TECHNICAL BULLETIN

VOL. 7

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

November, 1 9 7 3

ECONOMIC COMMISSION FOR ASIA
AND THE FAR EAST

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

SUPPORTED BY THE
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AND THE FAR EAST

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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) 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: Indonesia, Japan, the Khmer Republic, the Republic of Korea, Malaysia, the Philippines, the Republic of Viet-Nam 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/Co-ordinator, UNDP Technical Support for Regional Offshore Prospecting in East Asia, ECAFE, Sala Santitham, Bangkok-2, Thailand.

FOREWORD

It has been a privilege and honor 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 seventh volume here.

Since the publication of the first volume in 1968, CCOP has been extremely successful not only in co-ordinating the offshore prospecting work of the member countries, but also in arousing the interest of individuals and organizations in geosciences, government, mineral industries and other sectors related to the development of the ocean. This is clearly seen in the authors and contents of the papers published in the Bulletin during these years.

I deeply appreciate the co-operation of the authors, the staff of the CCOP Office of the Project Manager, and the editorial staff for producing this volume which will be a significant contribution to the earth sciences.

Isamu Kobayashi
Director,
Geological Survey of Japan

NOTE BY THE EDITOR

It is a great pleasure for the editor to present Volume 7 of the CCOP Technical Bulletin to the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP). Among the six articles included in this volume, the editor is glad to have four contributions from geoscientists of the countries in southern part of the region.

The editor feels that discussion of the technical contents of the articles appearing in the Technical Bulletins would be highly desirable for the advancement and promotion of marine geological and geophysical studies in the region. If readers wish to comment or raise questions regarding them, the editor will willingly act as intermediary and forward them to the contributors, who alone responsible for the statements made and opinions expressed in their respective articles.

CCOP is now expanding its activities beyond the continental shelves of the member countries to the adjoining oceanic areas, and planning scientific programmes for investigation of the tectonic development of the region in relation to mineral potential including hydrocarbon resources. In this connexion, it is felt that the CCOP Technical Bulletin should publish more articles on the geological structure of the continental margin, and that contributions should be considered for publication from all sources, irrespective of whether or not they may be connected with the CCOP or United Nations activities. The editor wishes, in view of past experience, to propose at the September 1973 session of the Committee that the deadline date for submission of manuscripts for the next regular volume be set at the end of January 1974.

A full-time United Nations Development Programme technical support group (UNDP/CCOP) for the Committee was organized in April 1972, with Dr. C. Y. Li serving as the Project Manager. He agreed to the request by the editor that Dr. D. J. C. Laming, Senior Geologist of the project, would assist in the editing of the papers submitted for publication in the CCOP Technical Bulletin.

The editor expresses his sincere gratitude to Dr. Laming for his kind co-operation and valuable suggestions regarding editorial standard. His deepest thanks are extended to the Director of the Geological Survey of Japan for the printing of this volume as one of the regular Technical Bulletins, as well as to the members concerned of the Geological Survey, particularly of its Publication and Library Office, for their co-operation in completing this volume.

November 1973

Shun-ichi Sano
Editor-in-Chief

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I. AGE ESTIMATION OF SUBTERRANEAN HEAT SOURCES BY SURFACE TEMPERATURE OR GEOTHERMAL GRADIENT ANALYSIS

By

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(with figures I–1 to I–8)

ABSTRACT

Evidence concerning ages of subterranean heat sources can be gained from analysis of heat flow profile data utilizing the method of differences of running mean values, which acts as a kind of filter for different wavelengths. Making assumptions concerning conductivity and of spherical heat sources, the ages of sources can be estimated.

The method has been applied in a preliminary manner to heat flow data in southwestern Hokkaido and central Honshu, and in both cases significant correlation with past igneous activity can be demonstrated.

INTRODUCTION

Subterranean temperature distributions may be constructed using the various assumed heat source models,but, in general, only the temperature data at the surface and at shallow depths are known in practice. Therefore it is necessary to presume underground temperature distributions from these data and, consequently, the heat source models. This is, strictly speaking, a very difficult matter, but the difficulty can be somewhat decreased by the adoption of some reasonable assumptions.

An analysis has been made by the author of surface temperature patterns and geothermal gradient distributions as one of these trials, attempting to reduce the data to several heat sources by making assumptions about thermal conductivities. For this analysis, the differences between so-called "running mean values" are utilized, and for the heat source models spherical sources are assumed.

The geothermal gradient distributions or heat flow values are usually interpreted as being the result of a balance between the disintegration of radioactive materials in the earth's crust and the heat discharge from the surface (not only of land, but also of sea bottom). However, in addition, it is quite possible to consider that these surface temperature or geothermal gradient distributions will be based upon anomalous heat sources such as magma or magma reservoirs.

From such points of view, any subterranean temperature distribution may display various kinds of wavelength when measured along a profile. Long wavelengths will correspond to large scale heat sources which probably originated a long time ago; smaller wavelengths represent origins of smaller scale, and thus probably younger than the large ones; very short wavelengths must represent temperature distributions caused by small anomalous bodies which would be very young by comparison.

Adopting the "running mean method", especially by using the differences of two running means for the analysis described above, it becomes possible to gain effective information about the subterranean heat sources; and from the presumed relationship between age and wavelength, to discuss the age of the heat source.

This method has been applied by the author to age estimation in southwestern Hokkaido and in an area adjacent to Suruga Bay, south coast of Honshu. The results obtained appear to have a very interesting relationship to known geological events.

EXAMPLE OF DIFFERENCES OF RUNNING MEAN VALUES APPLIED TO GRAVITY DATA

Of course, Fourier analysis is a very useful method for analysis of curves in general, but parallel with this the running mean method can also be effective when certain wavelengths can be noticed; it is also sometimes very effective to take the differences in running mean values as a kind of filter to show up other frequencies.

To make this idea clear, an example of gravity data from central Honshu is used (*Fig. I–1*). Here, the Bouger anomaly profile $g(x)$ can be used to illustrate the general principle of the running mean. The profile can be expressed using the Fourier series as in the equation

$$g(x_i)=\Sigma\, a_n \cos\left(\frac{2\pi x_i}{\lambda_n}\right)=\Sigma\, a_n \cos \omega_n x_i \tag{1}$$

where x_i represents the observation point, and the interval of successive observation points is $s=x_{i+1}-x_i$, and λ_n is the wavelength to be determined (see *Fig. I–2*).

The running mean is taken of $2N+1$ points at the middle point x_i. In this case, the running mean value $\bar{\Sigma}_N$ becomes

$$\bar{\Sigma}_N=\frac{\Sigma_N}{2N+1} \tag{2}$$

where

$$\Sigma_N=\sum_{\nu=-N}^{N} \cos \omega_n(x_i+\nu s),$$

which finally becomes

$$\Sigma_N=\left[\sin\frac{(2N+1)\omega_n s}{2}/\sin\frac{\omega_n s}{2}\right]\cos \omega_n x_i \tag{3}$$

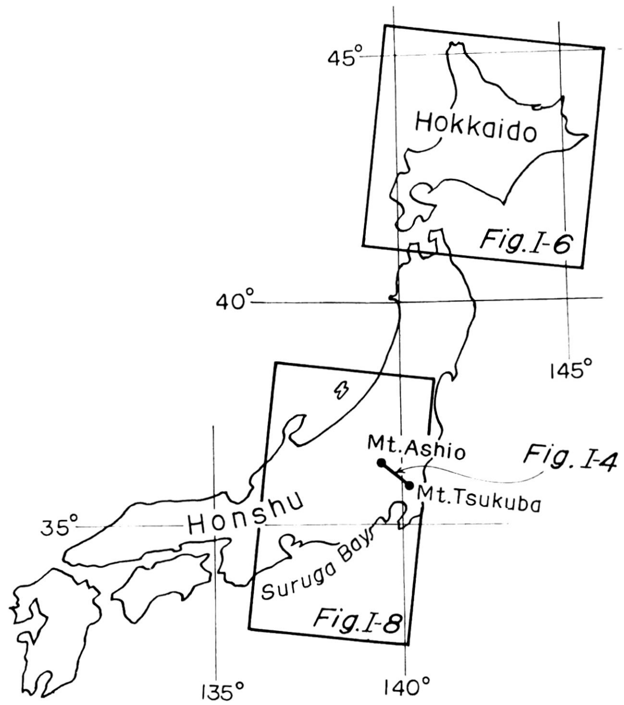

Figure I–1. Index map of Japan showing locations of heat-flow data used in age estimations.

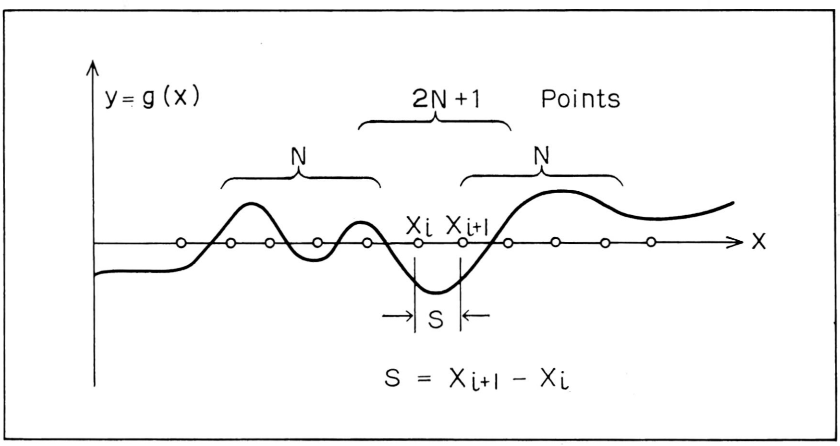

Figure I–2. Illustration of running mean method on profile data.

Then, taking the differences between any two running mean values, that is

$$\Delta\alpha\beta=\bar{\Sigma}_\alpha-\bar{\Sigma}_\beta$$

or

$$\Delta\alpha\beta=K_n(\alpha, \beta)\cos\omega_n x_i \tag{4}$$

Here $K_n(\alpha, \beta)$ can be expanded as follows

$$K_n(\alpha, \beta)=\frac{\sin\frac{(2\alpha+1)\omega_n s}{2}}{(2\alpha+1)\sin\frac{\omega_n s}{2}}-\frac{\sin\frac{(2\beta+1)\omega_n s}{2}}{(2\beta+1)\sin\frac{\omega_n s}{2}} \tag{5}$$

where $K_n(\alpha, \beta)$ is called the selection coefficient. To simplify and ease comparison, the so-called normalized constant $c_{\alpha\beta}$ is made, and multiplied by the selection coefficient $K_n(\alpha, \beta)$ so that the maximum value of each selection coefficient becomes unity, and the product is denoted by $K^*(\alpha, \beta)$.

Figure I–3 illustrates the physical meaning of the method, showing that the results correspond to some sorts of frequency filters. From this process it is possible to pick out patterns of long, medium and short wavelengths, for which suitable models can be considered.

The Bouger anomaly profile between Mt. Ashio and Mt. Tsukuba and corresponding subsurface structure is shown in *Figure I–4a* and *4b*. It can be seen that the Bouger anomaly curve (0) may consist of long, intermediate and short wavelengths, and the running mean process may be applied. If l_1 is taken as the short wavelength, the anomalies shorter than this are almost cut out, and the resulting curve (A) (*Fig. I–4c*) shows the intermediate and long wavelengths of the anomaly profile.

If, at this stage, a running mean process with intermediate wavelength l_2 is carried

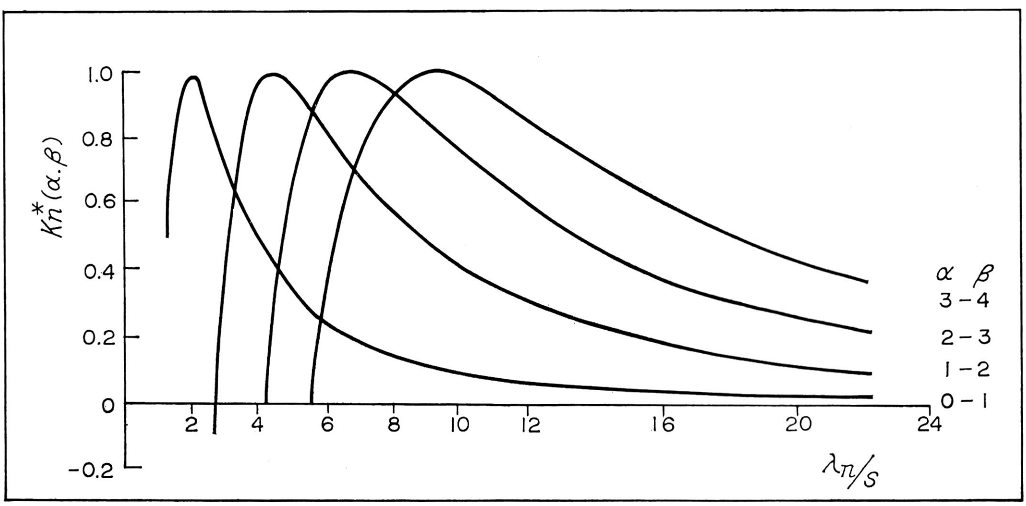

Figure I–3. Response curves obtained by the process of difference of running mean values (after Seya, 1959).

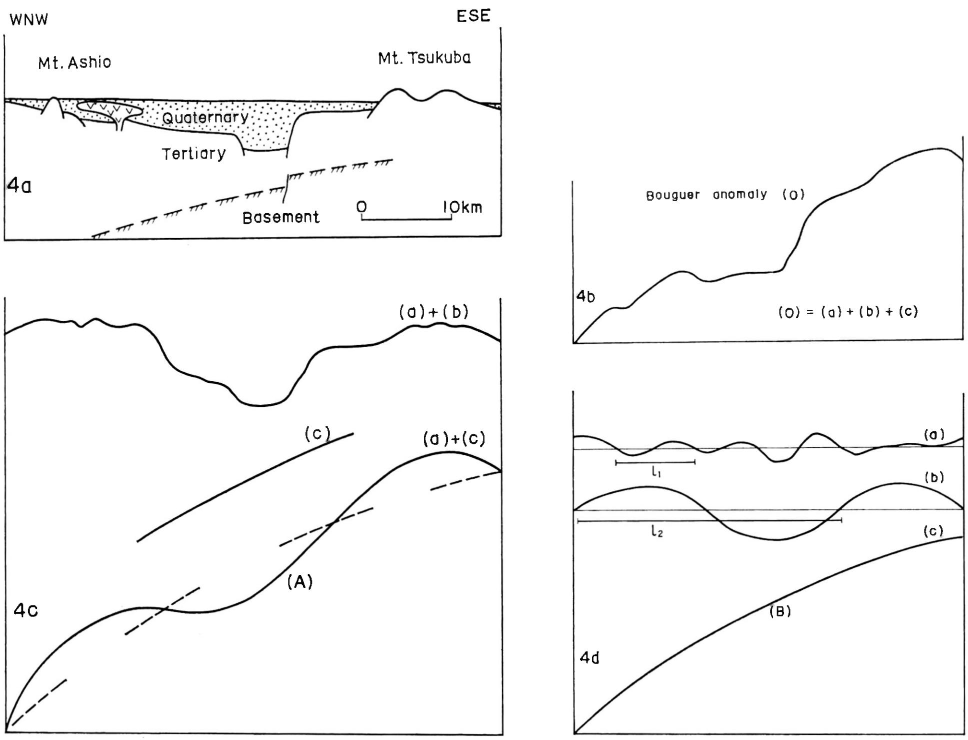

Figure I–4. Bouger gravity anomaly profile between Mt. Ashio and Mt. Tsukuba, central Honshu, and its analysis. 4a: geological cross-section; 4b: Bouger anomaly profile; 4c: anomaly profile; 4c: anomaly curve components (with relate to portions of the geological profile in 4a); 4d: long, medium and short wavelength components of anomaly curve.

out on curve (A), the result is curve (B) (*Fig. I–4d*) corresponding to the long wavelengths only. By subtracting this curve from the original profile, the curve (a) + (b) is obtained showing only medium and short wavelengths. Thus the difference of running mean values method has acted to filter out the long wavelength. The short and medium wavelength components of (a) + (b) can be derived by a similar method by (0) − (A) and (A) − (B) respectively (*Fig. I–4d*).

According to the theory of gravitational potential, shorter wavelength anomalies can correspond to shallower underground structures and longer wavelengths to deeper ones. Consequently, the curves (a) + (b) and (B) may correspond to the underground structures such as top of Tertiary and top of basement respectively in *Figure I–4a.*

PRINCIPLES OF AGE ESTIMATION OF SUBTERRANEAN HEAT SOURCES

As explained in the previous section, the difference of running mean values acts as a kind of filter, and it is possible and effective to apply this procedure to the analysis of surface temperature patterns or geothermal gradient distributions. Following their analysis into several wavelength curves, several subterranean heat sources can be postulated as being sources for these curves, and correspondence between the curves and sources may be derived if assumptions are made about thermal conductivity. Of course, very local geothermal fields may depend on heat transportation through faults, fissures, vents, etc., but these are exceptions to the present discussion.

For heat sources, these may be considered as magma bodies or reservoirs, and, for simplicity of analysis, heat sources have been assumed to be spherical, of different sizes and depths. When the analysed surface curves are compared to subterranean spherical sources, the method involves alignment of surface (and/or near-surface) temperature or geothermal gradient distributions (and consequently heat flow values) with the results of thermal conductivity calculations. In these calculations, the initial temperature of the heat source is assumed to be 1500°C, and the radius of the source is taken to be roughly the same as the depth of the centre.

A result of one calculation is given in *Figure I–5*, where the initial temperature θ is given a value of 1.0, d is the distance from the centre of an assumed spherical heat source body, a is the radius of the source, and represents $K/c\rho$, where K, c and ρ are the thermal conductivity, specific heat and density respectively.

Fortunately, in treating models using thermal conductivity, a convenient relation exists between scale (size), conductivity and time, i.e.

$$\frac{t_1 k_1}{l_1^2} = \frac{t_2 k_2}{l_2^2} = \text{constant}$$

where l, k and t are scale (length), thermometric conductivity ($K/c\rho$) and the required time respectively, and subscripts 1 and 2 refer to different media. From this, it is easy to make any desired model from one fundamental model by calculation: for example, if conductivity is kept constant, the time for heat transmission becomes 100 times longer if the distance (1) is increased ten times.

The above calculation of thermal conductivity considered a spherical heat source in an infinite medium, but when the results are applied to a practical model of a shallow part of the earth's crust, the presence of the soil interface has to be taken into considera-

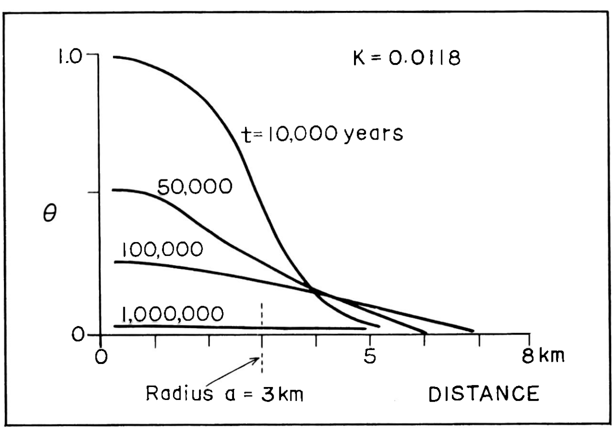

Figure I–5. Temperature distribution within and outside a spherical heat source with time.

tion. This can be done by making similar imaginary temperature distributions, having a negative sign with respect to distribution outwards symmetrical with the soil surface. In the present case, both soil distributions result from the thermal conduction from the spherical source model described above.

Application of these procedures make age estimations of heat sources possible, utilizing the parameters in *Figure I–5*.

AGE ESTIMATION OF HEAT SOURCES, SOUTHWESTERN HOKKAIDO

The first practical test of the method concerned the heat flow measurements in southwestern Hokkaido (*Figs. I–1* and *I–6*). A northern extension of the well-known Nasu volcanic zone on Honshu enters this area, and therefore heat flow values are comparatively high. The heat flow profile A — B across the area is shown in *Figure I–7*; some detailed data in the centre of the profile (at the peak around 5.0 HFU) have been omitted.

Analysis using the difference of running mean method results in four curves, *a* to *d*, of different wavelength. The long wavelength pattern (*d*) is estimated to correspond with an age of 50–60 million years; the intermediate wavelength pattern (*c*) for a medium size source becomes 15 million years, and the short (*b*) 2 million years. The very short wavelength pattern (*a*), omitted from the curve as stated, becomes of the order of 100,000 years.

These values seem very reasonable from various geological and geophysical data in the area: *a* corresponds to recent volcanic activity, *b* to activity during the Pleistocene

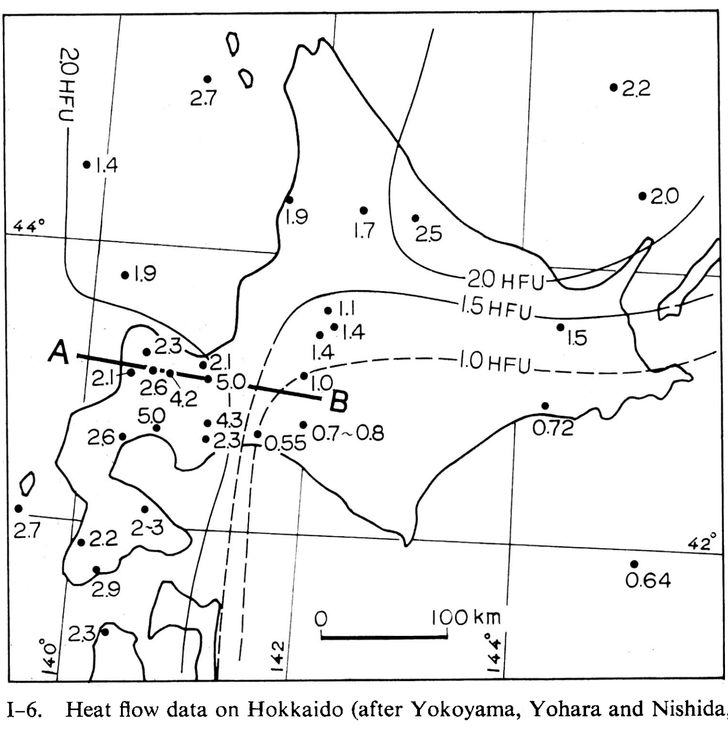

Figure I–6. Heat flow data on Hokkaido (after Yokoyama, Yohara and Nishida, 1970).

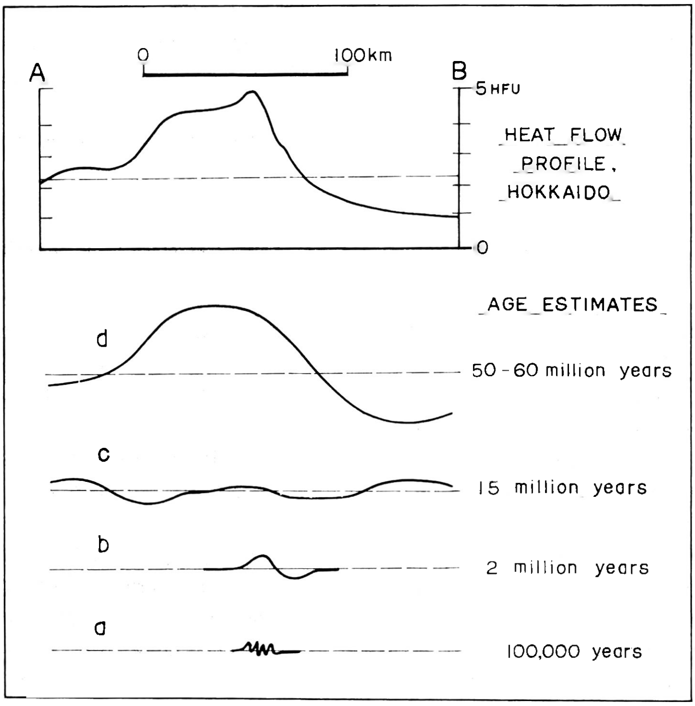

Figure I–7. Heat flow profile along line A–B in *Figure I–6*, analysed into wavelength components with age estimations.

reversely-magnetised epoch, *c* to igneous activity in the late Miocene, and *d* corresponds to the intrusion of granitic masses or metamorphism, which occurred from late Mesozoic to early Palaeogene.

AGE ESTIMATION IN SURUGA BAY AREA

Another trial of the method in its preliminary stage was made for the Suruga Bay area, central Honshu (*Fig. I–8*), which has an interesting geological history. During the Mesozoic era, after early Triassic orogenic movements, Japan was differentiated into internal land basins and external marine geosynclines. Granites were intruded extensively during the late Mesozoic in the internal areas, and the main fold structures, metamorphism and igneous intrusion had mainly been completed by the end of the Mesozoic or in the Palaeogene. Japan appears to have entered a new phase of geological evolution in the Miocene; depression, violent volcanism and some igneous intrusion took place on land, rather abruptly, and the Miocene sea began to transgress and finally to cover almost all of Japan. The deep depression of Fossa Magna formed, separating northeast and southwest Japan. Tectonism in the Tertiary was generally faulting, but with local folding. The sea largely regressed in the Pleistocene, but volcanism continued until the present time, constructing numerous volcanic cones and lava plateaus.

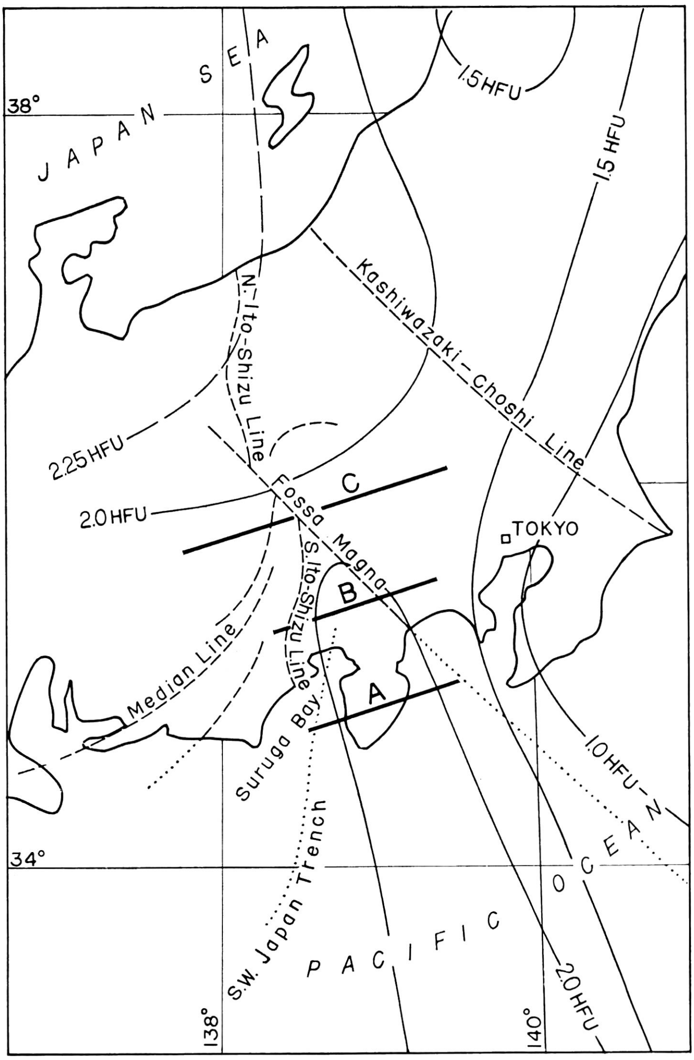

Figure I–8. Heat flow contours in the Suruga Bay area and adjacent central Honshu (after Yasui, Watanabe and Uyeda, 1968, and others), and principal tectonic lines (after Sugiyama, 1971).

Thus, the central area of Honshu should prove to be an interesting one to try out the heat flow method of age determination. The heat flow anomalies shown in *Figure I–8* are already based on running mean values for 100 km squares, and therefore details cannot be seen as for Hokkaido; so only the large-scale heat flow anomalies can be discussed.

Three profiles along lines A, B and C have been analysed by the running mean method. Major age estimations for the anomalies are 13 million years for A and B, and 60 million years for profile C. These correlate with late Miocene igneous activity in the areas of A and B lines, while the line C data can correspond to the formation of the Fossa Magna.

CONCLUSIONS

As stated in the introduction, there are various methods of age determination, of which surface temperature or geothermal gradient distribution have so far received very little consideration. The new method proposed here enables estimates to be made of the age of subterranean heat sources from heat flow data analysed by the method of difference of running mean values using assumptions of thermal conductivity.

Although at this stage results can only be obtained from profiles, the methods seem to be unique and instructive for the purpose, in a different sense from the methods of age determination so far utilized; it is applicable not only for gaining information on geological age but also on mineral resources including hydrocarbon accumulations. In the near future the author hopes to extend the method to two-dimensional applications.

The author wishes to acknowledge the encouragement to publish this article, by participants and Special Advisers of the CCOP ninth session held in Bandung, Indonesia, in 1972, and the Editor of the Technical Bulletin.

REFERENCES

Klemme, H. D., (in press), Geothermal gradient, heat flow and hydrocarbon recovery: Princeton University Press.

Seya, K., 1959, A new analysis method of gravity exploration: *Butsuri-Tanko* (Geophysical Exploration), vol. 12, no. 2.

Sugiyama, R., ed., 1971, Izu Peninsula: Tokai University Press.

Watanabe, T., ed., 1972, Kaitei Butsuri (Geophysics below the sea-bottom): Tokyo University Press and Tokai University Press.

Yasui, M., T. Kishii, T. Watanabe, S. Uyeda, 1968, Heat flow in the Sea of Japan: *Geophys. Monogr. Ser.* No. 13.

Yokoyama, I., Y. Yehara, and N. Nishida, 1970, Heat flow measurement in Hokkaido (in Japanese): *Proceeding of the Symposium on Thermal Structure in Japanese Island*, Earthq. Res. Inst., University of Tokyo.

(Manuscript received 18 April 1973.)

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II. DISTRIBUTION OF HEAVY MINERALS IN THE PHUKET AND PHANG-NGA AREAS, SOUTHERN THAILAND

By

Piphop ISARANGKOON

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Government of Thailand

(with figures II–1 to II–9)

ABSTRACT

Mineralogical analysis of 67 samples collected by hand auger from amang dumps at tin-mine localities in Phang-nga and Phuket Provinces, southern Thailand, showed heavy mineral concentrations ranging from 8.7 to 98.1 per cent. Ilmenite was dominant in 56 of the samples, in concentrations ranging from 0.6 to 94 per cent of heavy minerals. Garnet, zircon and tourmaline were also abundant locally, with maxima of 94, 46 and 50 per cent respectively, garnet being fairly wide-spread at lower concentrations. Monazite and rutile were also present in significant amounts. Columbite-tantalite occurrences were minor.

INTRODUCTION

All major tin deposits in Thailand are located in the southern peninsular area, especially in Phuket and Phang-nga provinces (*Fig. II–1*). They are mainly found as placer deposits which, apart from tin, contain ilmenite, zircon, rutile, columbite-tantalite, monazite and xenotime as associated minerals in these areas. Tin and valuable heavy minerals are also generally found in amang (by-product material of the tin-ore processing) and in sand tailing heaps.

The present investigation, which was undertaken between January 1971 and May 1972, had a three-fold objective:

(1) to find the distribution of tin together with the heavy minerals mentioned;

(2) to discover whether the associated heavy minerals could become a profitable by-product of tin mining; and

(3) to decide, as a result of the investigations, on the desirability of a follow-up survey.

Location and access

The Phuket-Phang-nga area is situated on the western side of peninsular Thailand approximately 900 kilometres SSW of Bangkok (*Fig. II–1 inset*). The area lies within latitudes 7° 45′N and 8° 55′N and by longitudes 98° 25′E and 98° 45′E, with an areal extent

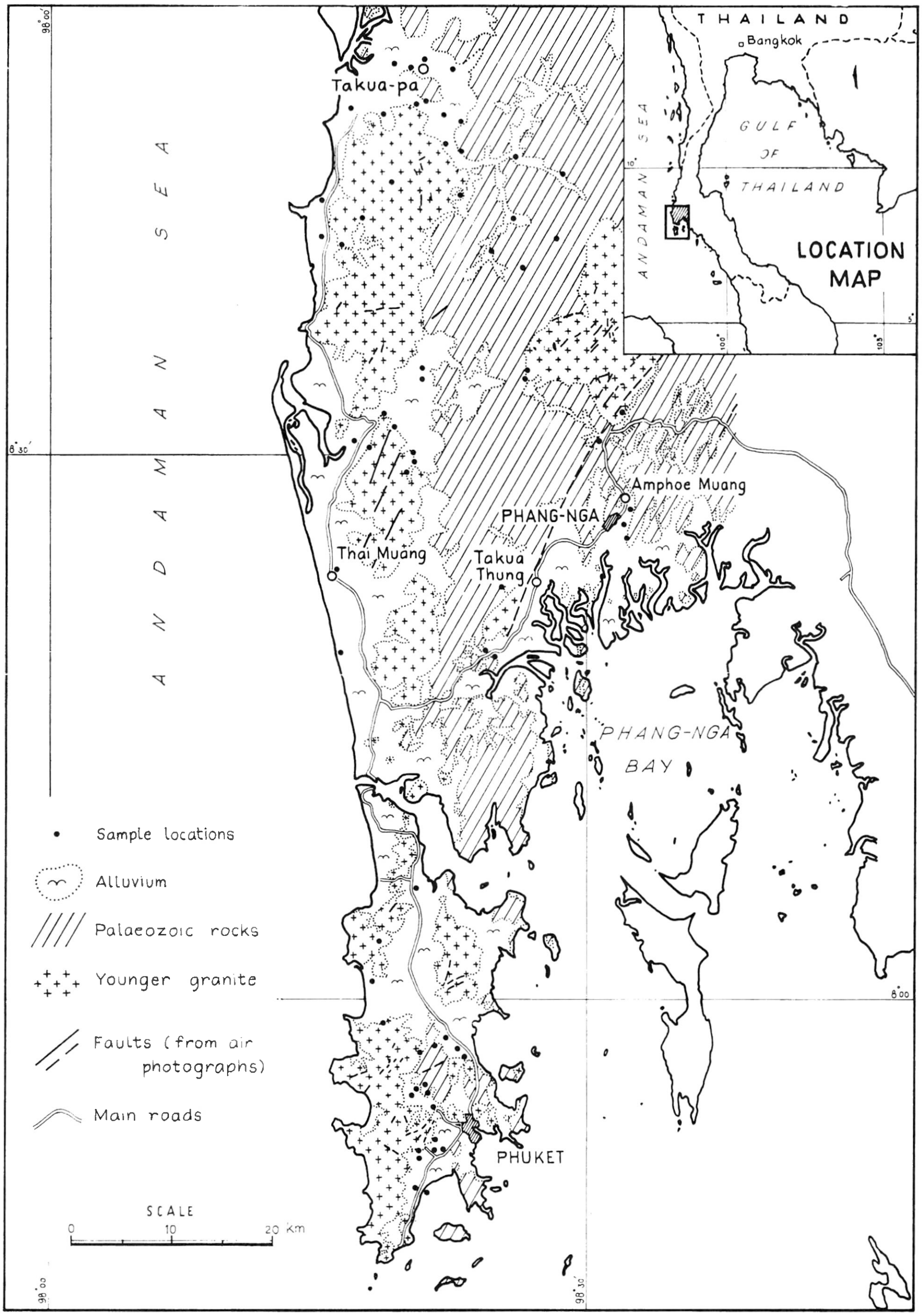

Figure II–1. Map of the Phuket-Phang-nga area, Southern Thailand, showing main geological features and locations of amang dumps that were sampled and analysed.

of about 4500 sq km. The area can be reached by roads extending from Highway 4, which is the main highway connecting Bangkok with southern Thailand and the border with Malaysia, and which extends down the western side of the area investigated. The nearest airfield is Phuket Airport, about 30 km north of Phuket.

Topography

The area investigated comprises densely forested dissected hills and mountains. Granitic masses along the west coast form hills of 500–600 m in height, and north of Phang-nga Bay hills of the granite intrusion reach a maximum altitude of 1050 m.

Drainage is either westwards to the Andaman Sea or southwards into Phangnga Bay by short rivers with numerous small tributaries. The river valleys are characterized by the development of alluvium along their length, with gravels up to 10 m thick in places. River estuaries are found south east of Phang-nga.

Field Work

Field work was undertaken in 1971 and 1972 under the supervision of Mr. Sa-ngob Kaewbaidhoon, Chief of the Economic Geology Division, Department of Mineral Resources, Government of Thailand. The investigation mainly concerned tin and heavy mineral distribution at tin mines and boreholes, and methods of study included:

(1) Collection of samples—a total of 250 samples were obtained from tin mines
(2) Surveying by Brunton compass—to locate tin mines and boreholes
(3) Drilling by Australian hand auger drill to sample "amang" and sand tailing heaps.

Previous Investigations

Geological investigations in the Phuket-Phang-nga area began with a field operation conducted jointly by the Royal Thai Department of Mineral Resources, the United States Geological Survey and the Overseas Geological Survey of the United Kingdom in 1968–1970. Reconnaissance sampling of heavy minerals along beaches and from alluvial tin mines has also been carried out by the Department of Mineral Resources since 1967.

In 1969, the Government of the Commonwealth of Australia provided the services of Mr. E. H. MacDonald, a technical adviser on detrital heavy minerals deposits, in order to make a preliminary assessment of the heavy mineral prospects. Also, Charan Poothai, Somboon Rattanawong and Sermsakdi Kulvanich of the Department of Mineral Resources, Rattanawong and Sermsakdi Kulvanich of the Department of Mineral Resources, conducted geological investigations of the heavy minerals of alluvial and beach deposits along the coast of southern Thailand and in some gravel pump mines of the Phuket-Phang-nga area.

GENERAL GEOLOGICAL SITUATION

Peninsular Thailand lies in the Tin Belt of southeast Asia, where syntectonic granite plutons intrude folded Palaeozoic sedimentary rocks. The belt of batholithic intrusion was emplaced within major anticlinal axes in the country rock, along the great orogenic-metallogenic belt which runs north-south in this region.

Most of the tin deposits of economic importance in Thailand are associated with Mesozoic granites, and the area investigated belongs to a metallogenic province in which tin-bearing acidic dykes and veins are confined to granite bodies. The major faults occur in two sets with approximately north-south and northeast-southwest directions, and appear to have been controlled by the intrusion of granites at various times.

The granites of the area are divided into a group of older granites, of Carboniferous to Triassic and possibly Jurassic age, and the younger granites, Cretaceous to Tertiary. Hornblende granite forms most of the older granite, with low content of tin and valuable heavy minerals; where the host rock is biotite granite, however, tin mineralization is more common. The younger granites are generally coarse-grained porphyritic biotite granites, finer grained near contacts with country rocks, and with higher values of tin and heavy mineral content than the older granites.

Many sites in Takua-pa and Phuket areas are very good locations for heavy mineral deposits, though tin-rich areas are related to granite occurrence, with the highest values associated with altered granites (Aranyakanon, 1969). Parts of these granites were altered by pneumatolyzation, the alteration resulting in the mineralization of tin and other valuable heavy minerals.

In parts of the area, a number of mines have produced a fairly high production of tin for years, most of it mined from secondary accumulations with accessory heavy minerals (amang). These secondary placer deposits originated from various sources, including mineralized altered granite found in the upper zones of the intrusions, granite with disseminated ore, pegmatites, aplites and hydrothermal lodes.

In the Cretaceous granites, the most favourable parts of the mineralized rock are those that were uncovered in the Pleistocene. By prolonged denudation and the sea-level fluctuations in the Pleistocene, the major part of the primary bedrock was exposed to erosion. With the rise of sea level, placer deposits which had been developed on the land areas were submerged or covered with beach deposits or alluvial gravels.

MINING AND ORE DRESSING PROCESSES

The main methods of tin mining in the area investigated are dredge and gravel pump; flow sheets of the ore-dressing processes are shown in *Figures II–2*, *II–3* and *II–4*. Waste material is rejected at various stages in each process, the earlier waste going to the sand tailings heap and material rejected from the latter parts of the processes going to the "amang" dump. Amang generally contains a high proportion of heavy minerals, including small quantities of cassiterite which have escaped the selection process.

SAMPLING

A total of 280 samples were collected by the writer from the spoil heaps and concentrate production at the various mines. A total of 87 amang samples were collected, 61 from Phang-nga Province and 26 from Phuket Province; 61 concentrate samples and 122 from sand tailing heaps were also collected, but at the time of writing only 67 of the amang

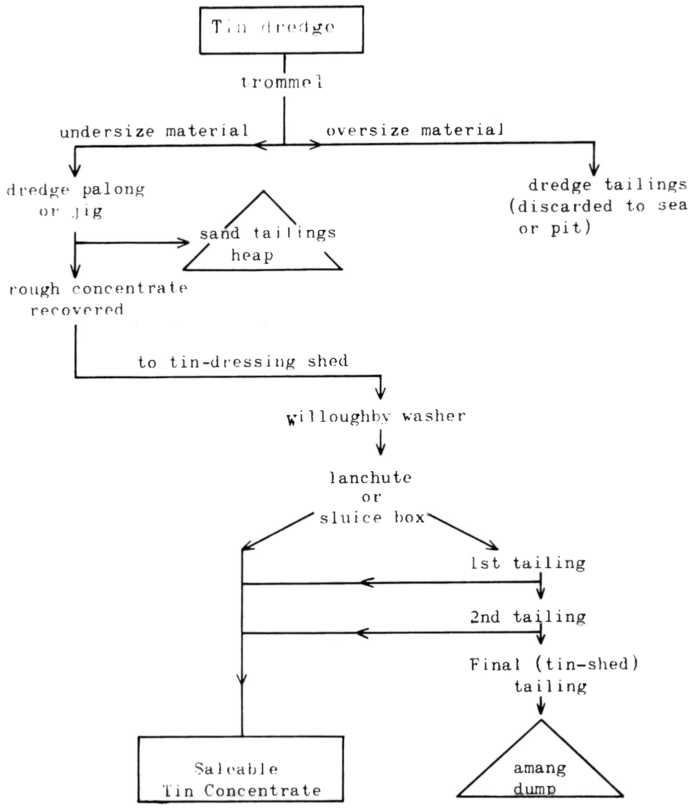

Figure II–2. Flow sheet of tin ore-dressing in dredge mines.

samples had been analysed.

Each field sample was divided into two splits and dealt with according to the procedures given in *Figure II–9.*

DISTRIBUTION OF HEAVY MINERALS IN THE AREA

Of the 67 samples analysed, 34 contained more than 80 per cent heavy minerals, 26 between 40 and 80 per cent, and seven less than 40 per cent; the lowest value was 8.7 per cent, the highest 98.3 per cent. Quartz made up the bulk of the remainder of the amang samples.

Within the heavy mineral portions of the samples, *ilmenite* was the most common mineral, being the most abundant in 56 of the total of 67. The highest concentrations, up to 94 per cent of the heavy minerals, occurred in the coastal area north of Thai Muang, Phang-nga Province, and in the area south and southwest of Phuket town. Very low concentrations were, on the other hand, noted in the centre of Phuket Island and in inland parts of the north of the area. The distribution of ilmenite is shown in *Figure II–5.*

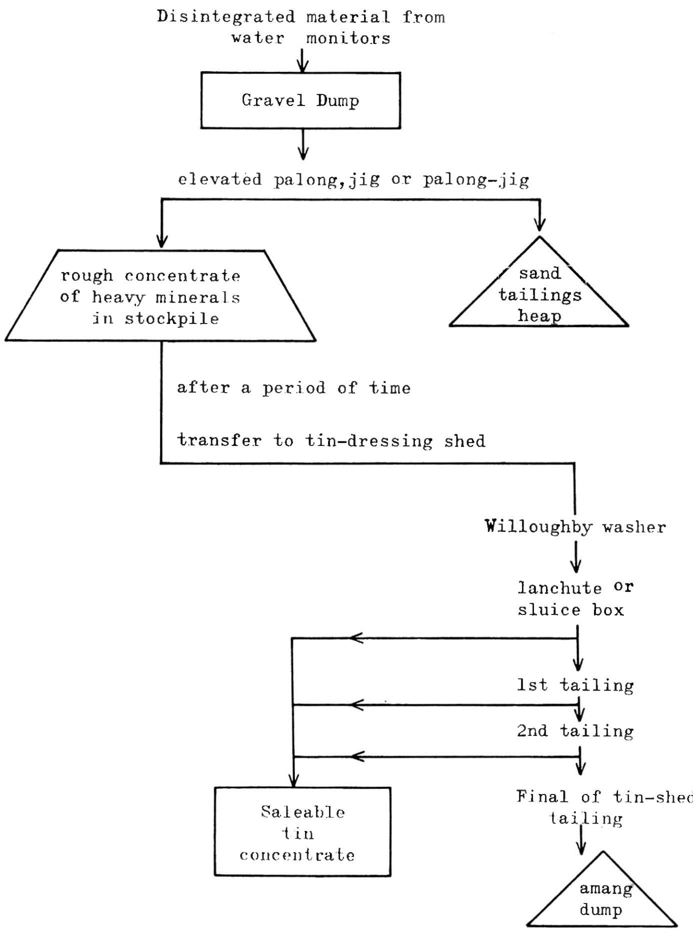

Figure II–3. Flow sheet of tin ore-dressing in gravel-pump mines.

Garnet was locally abundant (*Fig. II–6*), forming more than 20 per cent of the heavy minerals in 19 samples and being dominant in six, notably up to 94 per cent in the centre of Phuket Island and 53 per cent near Phang-nga. Percentage concentrations tended to be higher in inland areas, presumably because of the lesser abundance of ilmenite in those areas.

Zircon, however, was mainly absent from the inland parts north of Phang-nga. Only ten samples showed concentrations higher than 10 per cent (*Fig. II–7*), but in the northern coastal portion values up to 46 per cent were found, and other significant concentrations were present flanking the high-garnet-low-ilmenite locality northwest of Phuket.

Tourmaline (*Fig. II–8*) was present in significant percentages in the northern part of the area inland from the shore, up to 50 per cent of heavy minerals; smaller concentrations were found on Phuket Island. *Monazite* up to 29 per cent was found in the coastal areas near Takua-pa with scattered minor occurrences elsewhere. *Rutile* up to 16 per cent was found in northern inland areas. *Columbite-tantalite* occurrences were minor, however,

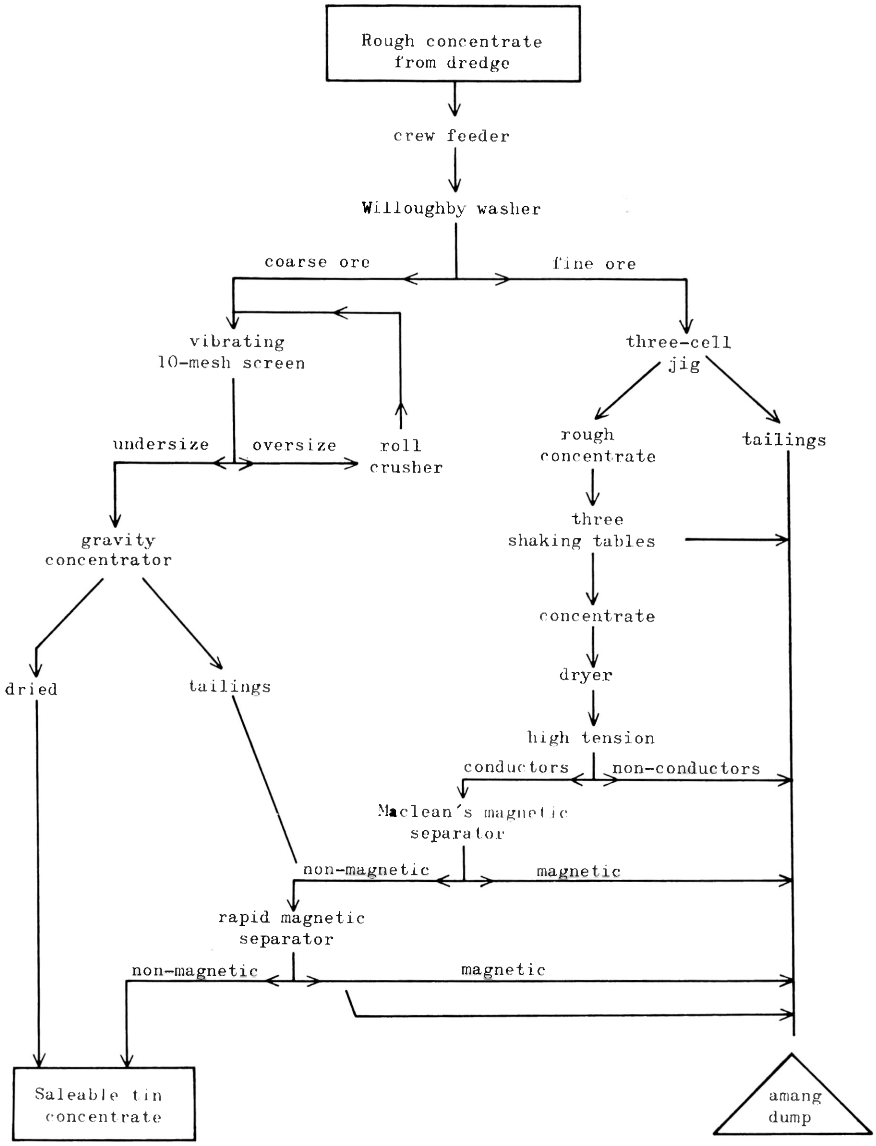

Figure II–4. Flow sheet of mechanized tin shed ore-dressing plant of Siamese Tin Syndicate Limited, Ngow Ranong.

except at Thoongkamin mine, south of Takua-pa, where 15 per cent concentration was found. Minor and scattered occurrences of ilmenorutile, xenotime, pyrite, leucoxene and wolframite were also found. Cassiterite often formed two percent or more (up to 12 percent) of the heavy minerals, but these values are dependent only on the efficiency of the ore-dressing processes at the various plants.

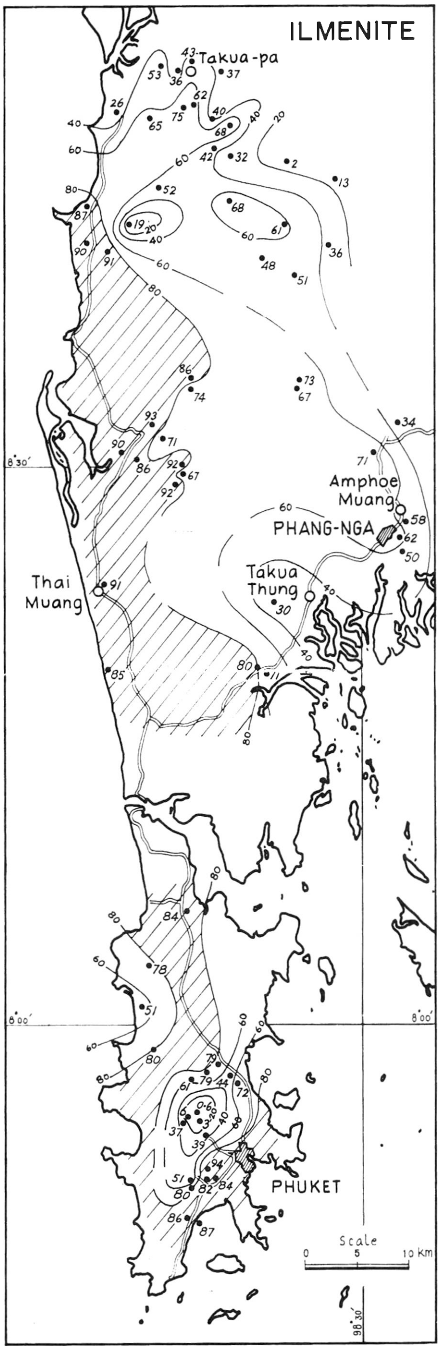

Figure II–5. Distribution of ilmenite in amang heaps in the Phuket-Phang-nga area.

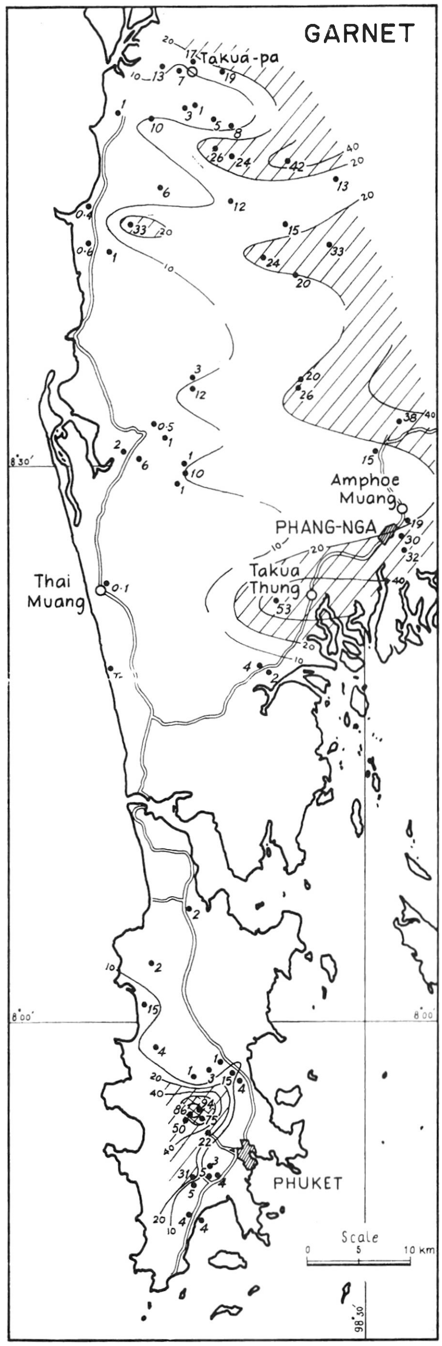

Figure II–6. Distribution of garnet in amang heaps in the Phuket-Phang-nga area.

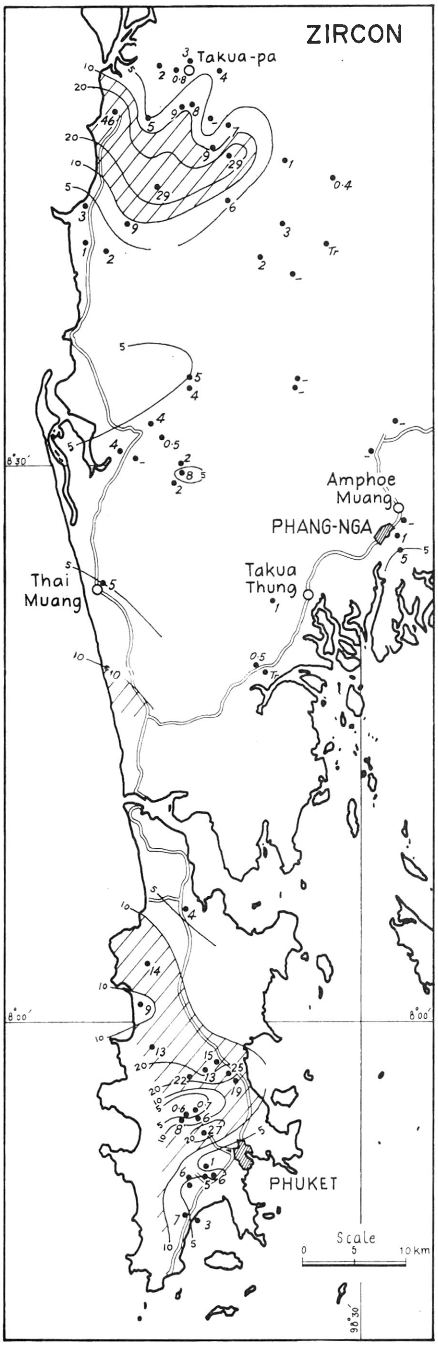

Figure II–7. Distribution of zircon in amang heaps in the Phuket-Phang-nga area.

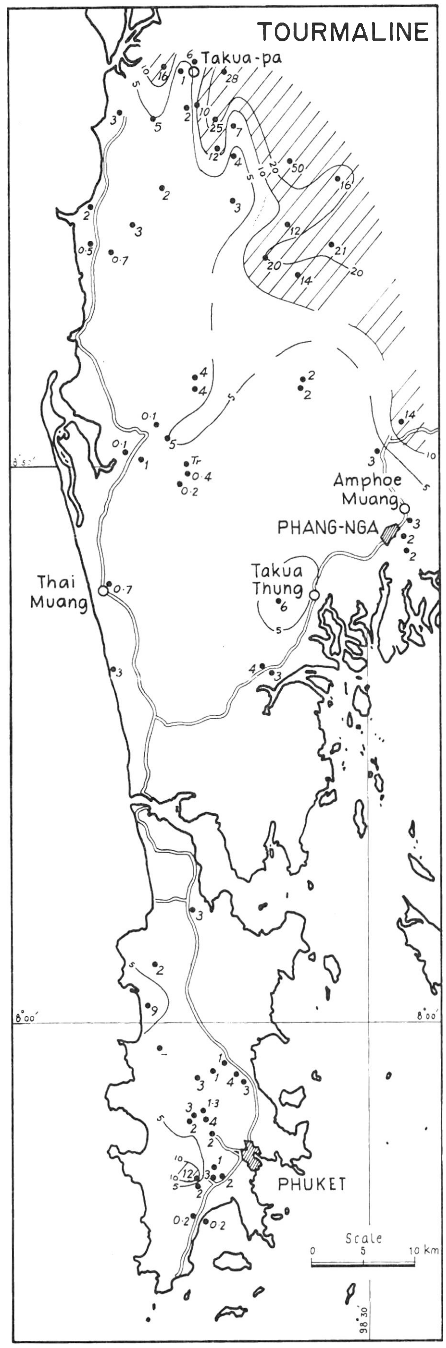

Figure II–8. Distribution of tourmaline in amang heaps in the Phuket-Phang-nga area.

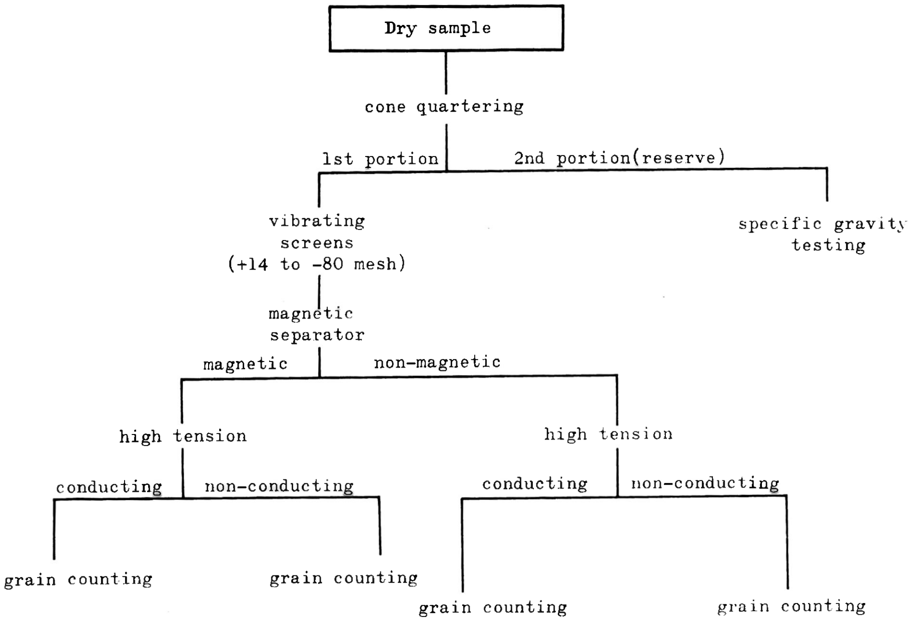

Figure II–9. Flow sheet of test dressing of amang samples.

MINERALOGY OF THE HEAVY MINERALS

Briefly, the characteristics of the heavy minerals separated from the 122 amang samples from Phuket and Phang-nga areas are as follows:

Ilmenite: occurs in flat or tabular euhedral crystals which may be brown, blue-grey, or black. The grains are sub-rounded to rounded, opaque, and have a metallic lustre in reflected light. The average grain size is about —42 mesh (Tyler Standard seive mesh).

Zircon: most zircon crystals are small and transparent, and of pink, brown, tan and purple shades. Grains are rounded and either anhedral or euhedral. Some brown zircons are tetragonal prismatic crystals with pyramidal faces. The average grain size is about —60 mesh.

Garnet: these crystals are usually pale pink to orange. Grains range in size from fine to coarse and average —35 mesh. Crystals are mostly euhedral with well developed faces.

Monazite: this is usually found as rounded to sub-angular grains which are honey-yellow to reddish brown and transparent or opaque. Grains range from fine to coarse and average —60 mesh.

Tourmaline: crystals are greenish brown and appear almost black in reflected light. Grains show sharp euhedral outlines. Average grain size ranges from —28 to 60 mesh.

Cassiterite: most cassiterite crystals have generally low pyramidal forms, but the so-called "needle tin" forms are acutely terminated and sometimes very slender. Colours range from dark grey to reddish brown. Grain sizes range from very fine to coarse, with a maximum size of about —48 mesh in the beach deposits.

In some localities cassiterite is poorly liberated from its rock matrix of feldspar, quartz, mica and garnet, together with secondary manganese oxides and fresh or altered pyrite. Black bladed grains, possibly columbite, are sometimes noted.

Columbite-Tantalite: this occurs as short prismatic crystals or bladed grains which are iron-black, opaque, hard, and brittle. The mineral has either a sub-metallic or brilliant sub-resinous lustre and a sub-conchoidal uneven fracture. Maximum grain size is about −48 mesh.

ACKNOWLEDGEMENTS

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Finally the writer wishes to express his gratitude to the Australian Government for providing equipment and the service of Mr. Eoin H. MacDonald to assist the investigation.

REFERENCES

Aranyakanon, Payome, 1961, The cassiterite deposit at Haad Som Pan, Ranong Province, Thailand: *Report of Investigation No. 4*, Department of Mineral Resources, Government of Thailand, 118 p.

Hummel, C. L., and Prachuap Phawandon, 1967, Geology and Mineral Deposits of the Phuket mining district, South Thailand: *Report of Investigation No. 5*, Department of Mineral Resources, Government of Thailand, 118 p.

Macdonald, E. H., 1969, Report on investigations on detrital heavy minerals in the Phuket and Phang-nga regions of Thailand: United Nations ECAFE, document CCOP/TAG(V)/8, sixth session of CCOP, 25 p.

Noakes, L. C. and Charan Poothai, 1967, Prospects for detrital heavy minerals other than tin in Thailand: United Nations ECAFE, *Report of the fourth session of CCOP*, p. 119–123.

Poothai, Charan, S. Kulavanich and S. Rattawong, 1969, Heavy minerals associated with tin in alluvial and beach deposits in southern Thailand: report prepared for the Second Technical Conference on Tin, 15 p.

Stephens, E. A. and J. H. Bateson, 1966, An investigation into the occurrence of diamonds and the regional geology of the Phuket-Phang-nga area of peninsular Thailand: Report, Overseas Division, Institute of Geological Sciences, United Kingdom, 31 p.

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III. PLATE TECTONICS AND ITS SIGNIFICANCE IN THE SEARCH FOR MINERAL DEPOSITS IN WESTERN INDONESIA

By

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(with figures III–1 to III–5)

ABSTRACT

An interpretation of the structure of the Indonesian island arcs on the basis of plate tectonic theory has led to the development of two crustal models, which illustrate the main features of the island arc systems. One model includes a continental plate and foreland basin, and relates to western Indonesia; the other shows a more complex arc system and a small deep-sea basin within it, and relates to the eastern arcs.

In both models, subduction and magmatic activity occur in parallel belts; former areas of such activity can be recognized in the Tertiary, Cretaceous, Triassic-Jurassic and probably the Permian of parts of Indonesia, evidenced by melange and similar deposits and by volcano/plutonic arcs respectively. Radiometric dating of granites from Sumatra and elsewhere support the interpretation of the regional geology as a series of generally parallel subduction zones and volcano/plutonic arcs of these periods. An earlier interpretation of the regional structure by Westerveld recognized a series of orogens, but geology and mineralization of each orogen showed a number of discrepancies; many of these are resolved by the plate tectonic interpretation, which links mineral provinces together in a more realistic way. The structural interpretation also predicted the presence of subsurface Cretaceous granites encountered in offshore drilling north of Java.

The plate tectonic interpretation can also be used to predict favourable areas for petroleum exploration, such as in foreland basins. It also explains some of the detrital heavy mineral occurrences in parts of the Sunda Shelf area, and suggests where tin accumulations might be found.

INTRODUCTION

The plate tectonic concept visualizes the Indonesian island arcs as a place of interaction of two or more crustal plates, and provides the best basis for explaining the various present day geological, geophysical and physiographic phenomena such as the deep submarine trenches, loop-shaped arcs, large transcurrent faults, the variation of andesitic magma type across the arc and the location of shallow, intermediate and deep earthquake foci (Katili 1972a).

The concept has been applied to Indonesia by Hatherton and Dickinson (1969), Fitch (1970, 1972), Fitch and Molnar (1970), Hamilton (1970, 1971, 1972) and Katili (1971, 1972a, 1973a, 1973b).

In western Indonesia, the concept has been utilized to explain the slight discrepancies between the present day geology and geophysics of Sumatra and Java (Katili 1971, 1972a). The Tertiary, Mesozoic and even the Palaeozoic geology of western Indonesia can also be interpreted using the plate tectonic model, whereby its geological evolution is interpreted in terms of past location of subduction zones, calc-alkaline magmatic arcs and foreland basins (Hamilton 1971, Katili 1971, 1972a, 1972b).

An attempt has also been made to construct a structural sketch-map of the western part of Indonesia depicting past subduction zones and volcano/plutonic arcs (Katili 1972b, 1973b).

It is the purpose of this paper to evaluate whether this tectonic scheme can be used as a basis for preparing a new metallogenetic map of Indonesia, which should also develop an understanding of the structural basis of the offshore geology and associated mineral deposits of the region.

PLATE TECTONIC PRINCIPLES AND MODELS WITH SPECIAL REFERENCE TO INDONESIA*

The new global tectonic theory features the earth's crust as consisting of a number of large and small rigid plates, which are moving relative to adjacent ones (Isacks *et al.*, 1968, Le Pichon 1968, Morgan 1968, and others). Deformation of crustal rocks by thrusting, folding and faulting is mainly concentrated at the plate margins. In general, three kinds of plate margins can be identified (Isacks *et al.*, 1968, Hamilton 1970, Dickinson 1971): (1) diverging margins, where new lithosphere is being produced in the widening gap between plates moving apart, such as the mid-ocean ridges; (2) converging margins where two plates moving towards one another either are both crumpled against the join, or else one is consumed while the other plate slides over it, such as in an island arc characterized by inclined Benioff (seismic) zones; (3) shear margins or transform faults, where two plates slide past one another.

For the purpose of this paper, only (2), converging margins, will be discussed in detail.

The physiographic, tectonic, magmatic and seismic activity occurring along a convergent juncture or island arc may now easily be explained in terms of the plate tectonic concept.

The submarine trenches accompanying island arcs, such as the Sumatra Java trench, Timor trench, etc., are now considered to be formed by the downbuckling or subduction of the under-riding oceanic plate, and represent boundaries between continental and oceanic plates or between pairs of oceanic plates themselves.

A typical subduction zone comprises tectonically chaotic complexes, including Alpine-type ultramafic rocks, serpentine, gabbro and basalt of dominantly abyssal, tholeiitic composition, and oceanic pelagic sediments consisting of lithified calcareous, siliceous and

* This material, with more extensive details of radiometric dating, are to be published in *Tectonophysics.*

clayey oozes. Unfossiliferous clastic and volcanogenic sediments introduced by slumping and interbedded with turbidites represent trench materials. Slices of metamorphic rocks are also present, including prehnite-pumpellyite, green-schist and blue-schist facies (Hamilton 1970).

Differential movement between the down-going ocean floor slab and the overlying continental plate could result in the tectonic emplacement of the trench deposits pinched between the plates at the trench margin. If the movement of the down-going plate should cease, isostatic adjustment would eventually result in uplift and erosion of these deposits, generally seen as a melange (Mitchel and Reading, 1971). Friction between the descending and overlying plates produces heat, which results in the high heat flow and magmatic activity typical of a volcanic arc (Oxburgh and Turcotte 1970).

The present-day active magmatic zone of Sumatra and Java is marked by intermediate and silicic calc-alkaline volcanism. Granite batholiths are now forming beneath the volcanic belt (Hamilton, 1970), and van Bemmelen (1949) already explained the genesis of the huge Toba ignimbrites, which occupy an area of 20,000 to 30,000 sq km in north Sumatra, by the presence of a granite batholith very close beneath the surface. Two ages have been given for the Toba ignimbrites, less than 300,000 years (Ninkovich, personal communication) and 75,000 years (Tjia, personal communication based on further information from Ninkovich).

Hatherton and Dickinson (1969) demonstrated also that in Indonesia there exists a correlation between the increase of K_2O content in recent volcanic products and the depth of the Benioff zone. They suggested that variations in K_2O content are determined by

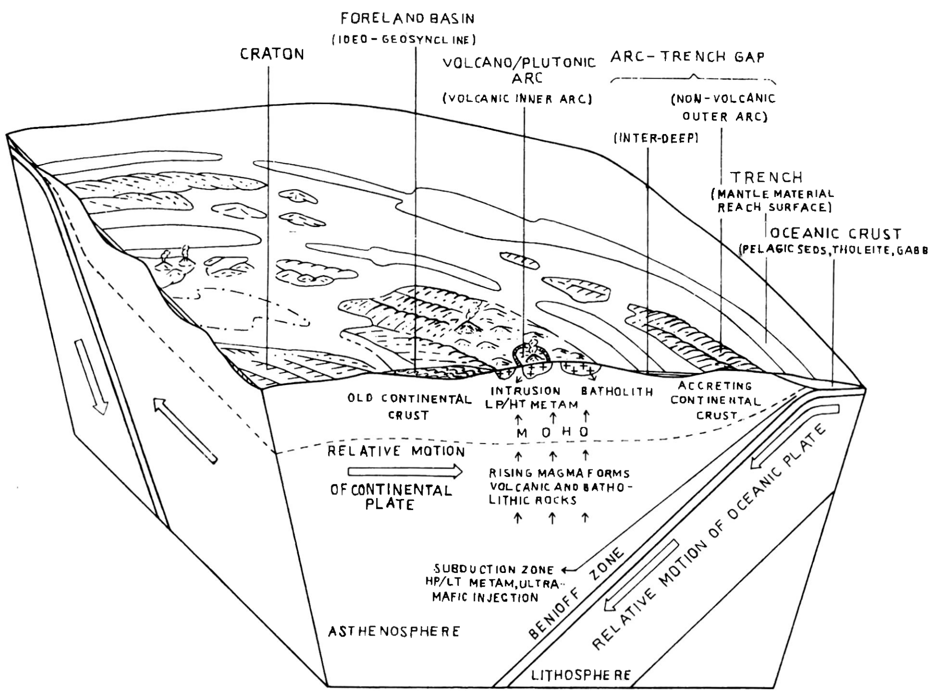

Figure III–1. Plate tectonic model of Western Indonesia (after Umbgrove).

differing degrees of melting either of mantle or of mantle and oceanic crust carried tectonically into the zone of the low velocity layer.

South of Java, the zone of intense seismic activity, now known as the Benioff zone, has a length exceeding 1000 km, and north of Flores reaches a maximum depth of 700 km. Below the depth of shallow seismicity (0–60 km) a zone of intermediate and deep earthquake foci dips away northwards from the trench south of Java and the Lesser Sunda Islands, at an angle varying between 55° and 70°.

Following Hamilton (1970) and Dickinson (1971), plate tectonic models of the Indonesian island arcs have been constructed by the author utilizing the excellent model of a double island arc shown by Umbgrove (1947). *Figure III–1* shows the model relating to western Indonesia. The structural zones, listed in order from the trench inwards across the continental plate, are:

(1) the active subduction zone
(2) the magmatic or volcanic arc and
(3) the foreland basin.

The non-volcanic outer arc and submarine ridge, situated respectively west of Sumatra and south of Java, and the intervening through or inter-deep, are called the arc-trench gap (Dickinson 1970). The characteristic rock assemblages of each belt have been described in detail by Hamilton (1970), Dickinson (1971) and Mitchel & Reading (1971).

The plate tectonic model for eastern Indonesia (*Fig. III–2*) shows much similarity to the previous one except that the foreland basin is not present inside the island arc. Instead,

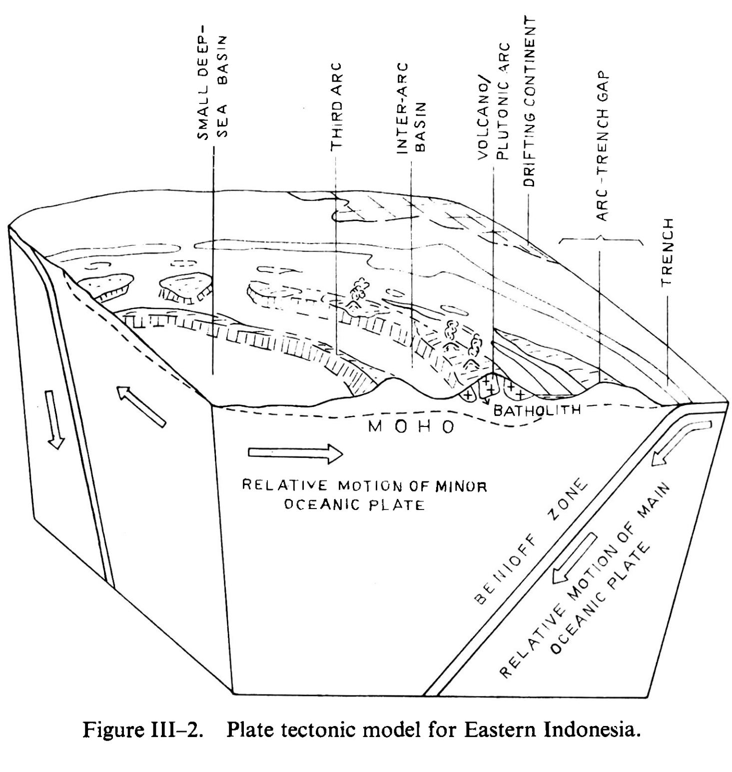

Figure III–2. Plate tectonic model for Eastern Indonesia.

more complicated structural belts are present in the form of an inter-arc basin, a third arc and a small deep-sea basin. Such a model has already been proposed by Karig (1971) who showed that the marginal basin, the active form of which is the inter-arc basin, comes into existence by a diapiric pull-apart mechanism. Matsuda and Uyeda (1971) proposed that marginal seas may be expanded by intrusions of magma from the Benioff zone inward from the volcanic arc, producing small oceanic (marginal sea) plates.

Hamilton (personal communication) considered the outer Banda arc as a special type of arc in which voluminous terrigenous sediments from a continental source (Australia and West Irian) are being subducted beneath an oceanic (Banda) plate. He did not exclude the possibility that continental crust was itself being subducted.

Two phases can apparently be distinguished in the formation of the Banda arc. In an earlier phase, oceanic crust of the Indian Ocean-Australian Plate was subducted under the Banda Sea oceanic portion of the Eurasian Plate, leading to the formation of a "Pacific style" island arc, consisting largely of a string of volcanic islands. Continuous northward movement and subduction of the Indian Ocean-Australian Plate eventually brought the continental crust of Australia to the Banda arc subduction zone.

The volcanic arcs of eastern Indonesia, such as the Banda arc, consist of rocks similar in composition to those of the western Indonesia arcs but bulk compositions are markedly more mafic. Non-volcanic clastic sediments are of minor occurrence in the subduction zone of the eastern Indonesia arc (Hamilton 1970). The distance between the trench and magmatic arc in eastern Indonesia is far shorter than that across a typical active continental margin, such as in western Indonesia, implying that the dip of the Benioff zone in the east is much steeper.

It should be emphasized that in these plate tectonic models parallel belts develop together and that each belt should have systematic cross-strike variations (Hamilton 1970). It has also been pointed out by Matsuda and Uyeda (1971) that in an orogenic zone with paired belts, the eugosynclinal environment and granitic magma intrusion may be active almost simultaneously in the juxtaposed outer and inner belts.

The oceanward front of the inner arc, called the magmatic front by Uyeda and Matsuda (1971), is defined according to Sugimura (1960) by the volcanic front.

The locations of the subduction zones change in time, and in western Indonesia show a strong tendency to migrate towards the ocean side (Katili 1971). The direction and rate of dip of Benioff zones also show temporal changes and account for the apparently irregular location of the volcano/plutonic arcs (Katili 1972a), which are the geological remains of pre-existing magmatic or volcanic arcs.

Based on knowledge concerning active subduction zones and active volcanic arcs, and the direction and angle of dip of present Benioff zones, a diagram (*Fig. III–3*) illustrates several possible arrangements of active trenches and their corresponding volcanic arcs (Katili 1973b).

Taking into account the migration of subduction zones oceanwards, and the possible development of minor spreading centres within a megaplate, *Figure III–4* demonstrates the evolution of island arcs throughout geological time. This diagram exhibits several features which can now be observed in older orogenic systems, such as the intrusion of magmas in older subduction zones giving the impression of the occurrence of granitic magmas in the same belt as the eugeosyncline (*Fig. III–4, a*), the regular zonal arrangement of volcanic and

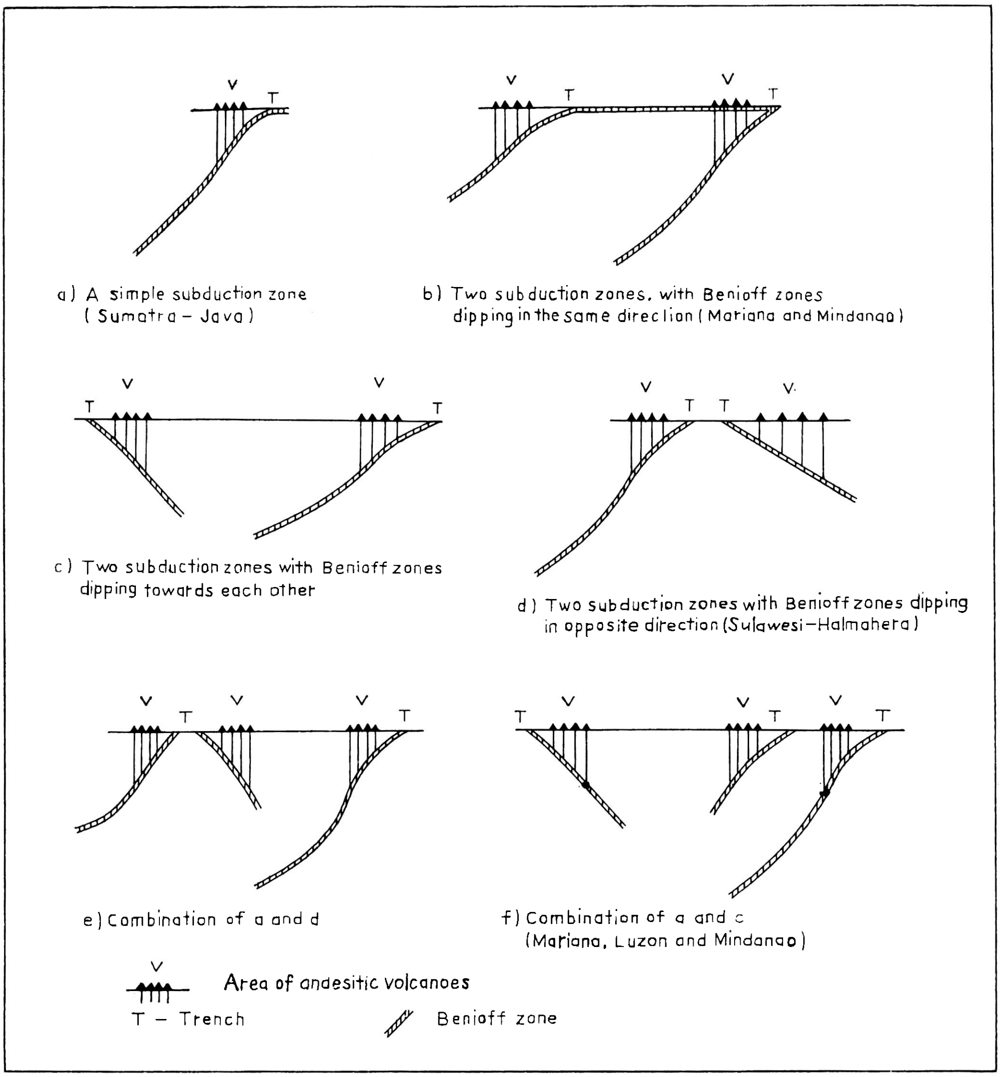

Figure III–3. Different positions of active subduction zones and corresponding volcanic arcs in the Western Pacific and Indonesian regions.

granitic rocks which systematically become younger towards the ocean (*Fig. III–4, b*), a zonal arrangement of granitic rocks which do not necessarily become younger towards the ocean (*Fig. III–4, c*) etc. It also demonstrates clearly how the presence of parallel opposing subduction zones of the same age gives rise to double volcano/plutonic arcs (*Fig III–4, d* and *4, c*).

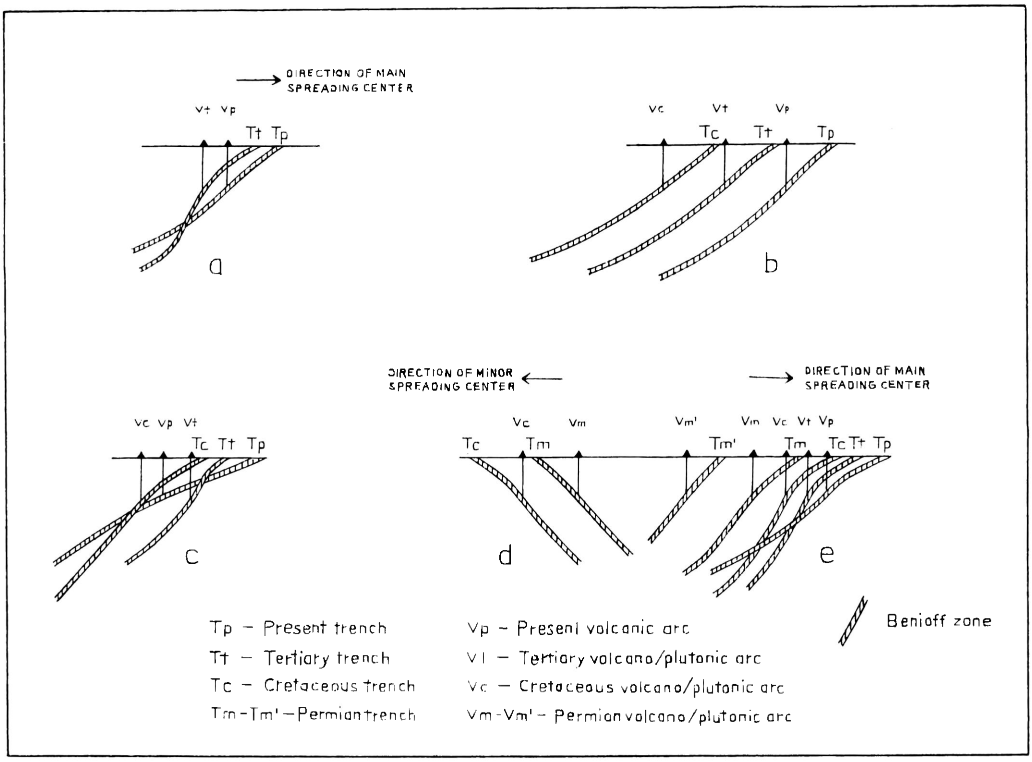

Figure III–4. Evolution of trenches and corresponding volcano/plutonic arcs. a: magmatic intrusion into older subduction zones; b: regular zonal arrangement with igneous rocks becoming younger towards the ocean; c: similar to b, but not necessarily becoming younger towards the ocean; d & e: parallel opposing subduction zones giving rise to double volcano/plutonic arcs (*see text*).

GEOLOGY OF WESTERN INDONESIA INTERPRETED ACCORDING TO THE PLATE TECTONIC CONCEPT

Utilizing the plate tectonic models, the following is an attempt to analyse the geology of western Indonesia. The interrelationship between and across the parallel belt provides valuable clues to solve ambiguities. The models can even be used to predict the distribution and age of certain granitic rocks, as they can be matched with correlative subduction zones.

An interpretation of the present-day geology and geophysics of western Indonesia in terms of plate tectonics has already been made (Katili 1972a) and will not be dealt with in this paper.

The **Tertiary** geology of Sumatra and Java can be interpreted in the following way. The Mentawai Islands, off the west coast of Sumatra, comprise Miocene and younger bathyal and neritic clastic and carbonate sedimentary rocks, lying unconformably upon complexes of clastic sedimentary, low-grade metamorphic and subordinate mafic and ultramafic rocks. The whole rock assemblage is highly deformed, with ocean-ward thrust structures. The sedimentary basin between these islands and Sumatra consists of a sedimentary series up to 6,000 m thick, comprising Palaeocene, Miocene and Pliocene deposits. The Miocene deposits reach a thickness of about 3,000 m and are affected by a high-angle thrust towards the ocean (Katili 1973b). The sedimentary deposits, consisting mostly of marine turbidites and tuffs distributed in narrow belts, have been interpreted by van Bemmelen (1949) and Mitchel and Reading (1971) as deposition in ancient trenches. The arc-trench gap west of Sumatra and south of Java is inferred by Hamilton (1970) to consist of subduction complexes formed in early Tertiary times. The correlative Tertiary magmatic arc may be found on the west coast of Sumatra and south coast of Java where andesites of early Miocene age are intruded by granitic complexes (Westerveld 1941, van Bemmelen 1949, Katili 1972a). The Tertiary age of these granites has been verified by radiometric dating. Results of K/Ar dating in western Sumatra, performed by Overseas Mineral Resources Development Co., Ltd. (unpublished report), point to an age of 42.7 m y for granodiorite east of Panti, and 47.7 m y for granodiorite west of Sontang, both in central Sumatra.

From this short discussion it is obvious that the Tertiary structural zones of Sumatra and Java can be fitted very well into the plate tectonic model. The distance between the Tertiary subduction zone and corresponding magmatic arc however is smaller in comparison with the present-day trench-arc system, indicating a steeper dip of the Tertiary Benioff zone in comparison with the present one (Katili 1972a).

The **Cretaceous** geology of Sumatra and Java can also be interpreted in terms of the model. The pre-Tertiary of Sumatra consists mainly of a complex assemblage of Permo-Carboniferous volcanic and sedimentary rocks. Triassic, Jurassic and Cretaceous deposits in south Sumatra are characterized by limestones intercalated with andesitic pyroclastic rocks and lavas. These deposits are partly overlain by Tertiary sediments, most of which were formed in a shallow marine environment.

Mesozoic granites are abundant in Sumatra, those occurring west of Sontang having been dated at about 89 m y (Katili 1972b) while the granites of the Lassi mass in central Sumatra show an age of 112 $\pm$ m y (Katili 1962). Results of whole rock K/Ar age determination carried out by Mobil Research and Development Co. gave ages ranging from 102 $\pm$ 2 m y to 104 $\pm$ 2 m y for the granites of Pulau Pandan in northern Sumatra. An average age of 88 m y utilizing the Rb/Sr method has been obtained by the University of Kyoto for the granites of the Lampong area, south Sumatra (Katili 1973b).

It is quite obvious that during Cretaceous time Sumatra was a volcano/plutonic arc. No Cretaceous melange has been encountered in Sumatra, but this type of rock assemblage could be present in the outer arc where Cretaceous ultramafic rocks have been reported by van Bemmelen (1949). This implies that the dip of the Cretaceous Benioff zone was towards the continental area, similar to that of the Tertiary Benioff zone.

Java, on the other hand, has no Mesozoic granites. Instead, the pre-Tertiary is characterized by a complex of old rocks which represent a subduction melange of Upper Cretaceous age (Hamilton 1970, Katili 1972b, Soekendar, personal communication). However, from the plate tectonic model, it was predicted that granitic rocks of Cretaceous age should be present off the north coast of Java. This has in fact been verified by IIAPCO (personal communication) who found an age of about 100 m y for offshore granites found in wells drilled northeast of Jakarta. The age determinations on the basement rocks in the northern offshore areas of Java, as described by Katili (1972b), again have reinforced the assumption that north of Java the age of plutonic rocks is about 100 m y.

The Cretaceous volcano/plutonic arc so clearly expressed in Sumatra does not continue into Java, but passes north of it, running parallel to the subduction zone of Java. These two zones merge in the Meratus Mountains of southeast Kalimantan, where Cretaceous ophiolites and radiolarites occur side by side with acidic plutonic rocks. The granites being on the west side indicate a westward dip of the former Benioff zone; however, detailed geological investigations and radiometric age determinations have to be carried out to check this opinion. The dip of the Cretaceous Benioff zone is also apparently steeper than the present one.

The occurrence of late Cretaceous granitic and volcanic rocks in Anambas (about 86 m y), Tembelan (about 85 m y) and Natuna (about 75.2 m y), described by Haile (1971), points to the existence of another Cretaceous magmatic arc than the one in Sumatra. This volcano/plutonic arc is situated east of the West Malaysian-Indonesian tin belt (*Fig. III–5*). The Natuna Swell, together with part of the Kuching zone and the Sibu zone in East Malaysia (Haile 1972) may also be considered as correlative subduction zones implying a west and southward dip of the Benioff zone. A minor spreading centre situated presumably in the present South China Sea can be postulated for Cretaceous time.

The presence of **Triassic-Jurassic** granitic rocks in West Malaysia and the Indonesian tin islands suggests correlative subduction zones to the west, if the dip of the Benioff zone was towards the South China Sea. These could perhaps be represented by the Mesozoic

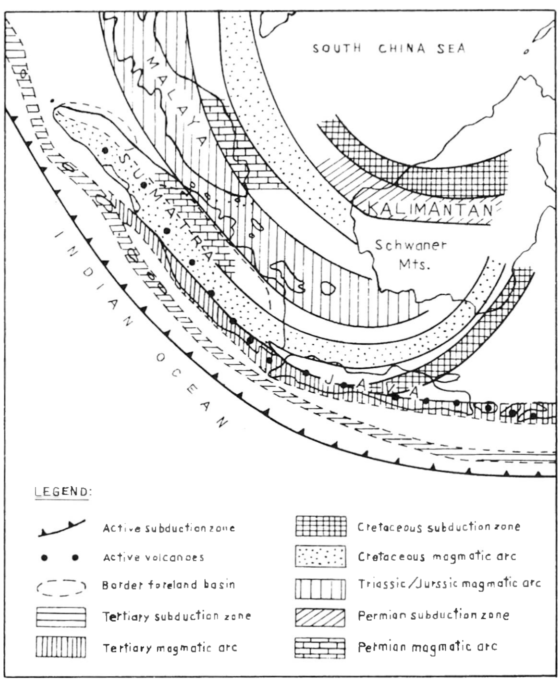

Figure III–5. Subduction zones and magmatic arcs of Western Indonesia.

ophiolites of the Gumai Mountains of south Sumatra.

The granitic rocks of the island of Karimata, situated at the northern boundary of the Triassic-Jurassic magmatic arc, exhibit a slightly potassic character (Esenwein 1933), implying that the dip of the Benioff zone was indeed towards the continent. If this is true then the dip of the Benioff zone is shallower than the Cretaceous one and is comparable to the present-day dip.

Turning to the **Permian** geology of Sumatra, a widely distributed andesitic volcanic-sedimentary sequence is seen, described (Katili 1962, 1969) as the Silungkang Formation. Based on field evidence, Musper (1930) speculated that the granites of Sumpur in central Sumatra are of Palaeozoic age. The results of radiometric dating of granites from the Setiti wells of southern Sumatra (Katili 1972b) are about 298 m y and can be considered as definitive evidence of the occurrence of late Palaeozoic granites in Sumatra. Granites from Sibolga, western Sumatra, yielding ages of 257 $\pm$ 24 m y based on Rb/Sr method, have also been described by Mobil. The plate tectonic model suggests that Permian granites should occur in Sumatra, and here again radiometric dating verifies the suggestion.

Permian andesites and basalts have also been described by Klompe *et al.* (1953) from West Malaysia and West Kalimantan, and this points to the existence of another Permian volcano/plutonic arc in western Indonesia, situated east of the Permian arc in Sumatra. Radiometric dating has proved the existence of late Palaeozoic granites in the Malay Peninsula (Bignell and Snelling 1972). The correlative Permian subduction zone in West Kalimantan might be found in the so-called Danau Formation, an ophiolite-radiolarite rock assemblage having a Permo-Carboniferous age (Klompe *et al.*, 1961). The inferred dip of the Permian Benioff zone in this case is to the west and south, implying the existence of a minor spreading centre presumably situated in the present South China Sea, already envisaged for the Cretaceous.

It is contented that during Cretaceous and Permian times a double opposing arc-trench system was present in western Indonesia. *Fig. III–5* illustrates the position of the subduction zones and volcano/plutonic arcs in this area during the present, mid-Tertiary, upper Cretaceous, Triassic-Jurassic and Permian times.

PLATE TECTONICS AND MINERAL PROVINCES OF WESTERN INDONESIA

In the past, most tectonic schemes of the Indonesian Archipelago were based on the classical theory of geosynclinal subsidence and climactic orogenic movement accompanied by several phases of magmatic evolution.

The geosynclinal cycle was seen as commencing with a long period of sedimentation in several adjacent troughs of diverse character, one of which (the eugeosyncline) was the site of intermittent orogeny and magmatism. The magmatic evolution comprised mainly (i) initial volcanism (ophiolite eruptions and mafic and ultramafic intrusions); (ii) synorogenic plutonism and subsequent volcanism (emplacement of granitic rocks and eruption of andesitic lavas and pyroclastic eruption). Sedimentation, orogeny and magmatism were thus linked in a continuous genetic process.

Based on the assumption that there is an intimate relationship between phases of folding, tectonic styles and epoch of mineralization, Westerveld (1952) published a tectonic scheme of Indonesia comprising four orogens which in everwidening arcs spread themselves towards the Indian Ocean. The Malayan Orogen, of late Jurassic age, which connects the folds of the Sunda Shelf area and the Malay Peninsula, harbours mainly cassiterite, gold and bauxite deposits. The Sumatra Orogen, Cretaceous, running through Sumatra, central Java and southeast Kalimantan, contains pyrometasomatic iron and gold-silver-base metal deposits, iron laterite and diamond-gold placers. The middle Miocene Sunda Orogen, occupying the area of the inner arc of Sumatra and Java, the Lesser Sunda Islands and the western arc of Sulawesi, is characterized by epithermal gold-silver and manganese ores. The Moluccas Orogen, late Cretaceous to middle Miocene, comprising the Mentawai Islands, Timor, the outer Banda arc and eastern Sulawesi, contains silicate-nickel and lateritic iron ores associated with peridotites.

However, when the geology, occurrence and distribution of minerals in western Indonesia are studied in more detail, considerable discrepancies are discovered in the type and age of rocks when the classical concept stated above is rigorously applied to the several orogenic zones. Thus, in the West Malaysian-Indonesian tin belt and the smaller islands of the Sunda Shelf, the "geosynclinal phase" preceding the late Jurassic orogenic movement was not characterized by ophiolites, mafic and ultramafic rocks as might be expected, but by extensive granitic and andesitic rocks of different ages. Neither is it possible to trace the abundant cassiterite deposits found in West Malaysia, Bangka and Belitung to the western part of Kalimantan although these areas were placed in the same orogenic system by Westerveld.

Turning to the Sumatra Orogen, it may be noticed that the "geosynclinal phase" which should precede the Upper Cretaceous orogenic movement was also not characterized by mafic and ultramafic rocks but by a large amount of andesitic volcanic products (Katili 1969). Central Java, which was supposed to belong to the Sumatra Orogen, is characterized by mafic and ultramafic rocks, while the expected Cretaceous granites are completely missing. The contact metasomatic iron ores associated with copper sulphides found in Sumatra cannnot be detected in Java, where the mineral deposits are closely connected with the ultramafic rocks of the Lok-Ulo area of central Java. Southeastern Kalimantan, on the other hand, shows more varieties of mineral deposits comprising contact metasomatic iron ores associated with granodioritic intrusions, and nickel and iron laterites which are intimately related to the mafic and ultramafic rocks.

Ophiolites are not present in the Sunda Orogen, which contains large granitic batholiths of Tertiary age. It is also not possible to detect granites and andesites in the outer arc that would accompany the late Cretaceous-middle Miocene main phase of folding, postulated for the Moluccas Orogen by Westerveld.

The structural sketch map of the western part of Indonesia (*Fig. III–5*), which has been constructed based on the plate tectonic model, might help in solving some of the problems encountered when utilizing Westerveld's scheme.

Based on this model, the following can be said regarding mineral occurrence and distribution in western Indonesia:

(1) Mineral occurrence and distribution in the Malayan Orogen are expected to be complicated since in this area parallel volcano/plutonic arcs of different ages are situated, merging in the Schwaner Mountains of West Kalimantan. The rarity of cassiterite in

comparison to the more abundant occurrence of gold, copper, molybdenum, zinc, lead and iron ores around the Schwaner Mountains, Sambas area and Chinese districts may partly be explained by the different ages and composition of granites in this area.

(2) Mineral occurrences and distribution along Westerveld's Sumatra Orogen show considerable differences, because during Mesozoic time Sumatra and Java were parallel belts which had developed simultaneously: Sumatra at that time represented a volcano/plutonic arc while Java was the correlative subduction zone. These two belts merge in the Meratus Mountains of southeast Kalimantan giving rise to the varieties of ore deposits mentioned earlier. The cassiterite-bearing pegmatite in the Suligi Lipat Kain Mountains in central Sumatra may be associated with the Permian plutonic arc postulated (Katili 1972b) in this area. Similar occurrences have been described by Hosking (1972) in two places along the west coast of West Malaysia.

The dacitic rocks in the South Serayu range in central Java (Reksolegora and Djumhani 1971) cannot be included in the Cretaceous subduction zone but apparently belong to the Tertiary magmatic arc present along the south coast of Java.

(3) Regarding the Sunda Orogen, it should be noted that the Tertiary volcano/plutonic arc occurs both in Sumatra and Java, and consequently should show only small differences in mineralization.

(4) Comparing the western and eastern part of Westerveld's Moluccas Orogen, mineralization is not similar since the Mentawai Islands represent the Tertiary subduction zone, while in the outer Banda arc older subduction zones are present in addition to the Tertiary one. The tectonic history of the Banda arc is very complicated, as collision of older subduction zones with the northward drifting Australian continent has to be taken into consideration.

It is proposed that a new mineral map of Indonesia be constructed utilizing the plate tectonic model and taking into account the temporal changes of location and differing direction and rate of dip of Benioff zones, as well as the possible existence of parallel opposing subduction zones. Several other factors such as the type of country rock, mineral composition, local structures, etc., should also be taken into consideration.

SOME IMPLICATIONS ON THE SEARCH FOR OFFSHORE MINERAL DEPOSITS

It has been mentioned previously that in the plate tectonic model, parallel belts develop together and that each belt has systematic cross-strike variation. The plate tectonic approach emphasizes the search for continuity of structural belts of different types and ages and calls attention to favourable terrains, including offshore areas, in which to look for petroleum as well as metallic ore deposits.

Petroleum, gas and coal are likely to be found in the foreland basins. Kormer shelf areas may also contain carbonate reef reservoirs. The Tertiary foreland basin of western Indonesia (*Fig. III*–5) projects eastward to the Sunda Shelf and significant petroleum discoveries have been made in the shelf basins north of Java.

The location of the Mesozoic foreland basin of western Indonesia, if one existed, can also be established utilizing the plate tectonic model: it is clear that this basin, which would have occupied a smaller area than the Tertiary one, would have been confined to the western part of the Java Sea area. Serious consideration should be given to exploring this area for hydrocarbon deposits as younger granitic intrusion seems not to have affected this post.

The distribution of zircon and rutile in the Sunda Shelf area as described by Hehuwat (1973) correlates well with the occurrence of granitic rocks predicted by the plate tectonic model. The zircon and rutile distribution north of Java shows a simple east-west trend which is compatible with the presence of a single Cretaceous volcano/plutonic arc in this area. In the Sunda Shelf north of the tin islands the distribution pattern of both minerals is more complicated and may be ascribed to the existence of volcano/plutonic arcs of different ages, possessing different orientations.

The termination of the West Malaysian-Indonesian tin belt in the offshore area east of Belitung, and the absence of cassiterite in most parts of West Kalimantan, is also compatible with the geology of western Indonesia as envisaged by the plate tectonic model.

The "molybdenum zone" (Reksolegora and Djumhani, 1972) with traces of tungsten and cassiterite in West Kalimantan, could perhaps be associated with the Permian magmatic arc which may be present in the Schwaner Mountains. If this assumption is correct then cassiterite deposits might be traced in the offshore region which connects the eastern West Malaysia tin belt with West Kalimantan (see *Fig. III–5*).

The analysis given above is based mainly on the assumption that the basement rocks of the continental shelf include the same range of sedimentary, igneous and metamorphic rocks as are found on the land. Marine conditions in the shelf areas, rate of transportation of the detrital heavy minerals and other factors controlling the deposition of more recent unconsolidated sediments have not been taken into consideration.

REFERENCES

Bignell, J. O., and N. J. Snelling, 1972, The geochronology of the Thai-Malay peninsula: *Abstr. Reg. Conf. Geol. Southeast Asia*, Kuala Lumpur.

Bothe, A. Ch. D., 1925, Geologische verkenningen in de Riouw-Lingga Archipel en de eilanden-groep der Pulau Tujuh (Anambas and Natuna eilanden): *Jaarb. Mijnw.*, II, p. 101–152.

Dickinson, W. R., 1970, Relations of andesites, granites and derivative sandstones to arc-trench tectonics: *Rev. Geophys. & Space Phys.*, 8, (4), p. 813–860.

———, 1971, Plate tectonics in geologic history: *Science*, 174, (4005), p. 107–113.

Esenwein, P., 1930, Die Eruptiv, Sediment und Kontakt-gesteine der Karimata-Inseln: *Wetensch. Meded. Dienst Mijnbouw in Ned. Ind.*, No. 24.

Fitch, T. J., 1970, Earthquake mechanism and island-arc tectonics in the Indonesian-Philippine region: *Bull. Seismol. Soc. Am.*, 60, p. 565–591.

———, 1972, Plate convergence, transcurrent faults, and internal deformation adjacent to Southeast Asia and western Pacific: *J. Geophys. Res.* 77, p. 4432–4460.

———, and P. Molnar, 1970, Focal mechanism along inclined earthquake zones in the Indonesian-Philippine region: *J. Geophys. Res.* 75, p. 1431–1444.

Hamilton, W. H., 1970, Tectonic Map of Indonesia, a progress report: *U.S. Geol. Surv.*, Denver, Colo, 29 p.

———, 1971, Petrologic keys to the tectonics of Indonesia: *Abstr. Pac. Sci. Cong.*, Canberra (unpublished).

———, 1972, Plate tectonics of Southeast Asia and Indonesia: *Abstr. Reg. Conf. Geol. Southeast Asia*, Kuala Lumpur.

Haile, N. S., 1971, Confirmation of Late Cretaceous age for granite from the Bunguran and Anambas islands, Sunda Shelf, Indonesia: *Geol. Soc. Malaysia, Newsletter*, No. 30, p. 6–8.

———, 1972, The Natuna Swell and adjacent Cainozoic basins on the north Sunda Shelf: *Abstr. Reg. Conf. Geol. Southeast Asia*, Kuala Lumpur.

Hatherton, T., and Dickinson, W. R., 1969, The relationship between andesitic volcanism and seismicity in Indonesia, The Lesser Antilles, and other island arcs: *J. Geophys. Res.*, 74, p. 5301–5310.

Hehuwat, F., 1973, The significance of zircon and rutile distribution patterns on the Sunda Shelf: *Report of ninth session of CCOP* (in press).

Hosking, K. F. G., 1972, Primary tin mineralization of West Malaysia: *Abstr. Reg. Conf. Geol. Southeast Asia*, Kuala Lumpur.

Isacks, B., J. Oliver, and L. R. Sykes, 1968, Seismology and the new global tectonics: *J. Geophys. Res.*, 73 (18), p. 5855–5899.

Katili, J. A., 1962, On the age of the granitic rocks in relation to the structural features of Sumatra: Crust of the Pacific Basin: *Monogr. Am. Geophys. Union*, 6, p. 116–121.

———, 1969, Permian volcanism and its relation to the tectonic development of Sumatra: *Bull. Volcanologique*, XXXIII, 2, p. 530–540.

———, 1971, A review of geotectonic theories and tectonic maps of Indonesia: *Earth Sci. Reviews*, 7, p. 143–163.

———, 1972a, On fitting certain geological and geophysical features of the Indonesian island arc to the new global tectonics: (in press, Univ. of Western Australia)

———, 1973a, Plate tectonics and the search for mineral deposits in western Indonesia: *CCOP Newsletter*, 1 (1), p. 14–17.

———, 1973b, Geochronology of West Indonesia and its implication on plate tectonics (in press, *Tectonophysics*).

Karig, D. E., 1971, Structural history of the Marania island arc system: *Geol. Soc. Am. Bull.* 82, p. 323–344.

Klompe, Th. H. F., J. Katili, Johannas and Soekendar, 1961, Late Palaeozoic-Early Mesozoic volcanic activity in the Sunda Land area: *Proc. 9th Pac. Sci. Congr.*, 12, p. 204–217.

Le Pichon, X., 1968, Sea-floor spreading and continental drift: *J. Geophys. Res.*, 73 (12), p. 3661–3697.

Matsuda,T., and S. Uyeda, 1971, On the Pacific-type orogeny and its model: extension of the paired belts concept and possible origin of marginal seas: *Tectonophysics*, 11, p. 5–27.

Mitchel, A. H., and H. G. Reading, 1971, Evolution of island arcs: *J. Geol.*, 79 (3), p. 253–284.

Morgan, W. J., 1968, Rises, trenches, great faults and crustal blocks: *J. Geophys. Res.*, 73 (6), p. 1959–1982.

Musper, K. A. F. R., 1930, Beknopt verslag over uitkomsten van nieuwe geologische onderzoekingen in de Padangse Bovenlanden, *Jaarb. Mijnw. Ned. Ind.*, Verh. p. 265–331.

Oxburgh, E. R., and D. L. Turcotte, 1970, The thermal structure of island arcs: *Geol.*

Soc. Am. Bull., 81, p. 1665–1688.

Reksolegora, W. and Djumhani, 1971, Metallic mineral deposits of Indonesia: 12th Pac. Sci. Cong., Canberra.

Sugimura, A., 1960, Zonal arrangement of some geophysical and petrological features in Japan and its environs: *J. Fac. Sci. Univ. Tokyo*, Sect. 2, 12, p. 133–153.

Umbgrove, J. H. F., 1949, Structural history of the East Indies: Cambridge, England, Univ. Press, 63 pp.

van Bemmelen, R. W., 1949, The geology of Indonesia: Government Printing Office, The Hague, 732 pp.

Westerveld, J., 1952, Phases of mountain building and mineral provinces in the East Indies: *Intern. Geol. Congr.*, Report 8th session, Great Britain 1948, Part XIII.

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IV. SONOBUOY REFRACTION MEASUREMENTS IN THE JAVA SEA[1]

By

Zvi BEN-AVRAHAM[2]

(with table IV–1; and figures IV–1 to IV–18)

ABSTRACT

Forty sonobuoy oblique reflection-refraction profiles obtained from the Java Sea were analyzed for velocity and depth of layers and acoustic basement. The profiles, together with concurrent normal reflection profiles, show differences between refraction velocities of the eastern and western Java Sea areas. These regional variations are probably due to differences both in basement type and in the material of the sedimentary columns in the two areas. Fourteen sonobuoy profiles and associated normal reflection profiles are presented and discussed to illustrate the main features of the records.

INTRODUCTION

Forty oblique reflection-refraction profiles were made with expendable AN/SSQ41 radio-sonobuoys in the Java Sea during the June–July 1971 cruise by R/V *Chain* of Woods Hole Oceanographic Institution, concurrently with normal-incidence reflection profiling (*Fig. IV–1*). A description of the equipment and methods used are given in Emery *et al.* (1972); a detailed treatment of the sonobuoy profiles, as well as two-ship refraction data from the deep seas south and east of the Java Sea and the northern Sunda Shelf, and the combination of the sonobuoy results with continuous seismic profiles, gravity and magnetic data are given by Ben-Avraham and Emery (1973). The main purpose of this paper is briefly to summarize the refraction results over the Java Sea; to discuss in more detail the operational method; and to demonstrate some refraction and oblique reflection sonobuoy profiles from this shallow shelf.

The sonobuoy profiles provided information on the depth to acoustic basement, the velocity of sound within it, and velocities at various depths within the overlying sedimentary

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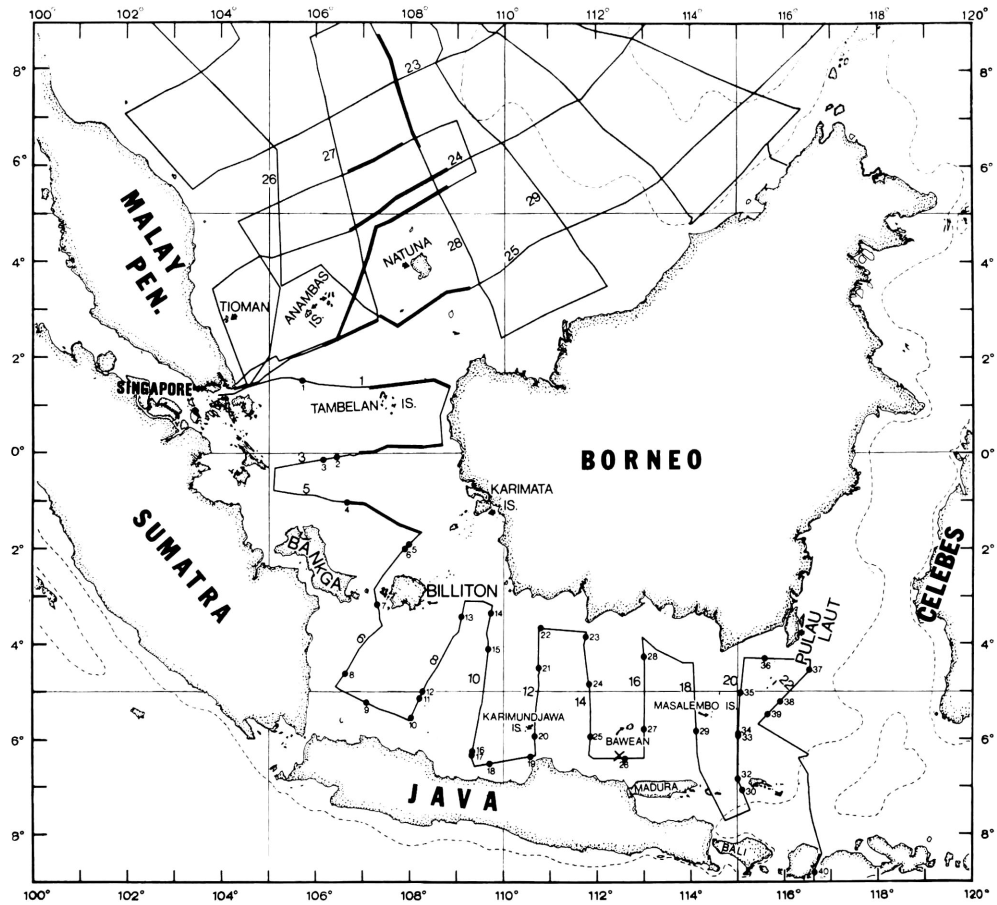

Figure IV–1. Position of traverse lines of geophysical measurements used by Ben-Avraham and Emery (1973). The small numbers indicate the positions of the radio-sonobuoys. The small x south of Bawean shows the position of the well from which a basement sample was used to measure compressional wave velocity in the laboratory (see text).

layers. Both spark and air-gun sound sources were used, with a 10-second firing interval. Because of the shallow water depth (40–60 m) the sonobuoy hydrophones were situated very close to the sea floor, and this combined with the 10-second repetition rate, allowed resolution of relatively small features in the basement and overlying deposits, and the distinguishing of a relatively large number of sedimentary layers having different velocities.

METHOD

The sonobuoy oblique angle reflection profiles are typically 10 to 25 km in maximum range. They were obtained concurrently with normal incidence reflection profiling from the ship, while the ship-sonobuoy separation opened at a speed of about 7 km/hour. The sonobuoy hydrophone signals were transmitted by radio to the ship, where they were recorded on a Precision Graphic Recorder (PGR) and on analog magnetic tape. The technique of using expendable sonobuoys and the velocity and depth calculations using oblique reflection and refraction, has been described by Le Pichon *et al.* (1968) and Houtz, *et al.* (1968).

The data interpretation was started by making several records from the analog magnetic tape using different bandwidth filters. A 10–28 Hz filter passband was found to be the best for data from this area, and was used for laboratory playback of all the buoys. Occasionally, higher filter settings, 25–75 Hz and 100–300 Hz, were used in order to distinguish between reflections whose entire transit was in the water column, such as side reflections, and reflections from buried interfaces that could not be recognized on the normal incidence profile. The final profiles were mounted on cardboard, and the refraction and oblique reflection arrivals traced on clear plastic overlays. Distance-time relations were digitized and the values fed into the computer to plot and compute the velocities within the sedimentary layers and basement, as well as the sediment thickness. All the calculations were done for the refraction arrivals by the slope-intercept method (Houtz *et al.*, 1968).

The horizontal ranges were determined on the assumption of a surface sound-channel velocity of 1.50 km/sec. The bottom topography was unusually smooth and no correction for slope was needed. Subbottom topographic relief in some areas, however, was so large that it had to be considered; if the refracting interface appeared in the normal incidence profile, the dip was approximated by fitting an average line through the reflection data. The velocities were then corrected by assuming that the dips in the layers too deep to be seen in the normal incidence profile were parallel to those observed in the shallower sediments or at the sediment/basement interface.

There were no refraction arrivals from the uppermost sedimentary layer except for sonobuoys 7, 17, 21, 32, and 37. At these stations a velocity of 1.60 km/sec was assumed for the surface layer, in agreement with velocity measurements from wells in the area (*Fig. IV-2*).

The shallow water depth and the long (50–75 ms) duration of the outgoing pulse allowed determinations of wide-angle reflection data in only a few instances. Where such data were available they were used to compute the mean velocity between reflection interfaces (interval velocity) (Le Pichon *et al.*, 1968) for comparison with the horizontal propagation velocities obtained from the refraction data for refraction arrivals from the same interfaces.

COMPARISON WITH VELOCITY MEASUREMENTS ON BASEMENT ROCK SAMPLES

A few basement rock samples from oil company wells in the Java Sea were available. They offered an opportunity to compare the basement velocities obtained by the sonobuoys with those measured on basement samples from the same area in the laboratory, but except one sample (location shown in *Fig. IV-1*), all the samples were too small for the measurement technique. This one sample was saturated with water before the measurements in order to achieve conditions similar to those in nature. The measurements on the water-

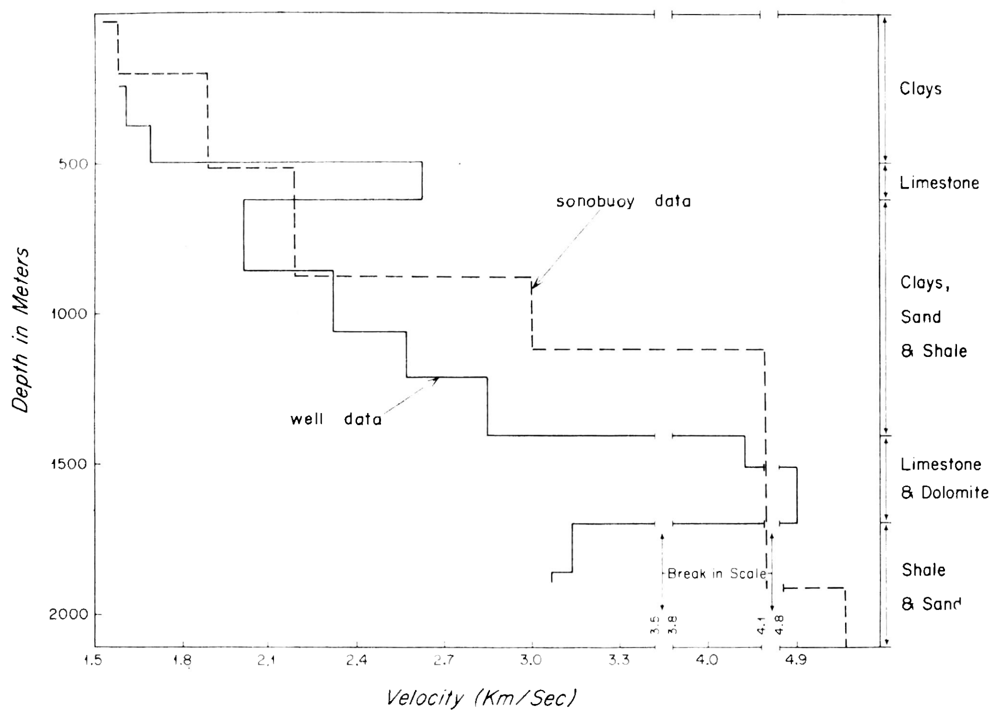

Figure IV–2. An average velocity and lithology log from some wells in the Java Sea basins, compared with an average result of sonobuoys over sedimentary basins (combining results of sonobuoys 8, 9, 10, 15, 21, 22, 26, 29).

saturated sample were made at zero pore pressure, utilizing a technique described by Nur and Simmons (1969). As the sample was obtained from a basin beneath about 3 km of sediment; assuming an average density of the overlying sediments to be 2.5 g/cc, the pressure at the basement would be 750 bar. The observed seismic velocity under pressure of 750 bar was 5.38 km/sec. The closest sonobuoy station to the well from which this sample came was number 26, but no basement velocity was detected at that station. Sonobuoys 25 and 27 were taken at about 70–80 km from the well, and they gave basement velocities of 5.35 and 5.30 km/sec respectively, which are in close agreement with that of the sample measured at the laboratory.

RESULTS

Seven groups of refraction velocities have been identified in the Java Sea (*Table IV–1*), although the complete succession of velocities was detected in no single location. The computations show some layers to be very thin, probably the result of discontinuous sedimentation, folding, and faulting. Because the source pulse length was 50–75 ms, the minimum resolution of layer thickness is about 40 m.

A comparison between velocity logs of some wells in the sedimentary basins of the west Java Sea with sonobuoy profiles over these basins (*Fig. IV–2*), shows a reasonable correlation. Possibly the main reason the refraction profiles show fewer velocity discontinuities as the well logs is the existence of two limestone layers having relatively high velocities which cause velocity inversion. Such inversions cannot be detected by the seismic refraction process.

Sonobuoy refraction velocities listed in *Table IV–1* appear as histograms in *Figure IV–3*. Velocities of the order 1.8—2.3 km/sec were the most frequently observed over the entire area with higher velocities tending to be confined to certain geographic locations. Refraction velocities of 2.5—4.2 km/sec were almost absent in the area between Sumatra and Borneo (*Fig. IV–3*) but they appear in the eastern Java Sea area between Borneo and Java. On the other hand, velocities higher than 5 km/sec appear rarely in the eastern Java Sea, but were more common in the north, between Borneo and Sumatra. The regional variations are probably due to the difference both in basement type and in the material of the sedimentary columns of the two areas.

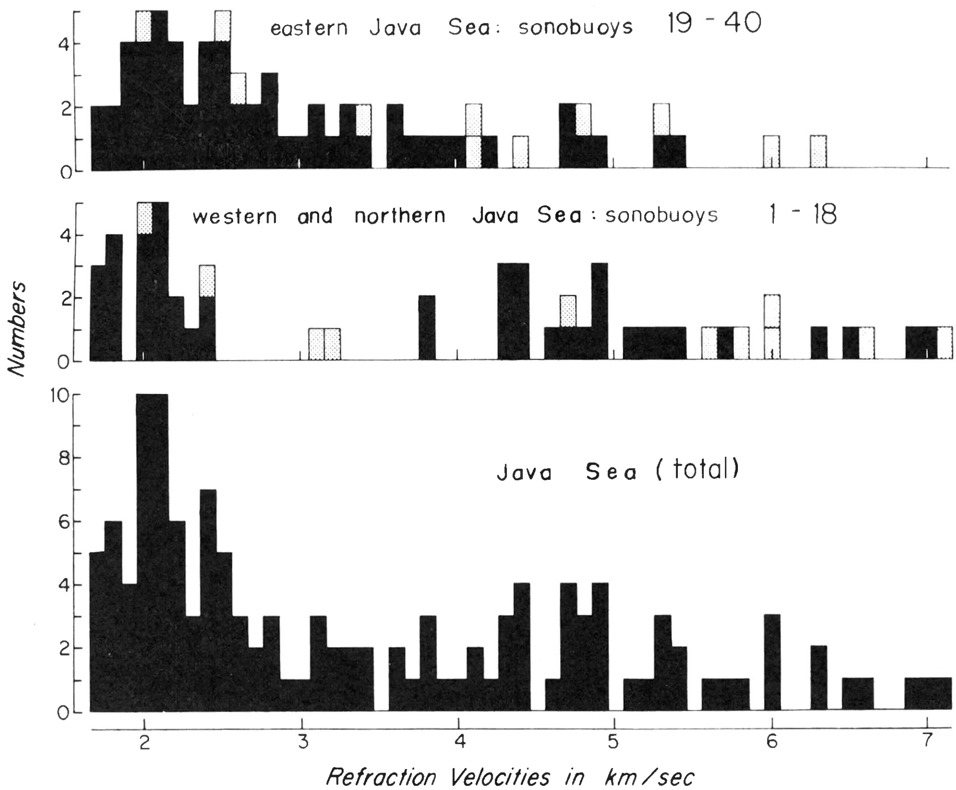

Figure IV–3. Histograms of sonobuoy refraction data from the Java Sea. Stippled entries represent velocities of doubtful accuracy.

SONOBUOY PROFILES

The sonobuoy results served as one of the most important tools for resolution of the subbottom structure, and for this reason some of the sonobuoy records are shown in *Figures IV–5* to *IV–18* together with information determined from them. The fourteen sonobuoy records illustrated were obtained in different structural provinces (*Fig. IV–4*). These records are about one-third of all those obtained on the shelf, and they cover almost all the circumstances in which the buoys proved helpful in determining basement structure and velocity (sonobuoys 3, 4, 5, 7, 20, and 25), detailed velocity profile of the sedimentary column inside the basins (sonobuoys 8, 10, 13, 21, 22, 26), and sedimentary structures (sonobuoys 10, 15, 24, and 26). Each of the accompanying figures shows a sonobuoy profile

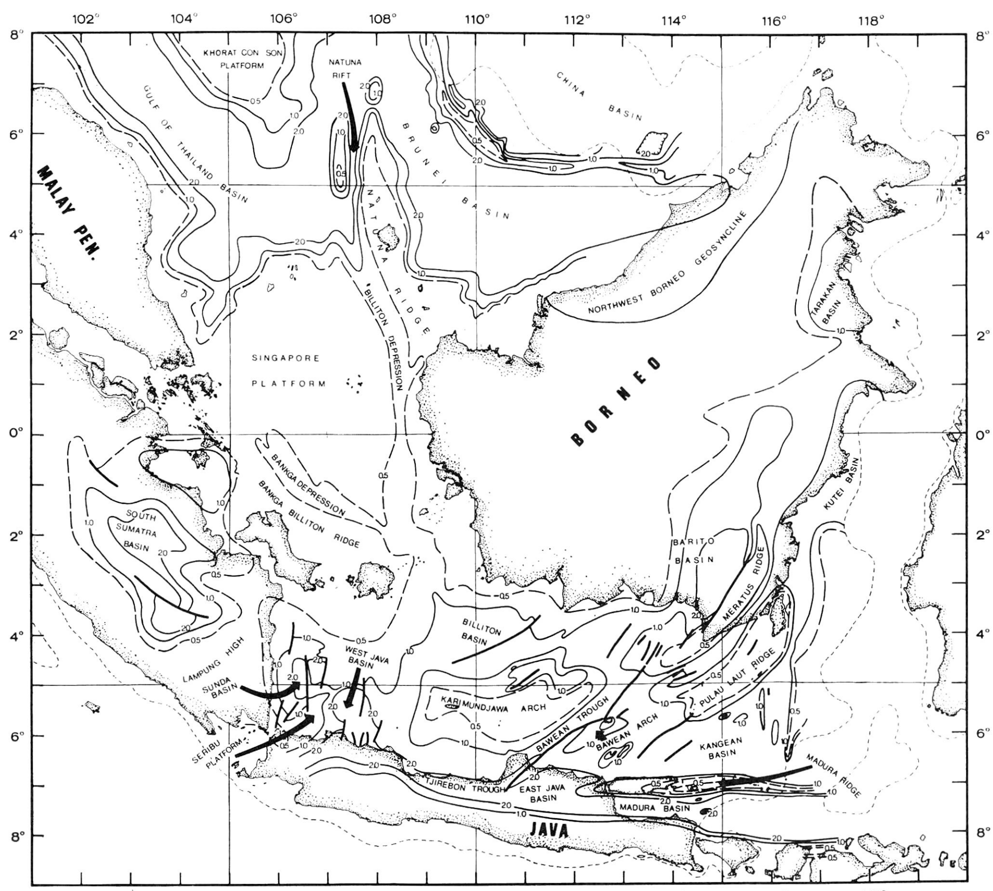

Figure IV–4. Structural contours on top of the basement. Contour interval is one kilometer, with the 0.5 km contour shown by long dashes (after Ben-Avraham and Emery, 1973).

Table IV–1. Sonobuoy refraction data from the Java Sea.

SONOBUOY STATION				Layer Velocity, km/sec								Layer Thickness, km						
Number	Lat.	Long.	Water Depth (m)	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	h_2	h_3	h_4	h_5	h_6	h_7	h_8
1	1.56°	105.75°	62	1.60*					4.44	4.93	5.27	0.09					0.64	0.74
2	−0.04°	106.47°	41	1.60*	1.84				4.28		(6.57)	0.04	0.30				0.75	
3	−0.09°	106.12°	47	1.60*	1.82				3.82		6.96	0.09	0.17				0.86	
4	−0.99°	106.70°	35	1.60*	2.00					5.22		0.05	0.54					
5	−1.84°	108.04°	41	1.60*		2.28			4.87	5.71	6.87	0.14		0.36			0.56	0.46
6	−1.98°	107.90°	38	1.60*	1.73	2.05			4.26	4.59	6.26	0.15	0.05	0.15			0.45	0.37
7	−3.13°	107.32°	54							4.70								
8	−4.57°	106.65°	21	1.60*	2.04	2.15					(5.84)	0.26	0.61	0.13				
9	−5.20°	107.08°	24	1.60*	1.67	2.06		(3.16)		5.39	(7.07)	0.09	0.08	0.84		0.11		1.43
10	−5.56°	108.01°	47	1.60*	1.98	2.04		(3.05)		5.08		0.13	0.58	0.09		0.21		
11	−5.12°	108.22°	41	1.60*		2.05			4.82			0.29		0.48				
12	−4.97°	108.28°	39	1.60*		2.19					6.47	0.32		0.66				
13	−3.38°	109.12°	38	1.60*	1.77	2.38			3.79	4.85		0.26	0.12	0.20			0.32	
14	−3.29°	109.75°	26	1.60*	1.76	2.14			4.36			0.19	0.05	0.22				
15	−4.08°	109.70°	41	1.60*		2.35			4.37		(6.04)	0.33		0.72			1.07	
16	−6.19°	109.35°	51	1.60*	(1.99)	(2.37)						0.11	0.19					
17	−6.29°	109.34°	45		1.71					4.72	(5.57)		0.25					2.03
18	−6.49°	109.71°	45	1.60*	2.10				4.26			0.14	0.16					
19	−6.32°	110.57°	47	1.60*	1.93	2.12	2.66		(4.75)			0.11	0.09	0.18	0.27			
20	−5.93°	110.69°	49	1.60*						4.83	(5.95)	0.09						0.12
21	−4.52°	110.78°	51		1.78	2.18	2.26			5.32			0.19	0.10	0.62			
22	−3.64°	110.83°	38	1.60*	1.90		2.65	2.76	3.98	4.69		0.09	0.48		0.16	0.40	0.46	
23	−3.81°	111.78°	30	1.60*	1.94		2.58		(4.35)			0.19	0.17		0.36			
24	−4.76°	111.84°	56	1.60*					4.19 2.56			0.11						
25	−5.95°	111.88°	66	1.60*		2.18	2.47	3.18		5.35		0.23		0.09	0.56	1.27		
26	−6.38°	112.63°	60	1.60*	1.99	2.37	2.55		3.78			0.07	0.06	0.17	0.74			
27	−5.81°	113.02°	71	1.60*	2.03	2.17		3.26	3.59	(5.30)		0.15	0.08	0.33		0.54	0.70	
28	−4.24°	113.01°	32	1.60*	1.73	1.77	2.46	2.79		4.85		0.05	0.16	0.17	0.34	0.36		
29	−5.69°	114.13°	66	1.60*	1.66	2.14	2.53	3.03	(4.12)			0.10	0.06	0.31	0.33			
30	−7.00°	115.08°	105	1.60*		2.19			3.90			0.10		0.41				
32	−6.82°	115.02°	73		2.14	2.45	2.88	3.12	3.29				0.17	0.06	0.09	0.37		
33	−5.99°	115.01°	50	1.60*	1.95	2.26				(5.40)		0.04	0.14	1.4				
34	−5.88°	115.03°	53	1.60*	1.89	2.36						0.05	0.29					
35	−4.99°	115.07°	30	1.60*					3.64			0.12						
36	−4.27°	115.57°	24	1.60*					3.44	4.73	(6.29)	0.02					0.69	0.26
37	−4.54°	116.56°	58		2.03	2.41							0.25					
38	−5.20°	115.92°	62	1.60*	2.08	2.40			(4.10)			0.15	0.25	0.66				
39	−5.44°	115.69°	58	1.60*	2.06			3.05	3.69			0.13	0.30			0.52		
40	−8.70°	116.67°	84	1.60*	—		2.82					0.15						
Average					1.90	2.21	2.59	3.04	4.09	5.02	6.27							
Standard deviations					0.14	0.16	0.17	0.17	0.43	0.33	0.56							

* assumed velocities. ( ) indicate doubtful refraction velocities. S Shear wave velocity.

and its tracing, together with the normal incidence reflection profile recorded concurrently with its interpretation.

Sonobuoy 3 (*Fig. IV–5*)

Station 3 is located in the area between Sumatra and Borneo. The shape of the basement is difficult to detect on the reflection profile since it is masked by bottom and subbottom multiple reflections. It seems that the basement consists of small isolated massive bodies. The V_9 horizon starts and terminates abruptly and seems to come from a small basement body. The V_7 layer also terminates abruptly and its depth and horizontal extension indicate that it originated from the body shown on the left hand side of the normal incidence profile. A thin veneer of low velocity sediment (V_3, 1.82 km/sec) overlies the basement reflectors.

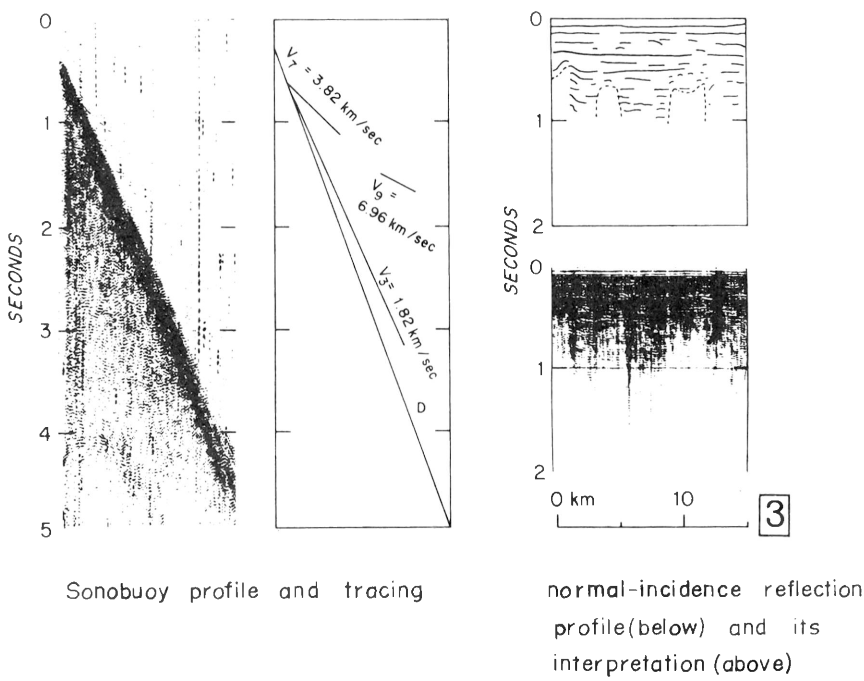

Figure IV–5. Sonobuoy profile from station 3 and normal-incidence reflection profile taken concurrently, showing tracing and interpretation. The following Figures IV–6 to IV–18 are shown in the same format; abbreviations used in the diagrams are D = direct arrival, V = computed velocities, R = oblique reflection, and m = multiple arrival.

Sonobuoy 4 (*Fig. IV–6*)

Station 4 is located about 120 km south of station 3 and in the same general area. Velocities of 4.69 and 5.74 km/sec obviously originate from the same horizon, 5.74 being the result of propagation upslope and 4.69 downslope; the true basement velocity thus lies between these two values. It is indicated as 5.22 km/sec (V_8) in *Table IV–1*. There is an abrupt change in slope between the 5.74 and the 4.69 km/sec lines.

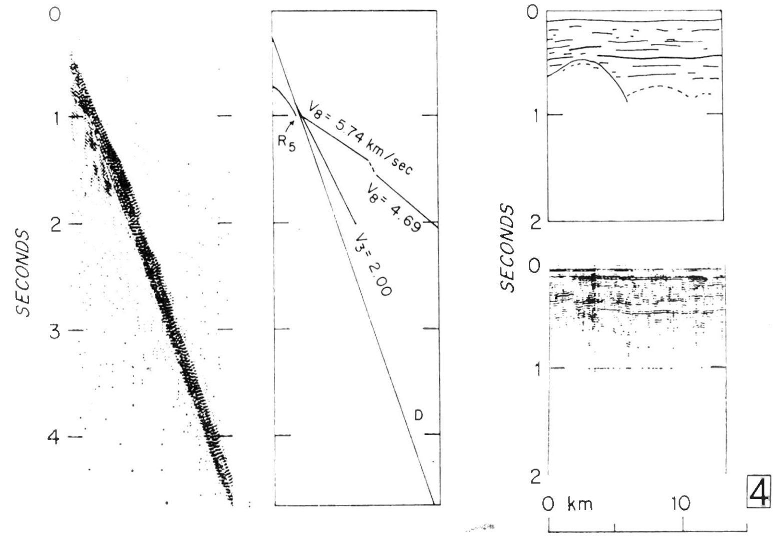

Figure IV–6. Sonobuoy station 4.

Sonobuoy 5 (*Fig. IV–7*)

Sonobuoy profile 5 was taken southeast of station 4 between the Karimata Islands and Belitung (Billiton). The most dramatic feature here is the sudden appearance of the V_8 and V_9 arrivals while those of V_4 and V_7 are continuous from the beginning. V_8 and V_9 originated from a basement structure, part of which may be seen on the normal incidence profile. The positions of these refractions and their slope intercepts suggest that the body extends nearer to the sonobuoy and deeper than is seen in the normal incidence profile. The velocity V_7 (4.89 km/sec) probably belongs to consolidated sediment or limestone. The lowest velocity detected (V_4, 2.28 km/sec) is considerably higher than at any other station in this area except station 1 where no low velocity arrivals were detected.

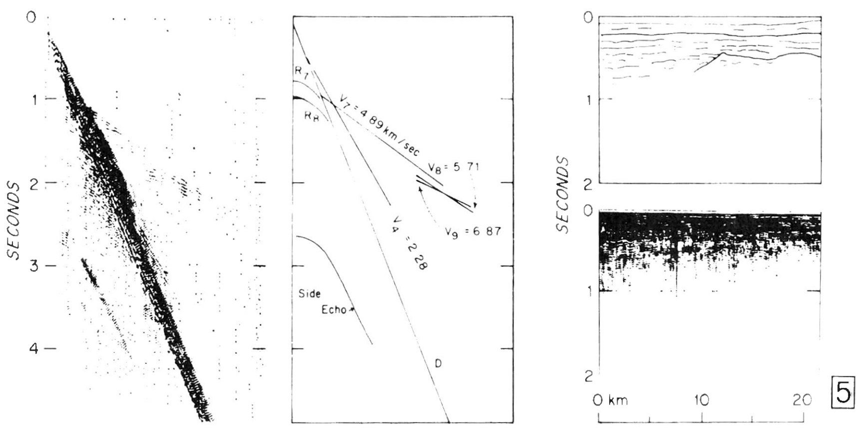

Figure IV–7. Sonobuoy station 5.

Sonobuoy 7 (*Fig. IV–8*)

Sonobuoy profile 7 was taken between the two large granitic islands Bangka and Belitung. Other surveys in this area (Untung, 1967) have shown the granitic basement to be very shallow. The V_8 (4.70 km/sec) refraction is probably from the top of the granite. The refraction arrival shows some undulations (travel-time differences) that probably reflect the basement topography. The 5.97 km/sec refraction arrival appears unreliable, mainly because of the short range over which it was observed. No evidence for such a deeper layer is visible in the normal incidence data.

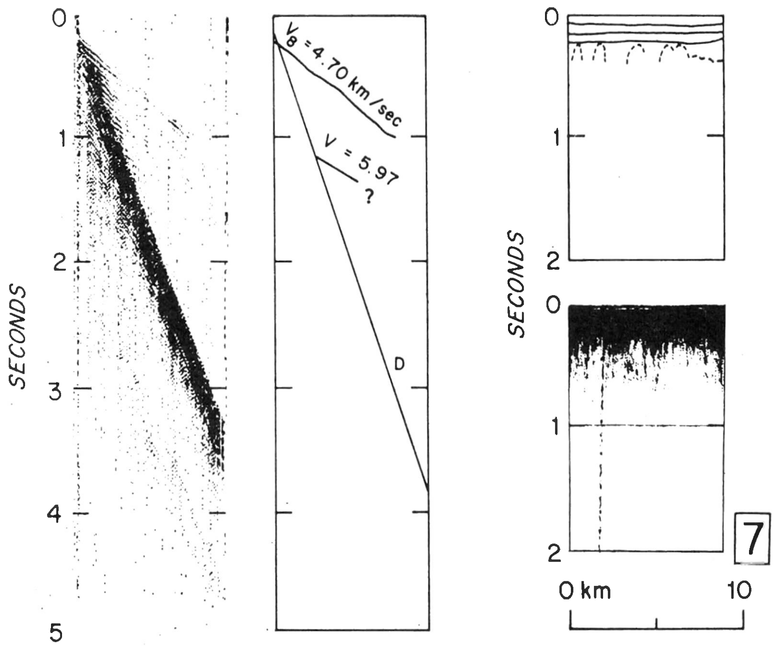

Figure IV–8. Sonobuoy station 7.

Sonobuoy 8 (*Fig. IV–9*)

Sonobuoy 8 is located in the Sunda Basin (*Fig. IV–4*) where offshore drillings show the basin to be the deepest (the Banuwati Deep of Todd and Pulunggono, 1971). The refraction with V_9 (5.84 km/sec) is very weak; however, the oblique reflection is clear and looks as though it corresponds to the strong reflector on the normal incidence profile. The depth of this reflector is approximately the same as that of a lower Miocene limestone reported by Todd and Pulunggono (1971). The refractors with velocities V_3 and V_4, 2.04 and 2.15 km/sec respectively, are very clear and straight and thus seem to belong to well stratified layers. The published stratigraphic sections show that these layers consist of series of sands and clays of lower Miocene and Mio-Pliocene age.

Sonobuoy 10 (*Fig. IV–10*)

Sonobuoy profile 10 in the West Java Basin (*Fig. IV–4*) is similar in many respects to

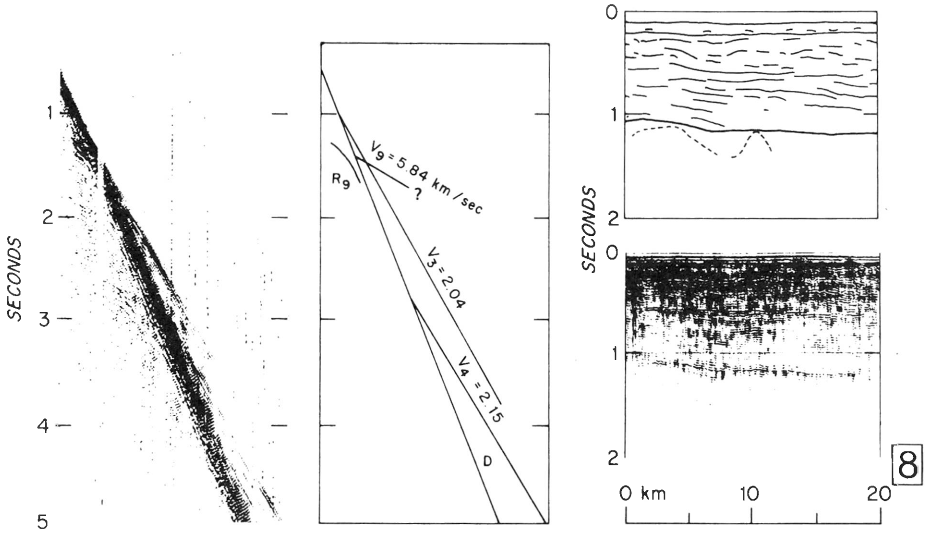

Figure IV–9. Sonobuoy station 8.

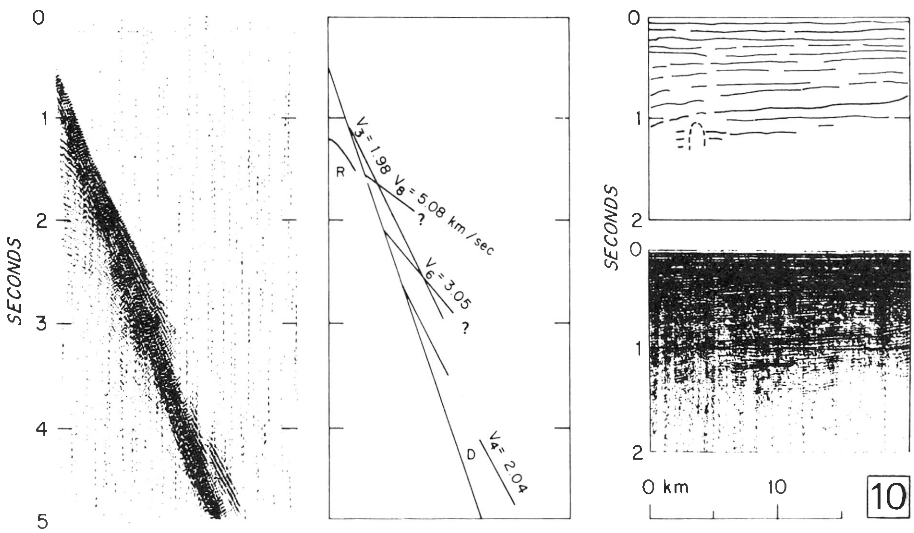

Figure IV–10. Sonobuoy station 10.

that of sonobuoy 8; both are in the same type of structural environment. The reason for presenting this profile is to show the discontinuities of the refraction arrivals V_3, at 1.98 km/sec, and V_4, 2.04 km/sec. Although the normal incidence profile shows apparently continuous horizontal reflectors to 1 sec depth, the refraction arrivals suggest that the layers are discontinuous, which may be due to faulting or to certain changes in the physical properties of the sediments.

Sonobuoy 13 (*Fig. IV–11*)

The sonobuoy 13 record is one of the best obtained in the Java Sea. It was taken southeast of Belitung in an area having no major basement lows or highs. The V_8 arrival (4.85 km/sec) corresponds to a strong reflector which is probably a lower Miocene limestone (Ben-Avraham and Emery, 1973). A discontinuity in this arrival results from some deeper structures that interrupt the limestone horizon. The other arrivals are very clear and continuous, indicating well stratified layers.

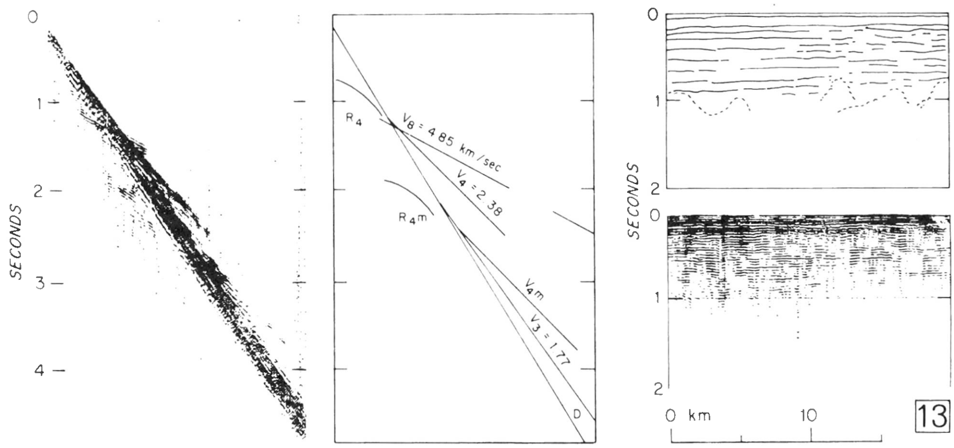

Figure IV–11. Sonobuoy station 13.

Sonobuoy 15 (*Fig. IV–12*)

Sonobuoy profile 15 was taken in the Belitung (Billiton) Basin (*Fig. IV–4*). The slight curvature of the direct arrival indicates a change of ship's speed during the profile, since both velocity and depth information are affected, there is some resultant error. The V_7 arrival (4.37 km/sec) comes from a strong reflector that seems to correlate with a lower Miocene limestone (Ben-Avraham and Emery, 1973). V_4 (2.35 km/sec) originates from a

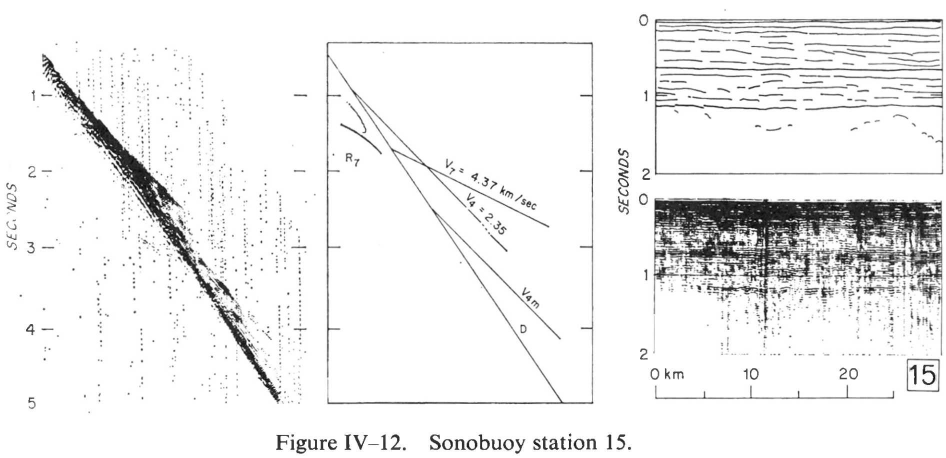

Figure IV–12. Sonobuoy station 15.

much shallower horizon. Both V_7 and V_4 arrivals show discontinuities at the same range, which suggests a vertical discontinuity over most of the sedimentary column. As the normal incidence reflection profile does not reveal this discontinuity, it may have resulted from the change in speed.

Sonobuoy 20 (*Fig. IV–13*)

Profile 20 over the Karimundjawa Arch (*Fig. IV–4*) is similar in many respects to that of sonobuoy 7. The basement is shallow and in places almost reaches the seafloor. The V_8 arrival (4.83 km/sec) shows undulations that may reflect the basement topography. The basement velocity of the basement (V_8) may suggest that it may also consist of a granitic body, as in the Bangka-Belitung area. This conclusion is in accordance with gravity and magnetic data (Ben-Avraham and Emery, 1973). The higher velocity (V_9) may be a part of the V_8 arrival.

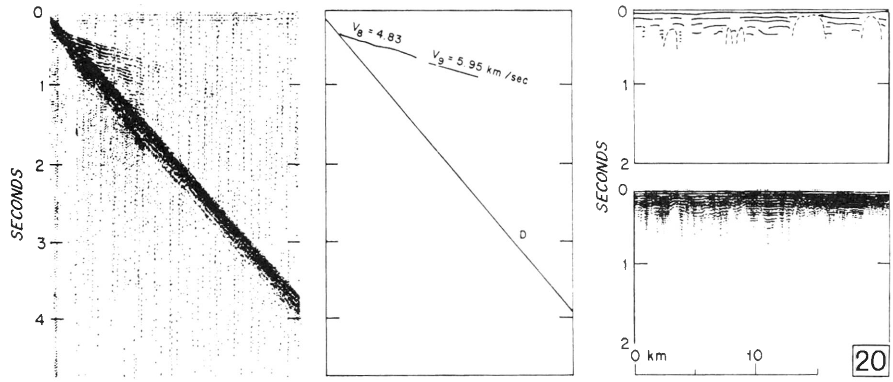

Figure IV–13. Sonobuoy station 20.

Sonobuoy 21 (*Fig. IV–14*)

Like sonobuoy 15 sonobuoy 21 was also located over the Belitung Basin (*Fig. IV–4*).

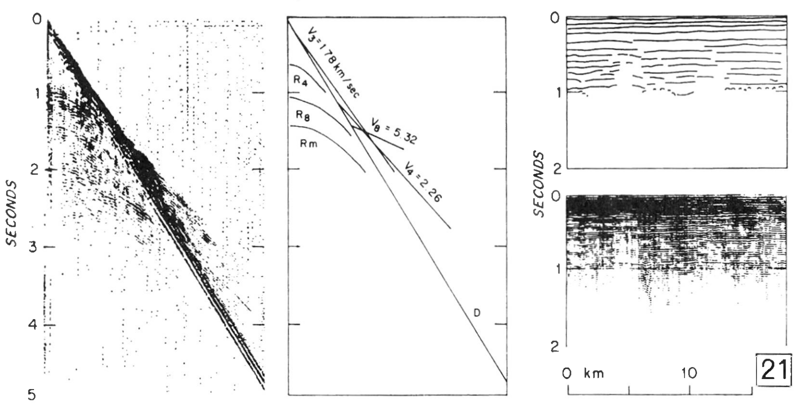

Figure IV–14. Sonobuoy station 21.

The normal incidence reflection profile is very similar to that of station 15, but the refracted arrivals show different characteristics. Here, sedimentary arrivals are clear and continuous, evidence of continuity in the sedimentary horizons. A difference in acoustic basement material may be indicated by the difference in the velocities: 4.37 km/sec for profile 15 and 5.32 km/sec for profile 21. The basement of profile 15 is probably a lower Miocene limestone while in station 21 it may be the granitic flank of the Karimundjawa Arch.

Sonobuoy 22 (*Fig. IV–15*)

Sonobuoy profile 22 is also in the Belitung Basin. This is presented as an example of an almost complete velocity sequence from a sedimentary basin.

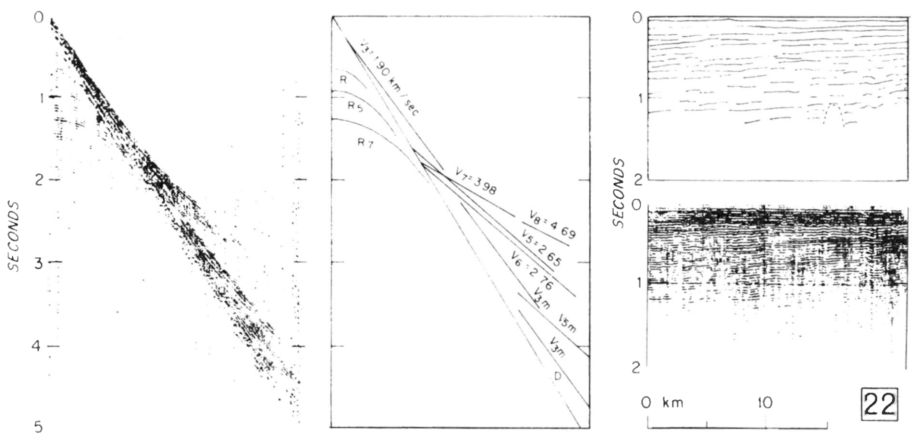

Figure IV–15. Sonobuoy station 22.

Sonobuoy 24 (*Fig. IV–16*)

Sonobuoy profile 24 was taken over the northern flank of the Karimundjawa Arch (*Fig. IV–4*). The V_7 arrival shows travel time excursions that reflect the folding in the sediments seen clearly in the normal incidence profile. The 2.56 km/sec velocity may be an example of shear wave arrival favored by the fact that the layer depth for V_7 (4.19 km/sec) and the 2.56 km/sec arrival are the same and that the ratio of the two velocities is 1.65. Shear waves have been reported previously for continental shelf sediments (Drake *et al.*, 1959).

Sonobuoy 25 (*Fig. IV–17*)

Sonobuoy profile 25 was taken west of Bawean Island (*Fig. IV–1*). Both the normal incidence reflections and the refracted arrivals show evidence of crossing a fault zone. The oblique reflection returns from the fault zone are scattered. This may be a deep fault since it intersects the basement as well as the sedimentary column, and may be the one bordering the Bawean Arch on its northern side (Cree, 1972 and *Fig. IV–4*). The seismic velocities from the sonobuoy should be considered tentative in light of the obvious structural discontinuities since at least some of the arrivals may have come from them.

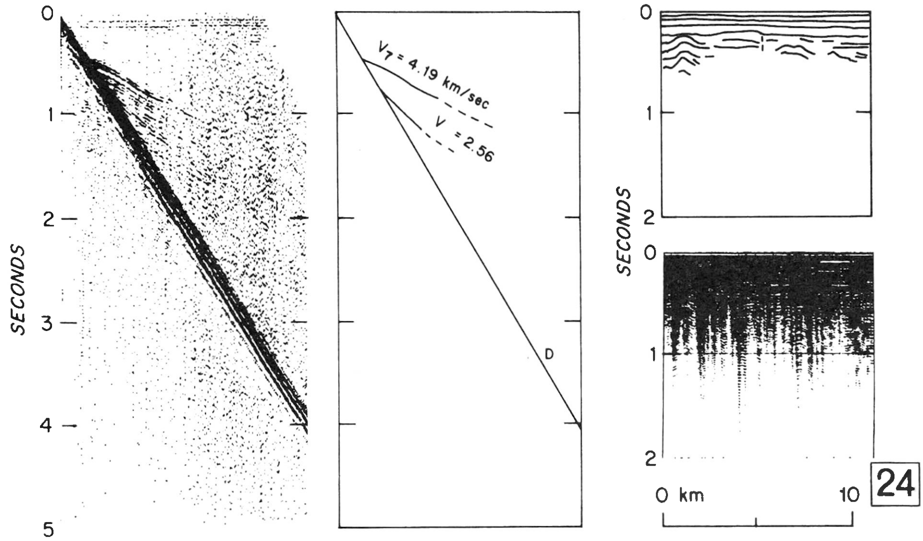

Figure IV–16. Sonobuoy station 24.

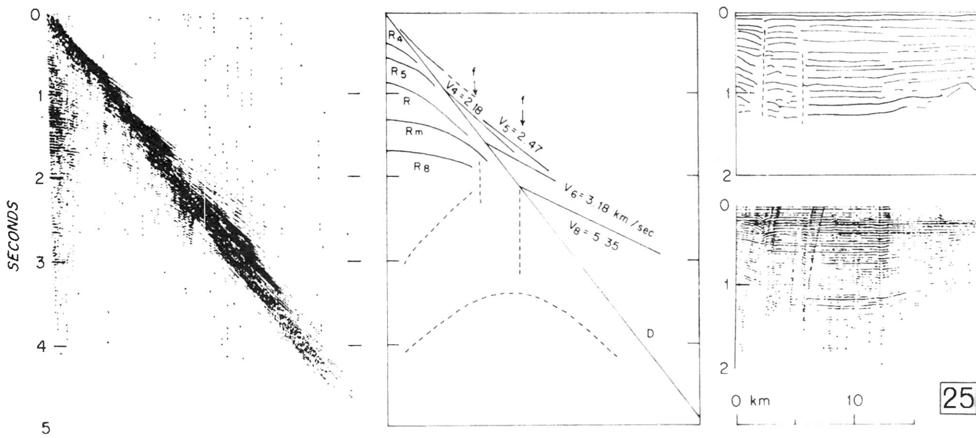

Figure IV–17. Sonobuoy station 25.

Sonobuoy 26 (*Fig. IV–18*)

Profile 26 was taken in the area between Bawean Island and East Java. All the arrivals terminate abruptly probably as a result of a fault shown in the reflection profile. This is one of seven sonobuoy records in which oblique reflections were used for interval velocity and depth determinations.

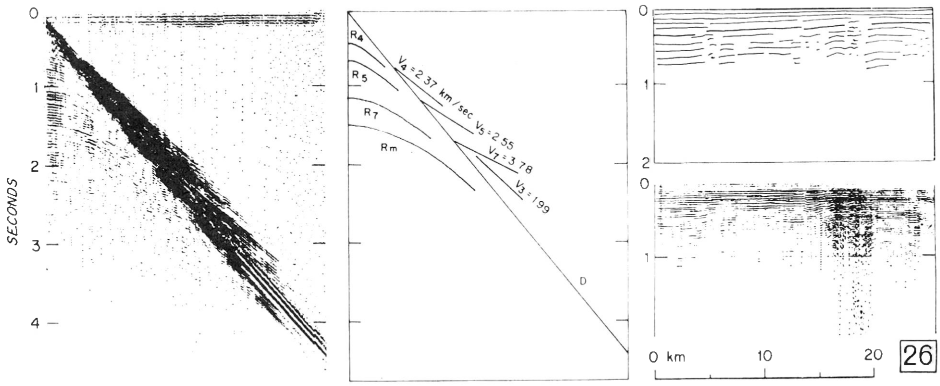

Figure IV–18. Sonobuoy station 26.

REFERENCES

Ben-Avraham, Z., and K. O. Emery, 1973, Structural framework of the Sunda Shelf: *Am. Assoc. Petroleum Geologists Bull.* (in press).

Cree, A., 1972, Industry looks at Java Sea geology: *Oil and Gas Jour.*, vol. 70, p. 72–74.

Drake, C. L., M. Ewing and G. H. Sutton, 1959, Continental margins and geosynclines: the east coast of North America north of Cape Hatteras: *Phys. and Chem. of the Earth*, vol. 3, p. 110–198.

Emery, K. O., E. Uchupi, J. Sunderland, H. L. Uktolseja and E. M. Young, 1972, Geological structure and some water characteristics of the Java Sea and adjacent continental shelf: United Nations ECAFE, *CCOP Tech. Bull.*, vol. 6, p. 197–223.

Houtz, R., J. Ewing and X. Le Pichon, 1968, Velocity of deep-sea sediments from sonobuoy data: *Jour. Geophys. Res.*, vol. 73, p. 2615–2641.

Le Pichon, X., J. Ewing and R. E. Houtz, 1968, Deep-sea sediment velocity determination made while reflection profiling: *Jour. Geophys. Res.*, vol. 73, p. 2596–2614.

Nur, A., and G. Simmons, 1969, The effect of saturation on velocity in low porosity rocks: *Earth and Planetary Sci. Letters*, vol. 7, p. 183–193.

Todd, D. F., and A. Pulunggono, 1971, Wildcatters score in Indonesia: *Oil and Gas Jour.*, vol. 69, p. 105–110.

Untung, M., 1967, Results of a sparker survey for tin ore off Bangka and Belitung islands, Indonesia: United Nations ECAFE, *Report of fourth session of CCOP*, p. 61–67.

(Manuscript received 5 March 1973.)

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V. STRATIGRAPHIC STUDIES BY THE INDONESIAN PETROLEUM INSTITUTE (LEMIGAS)[1]

By

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(with figures V–1 to V–3, in envelop on back cover)

ABSTRACT

Basin studies in four areas of Indonesia have increased the knowledge and understanding of Cenozoic stratigraphy of both surface and subsurface strata. In *Northeast Java*, three cycles of sedimentation mostly separated by unconformities are described and boundaries defined where possible. The biostratigraphy of the *Jambi area, Sumatra* is dealt with on the basis of benthonic and planktonic foraminifera. Biostratigraphic correlation in *Northeast Sumatra* is given from Palaeogene to Pleistocene. In *Kalimantan*, age determinations based on few and scattered samples are given as a preliminary biostratigraphic scheme, using larger foraminifera and planktonic foraminifera. The "letter stages", biostratigraphic assemblage zones based on larger foraminifera and molluscs, are explained, and the planktonic foraminifera zones are defined.

INTRODUCTION

The general activities of the Indonesian Petroleum Institute (Lembaga Minyak dan Gas Bumi, LEMIGAS) have been outlined in a recent document in the CCOP Report of ninth session. Basin studies undertaken in the last few years have provided important knowledge of petroleum areas, and the main parts of the stratigraphic studies are closely related to the basin studies. Since January 1969 the following basin evaluations have been carried out by LEMIGAS in co-operation with PERTAMINA, the Indonesian National Oil Company:

1. Northeast Java Basin (1969))
2. Jambi Basin, Sumatra (1970))
3. Kalimantan Basin (1970/71)) completed
4. North Sumatra Basin (1970/71))

[1] Revised July 1973

5. Java Sea area (1971/72))
6. Central and West Java area (1971/72)) not yet completed

Additionally, LEMIGAS also undertakes research and consulating work for PERTAMINA and some of its contractors.

During the above-mentioned activities some knowledge has been gained about the Cenozoic stratigraphy of these areas, and reports were prepared for internal use. This paper is a compilation of reports on the first four basin areas, including explanations of the Letter Classification and Planktonic Foraminifera Zones used in the stratigraphy of these basins. The author has been especially engaged in the Northeast Java Basin study, while studies of the other basins have been carried out by a team of LEMIGAS geologists and palaeontologists.

NORTHEAST JAVA BASIN

The area under consideration is situated in the northeastern part of Java and stretching from Muriah volcano to the island of Madura, and between the northern coast and the main east-west volcano line as its southern limit. Islands east of Madura (Raas, Kangean) and north (Bawean) are included in the report area. Nowhere high in altitude (generally 200—300 m above sea level), the area consists of low Tertiary hills, corresponding generally to structurally positive areas (anticlinoria). Between the Tertiary hills are plains, with fluviatile deposits, corresponding to structural depressions. As a consequence of the geological structure, the morphological trend is roughly east-west. The major rivers crossing the area are the Solo and the Brantas.

The Northeast Java Basin subsided strongly during Tertiary and Pleistocene, and filled up with more than 5,000 m of sediments, this figure corresponding to the sedimentary section known in the northern half of the basin. It probably amounts to much more, including the lower unknown part of the total sequence down to the basement, and much more in the southern depression.

The known sedimentary column in the Northeast Java Basin includes strata of Te to Tg-h age[2], Chattian (Oligocene) to Pleistocene, outcropping or penetrated by drilling. Only in Sangiran has older rock been encountered, nummulitic limestone of Tcd age in exotic blocks from a mud volcano. In fact, it seems reasonable to postulate a complete cycle of sedimentation, including Tab-cd sequences, underlying the already known series, by analogy with other basins in Indonesia (Southwest Java, South Kalimantan). Whether such a Tertiary sedimentary cycle either overlies older deposits or rests directly on an igneous/metamorphic basement is entirely hypothetical. A post-Laramide unconformity is probable.

The lithology of the cycle as a whole is mostly marl and clay, with sandy and carbonate layers. The latter are especially widespread in the high area of Tuban to Madura where reefal limestone was deposited during upper Tf and Tg-h stages. Except in this part of the basin, a major and general postorogenic unconformity is unknown; instead quite continuous sedimentation took place in a bathyal to neritic and paralic environment. Several

[2] The van der Vlerk letter classification is dealt with in later section of this paper.

cycles can be defined at certain times and in some places such as in Madura or the Paciran area, but more generally a simplified picture of the sedimentation sequence can be gained by considering three main periods of deposition:

Deposition of Kujung[3] Marls and Orbitoid Limestone (OK), (Oligocene-Lower/Middle Miocene)

Deposition of *Globigerina* Marls (Gl), (Upper Miocene-Pliocene)

Deposition of Marls and Clays (Mt and Trinil), (Pleistocene-Holocene)

The boundary between the first and second period may be only an oscillation with an emergent tendency, but in the eastern part of the North Rembang Anticlinorium (Tuban-Madura) it corresponds to a real epirogenesis with important erosion which started in upper Tf time and proceeded in some areas during all Tg.

The boundary between the *Globigerina* Marl and Marl-Clay sequences also corresponds to an epirogenic phase accompanied by erosion.

The three sequences from lithological units which are considered in this report as having **formation** status; so, with the oldest at the top, the succession becomes:

Rembang Formation
Kawengan Formation
Tambakromo Formation

Lower Tertiary, Ta-b-c-d

In the Northeast Java Basin, Eocene and Lower Oligocene deposits are not exposed, the only occurrences having been found in exotic blocks from Sangiran dome, Jiwo Hills, West Progo mountains and Nanggulan area, Lokulo area and Bayah area.

Rembang Formation (Oligo-Miocene, Te-Tf2/Tf3)

The Rembang Formation corresponds to the van de Vlerk letter stages Te and Tf1-Tf2 and part of Tf3, to benthonic zones 17/16 to 8, or, in the European stage nomenclature, to the Chattian-part of Helvetian (Oligocene and Miocene). It corresponds to the former 1952), and, apart from the Ngrayong (Ngrajong) Sand at the top, also to the Tuban Formation of Brower (1957), (*Fig. V-1*). The Kudjung and OK (= Orbitoid Kalk) Formations are now regarded as members of the Rembang Formation, re-named the Kujung Member and the Orbitoid Limestone Member (which has lower and upper divisions). The boundary between the two members is determined by the appearance of Te fossils (Kujung) when descending the sedimentary sequence, so the limit is a palaeontological one.

In the Rembang-Tuban area, the whole sequence is composed of marls and clays, calcareous marls and intercalations of Orbitoid Limestone; these intercalations are developed both in the Kujung Member as well as the Orbitoid Limestone Member, and there is no clear evidence for a subdivision on a lithological basis. The environment of deposition was bathyal to neritic and shallow water. Upwards, sandy material is more and more widely distributed, with a paralic to littoral facies becoming predominant (Ngrayong Sand).

Kujung Member. Based on the presence of Te fossils and corresponding to benthonic zones 17/16–13, the Kujung is still poorly known; it outcrops only in the Tuban-Paciran area and on Madura (Tanjung and Rancak anticlines). To the east, the Kujung is also

[3] Formerly spelled *Kudjung*.
[4] Bataafische Petroleum Maatschappij, Royal Dutch/Shell Group.

known in Raas and Kangean Islands, to the north on Bawean Island.

As a consequence of the few local occurrences of the member it is impossible to determine exact limits, thickness of sequence and provinces of facies distribution at the time of deposition. Also, the basal part has never been encountered.

The Kujung Member is also designated as "Base Marl" by B. P. M. The following threefold subdivision is adopted here:

Lower Kujung (Te 1–3, benthonic zones 17? and 16)

Middle Kujung (Te 4–5, benthonic zones 14–15)

Upper Kujung (Te 5, benthonic zone 13) including the Prupuh Limestone and overlying marl layers

Kujung localities are: Tuban-Paciran area (North Rembang Anticlinorium), Madura Island (Rancak anticline), Raas Island, Kangean Island, Bawean Island.

Orbitoid Limestone Member. This broadly consists of clays, shales, marls and Orbitoidal limestone (= Orbitoid Kalk = OK). The presence of quartz sandstone, increasing in percentage upwards, could be one of the main lithological differences with the Kujung Member. The progressive appearance of neritic to paralic deposits (Orbitoid limestone and sandstone) in the upper part of the sequence, following bathyal conditions in the Kujung, supports the idea of only one large Kujung-Orbitoid Limestone depositional cycle in the Rembang area.

The base of the unit corresponds to the Te/Tf boundary and benthonic zonation 12/13 boundary. The unit includes Tf2 and the lowermost part of Tf3. The upper limit adopted here is the top of zone 8, including 8a (Ngrayong Sands) from benthonic zonation. Being still controversional, this limit will be discussed further.

The member will be subdivided into Lower Orbitoid Limestone, including zones 8d to 12 and Upper Orbitoid Limestone including zones 8a-b-c.

Besides large and benthonic foraminifera, the Orbitoid Limestone Member is characterized by *Globorotalia trilobus*, *G. insueta-bisphaericus*, *G. fohsi barisanensis and G. fohsi fohsi* from the planktonic scale, giving a lower Miocene age (Burdigalian and partly Helvetian, in European stages).

Lower Orbitoid Limestone. Generally, in the central part of the North Remband Anticlinorium and the Middle Rembang Anticlinorium (west of Tuban), the lithology consists of predominant marine grey shales and marly shales with sandy limestone and sandstones. In the lowermost part, some of the latter are glauconitic while some carbonaceous material is associated with the sands. The maximum thickness is known from *Tawun-5* well, where a corrected thickness of more than 2,300 m of strata correspond to zones 9–10–12.

In the North Rembang Anticlinorium, in the Tuban-Paciran area, eroded Kujung Member is directly overlain by the Karren Limestones of the "*Globigerina* Marl" sequence. However, around this uplifted anticlinorium some sections of Lower Orbitoid Limestone, conformably overlying Kujung, are exposed (Prupuh, Kranji). Other localities are Madura and Sapudi Island. Eastwards a very thin section of Lower Orbitoid Limestone is still present on Raas Island but wedges out before Kangean Island.

Upper Orbitoid Limestone. The lower contact with Lower Orbitoid Limestone is only a palaeontological limit, while the upper limit is controversial. There are two main conflicting hypotheses: the Ngrayong Sand capping the sequence is either a regressive facies ending a sedimentary cycle, or a transgressive one initiating the "*Globigerina* Marl" sequence (see below), at the base of the Platen complex-Wonocolo series. The littoral-type environment of the Ngrayong is a valuable argument in both cases.

In an arbitrary type-section taken from Tawun-Cepu[5] area, the general facies consists of grey-brown to violet and chocolate-brown clays, Orbitoidal limestones and quartzose sandstones. The main development of limestone and quartzose sandstones is observed in the upper parts, corresponding to an increase in neritic to littoral-paralic conditions during deposition.

The thickness of Upper Orbitoid Limestone in this area decreases from 800–1,000 m in the north to 400 m (?) in the south. Locations: Tawun-Cepu area, Jepon, Kawengan, Candi, Madura.

Kawengan Formation (U. Miocene-Pliocene, Tf3-Tg).

Whether the Ngrayong Sand is a regressive or transgressive deposit, the Upper Orbitoid Limestone, as a whole, represents the end of a large depositional cycle, its regressive character being indicated by progressive upward development of neritic to paralic facies (Orbitoid limestone and quartzose sandstone with carbonaceous material).

A new period of sedimentation was initiated in late Miocene (Tf5) resulting in the deposition of the Kawengan Formation, formerly referred to as the Globigerina Marl (G1), corresponding to renewed subsidence from the neritic deposits of the Mundu. Depending on the area between these two limits, only oscillatory movements occurred, with a regressive tendency in the Upper Orbitoid Limestone, or a real break of sedimentation. It may be assumed that some epirogenic movement was responsible for erosion at the top of Ngrayong Sand in the Kawengan field. Such movements were probably earlier in Madura, where intra-Kujung or Orbitoid Limestone unconformities are observed. Also, in Tuban-Paciran area, similar movement is indicated on the southwestern flank of the Kujung anticline by the transgression of Upper Orbitoid Limestone directly onto the Prupuh Limestone. The geological history of the Madura-Paciran area shows that such palaeomovements were only the beginning of continuous instability and epirogenesis accompanied by erosion during part of Kawangan deposition, explaining the unconformity of even Pleistocene reefal limestone directly above eroded Kujung or Orbitoid Limestone sequences.

Generally, the Kawengan Formation consists of marls very rich in Globigerina, with some limestones mostly distributed in the lower part including a widespread calcarenite in a large part of the basin during Ledok time (top Tf3-base Tg).

Northwards in the Tuban-Paciran area, a reefal limestone (Karren Limestone) varying in age from zone 6 to zone 4 (and passing up into zone 2, Pleistocene) is developed on a positive carbonate shelf. This province corresponds to the above-mentioned disturbed and eroded area during Kawengan time. The limit between this platform and a calcarenitic-marly intermediate province is a submarine flexure, a very sharp hinge-line corresponding to the present Kujung fault zone.

Southwards another flexure is responsible for a strong increase of thickness south of Middle Rembang Anticlinorium, especially in the Kendeng zone. In this southern area marls and clays are developed, partly invaded by tuffaceous sandstones during the equivalent

[5] Formerly spelled *Tjepu*.

of the lowest part of the sequence.

The whole Kawengan Formation corresponds to Tf3 and Tg, and represents the palaeontological zones 7 to 4 of Hecht. A planktonic zonation is proposed in *Figure V-1*. According to the correlation, the series corresponds to upper part of the Helvetian, the Tortonian, Messinian and Pliocene (European stages). The whole unit corresponds to the Kawengan Formation of Brouwer (1957) but excluding the Ngrayong Sand.

A traditional undiscussed three-fold subdivision into members has been proposed for the Kawengan Formation, based on lithological and palaeontological criteria. From bottom to top, these are: Wonocolo (Wonotjolo) Member (zones 7–6), Ledok Member (zone 5) and Mundo Member (zone 4). This subdivision is only valid in the western part of North Rembang Anticlinorium and in almost the whole Middle Rembang Anticlinorium. In the other major provinces this subdivision is not suitable, either because the series is represented by a comprehensive lithological unit (such as the reefal Karren Limestone in the Tuban-Paciran area) or because important changes in lithology occur, leading to different formation names (as in the Kendeng zone, south of the southern flexure).

Wonocolo Member. In the Cepu-Kawengan area, the lithology consists of green clays and fine sandy marls, with sandy limestones (the Platen Complex) and fine-grained quartz calcareous sandstones developed mostly in the lower part. Other locations are: Tawun, Mahindu, *Bojonegoro-1* well, Gunung Anyar. The thickness of the Wonocolo increase from north to south from less than 400 m at Tawun to 910 m (Tobo 35) and 1,300 m in the Bojonegoro area.

Ledok Member. In Cepu-Kawengan area the general lithology consists of calcarenitic sandstones interbedded with green to grey sandy marls. In the upper part, cross-bedding is common. At the top of the unit, coarse glauconitic sandstone including quartz pebbles form a good and quite constant marker horizon ("grove groene lagen"). The lower contact with the Wonocolo is not very easy to define. The average thickness of the member is between 150 m and 200 m. Other locations: *Bojonegoro-1* well, Giri Limestone of Sekarkorong.

Mundu Member. The lithology of the Mundu Member is quite constant and local changes are very few, so that the description is valid for the whole Middle Rembang Anticlinorium and western North Rembang Anticlinorium. It consists of unstratified, yellow-white weathering, greenish-grey marls. An apparent sandy character is due to the high content of Globigerina.

Karren Limestone. In the Tuban-Paciran area (North Rembang Anticlinorium) reefal deposits (Karren Limestone) developed during Kawengan time. The Karren Limestone consists of granular, white-grey, cavernous limestone, bearing pelecypods, gastropods, coral and mostly lithothamnium algae. Generally the limestone is not bedded put locally exhibits cross-bedding. It is very often recrystallized, sometimes dolomitized and frequently conglomerates mark the basal unconformable contact.

Palaeontological zone subdivision cannot be defined in the Karren Limestone due to the lithological character of the unit. Lateral interfingering with the three members of the Kawengan Formation is only known near Jogjogan and on the southern flank of Mahindu, west of Rangel. In this area, the equivalence of the Karren Limestone with almost all of the Kawengan Formation (zones 6 to 4) can be ascertained.

The greatest thickness, 200 m, is known on the southern flank of Mahindu. Around Prupuh it is about 50 m.

Tambakromo Formation (Pliocene-Pleistocene, Th-Th)

Epirogenic movement, accompanied by the erosion of the uprising structures, took place after Kawengan time, marking the division between Pliocene and Pleistocene. In the low depressions preserved from erosion, a local deposit of calcarenitic sand composed only of foraminifera tests corresponds to the Selorejo Member (zone 4a) and contains *Globorotalia truncatulinoides*. Mostly developed north and northwest of Cepu area, it should be equivalent of the Calabrian stage in the European succession.

Following this tectonic phase a large transgression took place again, at the beginning of Pleistocene. Marine shallow water clays were deposited in a large part of the basin, frequently unconformable upon eroded structures of Kawengan Formation; volcanic material was supplied at the end of this period, while reefal sedimentation of Karren Limestone continued or started again after a hiatus in Tuban and Madura.

The representative deposits of this period are mostly clays and marls. The Tambakromo Formation corresponding to benthonic zones 2 and 1 of Hecht, was formerly known as the Marl-Clay or Mt (= mergelton or marl-clay), and was subdivided by B. P. M. into a lower part, the Tambakromo Member (zone 2) and an upper part, the Turi-Domas Member (zone 1) (see *Fig. V–1*). According to some authors a coquina limestone (the Malo Limestone) marks the separation between the two stages in the Cepu area, but it seems more likely that it occurs at several levels in the sequence.

Sedimentation may have been continuous from Kawengan time, with the intervening Selorejo deposit in the low areas, where the Tambakromo is generally thicker than on the anticlines. Unconformities are probably more common, the most important one being in the Surabaya area (Tambakromo-zone 6 contact, in Gunung Anyar) and in Paciran-Madura areas (zone 2-zone 7 contact in Madura).

A type section of the Tambakromo Formation can be taken from the Cepu area, where the lithology consists of homogeneous blue-grey clays with very fine laminated sand. The sequence is frequently barren of fossils, if present, only foraminifera are generally reported. At Tambakromo the thickness reaches 125 m. The upper part is mainly marls, including streaks of littoral shell limestones (Malo Limestone) which presents some reefal characteristics.

The former Turi-Doman Member is now divided into two members. The **Turi Member** is an extremely variable sequence of interbedded clays, marl clays, sandy marls and sands. The Turi is up to 200 m thick in Cepu area. The **Domas Member** was defined in the Surabaya area where it possibly overlies or replaces the Turi. The lithology consists of interbedded clays, sandy clays, sands and tuff-clays. Limestone beds are characteristic in the upper layers.

JAMBI AREA, SUMATRA

Lithostratigraphy and palaeogeography

The Jambi basinal area is a part of the broad South Sumatra Basin. Broadly speaking, the strata consist of shales, clays and sands with some carbonate and coal layers, Tertiary in age and unconformably overlying metamorphic rocks. The total thickness of sediment is up to 5000 m. Minimum thicknesses are present on the basement cross-highs.

The stratigraphic nomenclature used in this report corresponds to the classification proposed in 1955 by de Boer & Spruyt and generally adopted in the literature after 1956. It basically defines lithostratigraphic units using lithological criteria only. It has to be stressed that such units cannot be regarded as time-units.

The formations described by former geologists are now well know and their description is repeated in this report. For this reason the lithological descriptions are reduced as much as possible; they are taken from the J. M. Spruyt report (1956) and the recent paper from A. Pulunggono (1969). On the other hand, palaeontological studies carried out by the LEMIGAS team, based particularly upon planktonic and benthonic foraminifera, can be considered as a new approach to the time-stratigraphy problem in the South Sumatra Basin.

The Tertiary sediments of South Sumatra are subdivided into two groups, the Telisa and Palembang Groups corresponding, as a whole, to a large transgressive-open marine-regressive cycle.

Generally, after the pre-Tertiary orogenesis, the sediments of the Telisa Group were laid down unconformably upon as rough topography where basement structures, transverse to the Sumatra trend, were characteristic features. During this period the subsidence was greater than the sedimentary influx, resulting in progressive evolution from a non-marine to an open marine environment. After a period of epirogenic and orogenic movements in the adjacent areas surrounding the basin, reverse conditions of sedimentation occurred.

At that time the **Palembang Group** deposits, conformable upon the Telisa Group, correspond to the final filling up of the basin. Non-marine deposits end the sedimentary cycle.

The Palembang Group strata, folded during the Plio-Pleistocene orogenesis, were finally overlain by unconformable Quaternary sediments.

Telisa Group

The Telisa Group is subdivided into a number of formations, commonly referred to by abbreviated terms (*Fig. V–2*). They are considered sequentially from lodest to youngest.

Lahat Tuff Breccia Formation (LAF). This is restricted to the marginal parts of the basin. The formation consists of tuff deposits and volcanic flows, including tuffs, claystones, tuff-breccias and conglomerates, and andesite. The rocks are quite commonly a bright red colour. Only some sandy claystone layers contain some foraminifera; other fossils are non-marine shell and fish remains. A fresh water-to-brackish environment is assumed for this formation. The distribution of these strata in the basin is very scattered, as the formation was deposited in a rugged area, with slopes (giving rise to conglomerates) and intermontane depressions.

Talang Akar Shale and Sand Formation (TAF). This formation corresponds to one of the main and best oil reservoirs of the South Sumatra Basin, especially in the South Palembang Sub-basin (Limau Anticlinorium). Generally it lies directly upon the basement, or LAF where that is present; two members have been identified in the South Sumatra Basin:

Gritsand Member (GRM): consists of medium to coarse grained sands alternating with shale and coal layers. It is considered to be a deltaic-fluviatile deposit. The only fossils encountered are plant remains.

Transitional member (TRM = OVM of Spruyt): composed of clays and grey-to-dark grey shales alternating with fine medium grained quartz sandstone and bituminous clays and some coal layers. Glauconite is common, and the environment was probably paralic.

The whole TAF is overlain conformably either by the Baturaja Limestone Formation (BRF) or Gumai Shale Formation (GUF). The thickness varies from a maximum of 700 m in a northeast-trending cross-depression, thinning towards the former shelf areas, with a minor trough more than 400 m. The percentage of sand in the formation increases towards the areas of shelf deposition and decreases where the formation is thickest.

As far as the age of the formation is concerned, dating of the basal transgressive levels cannot be fixed due to the lack of characteristic fossils. The rest of the formation is top Te in age, according to the larger foraminifera. The smaller benthonic fauna is indicative of the *Vaginulina* 2 ecozone and the planktonic foraminifera always correspond to the *G. insueta-trilobus* zone.

Baturaja Limestone Formation (BRF). This carbonate formation, well defined in the South Palembang Basin, is developed in variable facies of erratic distribution. Generally its presence is tied to old basement highs, where littoral to neritic and reefal environmental conditions prevailed. In the Jambi area this is the case on the Ketaling and Merang highs. Actually, in some areas, especially in the South Palembang Basin, the real extension of the formation according to the type of deposit, lenses or continuous horizon, is questionable.

The sedimentary facies consist of platy limestone with marl intercalations, tuffaceous marly limestone, crystalline and hard limestone, sandy limestone and coral reef limestones. Its fossil content is high and indicates a **partly Te and partly Tf** age. In some areas (Palembang) the limestone directly overlies the pre-Tertiary basement. The rocks can have some permeability characteristics but most generally are hard and compact.

It can be said that the Baturaja Limestone marks the beginning of the invasion of the sea during the Telisa time interval.

Gumai Shale Formation (GUF). Having formed in open marine conditions, the GUF indicates maximum subsidence and has a more extensive and regular distribution than the deposits formerly laid down in the whole South Sumatra Basin. In the Jambi area, the facies consists of chocolate brown and grey clays and claystones and shales, sometimes calcareous. The formation is lithologically quite homogeneous and the sand content rather low. *Globigerina* are abundant and mark the deeper marine character of the sediments.

As far as the limits of the formation are concerned, the lower one, corresponding to the contact with TAF or Baturaja, is the rather abrupt upward appearance of shaly material characteristic of GUF, but this limit, due to the presence of some sand in GUF, can be questionable, especially in the subsurface. The upper limit of the formation was fixed in the subsurface of Jambi at the base of "Zone 1170" Kenali Asam, or the regionally-recognizable first sand influx in the overlying ABF. Also, on the surface, a contrasting colour from dark-brown clays in GUF to greenish clays in the Palembang Group can be taken into consideration.

The maximum thickness of the GUF in the Jambi area is about 1650 m (Kenali Asam) in the centre of the Jambi cross-depression.

Palembang Group

The sediments of the Palembang Group indicate a reversal of conditions of deposition as compared to the Telisa Group, from shallow marine to non-marine environment i.e. regressive characteristics. The time interval corresponds to the final filling up of the basin, deposition exceeding subsidence.

It is often postulated that the change from open marine conditions between the GUF and Palembang Group was related to orogenic or epirogenic movements in the surrounding areas of the basin, especially responsible for a new influx of sandy material and ending the sedimentary cycle. Such movements would correspond to the Middle Miocene orogenic phase of some authors. But actually in the area under study no indication of unconformity between the Telisa and Palembang Groups has been found.

The lower limit of the Palembang Group is fixed at the base of the deepest important sand layer (Zone 1170, Kenali Asan, in the Jambi Basin). The upper limit is tectonically marked since the strata included in the Palembang Group are folded beneath unconformable Quaternary deposits.

Three formations have been identified in the Group:

Air Benakat Sand & Clay Formation (ABF). This consists mostly of alternating sands and clays, the sand content increasing upwards. Glauconite is quite common, planktonic foraminifera are fewer compared to GUF, and *Rotalia* becomes abundant. The shallow marine environment marked, at that time, the beginning of regressive conditions, but it is noteworthy that the geographical extension of the formation is larger than the underlying open-marine GUF, especially eastwards over the shelf. This was due to the rapid infilling of the basin while subsidence was much reduced.

As far as thickness is concerned, two noteworthy maxima exist in the Duabelas-Telisa area (around 1100–1200 m) and locally in the Babat area (about 1100 m). Immediately south of Babat, on the contrary, there is a low value of about 400 m at Mangunjaya.

Muara Enim Coal Formation (MEF). This is generally a coal-bearing formation, though the lower part indicates still a shallow marine environment. Upwards, facies conditions progressively change into paralic and non-marine. Due to the lack of a characteristic fauna a correlation cannot be fixed, but is regarded as Upper Miocene-Pleistocene.

The lower boundary with ABF, generally marked in the South Palembang Sub-basin by a coal layer (Kladi coal layer) has to be taken in the Jambi area at the top of the highest glauconitic sand of ABF.

Two members are defined:

Brown member (MEMa) at the base: this is mostly composed of brown clays, sand-clays and sand (with coal in the Palembang Sub-basin). Some foraminifera and molluscs are present.

Bluegreen member (MEMb) at the top, composed of blue-green clays and some sands with coal. The presence of volcanic material seems to be the cause of the blue-green colour of the deposits. Apart from plant remains there are only very few brackish-water foraminifera.

The total thickness of the formation varies between 450–750 m and the geographic distribution is the same as the ABF.

Kasai Tuff Formation (KAF). This corresponds to a continental deposit ending the Tertiary sedimentary cycle in the South Sumatra Basin. These deposits are strongly tuffaceous, generally clays with some sand layers. In the Jambi area, above unbedded azure-blue tuffs, sandy pumice sediments are present. Fresh water molluscs and plant or leaf remains are the only fossils encountered in the formation. Due to the general erosion, thickness is difficult to determine but in the Gumai Mountains is probably between 430 and 100 m.

The lower limit, the contact with MEF, is placed in Jambi at the base of the lowest strongly tuffaceous layer.

The age of KAF is unknown.

After this deposit was formed, the major Plio-Pleistocene orogenic phase occurred which was responsible for the arching up of the Barisan Mountains and the folding of the Neogene sediments deposited in the South Sumatra Basin. The result was the formation of numerous parallel or *en-echelon* folded and faulted structures, elongated along the Sumatra trend, among which are the major oil bearing anticlines of the Basin.

The geological history ends with post-orogenic Quaternary non-marine sedimentation.

Biostratigraphy

The biostratigraphy of the Jambi area was always based on foraminifera. The numerous surveys have recently been summarized by Wijkhuizen, 1959 (smaller foraminifera) and by Ong & Muhar, 1962 (larger foraminifera).

New results could be expected from a closer examination of the planktonic foraminifera only. These have been examined in eleven wells in the Jambi Basin and five wells in the Palembang Basin, in order to form the regional picture. The planktonic zonation could be applied to part of the TAF, the GUF, and part of the ABF.

Benthonic foraminifera

The foraminifera faunas have been subdivided into the various assemblages on which the ecozones (actually "assemblage-zone") are based. The definitions of these ecozones are given in the two reports mentioned above.

The ecozones based on smaller foraminifera are generally believed to be of little chronostratigraphic value but they reflect comparable environmental conditions. If compared to the lithological units, it becomes evident that the same sediments have been deposited in different biofacies. For example, the different overlaps of the *Vaginulina* 2 ecozone with the GUF, and the difference between the base of the *Rotalia* 5 ecozone and the base of the ABF. All this hints at a basin with sharp lateral changes in biofacies.

The distribution of the ecozones based on larger foraminifera is of particular interest. Larger foraminifera live only within the photic zone because of their symbiosis with algae; rich occurrences of large foraminifera indicate a shallow environment.

The *Spiroclypeus* ecozone (Te) is restricted to distinct local highs.

The *Miogypsina* ecozone (Tf) has been modified by taking into account only those intervals which actually contained larger foraminifera. Two subzones can be traced in the central Jambi Depression. The lower coincides more or less with the top of the *Vaginulina* 2 ecozone, and might indicate the end of a first phase of "filling up" of the basin border. The upper subzone is in the lower part of the ABF and represents the shallow marine environment after the deposition of the basal ABF. In the northeastern corner of the Jambi Basin, the bisection is traceable no further due to continuous shallow deposition. Towards the South, the *Miogypsina* ecozone was encountered mainly on the prolongations of the

Ketaling and Merang highs. The small occurrence of this zone in the middle of the GUF is enigmatic (displaced fauna?).

The *Lepidocycline* ecozone is restricted to the Ketaling high, where conditions favourable to larger foraminifers continued up to MEF.[10]

Planktonic foraminifera

Due to their mode of life planktonic foraminifera are less influenced by facies and wider-spread than benthonic foraminifera. They are therefore good biostratigraphic markers and are preferred to the above-mentioned group.

The planktonic zones applied to the South Sumatra Basin are defined as follows:

Globigerinatella insueta-Globigerinoides trilobus zone: interval from the first occurrence of *G. trilobus* to the first appearance of *G. bisphaericus*. This large zone cannot be subdivided further, due to the absence of markers used elsewhere.

Globigerinoides bisphaericus zone: interval from the first appearance of *G. bisphaericus* to the first occurrence of *P. glomerosa* (s.l.).

Praeorbulina glomerosa zone: interval from the first occurrence of *P. glomerosa* to the first appearance of *Orbulina* sp.

Globorotalia peripheroronda zone (synonym: *G. barisanensis* zone): interval with zonal marker from the first occurrence of *Orbulina* sp. to the first appearance of *Globorotalia fohsi* sensu Bolli.

Globorotalia fohsi zone: interval from the first appearance of *G. fohsi fohsi* (sensu Bolli) to the first occurrence of *G. fohsi lobata* (sensu Bolli).

Globorotalia lobata zone: interval from the first appearance of *G. fohsi lobata* (sensu Bolli) to the last occurrence of *G. fohsi* (s.l.). Up to now the very base of this zone has been encountered in well *Geger-I* only.

The first occurrence of planktonic foraminifera in the TAF always indicates the *G. insueta-G. trilobus* zone (Lower Miocene, Te). An accurate dating of the transgression is not possible.

In the GUF, the planktonic fauna is well developed and this formation is easily datable.

There are several ingressions with planktonic foraminifera in the lower part of the ABF in the Jambi Basin. These ingression zones become more complete towards the Tebo Depression, it is therefore assumed that at least part of these ingressions came from that area. Unfortunately no data on the central Palembang Depression were available at the time of redaction of this report.

Considering the heterochrony of the limit GUF/ABP, it seems likely that some ingressions came from the south too. In the Palembang Basin similar ingressions were not found, and the planktonic fauna becomes practically extinct in the lowermost ABF.

The biostratigraphy of the GUF has been presented for the whole South Sumatra Basin. The lower boundary of the GUF fluctuates within the big *G. insueta-G. trilobus* zone. The upper limit, on the other hand, shows a distinct heterochroneity which can be proved because a finer zonation could be established. The GUF/ABF boundary rises from the *G. insueta-G. trilobus* zone in the northern part of the central Jambi Depression to the *G. bisphaericus* zone in the middle part of that depression. The pattern on the highs, which separate the Jambi from the Tebo Depression, becomes somewhat

[10] MEF = Muara Enim Coal Formation

erratic.

The last points of control are in the southern part of the Palembang Depression, where the GUF/ABF boundary was found to be within the *G. peripheroronda* zone. The planktonic fauna practically disappear there in the *G. fohsi* zone.

NORTHEAST SUMATRA AREA

Biostratigraphic Correlations

Figures V-2 and *V-3* represent a first attempt to compare the lithological units to the frame of the planktonic zones in the Northeast Sumatra area, but it must be recognized that these sketches will have to be altered and improved as increasing knowledge in modern biostratigraphic data becomes available. Points of control have been chosen in such a way that the planktonic foraminifera of all major units of the basin could be included.

Micazandsteen Formation

The age of this formation has been an issue for quite some time. In 1910, Hirschi reported the occurrence of *Nummulites*, *Assilina* and *Discocyclina* in a glauconitic sandy limestone of a rather vague lithostratigraphic position. Var Es (1919) mentioned *Nummulites* and *Discocyclina* in a limestone between his "Micaquartzbrekzien-horizont" and his "Micasandstein horizont", but gave no indications on the locality. And Douvillé (1912) determined *Alveolina*, *Assilina*, *Discocyclina*, and *Nummulites* in samples from breccias and conglomerates of the island of Nias. All the mentioned fossils are typical of Eocene strata.

In the upper part of the Micasandsteen Formation there are several intercalations of limestone reportedly bearing larger foraminifera indicative of Tc/d and Te stages (van Bemmelen, 1932; see also Marks, 1956).

As none of these occurrences of Eocene fossils could be verified, no definite opinion can be expressed on this topic. There is no convincing evidence for an Eocene age of this formation, and it rather seems that the Eocene key fossils have been reworked in Oligocene sediments, though the presence of these fossils indicates that Eocene marine sediments had formerly been deposited in the region. Therefore, in *Figure V-2*, a Palaeogene age is attributed neutrally to the lower part of this formation.

Zwartekleisteen Formation

This formation is rather poor in index fossils. The lower limit has tentatively been drawn within the *G. insueta-G. trilobus* zone. In the upper part of the formation, the first planktonic foraminifera appear; they are indicative of the *G. bisphaericus* zone (section on the Kr. Jinyeb, sample No. SM 33 on the Sgai, Simaimai, PERTAMINA survey).

Grensklei Formation

At the base of this formation several sand and limestone intercalations are present. They contain some planktonic foraminifera which are typical of the so-called *G. fohsi* zones (*G. peripheroronda* and *G. peripheroacuta* zone). The Peunulin Sands reportedly bear in Aceh (Arjeh) some larger foraminifera of an upper Te age. This would be one of the many indications that the limits of the "letter-stages" do not run parallel to the planktonic zones.

In its middle part, the Grensklei Formation is quite rich in planktonic foraminifera, and the planktonic zonation is easily applicable. Around the *G. menardii* zone, the planktonic fauna becomes very poor. Locally, sands have been deposited (Telaga Said Sands, and possibly the Tussenzandsteen). The impoverishment of the planktonic fauna and the deposition of these sands in probably connected to the beginning of the uplift of the Barisan Mountains.

In the Deli Province, the upper Grensklei Formation remains poor in foraminifera. But there is no support from the planktonic foraminifera for the wedging out of the upper Grensklei Formation in this area as postulated by Todd (1940).

Keutapang Formation

The lower limit of this formation is heterochronous, as can be proved by planktonic foraminifera. There is also a change in the faunal composition: marine shallow-water indicators become abundant among the benthonic fauna, while the planktonic foraminifera remain rare. The Keutapang Formation in the examined sections has been deposited in a marine environment.

Seurula Formation

The Seurula Formation is significantly richer in planktonic and benthonic foraminifera, full marine conditions having prevailed again. In the Deli region the upper part of the formation has been eroded and Quaternary sediments lie directly upon latest Miocene-to-early Pliocene layers.

Julu Rayeu (Djulu Rajeu) Formation

This formation has been examined in two wells. At its base a few small planktonic foraminifera were encountered which gradually disappear up section. The Julu Rayeu Formation was found above the upper *G. tosaensis* zone, which gives a latest Pliocene-to-Pleistocene age for this formation. The lower limit is probably heterochronous.

KALIMANTAN AREA

Micropaleontological investigations have been based on about 500 surface samples; 210 of these were collected by Asril and Perrier (1970) in the Barito, Kutei and Tarakan Basins. The remainder had been collected by Shell geologists after the war: Faber (1950) in the Ulung anticline, Francken (1951) and Adiwidjaja (1957) in the Bungalun-Sangkulirang area. Other samples have not been available.

The age determination of the sedimentary deposits of Kalimantan was formerly based almost entirely on larger foraminifera, expressed by means of the "letter stages". As larger foraminifera occur mainly in calcareous and shallow water environments, only this type of deposit has been dated exactly. The age of all other sediments, mainly marls, clays and siltstones, had been more or less estimated. For that reason the requirement was to investigate these sorts of strata with the help of planktonic foraminifera.

The small number of studied sections and the scattered samples, compared to the complexity of the stratigraphy of the different basins with environmental variation, makes clearly evident that, for the time being, a synthetic biostratigraphic correlation in Kalimantan is not yet possible. This study is a first attempt. A region as large as Kalimantan deserves much more work.

First, discussion of the letter stages is necessary, as these are still the most important biostratigraphical units in Indonesia. A lot of recent published work concerning the letter stages has been included in the review, to give a summary for further research on this subject in the region.

Classification by letter stages

The concepts developed for the letter stages are wholly biostratigraphical. The letter stages should be considered as biostratigraphical zones (assemblage zones based on larger foraminifera and molluscs) as the term stage means a chronostratigraphical unit based on a type section.

Tertiary ab. For Mohler (1943) it was not possible to make a subdivision of this interval into Ta and Tb in Southeast Kalimantan, as *Assilina* is not restricted to Ta as formerly believed. In addition *Alveolina*, an important key fossil for Ta, cannot be encountered south of Sangkulirang. *Alveolina* has also been found, only in samples from north of the Mangkalihat Peninsula. There, a subdivision in Ta and Tb might be possible. *Alveolina* has never been found in beds of Tb age in Indonesia. Some specimens mentioned to occur in Tb beds of Kalimantan might belong rather to primitive *Borelis* than to *Alveolina* (Adams, 1965). Therefore *Alveolina* of Kalimantan have the same stratigraphic distribution as those of the Middle East and the Mediterranean (Adams, 1965: Hottinger and Schaub, 1960).

Some species of *Nummulites* seems to be restricted to Ta, other to Tb. *Pellatispira* and *Biplanispira* are considered to occur only in Tb. *Discocyclina omphala* is a key fossil for Tb, as well. Therefore, it is believed that a subdivision into Ta and Tb is possible in southeast Kalimantan, also. However, it is emphasized that the faunal succession within these "stages" is not yet well known.

The age of the Ta and Tb stages is still doubtful. For Berggren (1969) the Ta/Tb boundary is marked by the first appearance of *Hantkenina*, that means it coincides with the Lower/Middle Eocene boundary. A typical Tb fauna with *Discocyclina omphala*, *Pellatispira* and various *Nummulites* was found in the eastern Basin,below a sample containing planktonic foraminifera indicative of Middle Eocene. This fact supports Berggren's view. Hence it follows that Ta corresponds at least partly to the Lower Eocene.

Planktonic foraminifera indicating lower Eocene or Palaeocene age are not known in this part of Kalimantan.

Tertiary cd. This stage is made up mainly by the *Nummulites fichteli-intermedius* group; *pengaronensis* is also found, its extinction coinciding almost with the Tc/d limit. The first *Borelis inflatus*, appears in the lower part, followed by *B. pygmaeus* in the upper part of this interval. The Tc stage is considered to be of early Oligocene. For Clarke and Blow (1969) Tc includes an interval of upper zone P17 to lower P19 of Blow's planktonic foraminiferal zonation (1969).

Tertiary d. This stage is characterized by the presence of the *Nummulites fichteli-*

intermedius group together with *Lepidocyclina* (*Fulepidina*). Sometimes one of these groups is absent. In such cases only a detailed study of the species indicates the right stage. Especially when working in the field, it might be better to use the term Tcd.

In Kalimantan the first *Austrotrillina striata* appears in the uppermost part of this interval (Adams, 1965, 1968), a form formerly delieved to be restricted to Te. The overlap of this species with *fichteli* is taken by Adams to define an interval Td/e (= Td' of Eames, in Adams, 1965) in Sarawak.

The age of Td is still somewhat unsure. For Clarke and Blow (1969) Td was an interval reaching from upper P19 to upper P20, that means of a middle Oligocene age. Present investigations in Kalimantan agree with this view, as a Td fauna was found within several samples containing planktonic fauna indicative of zone P20 in the South Kutei Basin (South Muru).

Tertiary e. A subdivision of this stage in five "substages", as was originally proposed by van der Vlerk and Umbgrove (1927), is not possible. Mohler (1949) distinguished Te1–4 from Te5 by means of *Flosculinella reicheli* (= *F.* "*globulosa*"), a form typical of Te5 particularly in the Barito Basin. Unfortunately this form is very rare.

For the time being Te is divided into two intervals by means of *Heterostegina borneensis*: an older one, Te1–3, from the last *Nummulites fichteli* to the youngest *H. borneensis*, and a younger one, Te4–5, from the last *H. borneensis* to the last *Spiroclypeus* spp.

In addition there seems to be an interval in the lowermost part of Te, where *H. borneensis* and *Spiroclypeus* are absent (the same observations was made by Adams, 1965).

A further possibility to divide the Te stage might be the appearance of *Miogypsinoides* spp. within the range of *Heterostegina borneensis* and the first occurrence of *Miogypsina* spp. shortly after the extinction of *H. borneensis* (Adams, 1965; Clarke and Blow, (1969). Such a faunal succession has not yet been examined sufficiently and has to be studied further on a continuous sections. Nevertheless, it would offer the possibility of a subdivision of the Te stage into five zones.

The limit Te/f was set by Clarke and Blow (1969) within an interval composed of zone N8-N9. They mentioned a Te fauna associated with *Praeorbulina* cf. *glomerosa* in the uppermost Melinau Limestone of Sarawak. They made similar observations also in the Telisa Formation of Sumatra. Berggren (1969) set the Te/f boundary within zone N9 (= *Globorotalia peripheroronda* zone, lowermost Middle Miocene).

Tertiary f. Tf can be divided in a lower (Tf1) and an upper (Tf2–3) interval. A subdivision in Tf2 and Tf3 is not possible. The easiest way to make this subdivision is by means of the different species of *Flosculinella*. *F. glomerosa* is restricted to Tf1, *F. borneensis* to Tf2–3.

The upper limit of this stage is marked by the extinction of *Lepidocyclina* spp. and *Miogypsina* spp. The extinction of *Lepidocyclina* spp. seems to have occurred shortly after that of *Miogypsina* spp. (Clarke and Blow, 1969).

The age of the upper limit of this stage compared with planktonic foraminiferal zones is still doubtful. Clarke and Blow considered most of zone N15 (= *Globorotalia menardii* zone) already as post-*Lepidocyclina*. For them even the upper part of N14 (= *Globorotalia siakensis* zone) might be part of Tg.

Tertiary g and h. These two stages were originally based on the percentage of recent molluscs. Tg contains 35–45% recent molluscs, Th 50–60% (Leupold & van der Vlerk, 1931). These stages have no relation to foraminifera.

In general, *Cycloclypeus postinornatus* is regarded as indicative of Tg-h.

PLANKTONIC FORAMINIFERA ZONES

Middle Eocene. The oldest Tertiary planktonic foraminiferal samples investigated were found by Asril and Perrier (1970) in the Bulungan region (Penyalin anticline). *Globigerapsis* cf. index, *Globorotalia spinulosa* and primitive *G. centralis* point to a middle-Middle Eocene age. Thalman (1941) described a fauna with *Hantkenina liebusi* from the same area. This form might have about the same age.

Another sample from the easternmost part of the Mangkalihat Peninsula shows about the same age, or slightly younger.

Planktonic foraminifera of upper-Middle Eocene age were found on the eastern edge of Barito Basin and in the Mangkalihat Peninsula. This shows clearly that at about the same epoch, in the Barito as in the Bulungan region, for the first time enough open marine influences prevailed to yield sufficient planktonic foraminifera. Nevertheless a zonation of this stage is not yet possible in this part of Kalimantan.

Late Eocene. In general the late Eocene can be divided in two zones, a lower one, *Globigerapsis semiinvoluta* zone, and an upper one *Globorotalia cerroazulensis* zone. These two zones can be recognized worldwide. Both zones were found in East Kalimantan, particularly in the Kutei Basin (Muru River and Bungalun region). The fauna consists of *semiinvoluta*, *G. tropicalis*, *Globorotalia centralis*, *G. cerroazulensis*, *Hantkenina alabamensis*, *H. primitiva* and *Cribrohantkenina inflata*, as everywhere.

Oligocene. Due to the lack of suitable samples it is not yet possible to give a complete zonation based on plankton of this age. The middle part is still missing.

Globigerina gortenii gortanii zone (gap-zone with zonal marker): from last occurrence of *Hantkenina* spp. to first occurrence of *sellii*. This is the earliest Oligocene zone.

Globigerina binaiensis zone (partial-range zone): from first occurrence of *binaiensis* to first appearance of *Globorotalia kugleri.*

Globorotalia kugleri zone (partial-range zone): from first occurrence of *kugleri* to first occurrence of *Globigerinoides primordius*. This is considered as the latest Oligocene zone.

The interval between the first *Globigerina sellii* and the first *G. binaiensis* has not yet been sufficiently studied in Indonesia to give the exact definitions of the zones.

Samples were investigated containing planktonic foraminifera from Bungalun and East Mangkalihat regions, and from South Kutei (Ulung and Muru region). Most of these samples are rich in forms belonging to the *Globigerina tripartita-tapuriensis-sellii-binaiensis* group.

The samples of the Ulung anticline show the faunal transition from late Oligocene to early Miocene. The limit between Oligocene and Miocene is set at the first *Globigerinoides primordius*.

Miocene. Only samples of the Kutei Basin and the Mangkalihat Peninsula yielded planktonic foraminifera of this age.

The Miocene of Indonesia can be divided in at least twelve zones. Most of them can be recognized worldwide in tropical and subtropical regions. It was found that the zonal scheme established in Java and Sumatra is suitable also in this part of Kalimantan. The Miocene zones will be discussed from the bottom to the top, as some of their names and definitions cannot be found elsewhere in the literature.

Globigerinoides primordius zone (concurrent-range zone): first occurrence of *G. primordius* to last occurrence of *Globorotalia kugleri.*

Globigerinoides trilobus zone (gap-zone): last occurrence of *Globorotalis kugleri* to first occurrence of *Globigerinoides bisphaericus.* Remark: *Globigerinita stainforthi* zone and *Globigerinita dissimilis* zone of Bolli (1966), the N5, N6, N7 zones of Blow (1969), cannot be recognized in Java and Sumatra. In one sample from the Mangkalihat Peninsula collected by Asril and Perrier (1970) a well preserved fauna was found with *Globigerinatella insueta*, a form that is very rare in Java and Sumatra. Therefore it is believed that it will be possible, after more samples of this interval have been studied, to make a subdivision of this zone in East Kalimantan.

Globigerinoides bisphaericus zone (partial-range zone): first occurrence of *G. bisphaericus* to first occurrence of *Orbulina suturalis.*

Globorotalia peripheroronda zone (partial-range zone): first occurrence of *Orbulina suturalis* to first occurrence of *Globorotalia peripheroacuta.*

Globorotalia peripheroacuta zone (partial-range zone): first occurrence of *G. peripheroacuta* to first occurrence of *G. fohsi lobata.*

Globorotalia fohsi lobata/fohsi robusta zone (concurrent-range zone): first occurrence of *G. fohsi lobata* to last occurrence of *G. fohsi* s.l.

Globigerinoides subquadratus zone (partial-range zone): last occurrence of *Globorotalia fohsi* s.l. to last occurrence of *G. subquadratus.*

Globorotalia siakensis zone (partial-range zone): last occurrence of *Globigerinoides subquadratus* to last occurrence of *G. siakensis.*

Globorotalia menardii zone (gap-zone): last occurrence of *G. siakensis* to first occurrence of *G. acostaensis* s.str.

Globorotalia acostaensis zone (partial-range zone): first occurrence of *G. acostaensis* to first occurrence of *G. plesiotumida.*

Globorotalia plesiotumida zone (partial-range zone): first occurrence of *G. plesiotumida* to first occurrence of *G. tumida.*

Globorotalia tumida zone (partial-range zone): first occurrence of *G. tumida* to first occurrence of *Sphaeroidinella dehiscens.* Remark: this is considered to be the latest Miocene zone. The first occurrence of *Sphaeroidinella dehiscens* is taken as the marker for the lower limit of the Pliocene.

Samples collected by Faber (1950) on the Ulung anticline yielded two zones of the earliest Miocene: *Globigerinoides primordius* and *Globigerinoides trilobus* zone. In samples taken northwest of Balikpapan along the Pamaluan River by Asril and Perrier (1970) planktonic forms were found indicative of the *Globigerinoides trilobus* zone.

In the Bungalun region the strata deposited after the Oligocene yielded no plankton at all.

Along the Sangkulirang Bay the samples collected by Adiwidjaja (1957) and Asril and Perrier (1970) yielded a well preserved planktonic foraminiferal fauna from the *Globorotalia perpheroronda* zone up to the Pliocene *Sphaeroidinella dehiscens* zone. This fauna points clearly to an open marine environment. The same conditions can be found at the easternmost Mangkalihat Peninsula where in samples collected by Asril and Perrier (1970) some Miocene zones could be found.

Pliocene. The Pliocene can be divided in two zones, a lower *Sphaeroidinella dehiscens* zone and an upper *Globorotalia tosaensis* zone.

Sphaeroidinella dehiscens zone (partial-range zone): first occurrence of *S. dehiscens* to first occurrence of *G. tosaensis.*

Globorotalia tosaensis zone (partial-range zone): first occurrence of *G. tosaensis* to first occurrence of *G. truncatulinoides.*

A planktonic foraminiferal fauna pointing to a Pliocene age has been found only in samples from the Sangkulirang Bay and the eastern Mangkalihat Peninsula. The youngest fauna indicating the *G. tosaensis* zone has been collected by Asril and Perrier in the Sumbang Bay (East Mangkalihat).

Recent publications and investigations by the Institute in Kalimantan show clearly that the letter-classification remains still the most important biostratigraphic tool in neritic calcareous deposits. There is, however, no doubt that further investigations will yield a more detailed subdivision of most of these "stages".

For sediments deposited in an environment with more open marine influences, planktonic foraminifera have been found to be excellent keyfossils in Kalimantan. By means of them, a more exact age determination gives the possibility of correlating specific stratigraphic events in Kalimantan with those of other regions of the Indo-Pacific region may be improved.

There has been no opportunity to study sections of paralic facies extensively developed in the Neogene and Pleistocene of the different Kalimantan basins, where probably larger and planktonic foraminifera are too scarce, and where other paleontological methods might be helpful.

REFERENCES

Adams, C. G., 1965, The foraminifera and stratigraphy of the Melinau limestone, Sarawak, and its importance in Tertiary correlation: *Q. Jl. Geol. Soc. Lond.*, vol. 121, p. 283–338.

Adams, C. G., 1968, A revision of the foraminiferal genus *Austrotrillina* Parr.: *Bull. Br. Mus. Nat. Hist. Geol.*

Blow, W. H., 1969, Late middle Eocene to Recent planktonic foraminiferal biostratigraphy: Proceedings, International Conference on Planktonic Microfossils (Geneva, 1967).

Bolli, H. M., 1966, The planktonic foraminifera in well *Bodjonegoro*-1 of Java: *Eclog. Geol. Helv.*

Clarke, W. J., and W. H. Blow, 1969, The inter-relationships of some late Eocene, Oligocene and Miocene larger foraminifera and plankton biostratigraphic indices: Proceedings, International Conference on Planktonic Microfossils (Geneva, 1967).

Douvillé, H., 1912, Les foraminifères de l'Ile de Nias: *Samml. Geol. Reichsmus*, Leiden.

Hirschi, 1910, Geographische-geologische Skirze vom Nord Sumatra: *Tydschr. Kon. Ned. Aardr. Gen.*, vol. 27.

Hottinger and Schaub, 1960, Zur Stufenein teilung des Paleocäns und des Eocäns. Einführung des Herdien und des Bearritzien: *Eclog. Geol. Helv.* vol. 53.

Leupold and van dc Vlerk, 1931, The Tertiary: *Leid. Geol. Meded.*, vol. 5.

Marks, P., 1956, Stratigraphic lexicon of Indonesia: Publikasi Keilmuan no. 31 (Geologi), Bandung.

Mohler, W. A., 1943, Stratigraphy of southeast and central Borneo: Report Geol. Survey 24/CX.

———, 1949, Overzicht van de Eoceen vindplaatsen op Java: internal report.

Ong and Muhar, 1962, Study of larger foraminifera from south Pladju: internal report.

Todd, J. U., 1940, Notes on the paleontology of the Grensklei-Pangkalan Brandan: internal report.

Trooster, 1937, Lithologische correlatie van de standaard profielen van het Kening-gebied en omgeving: internal report.

Umbgrove, J. A., 1938, Geological history of East Indies: *Bull. Amer. Assoc. Petr. Geol.*, vol. 32.

van Bemmelen, 1932, Geologische waarnemingen in de Gajolanden (Noord Sumatra): *Jaarb. Mijnw. Ned. Ind.*, Verh. III.

van Es, 1919, De tektoniek van de Westelijke helft van den Oost-Indischen Archipel: *Jaarb. Mijnw. Ned. Ind.*, Verh. II.

Vischer, 1952, Geologisch onderzoek Tuban.

Wykhuizen, 1959, Biostratigraphy of the Jambi area: internal report.

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VI. THE STATUS OF PETROLEUM EXPLORATION IN THE OFFSHORE AREAS OF INDONESIA

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(with tables VI–1 and VI–2; and figures VI–1 to VI–4 in envelop on back cover)

ABSTRACT

Offshore exploration for petroleum in Indonesia began in 1967, except for a prewar discovery off Seram. Twenty one companies are presently exploring Indonesian offshore areas in co-operation with PERTAMINA on a production-sharing system in 27 contract areas totalling 2,227,965 sq km. Intensive geophysical exploration has been carried out by 16 oil companies, including marine seismic, gravity and magnetic work totalling 76,221 line-km in 1971 and 21,912 line-km in the first half of 1972. A further 116,000 line-km were surveyed by research vessels.

Ninety one offshore exploratory wells in 16 contract areas were drilled in 1971, and 32 in the first half of 1972; of these, 14 were oil wells and four were gas wells. Total metreage drilled was 243,638 for those periods. Five new oil structures and three new gas structures were discovered.

Total crude oil production from offshore fields was 4,065,135 barrels, from 43 producing wells, and 971,538 Mcf of natural gas. In the first half of 1972, offshore oil production rose to 10,932,000 barrels, 5.7 per cent of Indonesia's total crude production.

INTRODUCTION

Drilling for oil in Indonesia was started in 1872 in Maja, West Java, but the first oil-bearing structure was discovered in East Java near Surabaya in 1887 by the Dordrecht Oil Company, which proved to be non-commercial for further development. The first commercial oil-bearing structure found was Telaga Said, Sumatra, which was exploited by the Royal Dutch Shell Group. Since then more and more oil provinces have become known in southern and central Sumatra, Java, East Kalimantan and West Irian.

Before World War II there were five oil companies operating in Indonesia and in 1940 the total crude production was 59 million barrels. With this figure Indonesia occupied fifth place amongst the oil producing countries, after the United States of America, the Soviet

Union, Venezuela, and Iran. After the war oil production declined for a considerable period of time, and petroleum exploration practically ceased. Prior to 1966, exploration activities were confined on limited onland areas, but then increased interest in oil exploration by foreign oil companies marked the beginning of offshore exploration work through the introduction of a production-sharing system. In 1967 a marine geophysical survey was conducted by Sinclair Exploration in the Java Sea contract area.

Indonesia has abandoned the concession system since *Law No. 44 Prp/1960* regarding the Mining of Mineral Oil and Gas came into effect on 26 October 1960. Three years later, in December 1963, Contracts of Work were introduced to the existing foreign oil companies. At present there are three oil companies continuing their onshore operations based on the contract of work, namely P. T. Caltex Indonesia, Calasiatic and Topco, and P. T. Stanvac Indonesia. The rest of the contracts are based on the production-sharing system.

Various efforts have been made to increase oil production and to search for new discoveries onland as well as offshore. Operations are carried out by PERTAMINA (the Indonesian Oil and Gas Enterprise) and its contractors.

The Directorate General for Petroleum and Natural Gas, one of the two directorates general in the Department of Mines, Government of Indonesia, is authorized to co-ordinate and supervise oil company and other matters related to the oil and gas industry. Aside from the activities performed by the afore-mentioned government agencies, research and training activities are entrusted to the Indonesian Petroleum Institute, officially named Lembaga Minyak dan Gas Bumi (LEMIGAS). This institute has a threefold task comprising research, training, and documentation/publication.

CURRENT ACTIVITIES AND RESULTS

Presently there are 28 foreign oil companies working in Indonesia as contractors to PERTAMINA. There are 27 offshore contract areas granted so far, covering areas of more than 2 million sq km of Indonesian waters and are operated by 21 oil companies. The foreign oil companies and respective offshore contract areas as of June 1972 are shown in *Table VI-1* and *Figure VI-1.*

Between January 1971 and June 1972, two offshore areas were granted to foreign oil companies. In January 1971 a production-sharing contract was signed between PERTAMINA and Shell Indonesia for a contract area located offshore south of Central Java, covering an area of 12,840 sq km. Another contract area offshore southwest of West Irian covering an area of 75,250 sq km was granted to Indonesia Offshore Operators, Inc. in March 1972.

During 1971, offshore geophysical surveys were carried out intensively in 25 contract areas by 16 oil companies. Geophysical work included marine seismic, gravity and magnetic surveys and about 65,831 line-km were completed of deep and shallow water seismic, 390 line-km of gravity survey and 10,000 line-km of aeromagnetic survey. Nine survey vessels owned by five geophysical contractors were involved in these surveys. For the first half of 1972, ten oil companies ran offshore geophysical surveys and completed some 21,327 line-km of marine seismic and 585 line-km of shipborne magnetometer survey. The geophysical seismic survey density as of June 1972 is shown on *Figure VI-2.*

Most oil and gas accumulations found in Indonesia occur in Tertiary strata and are produced from depths of a few hundreds to about 2000 metres,with some from greater depths. Offshore exploratory drilling reach total depths ranging from about 1000 to 4000 metres below sea level.

Ninety one offshore exploratory wells located in 16 contract areas were drilled in 1971 to test the possibility of hydrocarbon accumulations in structural and stratigraphic leads obtained from geological and geophysical surveys. Twelve oil companies conducted the exploratory drilling campaign using 12 offshore drilling rigs. Ten out of the 91 exploratory wells were completed as oil wells, three as gas wells, 74 were abandoned as dry holes and four were still drilling at the end of 1971. Total metreage drilled for that period was 179,765 m. Five new oil structures were discovered in the IIAPCO, ARCO and Union Oil contract areas and three gas structures were tested in the Cities Service and CONOCO contract areas.

Table VI–1. List of Offshore Contract Areas (At November 15, 1972)

Company	Contract Area	Size (Sq km)	Effective date
AGIP SPA	South China Sea Block "A"	106,437.00	19–12–1968
	Teluk Berau	104,750.00	10–10–1968
Frontier	South China Sea Block "C"	113,562.50	1–11–1968
White Shield	Lampung-Banten	72,500.00	9– 8–1969
Calsiatic & TOPCO	Lombok Block	72,000.00	9– 2–1970
IIAPCO/ARCO	Java Sea	53,437.50	19– 1–1967
Kondur	Strait of Malacca	39,770.00	5– 8–1970
British Petroleum	East Kalimantan	24,000.00	2– 3–1970
Cities Service	Java-Sea-Madura Strait	154,687.00	21–10–1967
CONOCO	South China Sea Block "B"	106,375.00	16–10–1968
IIAPCO	Southeast Sumatra	121,750.00	6– 9–1968
Indonesian Gulf Oil	South China Sea Block "D"	175,060.00	17–12–1968
	South Sulawesi offshore	99,750.00	14– 6–1969
Indonesia Offshore Operators, Inc.	South West Irian	75,250.00	3– 3–1972
International Oil	Timor	28,812.00	8– 4–1968
Jenney	Karimata	47,250.00	8– 8–1969
	Mentawai	69,250.00	8– 8–1969
Mobil Oil Indonesia	North Sumatra offshore	48,250.00	16–10–1968
Phillips & Superior	Arafura Sea	325,250.00	28– 5–1968
Shell Indonesia	South of Central Java	9,000.00	15– 1–1971
Java Sea Oil	Java Sea	8,700.00	6–11–1968
JAPEX	Mahakam	34,125.00	31– 3–1967
	Bunyu		
UCPI	South Kalimantan	127,062.50	17– 1–1967
	Southeast Kalimantan	70,812.50	19– 1–1967
Union Oil	East Kalimantan offshore	14,750.00	25–10–1968
	Northwest Sumatra	125,374.40	26– 1–1968
TOTAL		2,227,965.40	

Table VI–2. List of discovery wells in Indonesian offshore areas, January 1971—June 1972

Company	Area	Well name	Discovery
IIAPCO	S. E. Sumatra	Selatan 1	Oil
		Selatan 2	Oil
		Selatan 3	Oil
		Selatan 4	Oil
		Zelda 1	Oil
		Zelda 3	Oil
		Gita 1	Oil
ARCO	Java Sea	PSI U–1	Oil
		PSI P–1	Oil
		PSI L–2	Oil
Cities	Java Sea	JS 5–1	Gas
Service	Madura Strait	JS 2–1	Gas
CONOCO	South China Sea "B"	NE Paus 2	Gas
Union Oil	East Kalimantan	Attaka 4	Oil
		Attaka 5	Oil
		Santan 1	Oil
		Kerindingan 2	Oil
Total Indonesia	Mahakam contract area	Bekapai 1	Oil

Nine oil companies conducted exploratory drilling and 32 locations were drilled during the period of 1 January-30 June 1972. Results as of June 30, 1972 were as follows: four oil wells, one gas well, 22 abandoned as dryholes and five being drilled or tested. Total metreage drilled for that period was 63,873 m. The offshore exploratory drilling locations are shown in *Figure VI–3.*

The discovery wells for the period of January 1971-June 1972 are shown in *Table VI–2.*

In addition to the offshore discoveries of oil and/or gas, onland oil and gas deposits were found also by PERTAMINA and its onshore contractors in North, Central and South Sumatra, Java, East Kalimantan and West Irian.

As stipulated in the contracts, the contractors are obliged to surrender a certain percentage of their original contract area after a certain period of time. The total relinquished area as of June 1972 was 494,336,000 sq km or about 22.2 percent of total offshore areas under contract.

Apart from the marine geophysical survey conducted by foreign oil companies as contractors to PERTAMINA, several research groups affiliated to oil companies have completed reconnaissance geophysical survey programmes in Indonesian waters, consisting of seismic, gravity and magnetic survey. Bottom sampling and sea water salinity and temperature analysis had also been undertaken at several locations. The collected samples were turned over to government scientists for their use in locating possible concentrations of economically important heavy minerals.

Mobil Oil completed about 62,430 line-km of reconnaissance geophysical survey in June 1971 using the survey vessel M/V *F. H. Moore.*

Gulf Oil Research and Development Company with its research ship *Gulfrex* carried out a survey from August 1971 to January 1972 and completed about 17,927 line-km of reconnaissance seismic survey and 27,861 line-km of gravity and magnetic survey. Shell International also completed its geophysical reconnaissance programme in Indonesian waters using M/V *Petrel*; total traverses amounted to about 8,168 line-km and the programme consisted of seismic, gravity and magnetic surveys. The tracks of these three survey vessels are shown in *Figure VI–4.*

The results of these reconnaissance surveys should be very useful and add a considerable amount of additional information for further evaluation of the mineral potential of the offshore areas of Indonesia.

PRODUCTION OF OIL AND GAS FROM OFFSHORE AREAS

Total Indonesian crude oil production for June 1972 was 32,321,872 barrels, or over one million barrels per day, and natural gas production for the month was 11,688,312 Mcf. For the first half of 1972 the total crude oil production reached 191,314,493 barrels.

Offshore production was started in August 1971, apart from the Bula field, Seram, which was exploited before the war. The total crude oil production from offshore fields in 1971 was 4,065,135 barrels and it was produced from 43 producing wells. The total natural gas production for the year was 971,538 Mcf. In the first half of 1972, production from offshore fields in the IIAPCO, ARCO and Gulf & Western contract areas amounted to 10,932,000 barrels, about 5.7 percent of the total. Until June 30, 1972 a total of 187 locations in the offshore areas had been drilled and 182 exploratory wells were completed. From those exploratory drillings a number of structures have been proved commercial for further development in the IIAPCO, ARCO, and Union Oil contract areas.

Thirteen production platforms have been installed in the Cinta, Arjuna, and Attaka fields of the IIAPCO, ARCO, and Union Oil contract areas. Additional production platforms will be required to attain the expected crude oil production of over 100 million barrels for 1974.

(Paper delivered to the eighth session of the Technical Advisory Group of CCOP, held at Bandung, Indonesia from 20 to 27 November 1972.)

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III. Reports on the seismic refraction survey on land in the western part of Taiwan, Republic of China. By K. Sato, C. Y. Meng, J. Suyama, S. Kurihara, S. Kamata, H. Obayashi, E.

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III. Aeromagnetic survey in Region II of the Philippines. By Shun-ichi Sano, Katsuro Ogawa, and Felipe U. Francisco, pages 63–81, 7 figures, 1 table
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IV. Sediments of Taiwan Strait and the southern part of the Taiwan Basin. By J. T. Chou, pages 75–97, 10 figures, 4 tables
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VI. Structure and stratigraphy of the China Basin. By K. O. Emery and Zvi Ben-Avraham, pages 117–140, 17 figures

VII. Aeromagnetic survey of the Palawan-Sulu offshore area of the Philippines. By W. Bosum, J. C. Fernandez, E. G. Kind, and C. F. Teodoro, pages 141–160, 9 figures

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IX. Seismic investigations on the northern part of the Sunda Shelf south and east of Great Natuna Island. By B. P. Dash, C. M. Shepstone, S. Dayal, S. Guru, B. L. A. Hains, G. A. King, and G. A. Ricketts, pages 179–196, 18 figures

X. Geological structure and some water characteristics of the Java Sea and adjacent continental shelf. By K. O. Emery, Elazar Uchupi, John Sunderland, H. L. Uktolseja, and E. M. Young, pages 197–223, 18 figures

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By
K. O. Emery
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.
and Hiroshi Niino
Tokyo University of Fisheries, Tokyo, Japan

If the authors wish, the following style is also acceptable:

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]

——————— (footnote)
[1] Bundesanstalt für Bodenforschung, 3 Hannover-Buchholz, Federal Republic of Germany
[2] Bureau of Mines, Manila, Philippines

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Abstract: Every paper must have an English abstract. The abstract should, in a single paragraph, state the nature of the investigation and summarize the important conclusions. It should be suitable for separate publication and be adequate for indexing purposes. It should not be in the form of a list of contents and no references should be cited in it.

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Examples:

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Geological Survey of Japan, 1964, Geological Map of Japan: Scale 1: 2,000,000, one sheet.

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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In the course of editing Volume 6, it was found that illustrations submitted by several contributors were not adequate for reproduction and some of them had to be redrafted. On the other hand, increasing number of articles contributed to one volume has exerted pressure on the editorial staff in completing the printing in a limited period. In view of this, the contributors to future volumes are requested to pay attention to the following notes in addition to "SUGGESTION FOR CONTRIBUTORS" enumerated in the preceding pages.

Printed illustrations should be smaller than 14 cm $\times$ 20 cm including the space for caption. These dimensions and the fact that reduction at a scale of one half to two-thirds is most appropriate, should be kept in mind when the drawings are planned. Thickness of lines, and size of letters and symbols should be carefully determined taking the printed dimensions into account.

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Original figures drafted or printed on transparent plastic sheets are preferable in order to avoid damages during transport.

Editor-in-Chief

Annexed 3 Figures (Figure V–1 to V–3)
to
STRATIGRAPHIC STUDIES BY THE
INDONESIAN PETROLEUM INSTITUTE (LEMIGAS)
By
A. R. Udin Adinegoro
Indonesian Petroleum Institute

....

Annexed 4 Maps (Figure VI–1 to VI–4)
to
THE STATUS OF PETROLEUM EXPLORATION IN THE
OFFSHORE AREAS OF INDONESIA
By
Supraptono
Directorate General of Petroleum and Natural Gas, Indonesia