestern extension of the Southeastern fold belt—10 -60°. Dips of the platform structures, in contrast, are in the 1–3° range, locally somewhat greater (up to 13°). The sizes of the structures in the Southeastern fold belt range from 52 to about 400 km. The longest productive structure is the Shih–you–kou—Tung-ch'i anticline—about 52-60 km long.

Ying–shan field (Fig. 49)—This anticline, a surface structure with a subsurface closoure of more than 150 m, is 15 km wide and 50 km long, and is on the Central Szechwan platform. The structure is symmetrical with flank dips up to 13°. The field was discovered in the 1957-1958 period. Oil production is from the basal Liang–ho–shan Sandstone and other sandstones of the Tzu–liu–ching Suite (Late Jurassic) at depths of 1,400-1,500 m and from Shahsi-miao (Late Jurassic) sandstone at a depth of 400 m. Production is erratic, but generally the average production per well is in the 1-5 mt/d (7-36.5 bbl/d) range (Kravchenko, *in* Vasli'yev, 1968, p. 347). Oil gravity is 0.86. Ultimate recovery is estimated to be about 14,000,000 to 28,000,000 mt (100,000,000-200,000,00 bbl), and probably closer to 14,000,000 mt.

Nan-ch'ung field (Fig. 49)—Nan-ch'ung, discovered in 1958, is 10 km wide and 22 km long, and is mappable on the surface. The closure is 150 m. Flank dips are 1-3°. The field is on the Central Szechwan platform. The main oil production is from three sandstone zones of the Liang-ho-shan Sandstone of the Late Jurassic Tzu-liu-ching Suite. Depth to production is 1,400-1,500 m. Some oil has been found in sandstone of the Early to Middle Jurassic Hsiang-ch'i Suite at 2,200 m. IP's from the Liang-ho-shan range from 10 to 200 mt/d (73-1,460 bbl/d) (Kravchenko, *in* Vasil'yev, 1968). One IP was reported by Kudo (1966, p. 38) to be 1,900 mt/d (13,870 bbl/d). Oil gravity is 0.86. Ultimate recovery is estimated to be about 28,000,000 mt (200,000,000 bbl).

Lung-nü-ssu field (Fig. 49)—This structure was discovered by surface geology and was confirmed with the seismograph. The field was discovered in late 1956. (Antropov, 1958). It is 50 km long and 20 km wide, with a closure of 250 m. North dips are 2-5°; south dips are 1-2°. The field is on the Central Szechwan platform. The main production is from the Liang-ho-shan Sandstone of the Late Jurassic Tzu-liu-ching Suite at 1,100-1,450 m. Commercial oil also is present in the overlying Shahsi-miao Suite at 300 m. Oil IP's range from 30 to 80 mt/d (219-584 bbl/d). The oil reservoir of the Shahsi-miao Suite extends to the adjacent synclines. Total combined effective thickness of the oil column is 26 m. A gas cap is present in the Liang-ho-shan reservoir, with IP's greater than 150,000 m^3/d (5,250 Mcf/d). Oil gravity is 0.84-0.87 in the Liang-ho-shan and 0.82 in the Shahsi-miao. These cor-

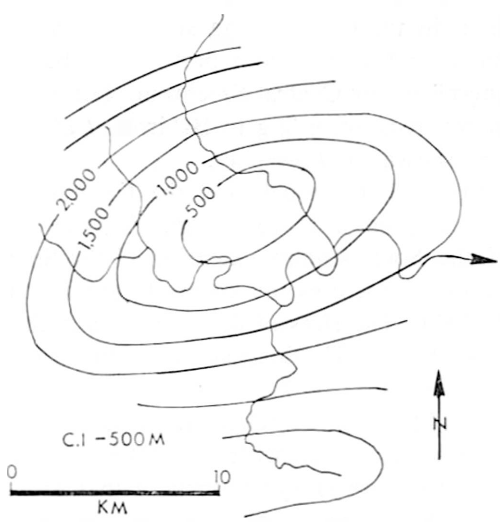


Figure 51. Schematic structural contour map of Peng-lai-cheng field, Szechwan basin. Scale is approximate. Location of structure is on *Figure 49*. From Chang Keng *et al.* (1958). Shows location of *Figure 52*.

respond to API gravity values of 30° and 39° respectively. A representative oil composition in the Liang-ho-shan Sandstone follows: density = 0.84 g/cm^3; sulfur = 0.29%; paraffin = 13.1%; benzine = 15.5%. In some fields, the paraffin content reaches 17%. The gas composition is: CH_4 = 90.5%; C_2H_6 = 5.1%; C_3H_8 = 1.6%; C_4H_{10} = 0.9%; C_5+ = 0.8%; CO_2 = 0.1%; and N_2 = 1.0% (Kravchenko, in Vasil'yev, 1968). Ultimate recovery is estimated to be not less than 82,000,000 mt (600,000,000 bbl).

Peng-lai-cheng field (Figs. 49, 51, 52)—This field on the Central Szechwan platform (a surface anticline) was discovered before 1910. By 1910, 20 shallow oil and gas wells had been drilled to 200-400 m (Chang Keng *et al.*, 1958, p. 99; Kudo, 1966, p.41). The structure is symmetrical with flank dips of 6-12° (Kudo, 1966, p. 41). The anticline is 25 km long and 15 km wide, with a closure of 50 m. The field ultimately was depleted; then the field was reopened in deeper zones during 1954. Oil was found at 1,600 m in the Late Jurassic Liang-ho-shan Sandstone and at 600 m in the Shahsi-miao Suite. Average IP's are 20 mt/d (146 bbl/d) (Kravchenko, *in* Vasil'yev, 1968). Ultimate recovery is estimated to be 2,000,000 mt (100,000,000 bbl).

Ho-ch'uan field (Fig. 49)—Discovered in the 1957-1958 period, Ho-ch'uan, which is in the Central Szechwan platform, produces oil from the Late Jurassic Liang-ho-shan Sandstone at a depth of 1,200–1,300 m. Oil gravity is 0.86. Ultimate recovery is estimated to be 4,000,000 mt (30,000,000 bbl).

Lou-tu-hsi field (Fig. 49)—This field on the Central Szechwan platform was discovered about 1958, produces from the Late Jurassic Liang-ho-shan Sandstone at 1,200–1,300 m, and has oil with a gravity of 0.86 g/cm^3. Ultimate recovery is estimated to be 4,000,000 mt (30,000,000 bbl).

Chi-liu-ching (Tzu-liu-ching) field (Fig. 49)—This, the oldest commercial hydrocarbon field in the world, was discovered by drilling with bamboo drill strings between 207 and 221 B.C.—probably in 211 B.C. (Chang Keng *et al.*, 1958, p. 98; Strubell, 1968). Confucius, about 600 B.C., referred to drilling on this anticline for salt, so that gas probably was discovered earlier than 211 B.C. However, the potential usefulness of the gas as a heat source for precipitating salt from brines does not seem to have been realized before 211 B.C. (Strubell, 1968). Wells were drilled to about 1,200 m by 1132 A.D. (Chang Keng *et al.*, 1958; Owen, 1975). More than 1,100 bamboo wells were drilled. The gas was used for heating the salt brines, for fuel, and for lighting.

The Chi-liu-ching is a surface anticline—as are all of the field of Szechwan. It is

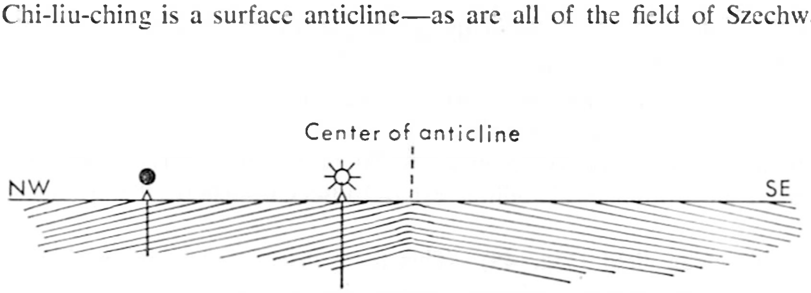


Figure 52. Northwest-southeast cross section of Peng-lai-cheng field, Szechwan basin. Location is on *Figure 51.* From Kudo (1966).

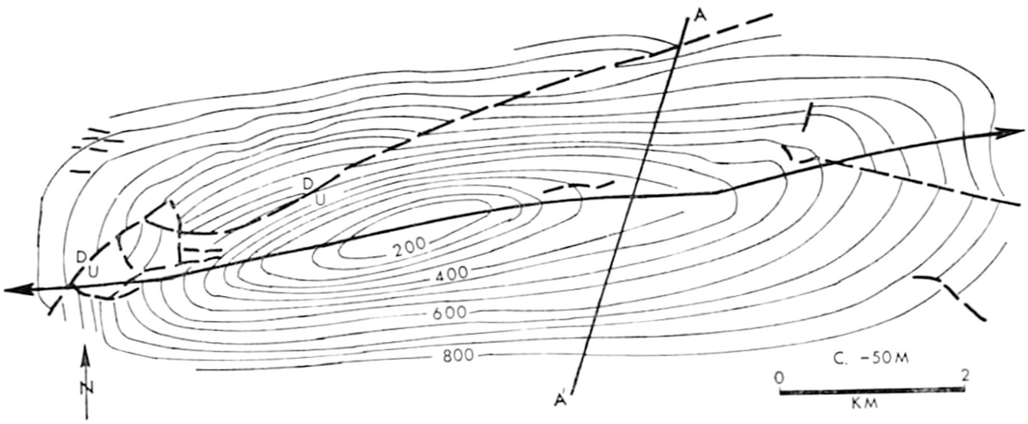


Figure 53. Structural contour map of Sheng-teng-hsan field, Szechwan basin. Structural datum is the top of the productive limestone, Middle Triassic Chia-ling-chiang Suite. Location of the structure is on *Figure 49*. From Chang Keng *et al.* (1958). Shows location of *Figure 54*.

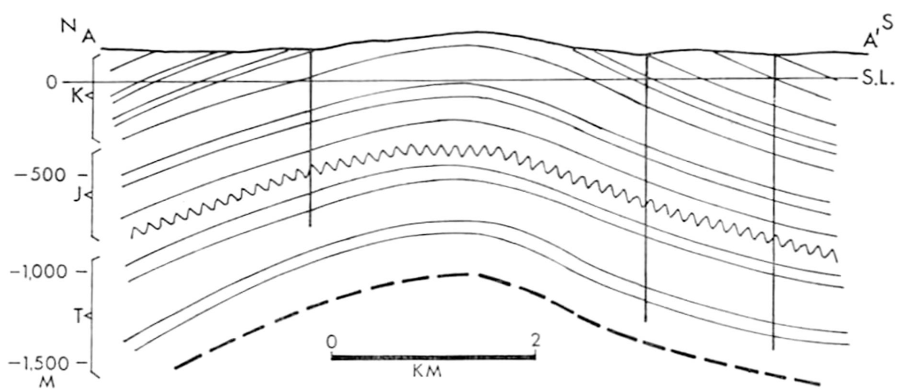


Figure 54. North-south structural cross section of Sheng-teng-shan field, Szechwan basin. Location is given on *Figure 53*. From Chang Keng *et al.* (1958).

in the subbasin of the same name at the southwestern end of the Central Szechwan platform. The structure is asymmetrical, with 10° northwest dips and 50° (and greater) southeast dips. Gas production is from fractured dolomitic limestone of the Middle Triassic Chia-ling-chiang Suite. The seal is halite and some anhydrite and gypsum. Ultimate recovery may be as great as 30 billion m^3 (1 Tcf). The field already had produced an estimated 12 billion m^3 (420 Bcf) by 1960 (P'ang and Ryabukhin, 1961).

Huan-chia-ch'an field (Fig. 49)—This field, discovered in the period 1955–1956, is a gas field in fractured carbonate reservoirs (Middle Triassic Chia-ling-chiang Suite) at about 1,200 m. Like Chi-liu-ching, it is an asymmetrical anticline with steep southeast dips and gentle north-west dips. The field is in the Chi-liu-ching subbasin. Ultimate recovery is estimated at 26 billion m^3 (900 Bcf).

Sheng-teng-shan (Lung-ch'uan) field (Figs. 49, 53, 54)—This field was discovered in 1943 (Chang Keng *et al.*, 1958, p. 97; Kravchenko, *in* Vasil'yev, 1968, p. 344) in the Chi-liu-ching subbasin. Gas was discovered in the fractured Middle Triassic Chia-ling-chiang Suite at 200 m and in fractured limestone of the Early Permian Mao-kou Suite at 400 m. The structure is an asymmetrical anticline 10.5 km long and 3.5 km wide. At the western end of the structure, south dips are 16–30°; north dips are 40–50° (*Figs. 53, 54*). The closure is 600 m; high-angle reverse faults are present

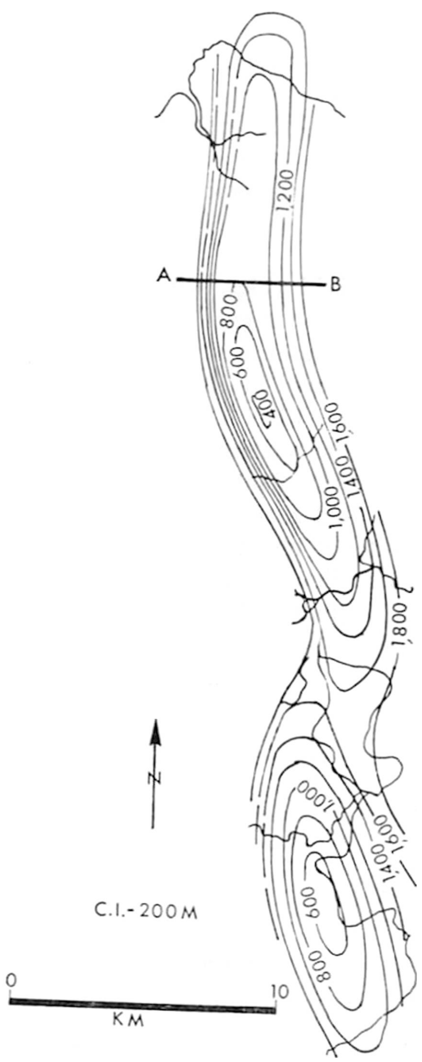


Figure 55. Structural contour map of Shih-you-kou field, Szechwan basin. Structural datum is top of the Middle Triassic. Location of the structure is on *Figure 49*. From Chang Kent *et al.* (1958). Shows location of *Figure 56*.

along the northern flank (*Fig. 53*). The gas of this field has high H_2 and CO_2 contents. Ultimate recovery is estimated at 30 billion m³ (1 Tcf).

Teng-ching-kuan field (Fig. 49)—Teng-ching-kuan, discovered in the Chi-liu-ching cubbasin during the 1955–1956 period, is about 16 km long and 3.5 km wide. Production is gas from fractured dolomitized limestone in the Middle Triassic Chia-ling-chiang Suite at about 1,200 m. Ultimate recovery is estimated at 30 billion m^3 (1 Tcf).

Huang-kuan-shan field (Fig. 49)—Huang-kuan-shan (Cucumber Mountain) field is a 25 km-long box fold, with 2–4° dips at the crest along its 4–5 km width. At 2 to 2.5 km from the crest, flank dips steepen abruptly to 70–80°. A highangle reverse fault is present along the northwestern margin. The field—a gas field—is in the Southwestern fold zone. It was discovered in 1956. In 1957, oil was found in the southern part of the structure. Development drilling subsequently revealed the presence of a narrow oil ring around the field. Depth to the oil ring is about 500 m. Production is from fractured limestone in the Middle Triassic Chia-ling-chiang Suite. The highest gas IP was 2.8 million m^3/d (98,000 Mcf/d). Ultimate recovery is estimated to be at least 86 billion m^3 (3 Tcf).

Shih-you-kou—Tung-ch'i field (Figs. 49, 55, 56)—This large fold has three closures, two of which are shown on *Figure 55*. The southern two closures comprise the Shih-you-kou structure (with surface oil seeps)—40 km long and 3 to 9 km wide. This part of the field was discovered in 1938 (Chang Keng *et al.*, 1958). The northern closure is the Tung-ch'i structure, 12 × 12 km, discovered in 1954. The eastern flank of Shih-you-kou dips 10–30°; the western flank dips 45–60°. The eastern flank of Tung-ch'i dips 20–22°; the western flank dips 25–40°. The field is on the Southwestern extension of the Southeastern fold zone. Depth to the fractured limestone (Middle Triassic Chia-ling-chiang Suite) is about 1,100 m. Oil comes from several thin Triassic sandstones above the fractured limestone. The gas is extremely dry—being 98% CH_4 with only small C_2 and C_3 fractions and some nitrogen. Reservoir pressures are high for this area (20–25 atm above normal), a fact which suggested to P'ang and Rya-

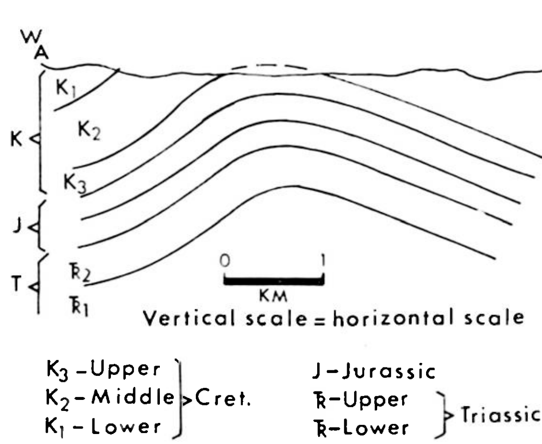


Figure 56. West-east structural cross section of Shih-you-kou field, Szechwan basin. Location is given on *Figure 55*. From Chang Keng *et al.* (1958).

bukhin (1961) that some of the gas come from greater depths and that there is interconnection between Triassic and Early Permian limestones. Minimum ultimate recovery from this field is estimated at 200 billion m^3 (7 Tcf).

Yen-kao-hsi field (Fig. 49)—This field, in the Southwestern extension of the Southeastern fold zone, was discovered in the 1955–1956 period. Production is from fractured Early Permian limestone. IP's average 2 million m^3/d (70,000 Mcf/d) with condensate. Production depths range from 400 to 2,000 m. Ultimate recovery is estimated at 30 billion m^3 (1 Tcf).

Na-hsi field (Fig. 49)—This field is in the Pre-Ta-lou Shan trough. It was discovered in the 1955–1956 period. It is an east-west-striking surface anticline. Producing depths are approximately 1,200 m. The gas reserves are in fractured Middle Triassic limestone of the Chia-ling-chiang Suite and of the Early Permian Mao-kou Suite. Ultimate recovery is estimated at 23 billion m^3 (800 Bcf).

Ch'an-yüan-pi field (Fig. 49)—This field is also in the Pre-Ta-lou Shan trough. It was discovered in the 1955–1956 period. The structure is oriented east-west, and is 8 × 6 km in size. Flank dips are 20°. Productive zones are fractured limestones of the Middle Triassic Chia-ling-chang Suite and the Early Permian Mao-kou Suite. IP's range from 5 to 10 million m^3/d (175,000–350,000 Mcf/d). Condensate also is present. Ultimate recovery is estimated at 20 billion m^3 (700 Bcf).

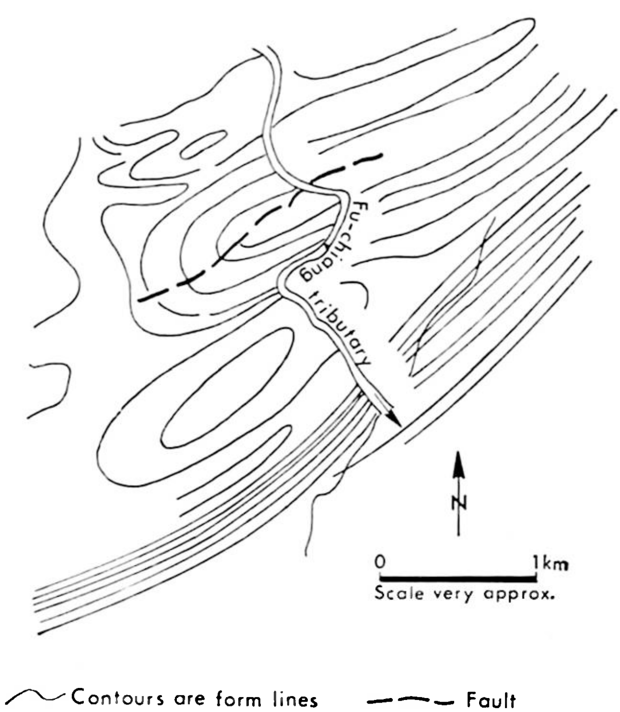


Figure 57. Structural contour map (form lines only) of the Chao-hua anticline, Szechwan basin. Location of the structure is on *Figure 49*.

Kao-mu-tin field (Fig. 49)—Kao-mu-tin was discovered during the 1955–1956 period in the Pre-Ta-lou Shan trough. It is oriented northeast-southwest, and has gas in the Middle Triassic Chia-ling-chiang Suite and the Early Permian Mao-kou Suite. Ultimate recovery is estimated at 23 billion m³ (800 Bcf).

Other structures—Several structures have been studied in the Chiang-yu area of the northwestern part of the Szechwan basin. One of these is the Chao-hua anticline, 100 km northeast of Chiang-yu (*Fig. 57*). In 1955, drilling of this structure resulted in the discovery of heavy oil in calcareous sandstone of Cretaceous age. Although the structure was not tested further, it has commercial oil potential.

The Ho-tai-p'o structure, just east of Chiang-yu, is an asymmetrical, faulted anticline (*Figs. 58, 59*). Jurassic is exposed in the center. The structure was tested with three wells, beginning in 1953. Shows of oil and gas were found in sandstones of Juras-

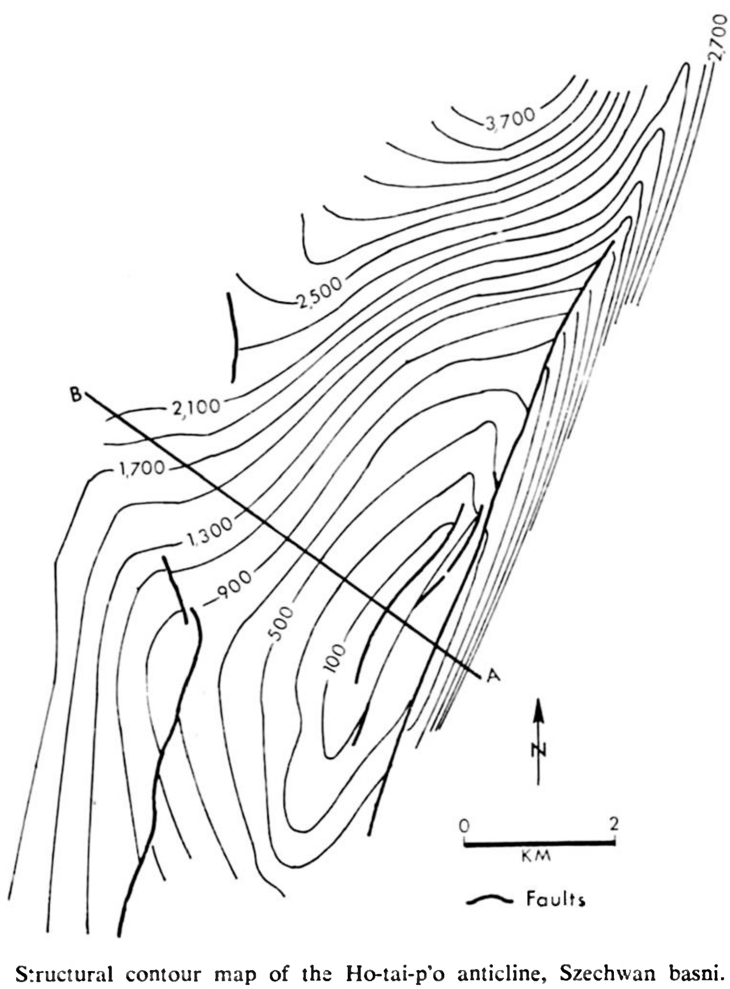


Figure 58. Structural contour map of the Ho-tai-p'o anticline, Szechwan basni. Structural datum is the top of the J_0 zone. Location of the structure is on *Figure 49*. From Chang Keng *et al.* (1958). Shows location of *Figure 59*.

sic age, but the size of the shows did not warrant additional drilling.

Conclusions

The Szechwan basin is China's largest gas-bearing province. Numerous structures of immense size are present. Many have not been drilled for lack of pipeline facilities and a market. Eventually the Szechwan basin will be one of the PRC's largest producing basins.

KWANGSI-KWEICHOW SYNECLISE

Oil and gas seeps are numerous in this area (*Fig. 1*) which is underlain mainly by deformed Sinian, Paleozoic, and Triassic rocks. At Lu-shan, Kweichow Province, a small (20 kg/d) flow of oil with gas was recovered from a Silurian sandstone (Brod, 1965, p. 324). Oil shows also are associated with the Devonian sandstones (Bakirov *et al.*, 1971, p. 492). At Pai-se (*Fig. 1*), an anticline was drilled in 1959 and yielded gas from three sandtsones in the Permian and Triassic (Kudo, 1966, p. 44). Near Kuei-yang a well drilled to 200 m recovered 1.5 mt/d (11 bbl/d) of oil from Permo-Triassic sandstone (Brod, 1965, p. 324). Through 1970, no commercial discoveries had been made (Bakirov *et al.*, 1971).

MISCELLANEOUS SOUTH CHINA BASINS

Brod (1965, p. 324) mentioned three basins between the Kwangsi-Kweichow

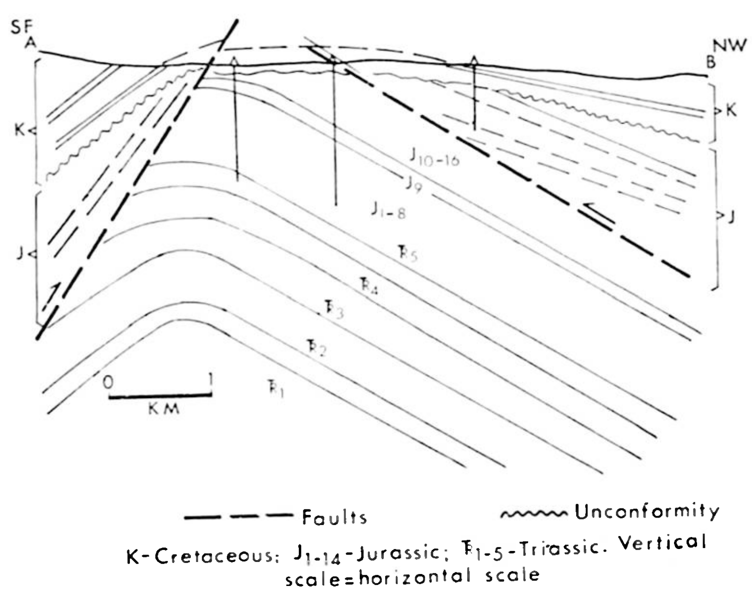


Figure 59. Northwest-southeast structural cross section of Ho-tai-p'o anticline, Szechwan basin. Location is on *Figure 58*. From Chang Keng *et al.* (1958).

syneclise and the eastern coastal basins. These are the Hsiang-fan basin at 32°N, 112°30′E; the Tung-t'ing basin at 30°N, 114°E; and the Yuan Shiu basin at 28°30′N, 116°F (*Fig. 62*).

The Hsiang-fan basin, 150 × 100 km, is underlain by about 7,000 m of Cenozoic and Mesozoic strata, including 2,000 m of light-yellow limestone and violet shale (Triassic), 450 m of coal-bearing shale and sandstone (Jurassic), 3,550 m of red and yellow sandstone and shale (Cretaceous), and 1,000 m of Cenozoic strata.

The Tung-t'ing basin, 300 × 150 km, contains a very thick section of Poleozoic marine rocks. Williams (1975, p. 256) mentioned a field discovery here, the "57" field (no. 7, *Fig. 62*). Discovery was in 1967. Actually, as of March 1975, seven fields had been discovered around Ch'ien-chiang. The total productive area is 85 sq km. Fourteen rigs were active; 324 wells were productive; and 158 new locations had been prepared. This area is fourth among the PRC's productive basins. Nothing is known of the petroleum geology—ages or depths of reservoirs. The 1975 production was about 4,100,000 mt (29,930,000 bbl; *Table 4*).

The Yudan Shiu basin, 250 × 100 km, contains 1,000 m of dark coal-bearing Jurassic and 600 m of green-gray Cretaceous sandstone, shale, and tuffaceous strata. These rocks are overlain by a continental Cenozoic section.

TIBETAN PLATEAU

Tibet contains numerous areas with some potential in Paleozoic and Mesozoic rocks. The structure is extremely complex, and it is doubtful that large accumulations will be found, although some enthusiasm has been expressed by PRC geologists. Seeps are known in Mesozoic and Tertiary strata just south of Kang-ta (Greater Himalayas), just west of Ting-ch'ing (eastern Tibet near the Tsinghai boundary), and at Na-mu Hu, Hei Ho (River), eastern Tibet. PRC geologists consider the most prospective areas to be north and south of the T'ang-ku-la Shan (Tanglha Range) of eastcentral Tibet and the Nien-ch'ing-t'ang-ku-la Shan area farther southwest. A few dry holes have been drilled in northern Tibet.

HU-LUN-CH'IH BASIN

Little has been published on this area of the Inner Mongolian Autonomous Region and Heilungkiang Province (*Fig. 1*). In the September 1967 issue of *Fei-ch'ing Yen-chui* (Taipei, v. 1, no. 9, p. 52–57), the following areas of Inner Mongolia were mentioned as sites of exploratory drilling: Erh-lien, Cha-la-no-erh, Hai-la-erh, and Ya-k'o-shih. A discovery in Lower Cretaceous continental sandstones was reported at Ya-k'o-shih (49°17′N, 120°48′E). Evidently the discovery has not been developed, possibly because of small size or possibly because of proximity to the USSR, or both. The geology is like that of southern Mongolia. In fact, the Hu-lun-ch'ih basin is the eastern extension of the East Gobi basin of southeastern Mongolia, where one commercial field, Dzuun Bayan, has been developed south of Saynshand (44°58′N, 110°10′E). At Dzuun Bayan, oil has been found in 40 nonmarine sandstones of Hauterivian and Valanginian (Early Cretaceous) ages (Vasil'yev, 1968, p. 316–321).

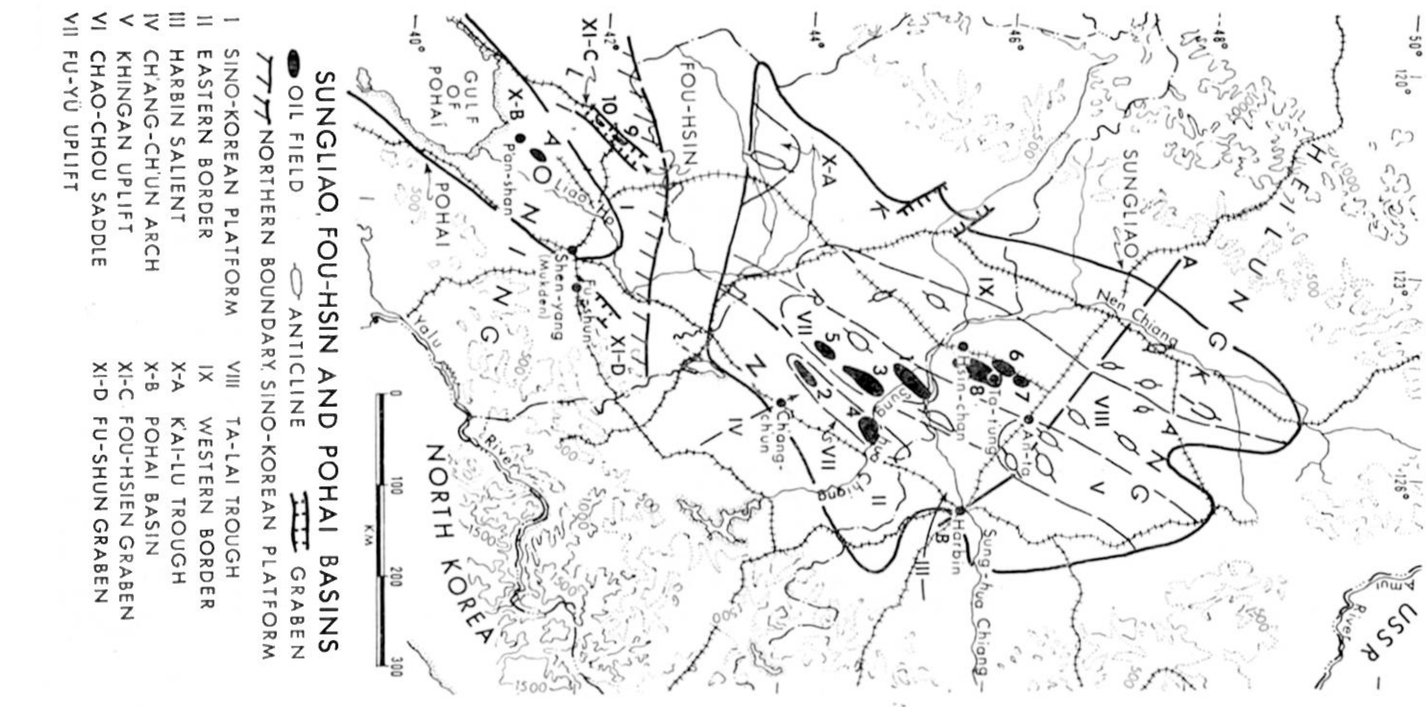


Figure 60 Index map of Sungliao basin, Fou-hsin graben, and northern part of Po Hai basin, Heilungkiang, Kirin, and Liaoning Provinces. Locations of fields and anticlinal structures (not known to have been drilled as of 1–1–71) are shown, together with principal tectonic elements. Location of *Figure 61* is given. Political boundaries are from 1975 edition of the *Times Atlas of the World*. Sungliao basin structures reported by Antropov (1958), P'ang and Ryabukhin (1961), Kravchenko (1968, *in* Vasil'yev, 1968), Bakirov *et al.* (1971), and Salmanov (1974) to be productive are: (1) Fu-yü, (2) Kung-chu-ling, (3) Ch'in-lou-kou, (4) Hsin-chen-kou, (5) Ch'ao-yu-tai, (6) Ta-t'ung-chen, (7) North Ta-t'ung-chen, and (8) East Ta-t'ung-chen. Fields of Fou-hsin graben are: (9) T'ung-an and (10) Hsin-k'ai-ling. (11) is P'an-shan field in the northern part of the Po Hai basin. Positions of the last three fields (9–11) are approximate.

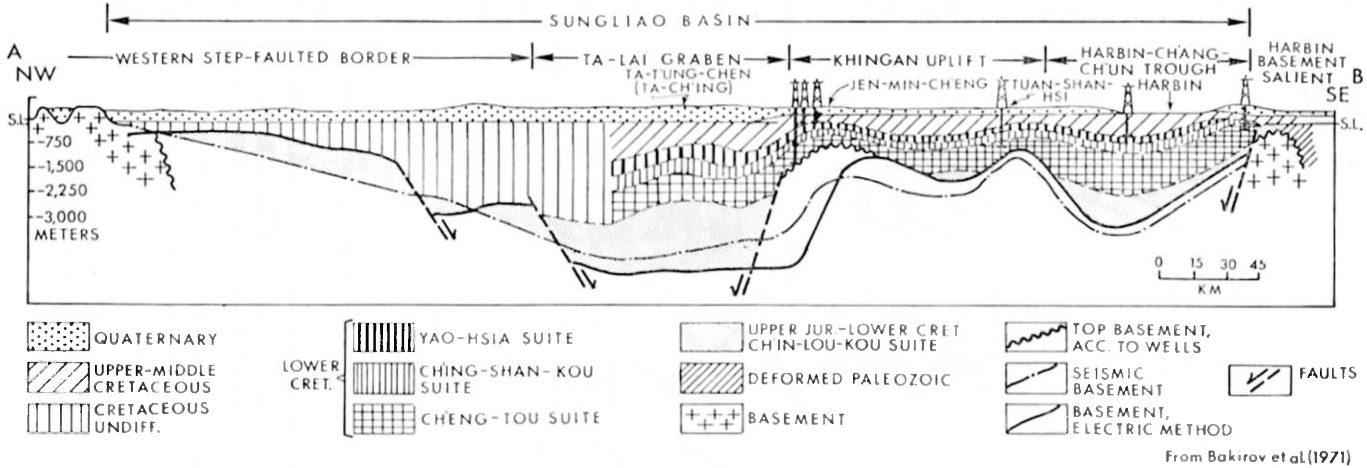


Figure 61 Northwest-southeast cross section of Sungliao basin, Heilungkiang Province. Location of the original "Ta-ch'ing" (Ta-ch'ing" (Ta-t'ung-chen) field is shown (*Fig. 60*). From Bakirov *et al.* (1971). Location of the cross section is on *Figure 60*.

SUNGLIAO BASIN

General

The Sungliao basin, with an area of 200,000 sq km and an average elevation of less than 200 m, is the most important oil-producing basin of the PRC (*Figs. 60, 61*). The basin, occupying a large segment of pre-World War II Manchuria, straddles Heilungkiang and Kirin Provinces, and contains several important fields, some or all of which are referred to in the PRC press as "Ta-ch'ing." Ta-ch'ing, which means "Great Joy" or "Great Celebration," is a party slogan and is a general term for several fields in the Sungliao basin. The great importance of Ta-ch'ing in PRC industrial and economic planning cannot be overemphasized, because the discovery came at the time when Soviet technicians were leaving China. This great discovery enabled the PRC to continue its programs of agricultural and industrial expansion after the Soviets left.

Geologically the Sungliao basin is a northeast-southwest-striking horst and graben complex (*Fig. 61*). Thus, the Sungliao basin is not a Zwischengebirge structure characteristic of the interior basins described in preceding pages, but has the structural style and trends which characterize all of the coastal and offshore basins of the PRC and Korea.

Figure 60 shows the principal tectonic elements of the basin: (1) the Sino-Korean platform on the south; (2) the eastern border of the basin, into which project (3) the Harbin salient and (4) the Ch'ang-ch'un arch; (5) the buried Khingan uplift (horst) with (6) the Chao-chou saddle and (7) Fu-yü uplift, both of which are on strike with and extensions of the Khingan uplift; the Fu-yü uplift has eastern and western branches; (8) the Ta-lai trough (main graben) with deep basement; (9) the western step-faulted border of the basin, also with deep basement; 10) grabens with Cretaceous or younger fill (A = K'ai-lu trough; B = Liao Ho or Po Hai basin); and (11) small synclinal grabens with Mesoziic-Cenozoic fill (C = Fou-hsin graben; D = Fu-shun graben).

A survey of Soviet literature indicates that oil was discovered first in 1958 at Fu-yü, and later during that year at Kung-chu-ling, Ch'in-lou-kou, Hsin-chan-kou, and Ch'ao-yutai fields (Kravchenko, *in* Vasil'yev, 1968; see also Antropov, 1958, and P'ang and Ryabukhin, 1961). At least 20 structures have been mapped in the basin (*Fig. 60*), and more than 100 are believed to be present. Ten, and possible more (Williams, 1975), are productive. The PRC press refers to some of them collectively as "Ta-ch'ing field." The productive structures, according to Kravchenko (*in* Vasil'yev, 1968) and Bakirov *et al.* (1971) are following: (1) Fu-yü, (2) Kung-chu-ling, (3) Chin-lou-kou, (4) Hsin-chan-kou, (5) Ch'ao-yu-tai, (6) Ta-t'ung-chen, (7) Ta-t'ung-chen (north), and (8) Ta-t'ung-chen (east). This information cannot be confirmed, except that (1) the three Ta-t'ung-chen structures are producing today and (2) at least these three structures comprise the "Ta-ch'ing" field of both the PRC and foreign press. The Ta-ch'ing (Ta-t'ung-chen) complex qualifies as a giant field (70,000,000 tons or more of recoverable reserves) (*Tables 5*). Estimates of Ta-ch'ing production differ—30 percent of the PRC total, according to Williams (1975); 33 percent, according to the National Council (1976); 54 percent, according to the Central Intelligence Agency (1975); and 40 to 60 percent, according to other foreign estimates (Bakirov *et al.*, 1971, p. 497). A 52 percent figure seems to be reasonable. In 1975, this percentage, converted to metric tons, would have been about 40.3 million mt, or 294,000,000 bbl (805,000 bbl/d) (see *Tables 4, 5*).

Because of the conflicting statements in Soviet, western, and Japanese literature, we carefully searched the PRC press and technical literature on the Sungliao basin. The following is a summary of our findings and interpretations:

(1) The three Ta-t'ung-chen fields (*Fig. 60*) are the PRC press' Ta-ch'ing field and have a productive area of about 1,000 sq km;

(2) The Fu-yü area has five productive closures; these are on both sides of the Sung-hua Chiang (Sungari River), and the total productive area is 95 sq km;

(3) In addition, two other small fields are present in the basin. One is near An-kuang, centered at 45°32′ and 123°54′; the other is near Shen-yang, centered at 44°47′ and 123°00′;

(4) Thus, ten separate closures may be present in the Sungliao basin. It is possible that the three Ta-t'ung-chen structures of *Figure 60* now are a single productive area;

(5) Soviet reports, reflected in our *Figure 60*, are not accurate unless (a) Fu-yü, Ch'in-lou-kou, Ch'ao-yu-tai, the structure shown just north of Ch'ao-yu-tai, and the structure shown just northeast of Fu-yü comprise the five Fu-yü fields; (b) the production near An-kuang is what Bakirov *et al.* (1971) called the Hsin-chen-kou field; and (c) the production near Shen-yang is whaat Kakirov *et al.* caled the Kung-chu-ling field. Fuyü is the PRC's sixth most important producing area (*Table 4*).

The five structures near Fu-yü are the sixth largest productive region in the PRC, and produced nearly 3,000,000 mt (21,900,000 bbl) in 1975. On January 1, 1976, nine rigs were active in the Fu-yü area, 1,050 wells were producing, and 161 new locations had been staked. Average production per well per day was 8.5 mt (62 bbl). Thus the five closures around Fu-yü have a tenth of the area of the Ta-ch'ing fields and their production is only 8 percent of that at Ta-ch'ing. However, well spacing is much closer than at Ta-ch'ing, because there are 1,050 wells in the Fu-yü area, compared with 4,069 wells at Ta-ch'ing. Thus, reservoir quality in the Fu-yü area is poor.

From the preceding, it is clear that the distribution and number of fields in the Sungliao basin still are unclear. The Soviet data, shown on *Figure 60*, and our own researches are compatible if the assumptions listed in paragraph (5), above, are correct.

Sungliao Basin Stratigraphy

The Sungliao basin is in the North China or T'ung-pai platform (Ch'ang Ta, 1963; Bakirov *et al.*, 1971), and is underlain by a a folded, metamorphosed, and—locally—intruded Paleozoic basement. The overall basin is a northeast-southwest-striking graben system with 0.2–2.0 km of sedimentary cover on the central Khingan-Fu-yü uplift (*Figs. 60, 61*), and 5 to 7 km of sedimentary cover in the Ta-lai trough. Sedimentary thicknesses of 0.5 to 4.0 km characterize the eastern and western border zones. Dips generally are in the 2–5° range, but in the graben zones near faults, dips may reach 20° or more. A description of this section penetrated along the eastern border zone and on the Khingan-Fu-yü uplift follows.

During the Jurassic, faulting of the Paleozoic basement (with Hercynian structures) began, and some Late Jurasic to Early Cretaceous mafic flows were extruded. At the same time as and later than the volcanism, a sequence of Lower Cretaceous fluviatile and lacustrine strata was deposited. The lowest unit (*Fig. 61*) is the Ch'eng-tou ("a") Suite, 500–2,000 m thick, the most important oil-bearing unit in the Sungliao basin, unconformable on all older rocks. The Ch'eng-tou consists of alternate violet-red and light-gray to green-gray sandstone and shale. Shale predominates in the middle part of the sequence. A basal conglomerate is omnipresent.

The Hsin-chang-kou ("b") Suite is conformable on the Ch'eng-tou. It consists of 130–220 m of strata. The basal part is shale with layers of lacustrine oil shale. The upper part is dark-red and gray green shale. Vasil'yev (1968, p. 338) wrote that the unit has oil shows, but Bakirov *et al.* (1971, p. 496) noted that the unit has no important sandstone bodies for oil production.

The Yao-hsia ("c") Suite, 100–400 m thick, consists of red shale with interbeds of gray-green shale and sandstone. Vasil'yev (1968, p. 338) reported oil shows in the sandstones.

Conformably on the Yao-hsia is the Nan-kuang ("d") Suite (Bakirov *et al.* called it the Neng-chiang Suite), 200–700 m thick. Several oil-productive sandstones are present. The lower part is light-gray shale with layers of dark oil shale. The upper part is gray sandstone and black to dark-gray lacustrine shale.

The Lower Cretaceous is overlain unconformably by the Late (?) Cretaceous Su-fan-tai ("e") Suite, 170–500 m of red and gray-green shale with lenses of sandstone and conglomerate. It grades upward into the Pa-yen ("f") Suite, 170–500 m of gray-green and dark-gray shale. This unit is an important seal for the hydrocarbons in the Sungliao basin.

Paleogene and Neogene strata are unconformable on the Cretaceous. The Paleogene is about 100 m of light-gray conglomerate, interbedded with red and green shale. The Noegene is 200–300 m of black shale with layers of sand and lignite. Quaternary is present in many areas—10 to 100 m of clay, sand, and gravel.

Sungliao Basin Oil Fields

General—The problem of field names in this area has been noted. The slogan "Ta-ch'ing" includes several fields, most notably the Ta-t'ung-chen group of fields, but whether other fields are included under the name "Ta-ch'ing" is not known.

Exploration of this area began in 1957, with teams of Soviet and PRC geologists and geophysicists. Apparently (Antropov, 1958; P'ang and Ryabukhin, 1961), the first discoveries were Fu-yü (*Fig. 60*; P'ang and Ryabukhin, 1961) and Kung-chu-ling, in 1958 (Antropov, 1958; Vasil'yev, 1968). In late 1958 through mid-1959, Ch'in-lou-kou, Hsin-chan-kou, and Ch'ao-yu-tai were discovered (Vasil'yev, 1968). On September 10, 1959, a field called "Ta-ch'ing" was discovered on the basis of Soviet-PRC seismic work and core drilling. The field is 60 km southwest of An-ta, in the Ta-lai trough, near the village of Ta-t'ung (Strong, *in* Anonymous, 1968). According to Bakirov *et al.*, subsequent detailed drilling showed that the Ta-ch'ing (Ta-t'ung or Ta-t'ung-chen) structure consisted of three closures—Ta-t'ung-chen proper and East Ta-t'ung-chen and North Ta-t'ung-chen (*Fig. 60*).

Fu-yü field (Fig. 60)—P'ang and Ryabukhin reported that Fu-yü was discovered in 1958 on the western branch of the Fu-yü uplift. Discovery was in Early Cretaceous sandstones of the Ch'eng-tou Suite. Several reservoirs are present, and range in thickness from 5–10 m. The structure is a broad anticline about 55–60 × 15 km. Porosity and permeability are problems in this sctructure. Additional data on Fu-yü and adjacent fields are given in the "General" section at the beginning of this discussion of the Sungliao basin.

Kung-chu-ling field (Fig. 60)—This field, on the eastern branch of the Fu-yü uplift, was discovered in 1958, and was described by Kravchenko (*in* Vasil'yev, 1968). The structure is 80×20 km, has a closure of 200 m, and flank dips of 2–4°. The productive area probably is very small. Several sharper folds or plications are associated with faults paralleling the western margin of the structure. Strata of the upper part of the Ch'eng-tou Suite are exposed in the center of the structure. Twenty-two sandstone bodies are oil-saturated in the Ch'eng-tou Suite. Producing dpths range from 500–900 m. Commercial oil also was found in the basal conglomerate above basement. Reservoir thicknesses range from 5–10 m each; total effective thickness is 66 m (Antropov, 1958). Porosity average 20 percent. The permeability range is 15 to 70 md. Water injection was initiated from the beginning of production in 1962. The performance of many wells is said to have been poor. However, many of the original wells have been worked over and are producing again. Ultimate recovery is estimated to be a minimum of 41,000,000 mt (300,000,000 bbl) and a maximum of 164,000,000 mt (1,200,000,000 bbl).

Ch'in-lou-kou field (Fig. 60)—This structure, on the western branch of the Fu-yü uplift, is 20×60 km, and was discovered in late 1958. The productive area is believed to be small. The uppermost beds of the Ch'eng-tou Suite crop out in the center. Flank dips are 3–5°. At least four productive sandstones are present between the depths of 170 and 1,700 m. Ultimate recovery is estimated to be a minimum of 8,000,000 mt (59,000,000 bbl) and a maximum of 24,000,000 mt (175,000,000 bbl). An extremely low recovery factor was assumed (−50 bbl/acre-ft with a maximum effective column of 12 m).

Hsin-chen-kou field (Fig. 60)—This field was discovered in late 1958—the easternmost discovery through 1960. It is on the eastern branch of the Fu-yü uplift, and is approximately 20×35 km. It is a flat-topped structure tilted southwestward toward the basin. There are several faults. Production is from several zones in the Ch'eng-tou Suite. The oil is quite viscous in the lower sandstones, but becomes less so upward. More viscous oil typifies the eastern part of the basin. The sandstones are thicker, 10–20 m each, because they are closer to their provenance. Estimated in-place reserves are 47,000,000 mt (345,000,000 bbl), of which 12,000,000 mt (87,600,000 bbl) may be recoverable.

Ch'ao-yu-tai field (Fig. 60)—Although Ch'ao-yu-tai may have been discovered in 1958, some sources (e.g., Bakirov *et al.*, 1971) indicate that the field was not discovered until 1969 or 1970. It is about 15×25 km, and is on the western branch of the Fu-yü uplift. Production is from the Early Cretaceous Ch'eng-tou Suite. Data are insufficient to estimate reserves.

Ta-t'ung-chen field (Figs. 60, 61)—This field was discovered on September 10, 1959. It is in the Ta-lai trough. It was the first of the Sungliao basin fields to be designated by the PRC press as a Ta-ch'ing field, and is on a structure 20 km wide and 50 km long. Depths to production are about 1,000–1,800 m. The deepest test well in this basin, as of January 1, 1968, was at Ta-t'ung-chen, and was 4,600 m deep.

Bakirov *et al.* (1971, p. 494) reported the presence of three separate closures within a northeast-southwest distance of 60–80 km—Ta-t'ung-chen, East Ta-t'ung-chen, and North Ta-t'ung-chen. Additional productive structures are rumored to have been discovered on trend toward the northeast, but no confirmation of this rumor is known to us.

Ta-t'ung-chen, as originally described by Kravchenko (1968, *in* Vasil'yev, 1968), was estimated by Meyerhoff (1970) to have recoverable reserves of not less than 85,500,000 mt (624,000,000), and possibly as much as 164,000,000 mt (1.2 billion bbl). These figures are now known to be far too conservative, if all three Ta-t'ung-chen structures are taken into account. More than 230 million mt (1.68 billion bbl) had been produced to the beginning of 1976 (*Table 5*), and at least 274 million mt (2 billion bbl) by January 1977. Ultimate production will be at least 400–500 million mt (3–3.65 billion bbl), and could be much more. There is much associated gas.

Ta-t'ung-chen, because of its enormous size and shallow depth, appears to be as anomaly among Sungliao basin fields, or field groups. The five Fu-yü-region fields, productive from the same sandstone reserves, have a much lower yield per well than those at Ta-t'ung-chen (27 mt/d = 197 bbl/d). Production per well from other fields in the Sungliao basin also is reported to be small. The reason are low

Table 5. Estimated Oil Production, Ta-ch'ing, 1960–1975.[1]

Year	Metric Tons	Barrels	Bbl/d
1960	793,000	5,788,900	15,860
1961	1,022,000	7,460,600	20,440
1962	2,726,000	19,899,800	54,520
1963	4,430,000	32,339,000	88,600
1964	5,765,000	42,084,500	115,300
1965	7,100,000	51,830,000	142,000
1966	8,793,000	64,188,900	175,860
1967	9,045,000	66,028,500	180,900
1968	9,297,000	67,868,100	185,940
1969	12,830,000	93,659,000	256,600
1970	17,665,000	128,954,500	353,300
1971	22,152,000	161,709,600	443,040
1972	25,550,000	186,515,000	511,000
1973	28,301,000	206,597,300	566,020
1974	34,648,000	252,930,400	692,960
1975	40,259,000	293,890,700	805,180
TOTAL	230,376,000	1,681,744,800	---

1) These figures are based on the National Council (1976), and modified by percentage figures taken from the PRC press.

porosity and permeability in mineralogically immature sandstone reservoirs with a large clay and shale matrix. Therefore, a major question which arises is why the Ta-t'ung-chen field complex is anomalous.

The answer probably is related to the fact that the field, unlike the other basin fields (*Fig. 60*), is not on a basement horst or arch, but in the deep Ta-lai trough or graben (*Fig. 61*), where lacustrine (and, therefore, winnowing) conditions were persistent during deposition. The presently unanswerable question, then, is this. Why have no additional Ta-t'ung-chen fields been discovered in the Ta-lai trough?

The field area is large—about 1,000 sq km. As of February 1962, 218 wells were on production. By June 1971, there were 2,872 producing wells. This number rose to 3,942 in June 1975 and to 4,069 on January 1, 1976. There were 9 active rigs and 169 new locations staked.

Table 6. Characteristics of Ta-ch'ing and Shengli Oils.
From Connell (1974) and National Council (1976).

	Early Cretaceous, Ch'eng-tou Suite, "Ta-ch'ing"	Early Cretaceous, Ch'eng-tou Suite, "Ta-ch'ing"	Tertiary, "Shengli" (Huang Ho Delta)
S.G. at 15.4°C	0.8717	0.8607	0.9059
API gravity	30.7°	32.8°	24.61°
Water and sediment, % volume	0.10	0.15	1.3
Water content	—	0.5	0.7
Pour point, °C	20.0	35.0	27.5
Sulfur content, wt. %	0.06	0.14	0.88–1.35
Visc. at 50°C (centistokes)	19.57	20.13	91.55
Carbon residue, wt. %	2.71	3.13	7.08
Wax content, wt. %	12.0	22.4	15.0
Salt content, wt. %	0.0005	11 ppm	259 ppm
Ash content, wt. %	na	0.01	0.023

	Product Yield				
	"Ta-ch'ing" (vol. %)		"Shengli" (vol. %)		
LPG	IBP–35°C	0.2	Naptha	IBP–170	7.3
Light naptha	35–90	5.4	Kerosene	170–240	5.0
Naptha	90–165	3.7	Gas oil	240–330	9.6
Kerosene	165–220	4.7	Residue	330–EP	77.1
Gas oil	220–275	6.9	Loss		1.0
HGO	275–320	7.0			
Residue	320–EP	68.0			
Water		2.6			
Loss		1.5			

We can compute the average daily production per well because we know (1) within a few percent, the volume of oil produced from the field during 1975 and (2) the number of producing wells. Therefore, PRC press reports are a puzzle to us, as illustrated in the following paragraph.

The whole problem of estimating the production and reserves of PRC fields discovered after 1960 (when USSR technicians left the PRC) is summarized ably by Smil (1975). A PRC publication reviewed by Smil stated that a typical Ta-ch'ing well[4] flows naturally ". . . under its own pressure at an unvarying yield of forty to seventy tons per well per day . . ." (Smil, 1975, p. 73). This is an IP range of 292–511 bbl/d. Yet another PRC statement was that typical wells have ". . . a lack of internal pressure and average well flows of about 10 tons per day" (Smil, p. 73). This is only 73 bbl/d, a very low figure for a large or giant field. There is no question that, on the basis of PRC press reports, the volume of oil recovered in some wells is rather small for typical giant-field wells. However, our own studies reveal that the average production per well in 1975 was 197 bbl/d. A summary of Ta-ch'ing production is shown on *Table 5*. Characteristics of Ta-ch'ing oils are shown on *Table 6*.

Conclusions

The Sungliao basin, because it is close to China's population and industrial center, has been developed at a very rapid pace. Almost all fields were waterflooded from the beginning of production, a system introduced by Soviet technicians. The purpose of the system is partly to increase production, but mainly to delay the installation of pumping units which are very scarce. However, as in the USSR, waterflooding, without attention to the abrupt lateral and vertical changes in reservoir porosity and permeability, has led to much coning and bypassing. The result was that many wells were producing water very early in the history of the field complex. The widespread early damage to Ta-t'ung-chen and other Sungliao fields has led PRC production personnel to take corrective measures to prevent such losses in the future.

As China's petroleum industry develops, the Sungliao basin will continue to play a major role in the PRC economy until other major crude sources are established.

FOU-HSIN GRABEN

General

This small northeast-striking graben in Liaoning Province is between the southern end of the Sungliao basin and the northern end of the Po Hai basin (*Fig. 60*). The graben is famous for its anthracite deposits, just as the nearby (*Fig. 60*) Fu-shun graben is famous for its rich deposits of oil shale. Both the coal and oil have been exploited for many years.

4) For the purpose of this brief discussion, we assume that Ta-ch'ing is the Ta-t'ung-chen and subsequently discovered fields. Information on older fields in which Soviet technicians were personally involved generally is reliable.

Fou-hsin Graben Stratigraphy

Basement is deformed (Hercynian) early Mesozoic and/or Paleozoic and older rocks, mainly igneous, which intrude Proterozoic and older strata (China Academy of Sciences, 1958).

The Early Jurassic Pei-p'iao Series consists of 2,000–3,000 m of the following units, from base to top: (1) green and brown-red ash-tuff, ash-tuff conglomerate, and trachyte flows; (2) yellow-gray and green-gray sandstone, gray-black to greenish-blue shale, conglomerate, and thick coal bearing gray-green and black shale. Conglomerate lenses are present.

The Middle Jurassic Chin-ling-shih Series is 2,500 m thick. The lower part is ash-tuff and ash-tuff conglomerate, and flows of trachyte, andesite, and rhyolite. The middle part is red-brown ash-tuff and sandy shale. The upper part is green-gray, cross-bedded sandstone and conglomerate. The sandstone is oil-productive.

The Late Jurassic Fou-hsin Series consists of 900–1,800 m of yellow, brown, green, gray, and black shale, sandstone, and conglomerate. A basal conglomerate overlies older units unconformably. The sandstones are oil bearing.

The Early Cretaceous Sun-chia-wan Suite is 1,000 m or more of tuffaceous sandstone and conglomerate with carbonaceous shale and coal. This grades upward into gray-green shale, sandstone, and conglomerate with black paper-thin beds of oil shale. The overlying Ch'ao-yang Group is 100–1,000 m of yellow, gray, green, and white sandstone, shale, calcareous shale, and coal, with black shale. Interspersed are tuff and flows of rhyolite, quartz trachyte, and andesite.

The Late Cretaceous is unconformable on the Early Cretaceous. It is called the Ch'eng-teh conglomerate—about 300 m of red-purple volcanic agglomerate, sandstone, and porphyry intrusion. A few thin Tertiary units underlie the Late Cretaceous.

Fou-hsin Graben Oil Fields

General—The Fou-hsin graben fields were drilled by the Japanese during their 1937–1945 occupation of this area. Exploratory work began in 1937. Drilling commenced in 1938. Two small discoveries were made in 1939.

T'ung-an field (Fig. 60)—This is a small surface anticline, 2–3 km wide and 5–6 km long (Kravchenko, *in* Vasil'yev, 1968, p. 343). Jurassic crops out at the crest. It is asymmetrical toward the southeast with 10° dips. Northwest dips are up to 8°. A total of 14 productive sandstones was penetrated (Chang Keng *et al.*, 1958, p. 107) in the Early and Middle Jurassic, with an average depth to production of 600 m. IP's range from a few kilograms per day to 3 mt/d (22 bbl/d). The Japanese drilled 105 cable-tool wells through 1945. Attempts to revitalize the field since 1949 have not resulted in important production. Ultimate recovery is estimated to be 300,000–500,000 mt (2,200,-000–3,650,000 bbl).

Hsin-k'ai-lin field (Fig. 60)—The structure, smaller than T'ung-an, was drilled in 1939. It is asymmetrical toward the south. South dips are 17–20°; north dips are 8–10°. The oil is in sandstone reservoirs of the Late Jurassic Fou-hsin Series and of the Middle Jurassic Chin-ling-shih Series (Vasil'yev, 1968, p. 343). IP's average 30–

50 kg/d. A total of 15 cable-tool wells was drilled. Ultimate recovery should not exceed 100,000 mt (730,000 bbl).

NORTH CHINA BASINS

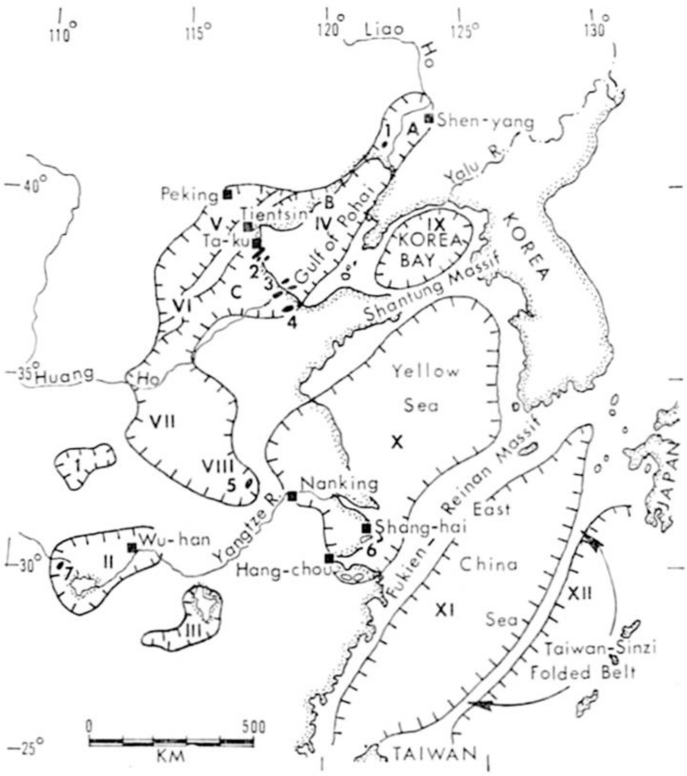
General

Figure 62 shows the principal northern China basins (excluding Heilungkiang and Kirin Provinces) as presently interpreted from field geology and geophysical data published in the USSR and the PRC[5]. The sources are given on the caption of *Figure 62*. The extents and shapes of offshore basins are the least known. It is very probable that each of the offshore basins contains more graben-type subbasins; the Korea Bay basin may not exist at all. Common features of all basins shown on *Figure 62*—with the exceptions of the Hsiang-fan, Tung-t'ing, and Yuan Shui-are: (1) each is underlain by grabens and horsts, like the Sungliao basin, and (2) the grabens and horsts have an overall northeast-southwest strike. Nonmarine deposits characterize the onshore basins, but the abundance of marine strata in the section increases toward the edge of the present continental shelf. Moreover, most of the graben basins have only post-Oligocene sediments in them. The Miocene fills the grabens and laps onto the adjacent horsts. Unconformably above the Miocene are Pliocene and younger strata. Paleogene rocks are scarce, at least in the areas known to date. Basement is Cretaceous and older (locally Precambrian) metamorphosed rocks, strongly deformed sedimentary and igneous rocks, and—in many places—Tertiary to Pleistocene volcanic rocks which intrude or cap the horsts and segments of the adjacent grabens.

Because of the young age of the graben structures, the PRC continental shelf is unlike most large shelves of the world of equivalent size. The shelf is not a progradational feature, but is a post-Paleogene (probably mainly post-middle Eocene) topography that was filled with Miocene terrigenous strata which gradually and slowly were transgressed westward by the Pacifiic as the continental margin subsided. Transgression and formation of the present shelf probably were not completed until Pliocene or Pleistocene time. The post-Miocene thicknesses of part of the shelf are shown on *Figure 63* (see also *Fig. 68*).

Another factor which must be kept in mind is that the entire PRC coastline, from Canton (south of the area of *Fig. 63*; see *Fig. 1*) to Shang-hai, is undrained by a major river system. Thus, the sediment provenances were limited in many parts of the shelf, and the post-basement sedimentary section is correspondingly thin. The largest volumes of sediments of the Huang Ho (Yellow River) were trapped in the graben system of the Po Hai basin—and possibly in the Korea Bay basin (Shantong Seismo-Geologic Group, 1975)—and those of the Yangtze were trapped in one or more grabens beneath the Yellow Sea (Emery *et al.*, 1969). The horsts between the various graben systems acted as dams or sediment traps for much of the material brought in by these two rivers.

5) The tectonic map of the Yellow Sea (Frazier *et al.*, 1976) was not available when this map was constructed.



I HSIANG-FAN	V PAO-TING
II TUNG-T'ING	VI LIN-CH'ING
III YUAN SHIU	VII K'AI-FENG
IV POHAI BASIN	VIII HO-FEI
SUBBASINS	IX KOREA BAY BASIN
A. LIAO HO	X YELLOW SEA (KIANGSU) BASIN
B. POHAI	
C. CHI-NAN	XI TAIWAN BASIN
XII OKINAWA	

Figure 62. Index map of North China basins of Liaoning, Hopei, Shantung, Honan, Anwei, Kiangsu, Hupeh, Kiangsu, and Chekiang Provinces. Basins shown are Hsiang-fan, Tung-t'ing, Yuan Shih, Po Hai, Pao-ting, Lin-ch'ing, Kai-feng, Ho-fei, Korea Bay, Yellow Sea, Taiwan, and Okinawa (outer margin of East China Sea). **Fields:** 1=P'an-shan; 2=Takang (nine separate fields have been reported as part of this complex); 3=Shengli (north)—(23 oil fields are in this complex); 4=I-tu; 5=Shengli (south)—(these fields have not been mentioned in the PRC press for several years); 6="Shang-hai"; 7="57" or Ch'ien-chiang fields of the Tung-t'ing basin. Compiled from Brod (1965), Emery *et al.* (1969), Shantong Seismo-Geologic Group (1975), and Williams (1975).

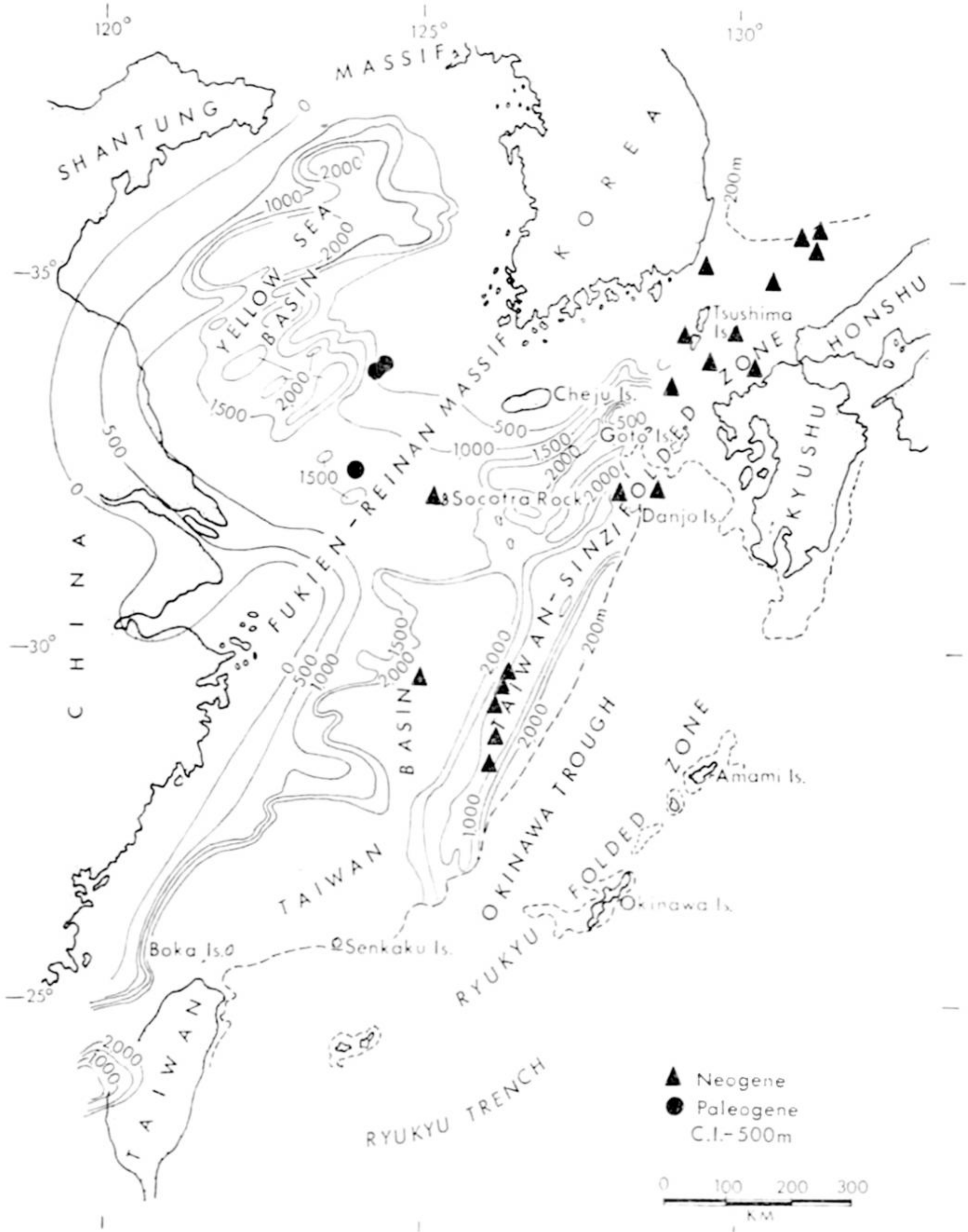


Figure 63. Generalized tectonic and isopach map of the Yellow Sea and East China Sea. Map shows (1) principal tectonic features interpreted from ECAFE single-channel seismic data and from offshore projections of the onshore geology; (2) dredge localities with the ages of the samples; and (3) isopach values of post-Miocene strata. Data are from Emery and Niino (1968), Emery *et al.* (1969), and Wageman *et al.* (1970).

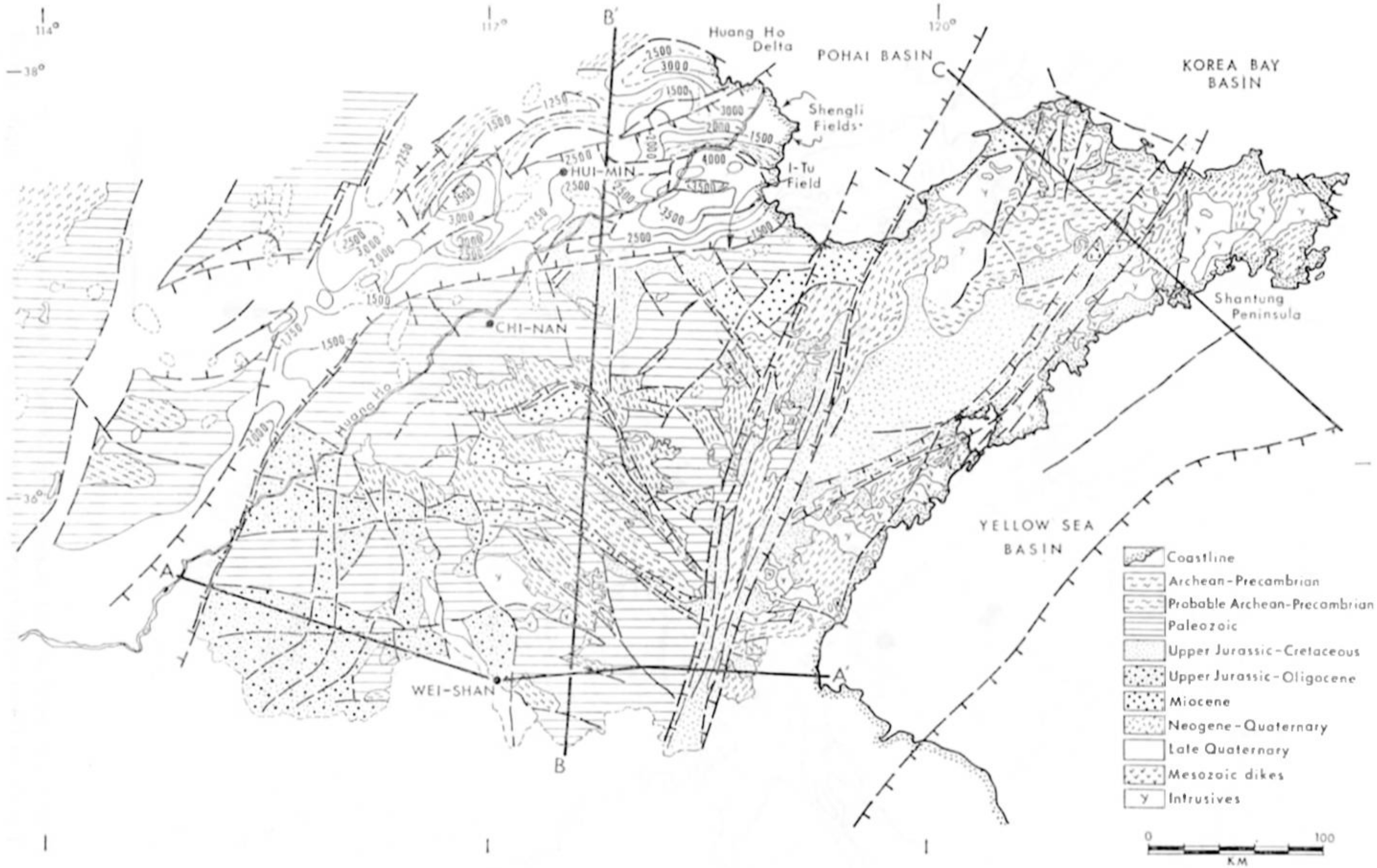


Figure 64. Geologic map of Shantung Province. In Huang Ho delta area, centered on the city of Hui-min, the structural contours are on the top of the basement and show the thickness of Neogene and Quaternary cover. Several of the structurally high closures within the contoured area are oil-productive fields—from the delta shoreline (and partly offshore) to west of Hui-min. These are the so-called Shengli ("Victory") fields of the PRC press. From Shantong Seismo-Geologic Group (1975). Locations of cross sections of *Figure 65* are shown. The writers thank M. J. Terman for his help in obtaining this map and the accompanying article.

Neverthless, it is clear from *Figure 63* that a thick post-Miocene sedimentary wedge (and possibly Miocene as well) underlies the Taiwan basin beneath the East China Sea. This section is thickest and most widespread near Taiwan and tapers northward toward Korea (*Fig. 63*). The principal provenances for the Taiwan basin section appear to have been (1) the Fukien-Reinan massif, (2) the site of the present ranges of northeastern Taiwan, (3) the east-west Penghu-Peikang high which joins Taiwan with the mainland (Meng, 1970), (4) the mainland itself, and (5) the Taiwan-Sinzi folded zone (*Fig. 63*). A large amount of drilling will have to be conducted and the results analyzed before the sedimentary provenances for the Taiwan basin can be determined with certainty.

Po Hai Basin

General—The Po Hai basin (*Figs. 60, 62*) has a total area of 270,000 sq km of which 97,000 sq km is offshore. It is subdivided here, following Brod (1965, p. 314), into three parts—the northern Liao Ho subbasin, the central, water-covered Po Hai subbasin, and the southern or Chi-nan subbasin. Drilling and detailed subsurface-geology and geophysical studies since the time that Brod's map was drawn have shown the Chi-nan subbasin to be more restricted areally and to be far more complex structurally than originally believed (*Fig. 64*). Presumably the Po Hai and Liao Ho subbasins also are as complex as the Chi-nan subbasin. Therefore, the three "subbasins" very possibly are artificial geographic subdivisions, unrelated to the true geology. Consequently, the three are discussed here under the single heading, "Po Hai basin."

The locations of the Po Hai basin oil fields are generally known. No gas fields have been mentioned in the press, but some could be present. Except for Shantung Province (*Figs. 64, 65*), the subsurface geology is almost unknown outside of the PRC. *Figure 64* does show several structural highs from west of Hui-min to the shoreline—some of which are oil and/or gas fields.

Stratigraphy—As noted by the Project Manager (1976, p. 4) of UNDP/CCOP, "Everywhere in the (eastern Asian) region the Mesozoic rocks are regarded as basement in the search for hydrocarbons. It is upon this Mesozoic and older erosional surface that the younger Tertiary sediments were deposited." This statement is true of all of the eastern PRC basins drilled to date, with the sole exception of the Sungliao basin which belongs to an earlier taphrogenic cycle. The Project Manager (1976, p. 4), referring to the eastern Asian area, noted further that "Most basins have only a minor portion of Palaeogene fills; the major part of the Tertiary sediment accumulation is of Neogene age. Typically, the oldest rocks that can be dated palaeontologically are Middle to Lower Miocene and younger. Beneath these rocks, older sedimentary beds are found in a fluvial or paralic facies and the fossil content, if any, is rarely diagnostic."

The oldest Tertiary rocks of the Po Hai basin were called Eocene in the Huang Ho delta region by the Shantong Seismo-Geologic Group (1975) (*Figs. 64, 65*). Discussions during 1976 between PRC geologists and M. J. Terman of the U.S. Geological Survey revealed that the "Eocene" strata are undated nonmarine beds which "could be Miocene as easily as Eocene" (M. J. Terman, ocal communication, May

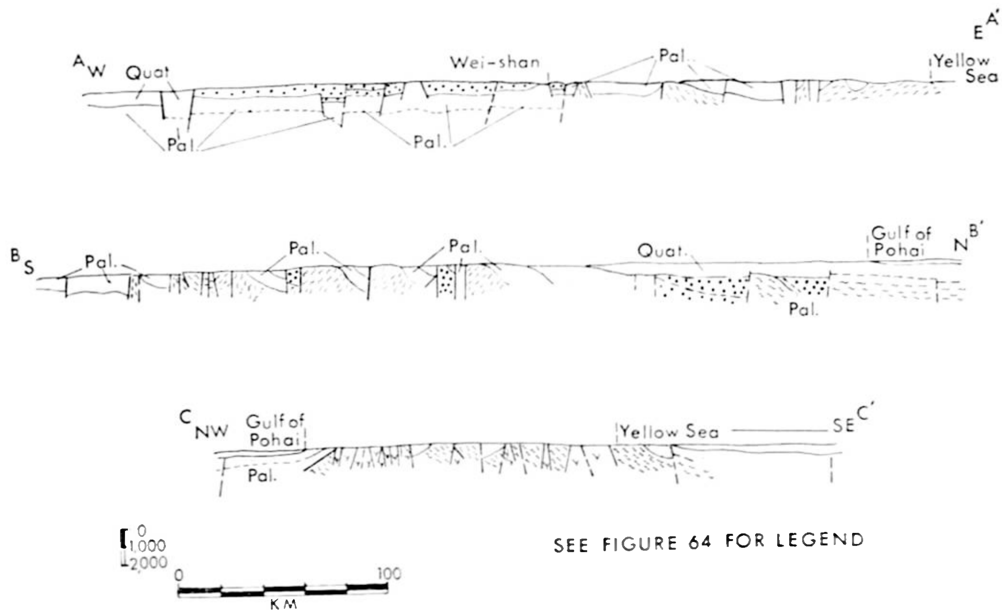


Figure 65. Cross sections of Shantung Province. Legend and locations of the cross sections are shown on *Figure 64*. From Shantong Seismo-Geologic Group (1975).

31, 1976). The published geology from the region supports Terman's statement. In fact, P'ang and Ryabukhin (1961) wrote that seismic and drilling data show many parts of the North China Plain to have three structural stages or "storeys." The upper is Pliocene and younger; the middle stage is mildly folded and is separated from the upper by an unconformity, and is Tertiary (pre-Pliocene); the lower stage is deformed Mesozoic/Paleozoic and older rocks.

Basement consists of deformed Proterozoic, Ordovician, and Mesozoic rocks (small oil flows have been obtained from Ordovician: P'ang and Ryabukhin, 1961; Brod, 1965). The basement is intruted by two or more generations of granite. These rocks are up to 4,200 m deep (*Fig. 64*) in the grabens of the Huang Ho delta area, but are only 755–955 m deep on the adjacent horsts.

Southeast of the Po Hai basin is the Shantung massif which separates this basin from the Korea Bay basin. On the Shantung massif are many rocks and islets underlain by Tertiary basalt flows.

Within the basin, the China Academy of Sciences (1958) and Ch'ang Ta (1963) reported the following section, from base to top:

(1) This unit consists of gray, brown, and purple marl and claystone, with lesser amounts of conglomeratic sandstone and sandy claystone. Shale(?) diapirs in the basin seem to originate in this part of the section. Nonmarine fossils, originally interpreted to be late Eocene, are more likely to be early or middle Miocene. This section ranges in thickness from 100 m at the outcrop to 1,000–1,300 m in the subsurface. Oil production is reported from this unit.

(2) This is a 200 m thick unit of marl, sandstone, and conglomerate. The marl is gray white. Some shale beds contain plants and thin coal seams. This upper part of the unit contains yellow-brown, poorly sorted sandstone and conglomerate. Oil production is reported from the interbedded sandstone.

(3) At the outcrop, this is a 700-m-thick unit of reddish, coal-bearing, sandy conglomerate. In the subsurface, it is largely shale with lignite seams.

(4) This unit, 480 mm thick, is composed of gray conglommerate and yellow-gray sandstone alternating with reddish-yellow siltstone, claystone, and fine-grained sandstone. The age is probably Pliocene.

(5) This unit is a basalt flow, 5–100 m thick.

(6) The Pleistocene is 0–1,100 m thick, averaging 960 m in the subsurface. A thin Quaternary river fill caps the Pleistocene.

Po Hai basin oil fields—At least 38 oil fields are present. They are being developed very rapidly, and both exploration and development drilling within this basin have a very high priority—as great as in the Sungliao basin.

Williams (1975, p. 257) reported the existence of the **P'an-shan oil field** in the Liao Ho subbasin (*Figs. 60, 62*). The "field" actually is six separate structures discovered in 1964. Development began in 1969. The total productive area is 100 sq km. On January 1, 1976, there were 46 rigs drilling, 229 wells producing, and 104 newly staked locations. P'an-shan is the PRC's fifth largest producing area. (*Table 4*).

In the Po Hai (marine) subbasin, the first of the **Takang fields** was discovered onshore near Ta-ku (*Fig. 62*) in 1964, and went on stream in 1967. A minimum of nine fields is present—eight onshore and one offshore. The structures are northeast-striking, complexly faulted noses and anticlines. Fault displacements are 15 to 90 m. Thirteen Miocene deltaic sandstones and three Miocene(?) fractured carbonate banks form the reservoirs. Net sandstone pay averages 37 m. There are many different oil/water contacts, complicated by faults. Drilling depths average 2,700 m. Reservoirs are erratic. When drilling began, most of the drillers had had no experience with fractured carbonates, and many wells were abandoned as dry holes. The subsequent discovery of shows in limestone cuttings and cores convinced the drilling teams to test the carbonates, and several "dry holes" were reentered and completed as producing wells. During the early history of the field, possibly one in three of the wells drilled was dry because of the numerous and adrupt facies changes and/or absence of fractures. This high dry hole percentage is reported to have been reduced considerably in recent years. On February 1, 1976, 52 rigs were active onshore; 700 wells were productive on eight structures; and 76 new locations had been staked. Some locations are on trest'es and causeways built from the shore.

Offshore drilling began in 1969 after a marine seismic survey was completed by a French firm. The original drilling, 16 km offshore and 40 km southeast of Ta-ku, was from a fixed platform in about 20 m of water (the whole Gulf of Po Hai is shallower than 25 m). The same geologic conditions were found offshore, with northeast-trending, strongly faulted, anticlinal features and basement highs (drape structures). The oil-bearing sandstones are thicker than those onshore. Drilling depths range from 2,700 m nearshore to 3,000 m in the center of the Gulf of Po Hai. By late 1973, there were seven widely scattered drilling platforms, including mobile jack-up barges (see chapter on "PRC Petroleum Technology"). By mid-1974, several dry structures had been drilled, and the drilling units were concentrated 40 km southeast of Taku where a sizable discovery had been made. In August 1976, three production platform were in place and three additional drilling platforms (for a total of ten) were active in the Gulf.

Onshore production began in 1967 (20,000 mt = 146,000 bbl) and, by 1975, was 4,340,000 mt (31,628,000 bbl = 86,650 bbl/d; see *Table 4*). The PRC press claims that the Takang fields complex has reserves as large or larger than those at Ta-ch'ing. If true, ultimate recovery will exceed 410,000,000 mt (3 billion bbl). Quality of the oil is similar to that of Ta-ch'ing; the specific gravity is 0.8; sulfur is 0.2 percent (wt); paraffin is 10 percent (wt). There is much associated gas. Aa at Ta-ch'ing, the oil must be heated in the winter in order to pipe it.

The first of the **Shengli fields (north)** (Shengli means "Victory," and is another "blanket" term covering a large group of fields from the Ho-fei subbasin in the south to the Chi-nan subbasin in the north) was discovered in 1960, and went on stream in 1962. According to Kudo (1966, p. 44), the term "Shengli" first appeared in the PRC press in April 1955, a fact which implies that exploration began early in the history of the PRC. Soviet published accounts of drilling in this large region substantiate Kudo's report (e.g., P'ang and Ryabukhin, 1961).

A total of 23 fields has been found in the northern Shengli area. Of these, 18 are at or near the mouth of the Huang Ho, and 5 are at Lin-i, 180 km west-southwest of the mouth of the Huang Ho, 65 km north of Chi-nan (Tsinan) and 15–30 km west of Hui-min (*Fig. 64*). The I-tu field, mentioned by Williams (1975), is one of the 18 Shengli fields near the Huang Ho delta (*Fig. 64*). I-tu was discovered in 1970 and was reported by the PRC press as a "giant" field.[6] It went on stream in 1971.

The Shengli fields produce from Miocene(?) continental sandstones and conglomerates at depths ranging from 1,800 m to 4,200 m. Statements by Li (1971) and the Project Manager of UNDP/CCOP (1974) that production is from the Permian Yang-hsing Series were labelled as incorrect by PRC geologists from a delegation to the United States in 1976. The PRC geologists stated that the production is from nonmarine Tertiary sandstones.

The wells have been difficult and expensive to drill with the turbodrill, but increasing numbers of rotary rigs are being brought in. Because of facies changes and poor reflection-seismic data up to two of every three wells drilled during the early years of development were dry. This situation improved as experience was gained and more modern equipment introduced. At least one field extends offshore. Shengli oil characteristics are shown on *Table 6*.

Figures 64 and *65* show the general subsurface structure (at the top of basement) within the northern Shengli fields. *Figure 64* shows approximately eight structurally high areas up to 60–70 km long and 10–20 km wide which indicate where the fields are located. The total productive area near the mouth of the Huang Ho is 565

6) We are quoting the PRC press; the PRC press' concept of a giant field may be very different from that of Holmgren *et al.* (1975).

sq km; near Lin-i, the five inland fields have a productive area of 119 sq km. In the delta area, on January 1, 1976, 56 rigs were active, 1,299 wells were producing, and no new locations had been staked. In the Lin-i area, 25 rigs were active, 285 wells were producing, and 63 locations had been staked. Total reserves are estimated to be at least equal to those at Ta-ch'ing (410,000,000 mt = 3 billion bbl). The area is the PRC's second largest, having produced 14,900,000 mt in 1975 (108,000,000 bbl = 298,000 bbl/d). Production now is greater than was Ta-ch'ing's after an equivalent period of production (*Table 4*).

Ho-fei Basin

The Ho-fei basin is the southernmost of the North China basins, in southernmost Shantung Province and parts of Honan, Anhwei, and Kiangsu Provinces (*Fig. 62*). The "blanket" term "Shengli" also applied originally to this region, and Meyerhoff (1970) termed it "Shengli south." The basin includes about 3,500 sq km of highly prospective territory, and, according to Ho K'o-jen (1968), some production had been established in this area by the early 1960's, possibly 1962. Many dry holes had been drilled. If oil is being produced today at **Shengli South** it is only in small amounts and is a fraction of the national output. Certainly it receives little notice in the PRC press. Production presumably is from Tertiary continental strata on deformed igneous and sedimentary Mesozoic rocks.

Other North China Basins

To the best of our knowledge, there is no major production from the Pao-ting, Ling-ch'ing, Nei-huang, and K'ai-feng basins shown on *Figure 62*. Several dry wildcat wells had been drilled by 1959 (Ch'ang Ta, 1963), but we have no additional information.

KOREA BAY BASIN

This offshore area covers 62,000 sq km (*Fig. 62*). Willums (1975) computed a minimum Miocene and younger sediment volume of 92,000 cu km. Seismic data from this area were not available to us, and no drilling has been done here, to the best of our knowledge. The section is believed to be thinner than elsewhere in the PRC offshore. It is possible that no basin (or basins) underlies the area and that it is a part of the uplifted Shantung massif (*Figs. 62, 63*). If so, the estimated volume of 92,000 cu km of prospective section is too large. The fact should be noted that the Yalu River drains from the PRC-North Korea boundary into the Korea Bay and, therefore, sediment accumulations of 2,000–3,000 m may be present.

YELLOW SEA BASIN

General—The Yellow Sea basin is a water-covered area containing 298,000 sq km underlain by prospective section within PRC-controlled waters. In addition, the onshore part (called the Kiangsu basin by Brod, 1965, and Meyerhoff, 1970) contains another 80,000 sq km. Thus the total area is 378,000 sq km. At least 714,000 cu km of Miocene and younger sediment is present in the PRC marine and onshore areas. Water depths range from 25 to 140 m.

The Shantung massif of deformed Precambrian and younger rocks (*Figs. 62, 63*), overlain locally by younger volcanic rocks, forms the northwestern margin of the Yellow Sea basin; the Fukien-Reinan massif, also underlain by Precambrian to Mesozoic basement and younger volcanic rock, forms the southeastern margin of the Yellow Sea basin (*Fig. 63*). Paleogene volcanic rocks and nonmarine to marine sedimentary rocks have been dredged from the flanks of the area (*Fig. 63*).

Figure 63 shows that at least five (or six) northeast-southeast-trending basins (presumably graben structures) underlie the PRC offshore area. In 1975, the PRC's catamaran drillship, *Kantan No. 1*, drilled a stratigraphic test hole in the Yellow Sea; the results of the drilling were not announced.

Stratigraphy—In the South Korea sector of the Yellow Sea, the Gulf Oil Corporation has drilled three tests. The first of these, II H–IX (35°30′34″N, 124°06′12″E) was suspended in December 1972 and was not reentered (Bowman, 1974). In 1973, the II H–IX–a (35°30′32″N, 124°06′12″E) was drilled to 3,468 m and abandoned in Cretaceous(?) basement. In the same year, the II C–IX (35°48′50″N, 124°32′38″E) was drilled to 2,018 m and was abandoned in metamorphic basement. The post-basement section consists of Tertiary (Oligocene?) and younger nonmarine strata up to 3,261 m thick. The section includes red-brown mudstone, sandstone, conglomerate, and lacustrine marl. An anhydrite-bearing shale is 300–400 m above the basement. No significant hydrocarbon shows were found (Frazier *et al*,. 1976).

The onshore section of southwestern Korea includes a tightly folded Paleogene(?) nonmarine conglomerate, sandstone, shale, mudstone, and coal sequence with rhyolite and basalt (Janggi Series). This is overlain unconformably by the gently dipping Miocene(?) Yunil Series—a sequence of shallow-marine shale, mudstone, sandstone, and conglomerate (Kim, 1974).

On the PRC mainland, the China Academy of Sciences (1958) reported the following units exposed near Shang-hai and Nanking.

(1) Economic basement is about 2,460 m of deformed Ordovician through Carboniferous marine and nonmarine platform facies, grading upward into coal-bearing Carboniferous and Permian. The Permian is overlain by about 2,000 m of Triassic and Jurassic coal-bearing nonmarine beds, with a marine Early and Middle Triassic section.

(2) The P'u-k'ou Suite, of probable Miocene age, overlies basement with an angular unconformity. The P'u-k'ou consists of 200–400 m of dark-red nonmarine sandstone and sandy shale with some conglomerate. The clasts consist mainly of Cretaceous volcanic rocks. Facies changes are abrupt.

(3) The Ch'ih-shan Suite is a very friable red sandstone, 10 m thick, with conglomerate at the base. The clasts consist of andesite, limestone, and fragments of the P'u-k'ou Suite.

(4) The Tung-hsüan-kuan Suite is 36 m thick, and is composed of six cycles of sandstone grading upward into sandy and calcareous clay.

(5) The 100-m thick Nanking Basalt overlies all older units.

(6) The Pleistocene consists of 10–30 m of clay, silt, and sand with marine interbeds.

The entire section, 576 m thick at the surface, thickens into the Yellow Sea (Kiangsu) basin.

Emery *et al.* (1969) and Wageman *et al.* (1970) found an unconformity on all seismic records from the Yellow Sea and East China Sea. They believed that this unconformity is at the base of the Miocene. In contrast, P'ang and Ryabukhin

Figure 66. Magnetic map of Yellow Sea and East China Sea. From Wageman *et al.* (1970).

(1961) and M. J. Terman (oral communication, May 31, 1976) believe that the unconformity separates the Pliocene from the Pleistocene, a view with which Emery now concurs (written communication, July 27, 1976). Mainguy (1970) suggested that the unconformity separates the Pliocene from the Pleistocene, but the data do not support his view.

Magnetic data—*Figure 66* shows the magnetic anomaly pattern beneath the Yellow Sea. The predominant strike is northeast-southwest. The highs and lows presumably reflect the presence of horsts and grabens underlying the Yellow Sea, and suggest that thick basins are present. The importance of the magnetic data is that they demonstrate conclusively that (1) the structures of the mainland continue offshore beneath most of the shelf between the PRC, Taiwan, the Korean Peninsula, and Japan; (2) the basement relief is great (up to 4–5 km); and (3) the source of the magnetic anomalies is shallow, but within the basement (Bosun *et al.*, 1970; Chai and Pan, 1975). In fact, the main anomaly sources appear to be about 2 km deeper than the top of the acoustic basement recorded on the ECAFE profiles (Emery *et al.*, 1969, Wageman *et al.*, 1970).

Shang-hai gas field—Oldest known production from the Yellow Sea basin is a small, shallow gas field which has existed south of Shang-hai (*Fig. 62*) since 1100 A.D. or earlier. The field produces from seeps, hand-dug pits, and shallow wells. The productive beds are Miocene, Pliocene, and Pleistocene sandstones and sands at depths of 25 to 70 m. Production per pit and well ranges from 5–6 m^3/d (175–210 cu ft/d) to 5,000–7,000 m^3 (175,000–245,000 cu ft/d) (Brod, 1965, p. 315). In Chekiang Province, south of Shang-hai more than 2,000 shallow gas wells were drilled in the early 1970's to supply the province (Williams, 1975, p. 243). In addition, some

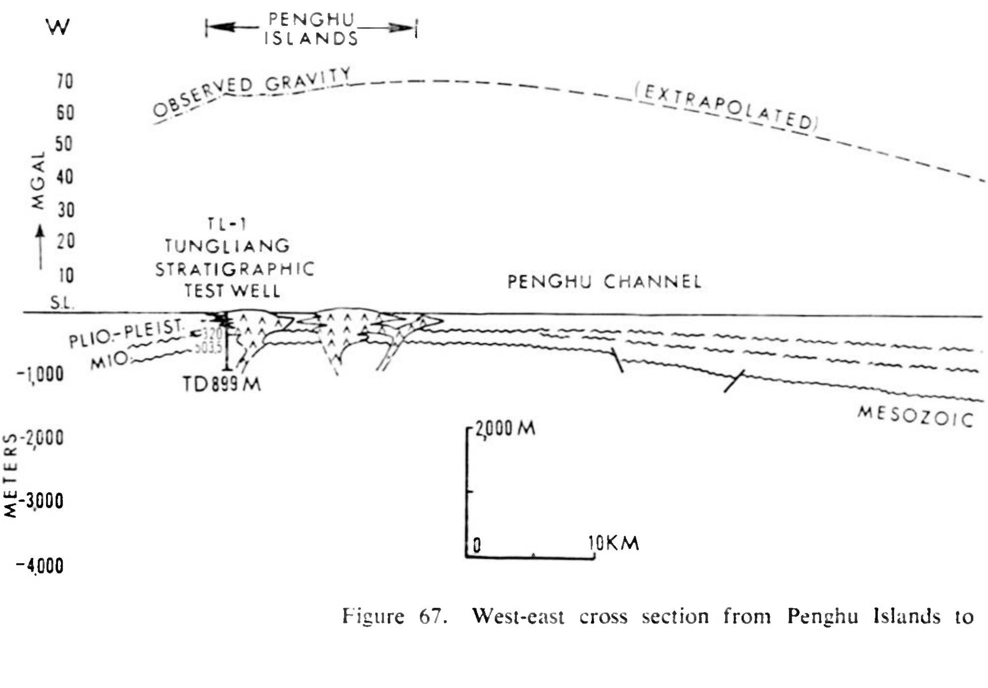


Figure 67. West-east cross section from Penghu Islands to

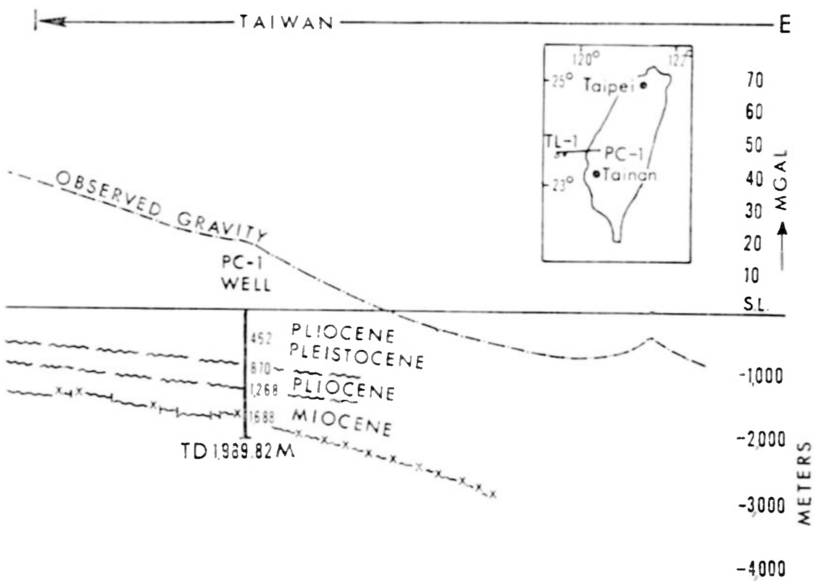
light oil is known from seeps just north of Shang-hai.

Conclusions—The Yellow Sea basin has major oil and gas potential, largely because of the Yangtze delta (Mainguy, 1970). Because of the lack of subsurface and geophysical data, reserve estimates for this basin are speculative. In the section on "Ultimate Hydrocarbin Recovery," we summarize the potential hydrocarbon recovery of all of the PRC, including the Yellow Sea Basin.

TAIWAN BASIN

General—As shown on *Figure 63*, the Taiwan basin is 1,600 km long and 80 to 320 km wide. The basin is bounded on the northwest by the Fukien-Reinan massif and on the southeast by the Taiwan-Sinzi folded zone. On the south are Taiwan and the Penghu-Peikang high and on the north are Korea and the Korea Strait. The area of the basin is about 300,000 sq km, and the volume of Miocene and younger sedimentary rocks is at least 800,000 cu km. Water depth range from 50 to about 200 m.

The term "Taiwan basin," used by Emery *et al.* (1969) and shown on *Figure 63*, implies that the Taiwan trough of western Taiwan and the basin complex between the Fukien-Reinan massif and the Taiwan-Sinzi folded zone are the same feature. Such a conclusion seems rather tenuous. The magnetic data alone (*Fig. 66*) suggest that the basement of the Taiwan basin is structurally complex, and that it is not a simple extension of the Taiwan trough. According to Emery *et al.* (1969) and Wageman *et al.* (1970), the folded zone of the Taiwan range does not connect with the Taiwan-Sinzi folded zone, further complicating the interpretation. Much drilling will



Taiwan on the Penghu-Peikang east-west arch. From Pan (1968).

have to be done before the true relations between Taiwan and the Taiwan trough can be determined.

Stratigraphy—Numerous Pleistocene, Pliocene, and Miocene outcrops on islands (including the Senkaku Islands just northeast of Taiwan) and several dredge samples (*Fig. 63*) indicate that the Taiwan basin is underlain by very shallow-water marine Miocene and younger strata in the north, and by deeper water marine facies farther south near Senkaku and Taiwan (Emery and Niino, 1968; Niino, 1968; Emery *et al.*, 1969; Wageman *et al.*, 1970). M. J. Terman (oral communication, May 31, 1976) believes that most of the section beneath the East China Sea is nonmarine, but the dredge hauls to date do not support Terman's views.

The total thickness of section within the Taiwan basin is unknown. The ECAFE (Emery *et al.*, 1969) seismic data indicate a minimum thickness of 2–3 km, but some CDP records seen by us show the post-basement section to be 4 to 6 km thick in several areas. Willums (1975) showed more than 5 km of Miocene and younger section in the deepest part of the basin (*Fig. 68*). A well drilled just southwest of the Fukien-Reinan massif and 150 km south of Cheju Island reached total depth of 1,186 m in economic basement. A second well drilled 120 km east of Cheju Island reached total depth in economic basement at 2,967 m. Another well drilled 40 km north of Taiwan reached a total depth of 3,585 m in economic basement. Thus, the little subsurface information available does demonstrate that about 3 km of prospective section is present in at least two areas of the Taiwan basin. Magnetic data support the interpretation that graben basins containing 3,000–5,000 m of Miocene and younger sediments underlie the Taiwan basin (Project Manager, 1974).

The China Academy of Sciences (1958) published the following stratigraphic section from coastal Chekiang Province (from base to top):

(1) The lowest units are 1,500 m or more of marine sandstone, conglomerate, shale, and limestone ranging in age from late Proterozoic through Early Permian.

(2) Unconformably above the Paleozoic is 755 m of Jurassic, coal-bearing, nonmarine shale and sandstone. Granitic intrusions, folds, and faults are widespread.

(3) Early Cretaceous, more than 250 m thick, overlies the Jurassic unconformably. It consists of tuff-conglomerate, agglomerate, andesite, porphyry, and related rocks with fossil plants. This section also is intruded by granitic rocks (Nanking University, 1974). Northeast-southwest-trending horsts and grabens are prominent.

(4) The Miocene(?) Chü-chiang Sandstone, 400 m thick, overlies the Cretaceous unconformably. It is friable, purple-red to white, micaceous sandstone with many conglomerate beds. The base almost everywhere is a thick conglomerate. Some yellow-green sandstone and tuffaceous sandstone are present. The section is nonmarine.

(5) The Ch'eng Hsien Basalt is 100 m thick.

(6) The Pleistocene and recent cover is 7 to 20 m thick—sand, silt, mud, and gravel.

Young volcanic rocks are widespread around the northern and western margins of the basin. Tertiary and Pleistocene volcanic rocks are present on Cheju Island and in several localities along the Fukien-Reinan massif (Emery and Niino, 1968; Niino, 1968). Volcanism evidently accompanied the formation of the grabens.

Figure 68. This is a modified version of Willums' (1975) interpretation of Miocene and younger sediment thicknesses in the offshore region of the PRC and Taiwan.

The Miocene and younger section thins southward into Taiwan Strait where it is only 503.5 m thick on the Penghu Islands (Huang, 1968; Pan, 1968; Chou, 1969). The Tungliang-1 (TL-1) well penetrated Pleistocene and Pliocene dolerite, basalt, basalt tuff, sandstone, calcarenite, shale, mudstone, and claystone from 0 to 320 m (*Fig. 67*). The basaltic-doleritic rocks comprise 152 m (in five layers) of the upper 320 m. The section from 320 to 503.5 m is Miocene limestone, sandstone, graywacke, subgraywacke, mudstone, and claystone. Good porosity is present in the sandstone and limestone. A *Miogypsina*-bearing shallow-water coquinoid limestone directly overlies the basement.

The basement was penetrated from 503.5 m to total depth 899 m. It consists of hydrothermally altered arkose, subarkose, sandstone, siltstone, and mafic (basaltic) intrusives. Porosity of the sandstones and arkoses is less than 7 percent. The section is presumed to be Aptian, because it closely resembles an Aptian ammonite-bearing sequence penetrated near the west coast of Taiwan, due east of the Penghu Islands. In the Taiwan well (Paochung PC–1), the Cretaceuous was reached at 1,677 m (Huang, 1968). However, Meng (1970) found Paleocene foraminifera associated with the Aptian ammonites and suggested that the two faunas were tectonically mixed.

In the Peikang area of western Taiwan, the Mesozoic or Paleocene rocks are absent. Instead, the Miocene directly overlies hydrothermally altered metamorphic rocks of unknown age.

OKINAWA BASIN

The Okinawa basin occupies the outer continental shelf, just east of the Taiwan-Sinzi folded zone (water depths are 100–200 m) and the deep Okinawa trough (maximum depth 2,719 m) between the shelf edge and the Ryukyu island arc. The prospective area (200 m and shallower) is about 180,000 sq km with a Miocene and younger sediment volume of about 600,000 cu km. The prospective section is more than 2 km thick (Emery *et al.*, 1969; Wageman *et al.*, 1970; see *Fig. 63*). CDP lines seen by us show that locally the section is up to 5–6 km thick.

Nothing is known of the stratigraphy of this basin. If sand (for reservoirs) was deposited, the Okinawa basin should be highly prospective. The magnetic trends (*Fig. 66*) are the same as those beneath the Taiwan basin.

SOUTH CHINA SEA BASIN

Figure 68, from Willums (1975), shows that the shelf portion of the South China Sea basin may be underlain by 4 km or more of sediments in its deepest part. The basin itself occupies an area of 285,000 sq km, with possibly 620,000 cu km of Miocene and younger objective section. A well located at 22°31′32″N, 119°18′28″E, 60 km southwest of Taiwan, was drilled to a total depth of 3,947 m. Gas was discovered during 1975 in Miocene sandstone. IP's were 686,000 m^3/d of gas (24,000 Mcf/d) and 34 mt/d of condensate (250 bbl/d) (Caldwell, 1975). This well proves the presence of a thick objective section in the northeastern part of the South China Sea shelf.

Volcanic rocks are present in many areas of the PRC coast, as well as on the Lui-chow Peninsula and Hai-nan Island (Meng and Li, 1970; ECAFE, 1971). The section on the Lui-chow Peninsula is 200–300 m of Tertiary basalt overlain by Pleistocene red clay and alluvium. In the Hsi Chiang delta, west of Hong Kong and south of Canton, a small coastal basin is present—the San-shui basin (Tang Xin and Zhou-Ming-zhen, 1964). The section includes 500 m of Late Cretaceous to Paleocene nonmarine, red and gray, cross-bedded conglomerate and sandstone intruded by granitic and rhyolitic rocks. This section is overlain by Paleocene-middle Eocene lacustrine and marine conglomerate, sandstone, mudstone, shale, and trona. Miocene and younger srata are absent in this onshore section. Williams (1975, p. 257) reported a possible oil discovery in the San-shui basin (*Fig. 1*). This "discovery" has not been confirmed. The future prospects of the South China Sea basin appear to be very attractive. Ultimately many oil and/or gas fields should be found in this basin. One or more fields are rumored near Canton.

Table 7. Number of Fields Known from PRC, 1975.

Basin or Subbasin	No. of Oil Fields	No. of Gas Fields	Total
Dzungaria	5	1	6
Tarim	2	2	4
Turfan	1	—	1
Tsaidam	11	4	15
Chiu-ch'uan	6	—	6
Jo Shui	1	—	1
Min-ho	1	—	1
Ordos	5	—	5
Szechwan	6	11	20[1]
Kwangsi-Kweichow	1(?)	—	1(?)
Tung-t'ing	7	—	7
Hu-lun-ch'ih	1	—	1
Sungliao	10	—	10
Fou-hsin	2	—	2
Liao Ho	6	—	6
Po Hai	9[2]	—	9[2]
Chi-nan	23[3]	—	23[3]
Ho-fei	1	—	1
Yellow Sea-Kiangsu	—	1	1
South China Sea (onshore)	1(?)[4]	—	1(?)[4]
Gulf of Tonkin (onshore)	1(?)[4]	—	1(?)[4]
TOTALS	101[5]	19[5]	123[1,5]

1 Bakirov *et al.* (1971) reported the existence in the Szechwan basin of "more than 20 fields," but showed only 17 of them. This explains the discrepancy in the total number of fields.

2 Eight are onshore; one is offshore. None is a minimum figure.

3 Eighteen fields are near the Huang Ho mouth; five are near Len-i, 180 km west of mouth.

4 These are rumored fields, with no confirmation.

5 The presence of several gas fields in the onshore (Kiangsu) part of the Yellow Sea basin, the discovery of several new fields in Tsinghai Province, and additional discoveries mentioned in the PRC press demonstrate that these totals are minimum figures. The several gas fields in Chekiang Province, south of Shanghai, also would add to the total.

GULF OF TONKIN BASIN

Figure 68 shows the presence of 3 km or more of Miocene and younger sediments in the Gulf of Tonkin between Hai-nan Island and Vietnam, an interpretation supported by aeromagnetic data (Mainguy, 1970). Neogene dredge hauls also were reported within the basin by Mainguy (1970). Few data were available to us. Consequently, we cannot evaluate this basin. Meyerhoff (1970) reported the presence of a small field, Ho-p'u, near the southern China coast, west of the Lui-chow Peninsula. We have been unable to confirm whether this field exists.

Overall, the Gulf of Tonkin basin appears to have considerable promise for future oil and/or gas discoveries. The Song-koi (Red River) drains into the basin and has built up a potentially thick section for petroleum generation and accumulation.

CONCLUSIONS

(1) Of the onshore basins, the Dzungaria, Tarim, Tsaidam, Szechwan, and Sungliao basins have great promise for large, commercial discoveries. The potential of the Dzungaria and Tarim basins scarcely has been tapped. The total number of known fields per basin is shown on *Table 7*.

(2) Of the offshore (including partly offshore and onshore) basins, the Po Hai, Korea Bay, Yellow Sea, Taiwan, Okinawa, South China Sea, and Gulf of Tonkin basins have a very high potential. The probability that pre-Miocene objectives are very limited and that all large accumulations will be in Miocene-Pleistocene rocks places some constraint on the volume of hydrocarbons that may be discovered in the offshore. The horst-and-graben structure of the offshore also limits the areas of interest and places further constraints on the volume of hydrocarbons to be discovered. At present there is no geological basis for the wild and exaggerated press claims that the offshore PRC is "another Middle East" or even greater. In fact, the known geology leads us to the conclusion that the volume of ultimately recoverable petroleum in the offshore will be of the same order of magnitude as that prognosticated for the eastern continental shelf of North America.

(3) A minimum of 104 oil and 19 gas fields has been discovered. It is probable—on the basis of PRC press reports—that many more fields have been discovered. Certainly the true number of fields is not less than 150. However, not all of these are on stream, and some of those listed are depleted or nearly so.

ULTIMATE HYDROCARBON RECOVERY

OIL

Any discussion on PRC reserves and ultimate recovery is an exercise in judgment. To judge from some "estimates" published in the popular press of Japan, the United States, and elsewhere in recent years, judgment suffered badly from a lack of exercise. As Williams (1975, p. 234) wrote: "The reader should be cautioned that without firm data from the Chinese, any discussion of oil reserves must be tentative."

Meyerhoff (1970) estimated that, as of January 1, 1969, ultimate recovery from the PRC onshore area would be 19.6 billion bbl or 2.7 billion mt. In 1975, Meyerhoff wrote that (1) the onshore ultimate recovery might be as great as 40 billion bbl (5.5 billion mt) and (2) the offshore potential might be as great as 30 billion bbl (4 billion mt) or a total of 70 billion bbl (9.5 billion mt). Williams (1975, p. 235) sug-

Table 8. Estimated Ultimate Oil Recovery from PRC Basins.

	Estimated Produced, Proved, and Probable		Estimated Potential		Estimated Total	
	Million Mt	Million Bbl	Million Mt	Million Bbl	Million Mt	Million Bbl
Dzungaria	120.2	877.3	548.0	4,000	668.2	4,877.3
Tarim	6.9	50.0	685.0	5,000	691.9	5,050.0
Turfan	6.9	50.0	62.0	450	68.9	500.0
Tsaidam	235.8	1,721.5	493.0	3,600	728.9	5,321.5
Chiu-ch'uan	84.6	615.5	68.5	500	153.1	1,115.5
Jo Shui	0.1	0.5	1.4	10	1.5	10.5
Min-ho	0.2	1.0	2.7	20	2.9	21.0
Ordos	6.0	43.8	27.4	200	33.4	243.8
Szechwan	134.0	1,060.0	274.0	2,000	408.0	3,060.0
Sungliao	410.0	3,000.0	820.0	6,000	1,230.0	9,000.0
Fou-hsin	0.4	2.9	1.4	10	1.8	12.9
Po Hai (onshore)	615.0	4,500.0	308.0	2,250	923.0	6,750.0
Subtotal	1,620.1	11,922.5	3,291.4	24,040	4,911.5	35,962.2
Po Hai (offshore)	205.0	1,500.0	548.0	4,000	753.0	5,500.0
Subtotal	1,825.1	13,422.5	3,839.4	28,040	5,664.5	41,462.5
A-la Shan	—	—	68.5	500	68.5	500.0
Koko Nor	—	—	6.9	50	6.9	50.0
Kwangsi-Kweichow	—	—	68.5	500	68.5	500.0
Hsiang-fan	—	—	68.5	500	68.5	500.0
Tung-t'ing	—	—	68.5	500	68.5	500.0
Yuan Shih	—	—	68.5	500	68.5	500.0
Hu-lun-ch'ih	—	—	137.0	1,000	137.0	1,000,0
Subtotal (including offshore Po Hai)	1,825.1	13,422.5	4,325.8	31,590	6,150.9	45,012.5
Offshore (except Po Hai) total	—	—	3,357.0	24,500	3,357.0	24,500.0
GRAND TOTAL	1,825.1	13,422.5	7,682.8	56,090	9,507.0	69,512.5

Note: From the above figures, the total estimated, ultimate **onshore** recovery adds up to 5,397.9 million mt (39,512.5 million bbl); and **offshore**, to 4,110.0 million mt (30,-000.0 million bbl).

Note: The estimate for the Tung-t'ing basin probably is too low. A more realistic estimate might be 274.0 mt (2 billion bbl).

gested a figure between 5.9 and 7.6 billion mt (43–58 billion bbl) by 1974. Willums (1975), using a different approach, came to conclusions similar to those of Meyerhoff. He wrote (p. 265):

"Reviewing the data available to us to date, the author estimates that a figure around 45 billion barrels for the **onshore areas** seems a most likely estimate for the present time, with a fractile range of 40 billion barrels (.25 fractile) to 65 billion barrels (.75 fractile). Our detailed geological evaluation of the **Chinese continental shelf** area leads us to a most likely estimate of 30 billion (.25 fractile) to 62 billion (.75 fractile). We may therefore set our estimate of **China's total ultimately recoverable reserves at 75 billion barrels, whereof 40% lie in the offshore areas."**

Table 8 shows a breakdown by onshore basin of our estimates of (1) produced, proved, and probable oil per basin; (2) potential oil still to be discovered in each basin; and (3) the totals. The offshore are, except for the Gulf of Po Hai is treated as a unit. The total is 5.4 billion mt (39.51 billion bbl) for the onshore, and 4.11 billion mt (30 billion bbl) for the offshore—a total of 9.51 billion mt (69.51 billion bbl). Clearly these figures are subject to revision in the future.

Of the 5,398 million mt (39.51 billion bbl) of estimated ultimate recovery for the onshore area, 424.2 million mt (3.1 billion bbl) already has been produced (*Table 1*), leaving an onshore reserve (proved, probable, and potential) of perhaps 4.97 billion mt (36.4 billion bbl). An estimated 118 million mt (860 million bbl) of the produced oil came from the Sungliao basin alone. In 1976, production will approximate 86,000,000 mt (627 million bbl), or 1,720,000 bbl/d—if a PRC news release in September 1976 is correct. This release stated that the PRC's growth rate for 1976 would be 12 percent. This decrease in anual growth has long been predicted.

All of the estimates cited above—whether by Meyerhoff (1970, 1975), Williams (1975), or Willums (1975)—are conservative figures based on geology, geophysics, and realistic appraisals of annual production history. They are far below the wild, undocumented claims made by the sensationalist press which has stated that the PRC offshore alone has reserves "as great as those of the Middle East" and even "ten times those of the Middle East." Salmanov (1974), in what must be one of the shortest and truly great analytical essays in petroleum geology, demolishes the sensational press whose excessive claims have even been entertained seriously by governments and their parliamentary bodies.

GAS

Most of the PRC's gas reserves are in the Szechwan and Tsaidam basins. Small gas fields are present (but shut in) in the Dzungaria and Tarim basins. Several small gas fields are present in the Chekiang Province part of the Yellow Sea (Kiangsu) basin. Some gas may be shut in within the Po Hai Gulf basin. Future exploration should discover substantial quantities of gas within the Miocene, Pliocene, and—possibly—the Pleistocene sections of the offshore, and some commercial fields in the onshore northern China basins (Pao-ting, Ling-Ch'ing, K'ai-feng, and Ho-tei).

Gas production was not important during the early history of the PRC because of a lack of pipelines and distribution systems. This statement is partly true today.

However, if the January 12, 1974, issue of Hong Kong's *Ta Kung Pao* is to be believed.

"A total of 31 cities now have gas service, in contrast to 16 in 1965. The present supply of gas is twice that of 1965. China used to manufacture gas for domestic use by the dry distillation of coal. The growth of the fuels, chemical, and metallurgic industries has added to the source of gas. Included are oil-field gas, pure natural gas, LPG from oil refineries, fire-damp, coke-oven gas from coking gas, and combustible gas discharged by chemical fertilizer plants.

"The Peking General Petrochemical Works is supplying quantities of its by-product, LPG, for 110,000 households and 900 plants in Peking and Tientsin. The municipality of Nanking in 4 months laid 51 km of pipelines and built other related installations which transmit 300,000 cu m per day of coke-oven gas to city dwellers. Other major cities such as Shanghai, Fushun, Changchun, Shihchiachuang, and Lanchow also have acquired combustible gas discharged from industrial enterprises.

"In Shanghai coke-oven gas is used not only in light industrial enterprises, but also in heavy industrial units of metallurgy, chemical-machine buildings, and power generating. About a third of the inhabitants of Anshan, China's major iron and steel producer, use gas from coking ovens. Projects to expand and rebuild facilities in major cities are making rapid progress."

According to Connell (1974, p. 2160), who cited French sources, China produced 4 Bcm (140 Bcf) of gas in 1971 and 4.6 Bcm (162 Bcf) in 1972. These figures contrast sharply with those of Williams (1975, p. 263) who gave a 1972 gas production figure for the Szechwan basin alone of 49.01 Bcm (1.7 Tcf). In the face of the many and presently irreconcilable conflicts in published information, we adopt Williams' figures for the Szechwan basin and extrapolate for the years which he did not list. We arrive at a conservative cumulative production figure for 1955–1976 of 390 Bcm, or 13,650 Bcf. (About 60 Bcm—2,100 Bcf—was produced in all of the PRC during 1974, excluding manufacturing and associated gases.)

Meyerhoff (1970) estimated Szechwan's produced, proved, and probable gas reserve as of January 1, 1969, to be 528.6 Bcm (18,500 Bcf). This would leave a remaining reserve of 138.6 Bcm (4,850 Bcf) as of January 1, 1976. The annual rate of production in Szechwan is more than 53 Bcm (1,855 Bcf). Press reports in the PRC indicate that "several new gas fields" were discovered during 1973 alone (see Williams, 1975, for a review). Because two thirds of Szechwan's iron and steel plants use natural gas as a fuel and more than 70 percent of the nitrogen fertilizer produced there is made from natural gas, it is reasonble to assume that (1) Meyerhoff's estimated produced-proved-probable reserve figure was conservative (Meyerhoff did not compute *potential* natural gas reserves for any part of China) and (2) the PRC has indeed found new reserves and new fields in the Szechwan basin.

The only other large, established, natural gas reserve (81.4 Bcm = 2,850 Bcf, estimated as of January 1, 1968) is in the Tsaidam basin. This gas is largely untapped because of the absence of pipelines.

A reasonable estimate of the Szechwan basin's ultimate gas recovery (including what has been produced) is 4,286 Bcm (150,000 Bcf; based on the number of known anticlines there). For the onshore area as a whole, 5,714 Bcm (200,000 Bcf) would be a conservative figure and, for the offshore, an additional 2,857 Bcm (100,000 Bcf) is conservative. Thus total—and admittedy very tenuous—ultimate natural gas (not including associated gas) recovery in the PRC, onshore and offshore, is not less than 8,571 Bcm (300,000 Bcf).

CONCLUSIONS

(1) The estimated ultimately recoverable oil in the PRC—onshore and offshore—is 9.51 billion mt (69.5 billion bbl). The estimated ultimate recovery of gas is expected to be not less than 8,571 Bcm (300,000 Bcf).

(2) Ultimate oil recovery from the **onshore** now is estimated to be 5,397.9 million mt (39,512.5 million bbl), including 424.2 million mt (3.1 billion bbl) already produced. Thus remaining reserves onshore (January 1,1976) are 1,195.9 million mt (8,855.9 million bbl) of proved plus probable and 3,777.8 million mt (27,590.0 million bbl) of potential.

(3) Ultimate oil recovery from the **offshore** (including the Gulf of Po Hai) is estimated to be 4,110 million mt (30,000 million bbl). Of this amount, 205 million mt (1,500 million bbl) is considered to be proved plus probable and 3,905 million mt (28,500 million bbl) is considered to be potential.

(4) Ultimate gas recovery from the **onshore** is expected to be—on the basis of existing geologic knowledge—about 5,714 Bcm (200,000 Bcf).

(5) Ultimate gas recovery from the **offshore** is expected to be not less than 2,857 Bcm (100,000 Bcf).

(6) The annual increases in production—about 20 percent per year for the past few years—should begin to taper off in the 1976–1980 period. A New China News Agency report in September 1976 stated that the 1976 growth rate was only 12 percent. This low figure may be the result, in part, of 1976 earthquake damage, but it also may be the result of the normal decline of growth. That of the PRC has been phenomenal. As a result of the 12 percent figure given by NCNA in September, the 1976 production is expected to be about 86,000,000 mt (627,000,000 bbl), or 1,720,000 bbl/d.

(7) The ultimate pace at which the PRC petroleum industry will grow depends not only in the rate of exploration and drilling, but also on technology growth. In the last section of this paper, we examine this technology briefly.

PRC PETROLEUM TECHNOLOGY

In 1949, the PRC was left with an almost nonexistent petroleum industry, a few outmoded rotary rigs, and several old cable-tool rigs of U.S., Soviet, and Japanese manufacture. Seismic equipment was not available.

The development of the PRC's petroleum industry since 1949 has been most unusual and quite different from the industry's development in other parts of the world. From 1950 through 1959, there was a large infusion of Soviet technology—in seismic, gravimetry, magnetic, and telluric exploration methods; in drilling techniques; and in refining. The refineries built with Soviet aid lacked depth in terms of refined products

—a problem which also existed in the USSR.

Most of the drilling rigs that were imported from the USSR were turbodrills, which are very inefficient below depths of 2,000 to 2,300 m. The Soviet seismic equipment was of a type which had been discarded in Western countries in the 1930's. Even the drilling equipment was outmoded. However, most of the known PRC drilling objectives in the early days of exploration were shallow and the Soviet equipment available generally was adequate. As exploration objectives became deeper, the inadequacy of the Soviet-built equipment became increasingly apparent.

The departure of the Soviet technicians in the 1959-1961 period left the PRC with severe problems—an infant industry, a small group of Soviet-trained PRC geologists and engineers, and numerous unfinished projects (particularly in refining; the Soviets simply returned to the USSR with the blueprints). Because of the Soviet abandonment of the PRC, the Chinese became determined never again to be dependent on any foreign power for the development of any part of its economy. As a consequence, the central issue of PRC petroleum policy has been that of self-reliance. This aim of being independent from other nations' technology marks the PRC's petroleum industry even today, and has probably been a handicap with respect to exploring and developing the nation's onshore and—most notably—offshore potential. Although it is difficult to predict the PRC's petroleum policy in the future, especially in these times of internal changes, it seems reasonable to assume that the theme of self-reliance will continue to play a major role. This trend is evident from the fact that most Chinese drilling rigs are now built in the PRC, although about 30 Rumanian rotary rigs are imported each year.

Today, the PRC hydrocarbon-prospecting technology has reached a level similar to that used in the USSR which introduced to the PRC the first "modern" methods. The Chinese are well aware of Western technology and are following closely new developments in the West. Through the French Compagnie Générale Géophysique, they have obtained access to sophisticated Western offshore survey systems, and are interpreting geophysical data by means of U.S. processing equipment.

Production technology in China has been very Soviet-oriented. The so-called line-drive waterflood system, typical in USSR petroleum field development, has been used in most of the PRC' oil fields until now. Only recently have the Chinese begun to experiment (e.g., in the Ta-ch'ing field) with more advanced development schemes, such as 5- or 9-well reinjection, systems commonly used in the West. In addition, they have drilled several deep tests—beginning with a 4,600-m well in the Sungliao basin in 1967 and, most recently, a 6,011-m test in the Szechwan basin during 1976.

In the offshore, progress has been rather slow, despite a few promising leaps forward in technology. The first offshore adventure in the Gulf of Po Hai during the late 1960's began rather hesitantly with the construction of earthen causeways and fixed platforms close to shore at Ta-ku (*Fig. 62*). Drilling was with proved PRC and/or Rumanian technology. The first fixed platform built for offshore, 40 km southeast of Ta-ku and 16 km offshore, was in 1969. The platform was built to test a seismic structure shot by the CGG earlier during the same year.

The PRC entered the field of Western technology with the purchase in 1972 of the Japanese jackup rig, *Fuji* (renamed *Po Hai No. 2*). The *Fuji* was delivered in

1973, and is capable of drilling to 4,575 m in water up to 54 m deep. At the same time, the PRC in 1972 built the *Po Hai No. 1*, a near copy of the *Fuji*, except that it lacks a helicopter pad. It is 73 m long, and the rig on it can drill to 2,500 m. Two smaller PRC-built jackup rigs also have been in service since about 1972. These are 17 m long, and can operate in water only 20–25 m deep. The rigs can drill to 2,000–2,500 m. In addition, two PRC-constructed barges are in use—the *Pinhai* (*Binhai*) *No. 1* and *No. 2*.

The original fixed platform built 40 km southeast of Ta-ku and 16 km offshore has been joined with another equipped with a derrick and a flare tower. One of them has undergone enlargement several times since 1971, and both platforms are now used for production. These two platforms are accompanied by several support platforms.

Because the most promising offshore areas are in water too deep for existing equipment, it is understandable that the Chinese investigated at a very early stage the development of floating drilling units. The first prototype of a semisubmersible rig had been rumored as early as 1971. Later reports from Japanese negotiators referred to this prototype as a ferro-cement or concrete floating structure. No further reports are available, although the Chinese are well versed in ferro-cement constructoon for shipbuilding purposes. Late in 1974 the Chinese confirmed the existence of a floating platform, *Kantan No. 1*, a catamaran built at the Shanghai Hutung Shipyard by joining the hulls of two British Liberty ships. The vesel began test operations during 1975 in the Yellow Sea, and has operated quite well in these medium-deep and generally calm waters of the Chinese continental shelf. If the vessel is to be capable of operating in the deeper areas of the East China Sea, where the nation's major offshore petroleum potential lies, dynamic positioning must replace the present multianchor system. A second catamaran, *Kantan No. 2*, was under construction in 1975 and now is in operation.

The Chinese have been in negotiations with Mitsubishi in Japan ever since they bought the *Fuji* and in 1974 ordered a large jackup rig. Negotiations for a Norwegian-designed Aker H-3 semisubmersible, to be built in Singapore, have been going on since 1973. At present two *Scarabeo* semisubmersible units, being built in West Germany, are reportedly for the PRC. These can drill 2,700 m in water 90 m deep. Delivery of two JU rigs from Singapore's Robin Loh yard has been delayed because of technical difficulties.

The Chinese offshore drilling fleet for 1976–1977 thus consists—in addition to fixed platforms—of two shallow-water barges, two shallow-water jackup rigs, one older Western-type jackup, one near copy of that rig, and two catamaran drillships. Even if some of the expected additional modern Western drilling rigs come in operation during 1977, it will be impossible to reach the high production levels (estimated in some Western studies) from offshore fields by the 1980's.

The other two bottlenecks in raising the production level of crude oil and refined products are in processing (refining) and transportation. The refining capacity has been increased substantially during the last few years, although it is still lagging behind crude output (National Council, 1976). Assistance obtained from Cuba during the early 1960's had a significant impact on refining, because the PRC was given access to technical data on the Cuban-based refineries formerly run by Exxon, Shell, and Texaco. The PRC probably received some technical assistance from Cuban engineers. In addition, major purchases from German and Italian firms in 1963 and 1965 gave the PRC access to more recent Western technology. By the end of 1973, most of the nation's refineries were equipped with catalytic cracking, platforming, and delayed cooking units. Based on sketchy information available from Chinese sources, experts believe that the total refining capacity in 1975 was around 61.4 million mt (National Council, 1976), and Chinese officials have indicated a planned growth rate of 15 percent annually for the next five years. This would, consequently, lead to a slower rate of increase in refinery capacity than in production capacity, suggesting the wish to export petroleum abroad.

Construction of a pipe connecting Ta-ch'ing with the port of Ch'in-huang-tao was begun in 1970 and completed in 1973. It is 1,152 km long, is at least 24 inches in diameter, and has 19 pumping stations. Construction of a second pipeline parallel with the initial one began in 1973, and was completed to T'ieh-ling in October 1974. An extension to the port of Lu-ta (Dairen) probably will be added soon. Also completed in late 1974 was the pipeline connecting the Shengli field complex with the port of Huang-tao (Ch'ing-tao). Early in 1976 a pipe-line connecting China with North Korea was inaugurated by the Vice Minister for Foreign Trade. Little is known of this pipeline's technical specifications, except that it was built as a joint Chinese-Korean technology venture. Thus, the PRC now has 18 oil and gas pipelines totalling about 7,500 km—a considerable improvement over the pipeline situation reported by Kudo (1966) and Meyerhoff (1970).

The same intensive effort has been observed in port developments. Because the main petroleum loading ports around the Gulf of Po Hai cannot easily be dredged very deep, it is the single-buoy mooring system that has attracted Chinese interest. Investments at the PRC's nine major ports doubled from 1972 to 1973, and probably tripled again between 1973 and 1974. Much emphasis was placed on oil-transfer installations. New oil-loading installations are now operational (1) at Ch'in-huang-tao, northwest of Lu-ta (Darien), which is connected to Ta-ch'ing by 1,144 km of pipeline; (2) at Ch'ing-tao, Shengli's terminal; and (3) at Chan-chiang in the southern PRC, the first port capable of handling 50,000-Dwt tankers. Very recently the Chinese have reported that the newly completed export terminal in Lu-ta (Darien) is capable of handling 100,000-Dwt tankers.

Tanker construction also was stepped up and the Hung-chi shipyard in 1974 launched the 24,000-Dwt tanker, *Ta-ch'ing No. 61*, by that time the largest Chinese-built tanker. In addition, China purchased foreign tankers in 1974 for their international crude transports—among these a 75,000-Dwt tanker from a Norwegian company.

CONCLUSIONS

Based on the present understanding of the geology of the PRC as it pertains to that country's onshore and offshore hydrocarbon potential, one can classify the People's Republic of China as a country with substantial hydrocarbon reserves and a major production potential. The total amount of recoverable hydrocarbons (proved +

probable + potential) is of the order of 9.51 billion mt (69.5 billion bbl), of which approximately 4.1 billion mt (30 billion bbl) is offshore.

The actual production level in the PRC is at present rather low. In 1976 about 86 million mt (627 million bbl) will be produced, which is about a fifth of U.S. production and 16 percent of USSR production. However, large and significant areas of the onshore (e.g., Dzungaria and Tarim basins) are scarcely tapped and could contribute significantly to the total PRC production in the future.

The PRC's petroleum-industry policy clearly has been influenced by the ideology of "self-reliance." The reason for this policy, which at times has been very hindering to the development of the petroleum industry, relates directly to the 1960 withdrawal of Soviet advisors. The resulting PRC attitude has prevented Peking from taking full advantage of Western onshore and offshore technology needed for the development of the hydrocarbon potential of the Chinese mainland and—more important—the continental shelf.

Although the technological advances during the last few years in the PRC have been remarkable the development of remote parts of the onshore and most of the offshore is likely to lag behind Western levels of technology in the years to come unless the Chinese depart from their self-reliance policy. Such a change in policy seems unlikely at the moment. The PRC's onshore activity, therefore, will be on a "do it ourselves" basis, and offshore activity will concentrate on the Gulf of Po Hai area, which is very shallow and environmentally not so difficult in which to operate. This means, however, that potentially large oil and gas resources which might underlie the Yellow Sea, the East China Sea, and the South China Sea will not be in the developmental stage within the next five years. Therefore, Japanese oil and gas production forecasts, which are based on the assumption that these offshore areas will play a major production role, must be regarded as unrealistic.

Today, Peking seems to be interested in developing the offshore potential within the framework of a "go-slow" policy. Direct foreign participation is out of the question at this time. Only foreign contracts, which could contribute substantially to the transfer of technology to the PRC, will be regarded as acceptable by the Chinese.

Although the sale of Western onshore and offshore petroleum technology has been increasing during the last few years, the number of sales, particularly of major equipment, is only a small percentage of what Peking needs. It is likely that Peking will adhere to this policy of limited purchases, because of the determination not to become dependent again on foreign powers. This Peking policy, in turn, will hamper a faster development of the country's oil and gas industry. However, from a Chinese long-term planning point of view, such a "go-slow/go-Chinese" policy makes sense for a nation whose population soon will reach the one-billion mark, and whose future innependence will depend on a sufficient energy and resource base at home.

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CORRECTIONS TO PAPER BY A.A. MYERHOFF AND J.-O. WILLUMS, "PETROLEUM GEOLOGY AND INDUSTRY OF THE PEOPLE'S REPUBLIC OF CHINA"

The list of corrections originally given by the authors was supplemented by T. Saito and T. Kambara at the request of the Editor-in-Chief. These corrections pointed out by the latter are indicated by asterisk (*).

Present Text	Corrected Text	Present Text	Corrected Text
*Page 103, line 18		Page 115, line 7	
9.507	**9.508**	uncomformable	unconformable
Page 103, line 20		Page 119, Table 2	
209.000 Bcf	200.000 Bcf	Paraffin Coutent	Paraffin Content
Page 106, line 9		Page 120, line 23	
soliders	soldiers	Brod.	Brod,
*Page 107, line 28		Page 122, line 4	
Pre-Nan Shan, Ordos, Sungliao	Pre-Nan Shan, Sungliao	area well	area **was** well
*Page 107, line 29		Page 122, line 11	
target	target **in 1957**	July 1968	July 1958
Page 107, line 29		*Page 122, line 19	
1.4 million	**2.0** million	6.85–13.0 million	6.85–13.0 million **mt**
Page 107, line 30		Page 123, line 24	
16.2 milliin	10.3 million	(Su-fu))	(Su-fu)

*Page 123, between lines 24 and 25

insert: "west; (4) Pre-Kunlun Shan foredeep on the south; (5) Charchan foredeep on the"

Present Text	Corrected Text
Page 124, Figure 10 caption, last line	
Kosartok	Kosaptok

*Page 125, line 21

delete: "The "Dark-brown zone" ranges in thickness from 500–1,600m."

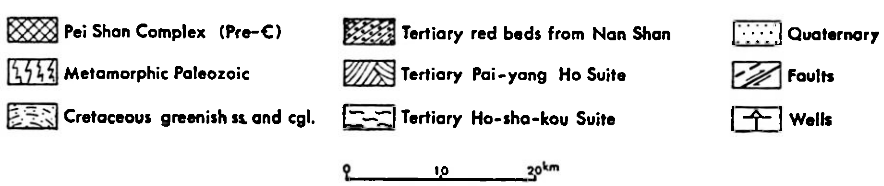
Present Text	Corrected Text	Present Text	Corrected Text
Page 127, line 32		Page 132, line 19	
Tien Shan K'u-lu-k'o	Tien Shan, K'u-lu-k'o	uncomformable	unconformable
*Page 127, line 35		Page 134, line 31	
depth	elevation	Radchenko, 1965).	(Radchenko, 1965).
Page 131, Figure 17 caption		Page 135, Table 4	
Fiure 16	Figure 16	Fu-yü	Fü-yü

In fact, the dots have been left off the first u of Fü-yü on almost every page.

Present Text	Corrected Text	Present Text	Corrected Text
Page 135, Table 4		Page 138, line 11	
Yumen	Yümen	Permian with	Permian—with
Page 138, line 5		Page 138, line 13	
Shin-	Shih-	stone with	stone (with

Page 139, Figure 22 legend

The following part of legend was cut off.



Present Text	Corrected Text	Present Text	Corrected Text
Page 140, line 1		Page 158, line 16	
1938, was mainly	1938, were mainly	wih	with
Page 140, line 4		Page 162, line 42	
smal	small	Southeatesrn	Southeastern
Page 141, line 3		Page 163, line 8	
sandstoned	sandstones	grade	grades
Page 142, line 19		Page 163, line 8	
asociated	associated	uspward	upward
Page 142, line 23		Page 163, line 14	
36,500,000 bbl	(36,500,000 bbl)	Creataceous	Cretaceous
Page 143, line 5		Page 163, line 24	
asymmetircal	asymetrical	Ealry	Early
Page 145, Figure 30		Page 163, line 24	
caption		Trissic	Triassic
Chiu-Chao-wan	Chin-chao-wan	Page 164, line 3	
Page 150, line 1		200,000,00	200,000,000
conglometrate	conglomerate	Page 164, line 15	
Page 150, Figure 37,		1956.	1956
drafting error		Page 164, line 24	
5000	500	Shahsi-miao.	Shahsi-miao **fields.**
Page 151, line 12		Page 166, Figure 53	
asndstone	sandstone	caption	
Page 151, line 13		Sheng-teng-hsan	Sheng-teng-shan
Jurasic	Jurassic	Page 168, line 4	
Page 153, line 8		cubbasin	subbasin
midle	middle	Page 170, Figure 58	
Page 153, line 11		caption, first line	
late	Late	basni	basin
Page 153, line 29		Page 171, line 13	
aditional	additional	sandtsones	sandstones
*Page 157, line 14		Page 172, line 8	
northwestern	western	Poleozoic	Paleozoic
Page 173, Figure 60		Page 172, line 16	
		Yudan	Yuan

Here, and in subsequent pages (also in Pages 135), Fü-yü is spelled Fu-yü. The authors are not certain whether this is important or not. T. Saito and T. Kambara indicated the view that spelling, Fu-yü is acceptable. They also expressed the view that the spelling, Yumen (in Page 135) is acceptable instead of Yümen.
Also note that there is no period after the beginning of the caption, "Figure 60." This is true of several other figures.

*Page 173, Figure 60	
caption, line 6	
(4) Hsin-chen-kou	(4) Chin-shan-kou

Also in subsequent pages of the chapter on SUNGLIAO BASIN, Chin-shan-kou (Field) is spelled Hsin-chen-kou.

Page 175, line 24		Noegene	Neogene
basement; 10)	basement; (10)	Page 178, line 10	
Page 175, line 26		dpths	depths
Mesoziic	Mesozoic	Page 178, line 13	
Page 176, line 20		average	averages
Kakirov	Bakirov	Page 179, line 20	
*Page 176, line 33		reason	reasons
T'ung-pai	T'ung-pei	Page 182, line 24	
Page 177, line 25		Ch'eng-teh	Ch'eng-teh

Present Text	Corrected Text
conglomerate	Conglomerate
Page 182, line 25	
underlie	**overlie**
Page 182, line 39	
2,200,-000	2,200,000
*Page 184, Figure 62, basin name	
III YUAN SHIU	III YUAN SHUI
caption, line 4	
*Page 184, Figure 62	
Yuan shih	Yuan sh**ui**
Page 187, last line	
ocal	**oral**
Page 188, line 9	
intruted	intru**d**ed
Page 189, line 34	
adrupt	ab**r**upt
Page 190, line 12	
Aa	A**s**
Page 191, line 12	
also applied	also **was** applied
Page 191, line 24	
motion	mation
Page 195, line 5	
Hydrocarbin	Hydrocarbon
Page 195, line 13	
range	ranges
**Page 196, Figure 68 caption, second line	
the PRC and Taiwan.	the PRC and **adjoining area.**
Page 199, Table 7, footnote 2	
None is a minimum figure.	**These are** minimum figures.
*Page 199, Table 7, footnote 3	
Len-i	Lin-i
Page 201, Table 8, line 4, 5th column	
728.9	728.**8**
Page 201, Table 8, line 13, cilumn 6	
35,962.2	35,962.**5**
*Page 201, Table 8, line 21	
Yuan Shih	Yuan Shui
Page 201, Table 8, last line, 5th column	
9,507.0	9,507.**9**
*Page 201, Table 8, second note, line 2	
274.0 mt	274.0 **million** mt
Page 202, line 13	
offshore are	offshore are**a**
Page 202, line 13	
Po Hai is	Po Hai, is
Page 202, line 20	
estimated 118	estimated **230**
Page 202, line 20	
(860 million bbl)	**(1,681** million bbl)
Page 202, line 24	
anual	annual
Page 202, line 41	
Ling-Ch'ing	Lin-Ch'ing
*Page 202, line 41	
Ho-tei	Ho-fei
Page 203, line 2	
believed.	believed,
Page 205, line 32	
PRC'	PRC
Page 205, line 34	
reinjection, systems	reinjection systems
Page 206, line 18	
constructoon	construction
Page 206, line 21	
vesel	vessel
Page 206, line 39	
reach the high	reach high
Page 207, line 12	
pipe connecting	pipe**line** connecting
Page 207, line 30	
1,144	1,1**52**
Page 208, line 16	
remarkable	remarkable,
Page 208, line 18	
reliancc	reliance
Page 208, line 38	
innependence	independence
Page 212, line 3	
Palasiatica	Palaeoasiatica
Page 212, line 25	
evaluation oil and gas	evaluation **of** oil and gas

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Tokyo University of Fisheries, Tokyo, Japan

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AEROMAGNETIC SURVEY OF THE PALAWAN-SULU
OFFSHORE AREA OF THE PHILIPPINES

By
W. Bosum[1], J. C. Fernandez[2], E. G. Kind[1] and C. F. Teodoro[2]

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2 Bureau of Mines, Manila, Philippines

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Emery, K. O., 1968, Relict sediments on continental shelves of the world: *Bull. Amer. Assoc. Petroleum Geologists*, vol. 52, p. 445-464.

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Menard, H. W., 1964. *Marine geology of Pacific:* McGraw-Hill, New York, U.S.A., 271 pp.

Murauchi, S., and H. Hotta, 1968, Studies of the continental slope off the Sanriku Coast by seismic profiler survey (in Japanese): *Natl. Sci. Museum. Mem.*, no. 1, p. 37-40.

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Annexed 11 Figures (Figures 2 to 12)

to

A REVIEW OF OIL EXPLORATION AND STRATIGRAPHY OF SEDIMENTARY BASINS OF THE PHILIPPINES

BY

Mineral Fuels Division, Bureau of Mines