Banda Sea
Banda island arc
Mesozoic magnetic anomalies
Magnetic lineations
Trapped oceanic crust
Mer de Banda
Arc insulaire de Banda
Anomalies magnétiques mésozoïques
Linéations magnétiques
Croûte océanique piégée

Age and origin of the seafloor of the Banda Sea (Eastern Indonesia)

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Received 7/12/84, in revised form 24/5/85, accepted 30/5/85.

ABSTRACT

Within the framework of a French-Indonesian oceanographic cooperative programme, two marine geophysical surveys were conducted in the Banda Sea (Eastern Indonesia) in 1981 and 1982. Both surveys recorded 7400 nautical miles of magnetic and bathymetric profiles, of which 3 800 miles included single channel seismic-reflection.

Previous results of seismic-refraction by US investigations have shown the crust of the South Banda basin to be of oceanic type. Our surveys suggest the existence of magnetic anomalies as old as 130 to 120 m.y. (Lower Cretaceous) in this basin. In the North Banda basin magnetic anomalies show much lower amplitudes and long wavelengths. This could indicate that the crust of the basin was created during the Middle to Upper Cretaceous magnetic quiet period. This hypothesis fits a continuity between the North and South Banda basins, both of which thus comprise a single basin.

From the identification of these anomalies (M 13 to M 8 in the south and possibly M 3 to M 0 in the north) and the orientation of the magnetic lineations (N 55 to 70°E in the south and N 40°E in the north), it is possible to connect them with those present in the Northeast Indian Ocean (Argo abyssal plain) and to deduce that the Banda Sea was previously part of the Indian Ocean which was trapped during Miocene by the present subduction in the southeast Indonesian trench (Timor Trough).

We conclude that the crust of the Banda Sea originated in the eastern Tethys Sea as part of the eastern Indian Ocean and western Pacific Ocean during the Mesozoic era, before being parted by north-south transform faults and later by the present Indonesian subduction.

Oceanol. Acta, 1985, **8**, 4, 379-389.

RÉSUMÉ

Age et origine du plancher océanique de la mer de Banda (Indonésie orientale)

Dans le cadre de la coopération océanologique franco-indonésienne, deux campagnes de géophysique marine ont été réalisées en 1981 et 1982 en mer de Banda (Indonésie orientale). L'ensemble des deux campagnes a permis d'obtenir 7 400 milles nautiques de profils de magnétisme et bathymétrie, dont 3 800 avec de la sismique-réflexion monotrace.

Les résultats de travaux de sismique-réfraction effectués auparavant par des laboratoires américains, avaient montré le caractère océanique de la croûte du bassin Sud-Banda. Nos propres travaux montrent l'existence dans ce bassin d'anomalies magnétiques que l'on date de 130 à 120 m.y. (Crétacé inférieur). Dans le bassin Nord-Banda les anomalies magnétiques présentent, outre des amplitudes faibles, de très grandes longueurs d'onde. Ceci pourrait indiquer que la croûte de ce bassin a été créée au moment de l'époque magnétiquement calme du Crétacé moyen à supérieur. Cette hypothèse implique donc une continuité entre les bassins du nord et du sud de la mer de Banda qui auraient alors formé à l'origine un seul bassin.

De l'identification des anomalies magnétiques, M 13 à M 8 dans le sud et peut-être M 3 à M 0 dans le nord, et de l'orientation des linéations qu'elles forment, N 55 à 70°E dans le sud et N40°E dans le nord, on peut déduire un lien avec celles qui existent dans le nord-est de l'Océan Indien (plaine abyssale de Argo) et en conclure que la croûte de la mer de Banda a d'abord fait partie de l'Océan Indien avant d'être piégée par la subduction actuelle qui a débuté au Miocène dans la fosse indonésienne orientale (fosse de Timor).

On en conclut finalement que la croûte de la mer de Banda a pris naissance dans la mer de Téthys orientale (Océan Indien oriental-Océan Pacifique occidental) au Mésozoïque; après quoi elle a été séparée de l'Océan Pacifique par des failles transformantes nord-sud, puis de l'Océan Indien par l'actuelle subduction indonésienne.

Oceanol. Acta, 1985, **8**, 4, 379-389.

PRESENTATION OF THE CRUISES AND METHODOLOGY

This report presents some of the results of two joint French-Indonesian surveys carried out with the "R. V. Coriolis" of IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer), in March 1981 (Corindon III), and in July-August 1982 (Corindon VII). During these two three-week cruises, the primary objective of which was to study the superficial crust of the Banda Sea, 7400 nautical miles of magnetic and bathymetric profiles were recorded, including 3 800 miles with single channel seismic-reflection.

Positioning of the ship was given by the Transit system of satellite navigation using a "Magnavox MX 1112" (one channel receiver and computer) coupled to a BEN electromagnetic speedmeter and to a gyrocompass connected to the automatic pilot. The heading and speed data were digitized every two seconds and fed into the navigation system to give the fix at any time. An HP computer recorded the estimated fixes every minute and the satellite fixes. Positioning was updated at each satellite fix.

Depth measurements were recorded on an EDO echo sounder with a 1-second sweep during the first cruise and a sweep of 2 seconds during the second cruise. Bathymetry was obtained with a precision of ten fathoms by manually digitizing the echo sounding records, assuming a sound velocity in sea water of 800 fathoms/second.

The measurements of the total magnetic field were carried out successively with a Barringer then a Varian magnetometer and recorded every minute, giving data every 200 or 300 m, for a ship velocity of 6 to 10 knots, above floors located between 4000 and over 5000 m.

The seismic source was for most of the time a TWG gun, a modified air gun in which a second chamber neutralizes the effect of the bubble, thus allowing higher shooting frequencies, *i. e.* a shot every 10 seconds, and therefore a better resolution power; the volume of the chamber is 86 cubic inches. This gun, replaced during its failure periods (about 12 hours for both cruises) by a standard gun, was immersed at a depth of about 6 m.

The reflected seismic waves were collected by a 4 channel AMG streamer, only one channel of which was active (channel 2 or 3 depending upon the noise level), immersed at about 8 m. The signal from the streamer is introduced into a pre-amplifier "Le Matériel Magnétique" with a pass band of 26 to 220 Hz and with a 40 db gain. The pre-amplifier output is either connected (a) to a Sobrelec amplifier with constant gain, or variable gain following a slope, or automatic depending on the level of the signal (this last mode was used most of the time, with an initial gain of 15 to 21 dB and an expansion rate of 300 dB/octave); or (b) to a Krohn-Hite filter-amplifier. The signal obtained is then sent to two EPC recorders with an 8-second sweep on one, to have a general sight and a moderated vertical amplification ($\sim$6), and a 3-second sweep on the other, to obtain a better definition of the upper sedimentary layers. The depth of penetration was often over 3 seconds two-way time. Analogic magnetic recordings were also made on a Schlumberger recorder for about fifty hours during the second cruise.

LOCATION, MORPHOLOGY AND STRUCTURE OF THE BANDA SEA

The Banda Sea (Fig. 1) is a marginal sea located at the back of the eastern Indonesian island arc, also called Banda arc, created by the subduction of the Indo-Australian plate under the Southeast Asia plate (Cardwell, Isacks, 1978). With a small surface, located between longitudes 123 to 131°E and latitudes 2 to 8°S, its morphology and the structure of its floor are complex, and a probable consequence of the long tectonic history of this region. On a local scale, the Banda Sea is constituted by small basins whose bottom is covered by a sedimentary layer of 1 to 3 seconds t.w.t. (two-way time) in thickness; these basins are separated by rises and outcrops which may or may not be volcanic. On the regional scale, the Banda Sea is formed by two main basins, north and south, with a depth of over 5 000 m (Fig. 2 and 3). The two basins are separated by a rise which seems to be a sedimentary one, due to the absence of magnetic anomalies, but of which only a superficial thickness less than a few tenth of seconds

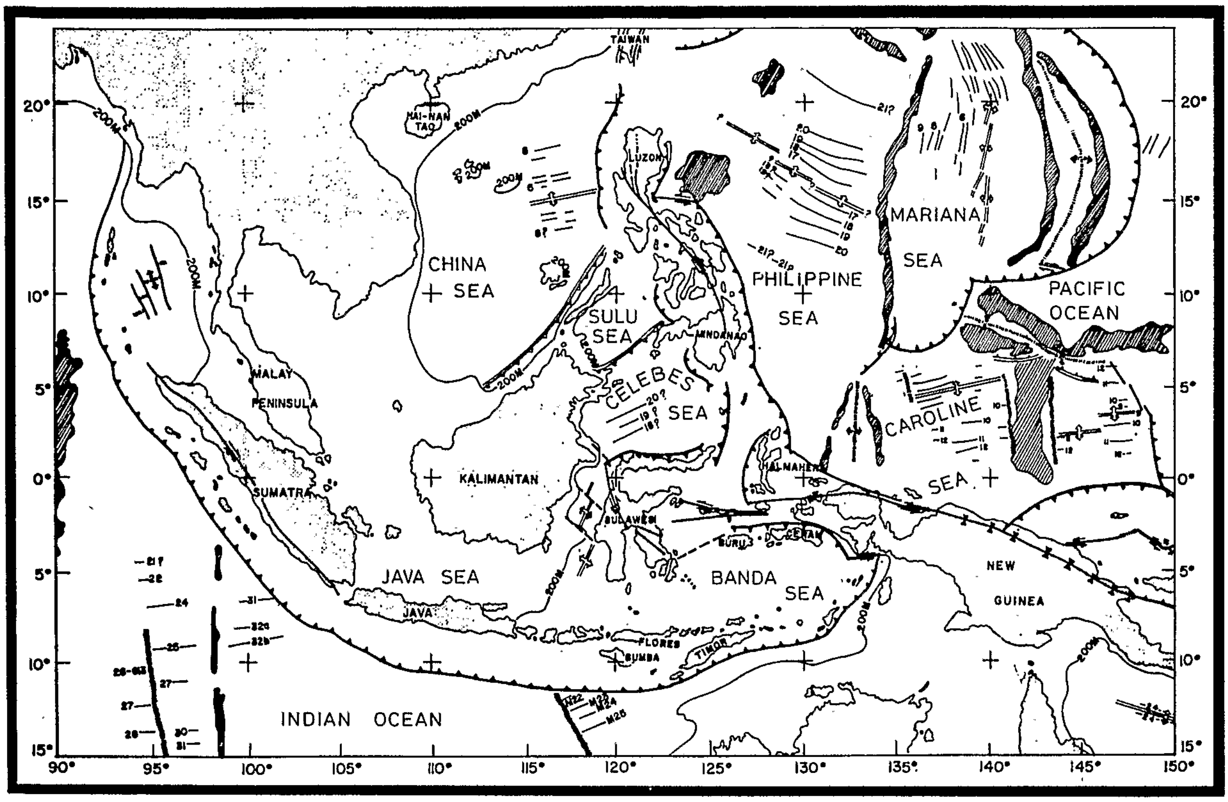

Figure 1

Physiographical and tectonic map of the Southeast Asia area (from J. K. Weissel, 1981 – Magnetic lineations in marginal basins of the western Pacific, Philos. Trans. R. Soc. London, A 300, 223-247).

Carte physiographique et tectonique de la région Sud-Est Asiatique (d'après J. K. Weissel, 1981).

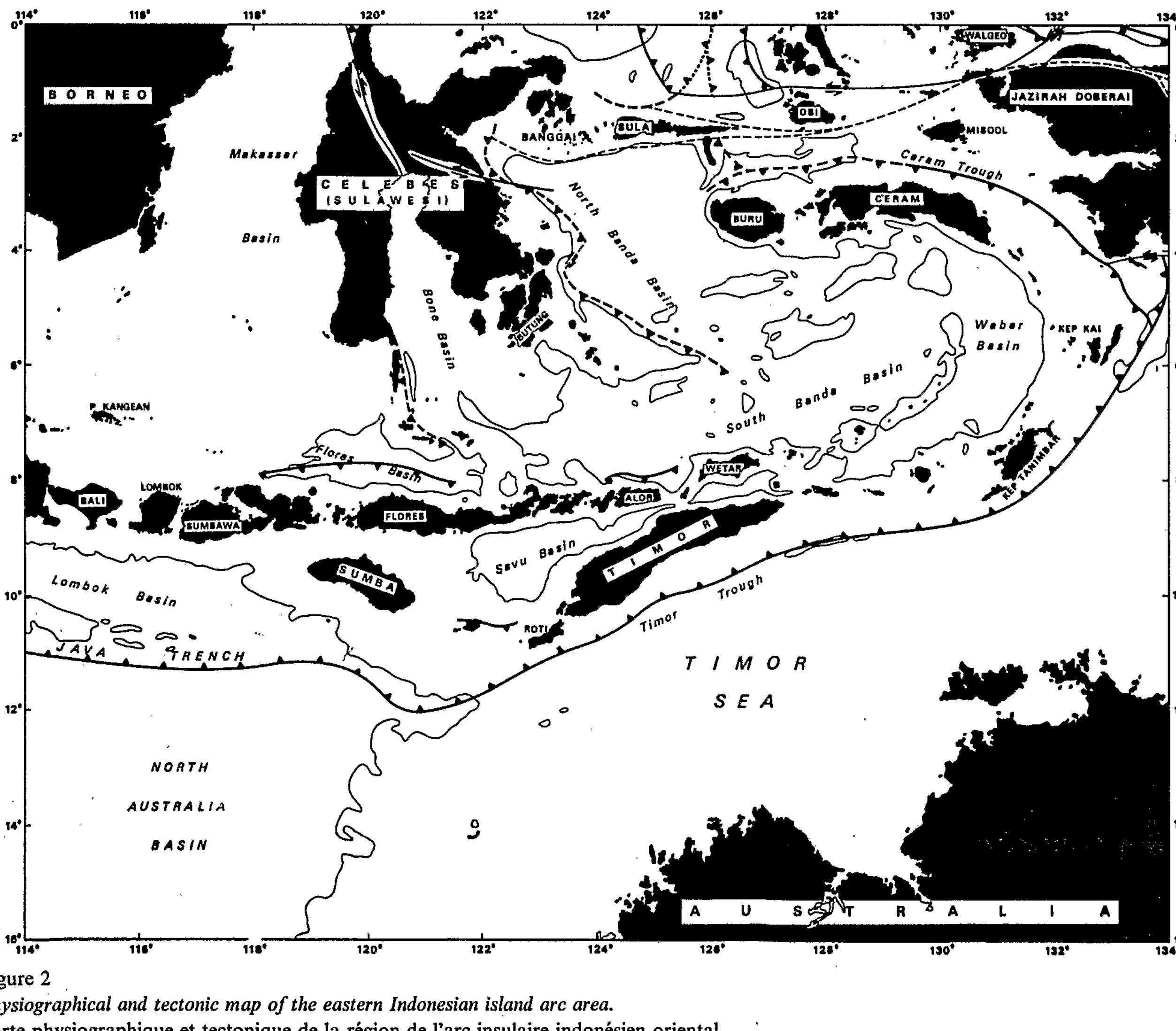

Figure 2

Physiographical and tectonic map of the eastern Indonesian island arc area.

Carte physiographique et tectonique de la région de l'arc insulaire indonésien oriental.

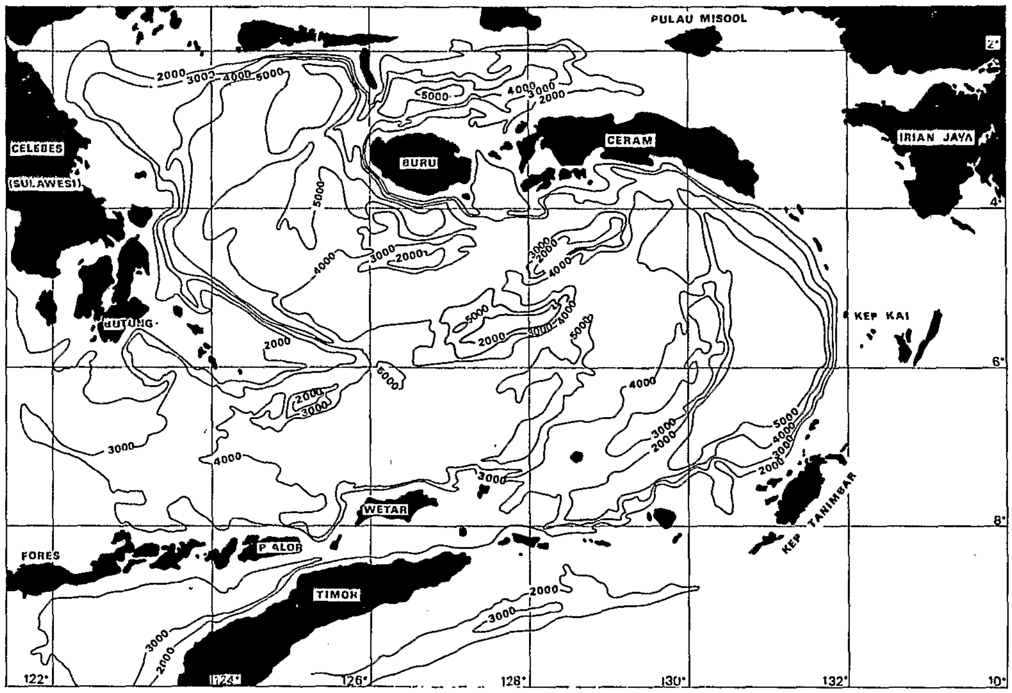

Figure 3
Bathymetric map of the Banda Sea (isodepths in meters; from US Geological Survey, 1974).
Carte bathymétrique de la mer de Banda (isobaths en mètres) (d'après le US Geological Survey, 1974).

t.w.t. has been penetrated; however in some places volcanic islets emerge from this rise.

The southern basin has an elongated shape in ENE-WSW direction on about 800 km. With a width of 150 to 250 km, it is located above and parallel to the subduction of the Indo-Australian plate under the Southeast Asia plate (Fig. 2). Its boundaries are: to the South and East the internal volcanic Banda arc; to the North the rise which separates it from the North Banda basin; and to the West the southward extensions of Sulawesi island. As for the northern basin, it nearly forms a quadrilateral with a 300 km side, limited to the North, West and Southwest by the arms of Sulawesi island, to the East by Buru island and to the Southeast by the rise which separates it from the southern basin.

Previous studies made in the Banda Sea have essentially been studies of seismic-refraction made by American laboratories. They determined the crust of the South Banda basin to be of oceanic structure (Bowin *et al.*, 1977; Curray *et al.*, 1977; Purdy *et al.*, 1977; Purdy, Detrick, 1978). This result has been confirmed (Bowin *et al.*, 1980) after a survey made with the "R.V. Atlantis II" of Woods Hole Oceanographic Institution and "R.V. Thomas-Washington" of Scripps Institution of Oceanography, which, by the means of 19 seismic-refraction profiles, showed the oceanic nature of the crust not only in the South Banda Basin but also in the inter-arc Weder Basin (Fig. 2). These same profiles also show that the continental crust, 35 to 40 km thick, of the Australian shelf advances under the Southeast Asia plate until reaching the level of Timor and Kep Tanimbar islands (Fig. 2); this underthrust of the Australian crust is confirmed by the magnetic anomalies with large wavelengths and low amplitudes of the Australian shelf which are present up to the internal edge of the external Banda arc (Bowin *et al.*, 1980).

HYPOTHESIS CONCERNING THE ORIGIN OF THE BANDA SEA

The origin and the age of the crust of the Banda Sea have been the subject of various theories. Some authors think that the Banda Sea was formed during the Neogene (Mio-Pliocene; Hamilton, 1973; 1977; Carter *et al.*, 1976) or between Paleocene and late Pliocene (Audley-Charles *et al.*, 1972) by the creation of crust at the back of an island arc (Karig, 1971), pushing the volcanic arc outwards (Hamilton, 1973; 1977). According to another hypothesis the Banda Sea would be a piece of the seafloor of the Pacific Ocean, trapped in the Southeast Asia plate by subduction and transform faults (Crostella, 1977; Katili, 1978). Finally, other authors (Bowin *et al.*, 1977; Bowin *et al.*, 1980) suggest that the crust of the South Banda basin could be part of the Indian Ocean crust dating back to Cretaceous because of the similitude of the direction, N60 to 70°E, and the wavelengths of some magnetic anomalies evidenced in this part of the Banda Sea and the direction, N55 to 82°E, of the magnetic lineations of the Northeast Indian Ocean (Heirtzler *et al.*, 1978) at the south of the subduction zone of Java.

However, if we consider the great depth of the oceanic basement, sometimes more than 5 000 m, the low heat flow, an average of 1.24 HFU and generally under 1.5 HFU (Jacobson *et al.*, 1977), and the sedimentary thickness, 1 to 3 seconds t.w.t., it can be inferred, by using the relations between depth and heat flow versus age (Parsons, Sclater, 1977), that the seafloor of the Banda Sea dates back at least to the Paleocene of Cretaceous.

PRESENTATION OF MAGNETIC DATA

Definition of magnetic anomalies

A theoretical reference field (International Geomagnetic Reference Field of 1975, accounting for the secular variation) has been subtracted from each data of the measured total magnetic field: variations, or magnetic anomalies, of the measured field as compared to the theoretical field are then obtained, the wavelengths of which correspond to magnetization sources located in the upper part of the earth's crust. The magnetic anomalies obtained during the 6 000 nautical miles covered in the Banda Sea (Fig. 4) are represented along the ship's tracks with the positive part of the variations on the northern or eastern side of the tracks (horizontal hachures) and the negative part on the southern or western side (vertical hachures; Fig. 5).

The magnetic anomalies of the basins of the Banda Sea have low amplitudes, generally less than 200 gammas (or nanoteslas), especially in the north basin. Also in this north basin the wavelengths are larger than in the south basin, in which they are about 20 km, and at the same time not as well defined. The

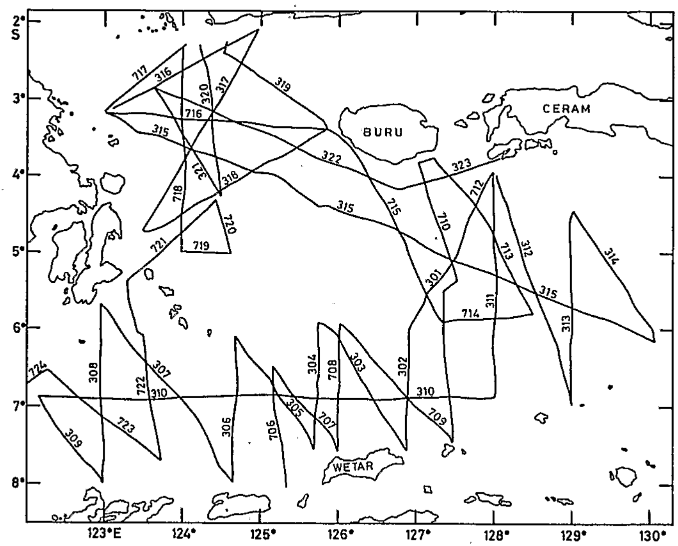

Figure 4

Ship's tracks of Corindon III and Corindon VII cruises in the Banda Sea and numbering of profiles.

Trajets du bateau durant les campagnes Corindon III et Corindon VII dans la mer de Banda et numérotation des profils.

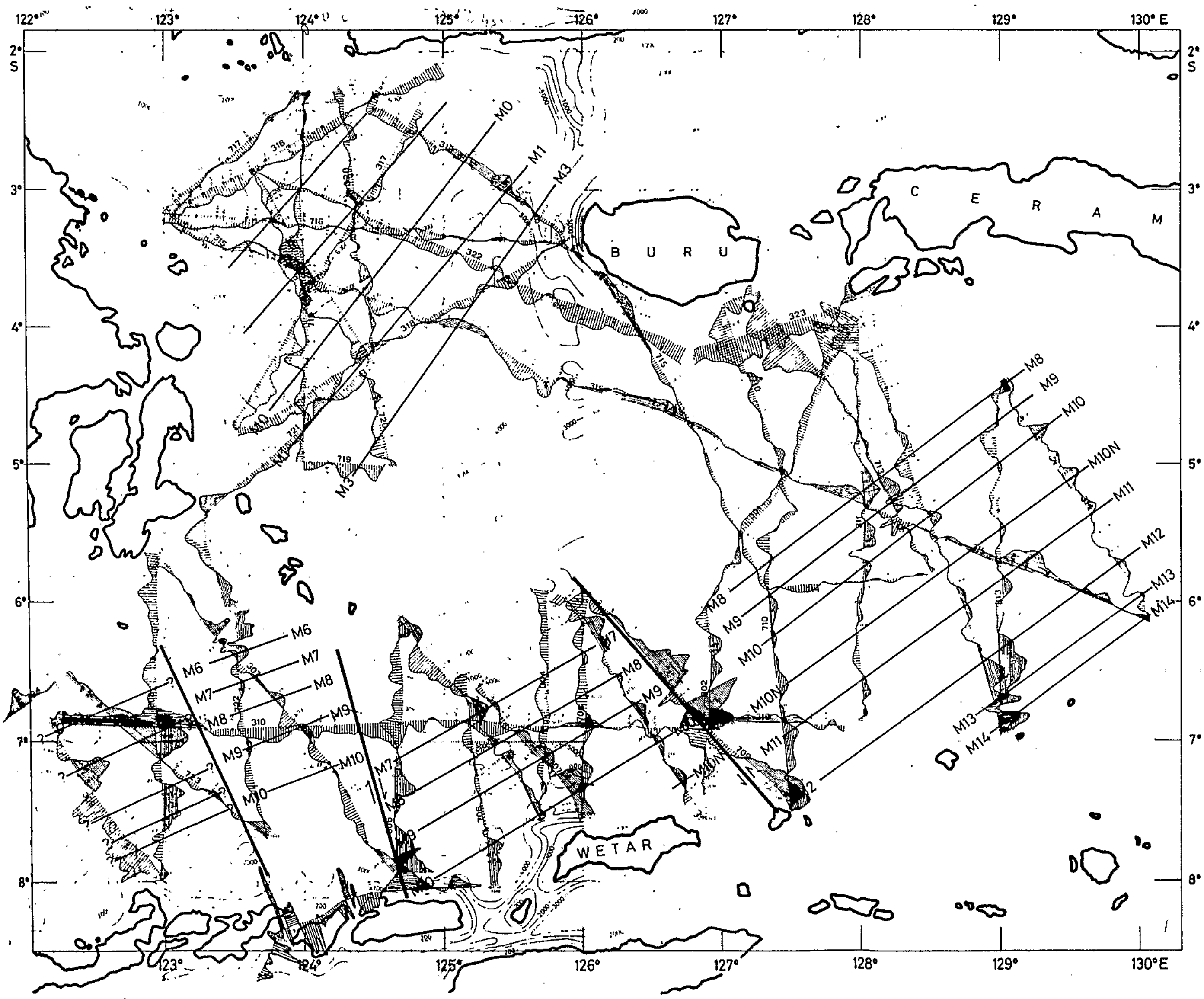

Figure 5

Magnetic anomalies and lineations in the Banda Sea. Anomalies magnétiques et linéations dans la mer de Banda.

reason for this morphology of the magnetic anomalies may be the great depth of the basins, over 5000 m in the south and almost 6000 m in the north. It could also be due to the relative proximity of the magnetic equator which is located at latitude 8°N around 120°E; however in the basin of the Celebes Sea, north of the Banda Sea, between 2°N and 4°N (Fig. 1), where the depth is between 4000 and 5000 m, Eocene magnetic anomalies are well defined with amplitudes of 250 gammas (Weissel, 1980). Finally, this morphology of the magnetic anomalies of the Banda Sea may also be due, and we shall see that this is apparently the main reason, to a low frequency of the reversals of the earth's magnetic field at the time of formation of the crust of these basins. A few higher amplitude anomalies in the south basin have been correlated with the presence of volcanoes either active or not.

Influence of the temporal variations of the magnetic field

In an attempt to determine the influence of temporal variations of the earth's magnetic field (daily and transitory variations) on the recorded geographic variations, we have studied the three-hourly geomagnetic planetary indices Kp as given by the Institut für Geophysik of Göttingen and also recordings of the Indonesian Magnetic Observatory of Tangerang (06°10′S, 106°38′E).

During the first survey (Corindon III, from March 8th to March 31st 1981) the disturbance of the magnetic field was generally low, with a mean three-hourly value of $\overline{Kp}=2+$ (the maximum degree of the scale is Kp=9); during the second survey (Corindon VII, from July 15th to August 5th 1982) magnetic disturbances had a higher level, with a mean three-hourly value of $\overline{Kp}=4-$. The mean three-hourly values Kp during every profile are shown on Figure 6.

Because of the definition of the three-hourly geomagnetic planetary indices Kp, which represent the disturbance as compared to the daily variation of the magnetic field, they do not seem to have a visible influence on the studied geographical variations, first because of the low amplitudes of the temporal disturbances that they reflect and secondly especially because of the duration of the disturbances, from a few seconds to a few minutes, giving wavelengths much smaller than those of the studied geographical variations which are longer than about 20 km.

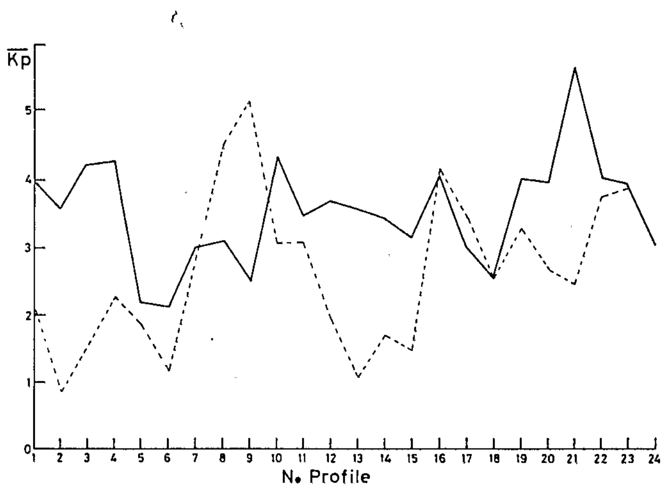

Figure 6

Disturbances of the magnetic field, represented by the mean three-hourly value $\overline{Kp}$, during the surveys Corindon III (----) and VII (——).

Perturbations du champ magnétique, représentées par les valeurs tri-horaires moyennes $\overline{Kp}$, durant les campagnes Corindon III (----) et VII (——).

The effect of the daily variation on the observed phenomena is no doubt more important. The amplitude of the diurnal variation reaches nearly a hundred gammas on the quietest days and exceeds 200 gammas some disturbed days, which is in the same range as the geographical variations. But, on the other hand, the duration of the diurnal variation, representing an increase of the intensity of the magnetic field during about ten hours, gives wavelengths of 100 to 200 km for a speed of the ship between 6 to 10 knots, *i. e.* 5 to 10 times longer than the wavelengths of the studied anomalies. Thus, even if the amplitude of the diurnal variation has a visible effect on the amplitude of the geographical variations since it is in the same range, the distribution of this increase of amplitude on a distance of 100 to 200 km does not change the morphology of the studied anomalies, characterized by average wavelengths of 20 to 40 km, which are superimposed to the daily variation; in other words, the definition of the zero level is secondary because we are studying relative variations and not absolute values.

IDENTIFICATION OF THE MAGNETIC ANOMALIES AND AGE OF THE SEAFLOOR OF THE BANDA SEA

Methodology

It has previously been shown that the crust of the South Banda basin is of oceanic type (Bowin *et al.*, 1980). It must therefore have originated, like all the known oceanic crusts, from an oceanic or a back-arc spreading centre, following the statement of Vine and Matthews (1963).

To identify the magnetic anomalies of oceanic basins as compared to the anomalies caused by the reversals of the earth's magnetic field and fossilized in the crust as it was cooling off, we set a geological model to which we attribute reversals of magnetization in accordance with the geomagnetic reversal time scale. The magnetic field created by this model is calculated and compared to the anomalies recorded along the marine profiles.

South Banda basin

The two-dimensional model selected (Fig. 7) represents the section of a magnetized flat layer with infinite dimension in the direction N70°E; its thickness is 500 m and its top is placed at 4.5 km below the sea level which is the average depth of the oceanic basement in this basin. Assuming that the crust of the South Banda basin would be a trapped piece of oceanic crust from the Indian Ocean (Bowin *et al.*, 1980), it is attributed

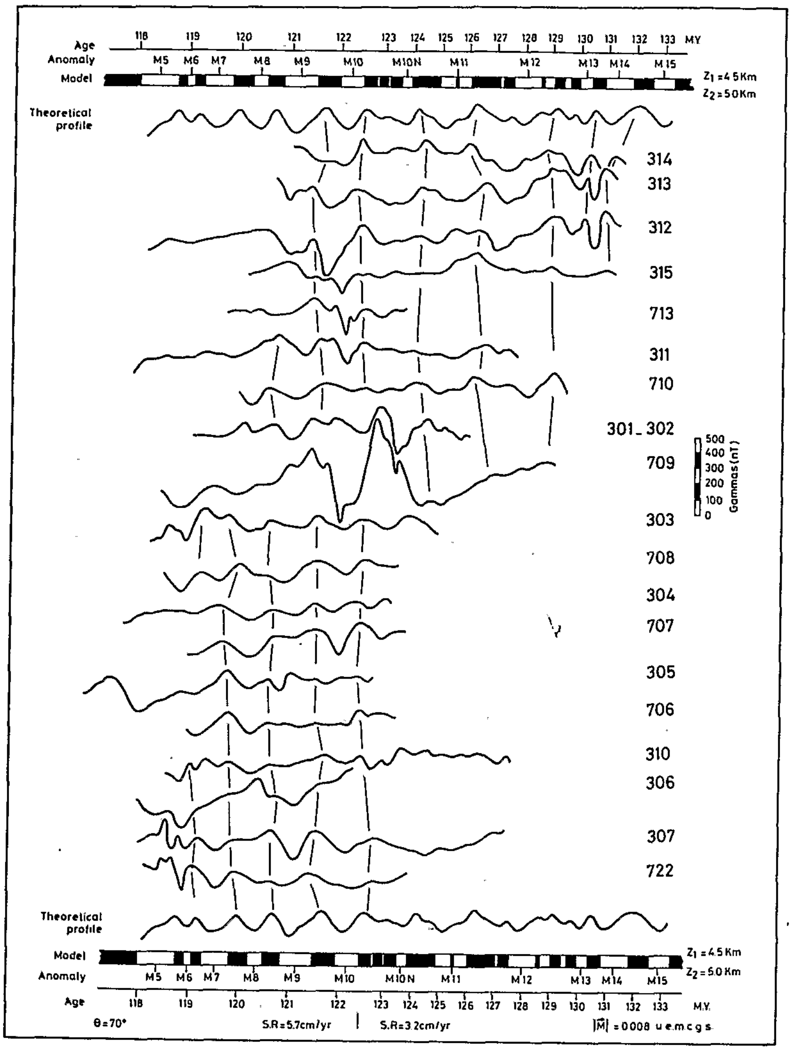

Figure 7

Magnetic model of the South Banda basin: identification of the magnetic anomalies by comparison of the measured profiles with a theoretical profile deduced from the reversals of the earth's magnetic field during lower Cretaceous.

Modèle magnétique du bassin Sud-Banda : identification des anomalies magnétiques par comparaison des profils mesurés avec un profil théorique déduit des inversions du champ magnétique terrestre au Crétacé inférieur.

to the layer a magnetization alternatively positive or northwards (dark blocks) and negative or southwards (light blocks) according to the geomagnetic reversal time scale (Larson, Hilde, 1975) during lower Cretaceous. The width of each magnetized block depends upon the formation rate of the crust, which we have taken identical to the one adopted in the Northeast Indian Ocean (Heirtzler *et al.*, 1978), *i. e.* 5.7 cm/yr till 122.5 m.y. and 3.2 cm/yr after this date: this change in rate has been necessary to obtain the best possible similitude between the magnetic field of the model and the recorded anomalies.

A remanent magnetization of 0.008 c.g.s.e.m.u. in intensity (average intensity of basalt magnetization) with a nil declination and an inclination of $-30°$ (positive magnetization) or $+30°$ (negative magnetization) is attributed to the model so defined. The presnet magnetic field in the considered region is defined by an average intensity of 44 000 gammas, a nil declination and an inclination of $-30°$.

The magnetic field created by this model is then computed and represented by the theoretical profile of Figure 7. By comparing the sequences of recorded anomalies to this theoretical profile, a fairly good similitude on some profiles is obtained, especially in the eastern part of the basin.

Anomalies M13 to M10 are easily identified on profiles 314, 313 and 312, and may be also M9 on profiles 313 and 312. On profiles 315 and 311, anomalies M10, M10N and M11 are also evidenced, even with the subdued amplitude of M10N which is located above the deepest part of the South Banda basin, over 5 000 m. Anomaly M9 of profiles 315, 311 and 713 can be deformed by the influence of the boundary rise between the South and North basins since it is just above it. These six profiles have been carried out under quiet magnetic conditions ($\overline{Kp} \leq 3$ O). The sequence of anomalies of profile 710, recorded under high magnetic disturbance ($\overline{Kp} = 4+$), is however quite similar to the one of the theoretical profile. These anomalies in the eastern part of the South Banda basin form lineations which have been drawn on Figure 5.

The following profiles, located in the centre of the basin (Fig. 4 and 5), pass near a volcano emerging over the sea bottom by about 5 000 m (Fig. 2) and creating very high magnetic variations hiding possible anomalies due to reversals of the field: these are profiles 301-302 and especially 709, which have been obtained under quiet magnetic conditions ($\overline{Kp} \leq 2+$). This very important volcano is located on a bathymetric discontinuity which extends southeastwards the Neogene fossil subduction zone indicated by Hamilton (1979; Fig. 2); profile 709 runs practically along this discontinuity.

On profile 303, also obtained under quiet magnetic conditions ($\overline{Kp}=2-$), some magnetic anomalies can no doubt be identified by extrapolating the magnetic lineations deduced from the previous profiles. On this profile the bathymetric floor is very flat but the sedimentary cover, several hundred metres thick, lies on the basement affected by numerous low amplitude escarpments.

On profiles 708, 304 and 707 with an also flat bathymetric bottom, formed by a slightly thicker sedimentary layer than on the previous profile which fills up a depression of the basement, the magnetic anomalies can no longer be defined by their shape; variations can however be correlated, each of the maxima of these sequences, with anomalies M7 to M10 of the theoretical profile. Magnetic disturbance during recording of these profiles was moderately quiet ($2+ \leq \overline{Kp} \leq 3$ O).

The variations of the profiles 305 and 706 look dissimilar to the previous ones but can however be correlated to the variations of the theoretical profile, thus enabling identification of anomalies M7 and M8. These two anomalies are above a flat bottom constituted by a sedimentary layer having a maximum thickness of 2 seconds t.w.t. and filling up the depression of the basement. An under sea outcrop causing a raise in the basement of 3 seconds t.w.t., even though weakly magnetized, hides anomaly M9. There again the magnetic disturbance ($\overline{Kp} \leq 2+$) does not influence the shape of the variations, only the relief of the basement influencing the magnetic anomalies.

During profile 306 temporal variations of the magnetic field are even quieter ($\overline{Kp}=1$ O). However, themorphology of the sequence of magnetic variations is different from that of the theoretical profile. This profile is located on the edge, indicated by the 4 000 m depth line, of the large occidental platform of the South Banda basin, and the effects of undersea volcanism mask possible anomalies due to the reversals of the magnetic field.

Anomalies sequences of profiles 307 and 722, located on this very wide platform between 4 000 and 3 000 m deep, are morphologically different from the sequence of the theoretical profile but however can be correlated to it, enabling us to recognize anomalies M6 to M10. Such an identification supposes a discontinuity between profiles 306 and 307 which can be illustrated by a fault oriented NNW-SSE. This discontinuity is, moreover, topographically marked by an inflextion of the isodepths towards the NNW. The portion of the crust corresponding to these profiles has probably supported a movement towards the northwest. The level of magnetic disturbance increased during these profiles ($\overline{Kp}=3$ O during profile 307 and 4 O during 722).

Finally the westernmost profiles of the South Banda basin – profiles 308, 309 and 723 – seem, in view of the morphology of the sequences of magnetic variations, to be due to a continental crust and are not geologically speaking part of the South Banda basin *sensu stricto*.

It is therefore established that the magnetic lineations, formed by the identified anomalies, show different domains in the crust of the South Banda basin, each of which is bordered by the faults that we have drawn on Figure 5. In the eastern part the sequences of magnetic anomalies M9 to M13 (or M14) forming lineations orientated N55°E are certainly evident. The central part, bordered on each side by two bathymetric and magnetic discontinuities oriented NW-SE (to the east) and NNW-SSE (to the west), is characterized by sequences of magnetic variations less typical morphologically speaking but which can however be identified by correlation as being anomalies M7 to M10; these anomalies form lineations oriented N60°E. Regarding the western part, topographically constituted by the large platform between depths 4 000 and 3 000 m, it seems to be constituted by two parts: to the east a part on which anomalies M6 to M10 seem to be recognizable, forming lineations oriented N70°E, and to the west a part magnetic variation profiles do not permit identification of any anomalies of reversals of the field, but according to which it nevertheless seems that a structural orientation N65°E can be recognized.

North Banda basin

The magnetic anomalies of the North Banda basin (Fig. 5) are far less morphologically typical than those of the South Banda basin: in fact the amplitudes are low, the wavelengths long and no preferential orientation appears. However, after a careful study of the variations along the profiles oriented in every direction, an orientation in the direction NE-SW seems to be slightly marked.

We have therefore tried to extrapolate the results of the southern basin (crust younger and younger towards the northwest) by extending in time the previous model to the Upper Cretaceous. We thus reach an epoch during which the reversals of the magnetic field are becoming less frequent up to a long period of 30 million years, between 110 and 80 m.y., during which no reversal occurred (commonly named the Cretaceous magnetic quiet epoch); this could therefore explain the morphology of the magnetic anomalies of the North Banda basin.

The model used in the South Banda basin has thus been extended by using the reversals of the magnetic field until 105 m.y. (Fig. 8). The depth of the North Banda basin being greater than that of the South (Fig. 3), the top of the magnetized layer has been set in our model at 5.0 km. In addition, in order to obtain the best possible correlation between the theoretical profile, the magnetic field created by the model, and the profiles of the observed anomalies, a drift rate of 1 cm/yr towards the northwest has been attributed to the crust of this basin. On Figure 8 some of the profiles projected according to the direction NW-SE are represented for purposes of comparison with the theoretical profile.

Although correlations are possible, identification of the anomalies is difficult due partly to the low frequency of the reversals of the magnetic field and partly to the great depth of the basin which subdues still further the magnetic variations. The bottom of the basin is flat and relatively evenly shaped, covered with a thin sedimentary layer except in the northwest part where this layer thickens. The isodepths appearing preferentially

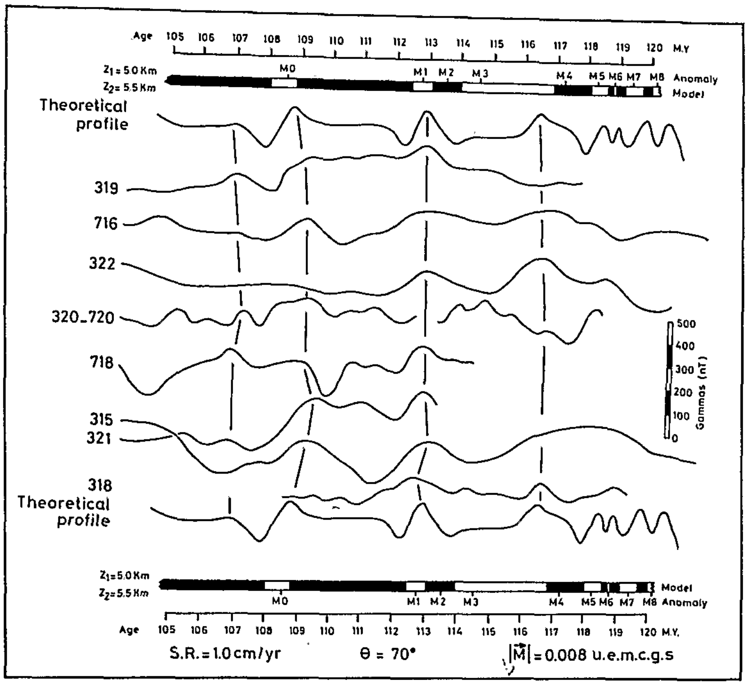

Figure 8

Magnetic model of the North Banda basin: identification of the magnetic anomalies by comparison of the measured profiles with a theoretical profile deduced from the reversals of the earth's magnetic field during middle Cretaceous.

Modèle magnétique du bassin Nord-Banda : identification des anomalies magnétiques par comparaison des profils mesurés avec un profil théorique déduit des inversions du champ magnétique terrestre au Crétacé moyen.

elongated in the direction NE-SW (Fig. 3), some recorded magnetic variations can have at least a partial origin in the structural design of the basement. Finally, taking into consideration the large wavelengths of the observed anomalies, the daily variation of the earth's magnetic field has a less negligible influence than in the south for the definition of the zero level.

With all the above mentioned restrictions, we adopted the model of Figure 8 representing the identification obtained by correlation of some of the variations of profiles projected in the direction NW-SE. The anomalies so recognized, M3 to M0, form the lineations oriented in the direction N40°E and showed on Figure 5.

Our model thus implies a continuity of the crust of the South and North Banda basins. The part of the crust representing the rise between both basins, on which it does not seem possible to detect any magnetic variation, should thus have been, at least at the origin, an oceanic crust which would have supported modifications; the problem of its present nature remains therefore unsolved. Furthermore the distance between lineations M8 of the eastern part of the South Banda basin and M3 of the North Banda basin indicates a spreading rate of 7.0 cm/yr for the corresponding crust; this drift rate, although high, is not impossible, especially if compared to the value of 5.7 cm/yr taken for the youngest part of the South Banda basin.

TECTONIC IMPLICATIONS

The existence of Mesozoic magnetic anomalies M13 to M9 has been shown in the eastern part of the South Banda basin, M10 to M7 in the central and western parts, and M3 to M0 in the northern basin. These anomalies form lineations respectively oriented N55°E, N60°E, N70°E and N40°E (Fig. 5).

Thanks to the identification of the magnetic anomalies we are able to date the seafloor of the Banda Sea: 131 to 121 m.y. for the southeast region, 123 to 119 m.y. for the southwest region and 114 to 100 m.y. for the north; the region located between the southern and northern basins is inferred to have been formed between 120 to 115 m.y. ago. The orientation of the lineations shows the way the crust was formed and enables us to follow its evolution. Thus, considering that the age of the crust of the Banda Sea increases from northwest towards southeast, we conclude that it has been created in a spreading centre located in the northwest from which it has drifted towards the southeast at the rate of 3.2 cm/yr until 122.5 m.y., then at 5.7 cm/yr until 119 m.y., then 7.0 cm/yr until 115 m.y. and finally 1 cm/yr after this date.

The breaks in the magnetic lineations point to discontinuities in the crust, which is therefore divided into various parts that have slid one upon the other along faults. In the southern basin, a very important discontinuity goes practically along profile 709 and separates two sections of crust, the difference between which is reflected not only in the orientations of the magnetic lineations, which differ by 5° (proof of the rotation of these two parts in regard to each other), but also in the morphology of the anomalies. The morphology of the anomalies in the western part of the South Banda basin is less typical of reversal anomalies; this may be due to tectonic movements which have affected the structure of the corresponding crust, thus deforming the anomalies created by this crust. The seismic-reflection sections show that the southwest part of the Banda Sea is formed by a depression elongated between meridians 123°E to 127°E; the flat topographic bottom is formed by the top of the sedimentary cover 2 to 3 seconds t.w.t. thick, somewhat thicker than in the eastern part or in the northern basin; this cover fills up the depression of the basement and the upper layers are discordant as compared to the top of the basement. The limits of this basin and the thinning down of the

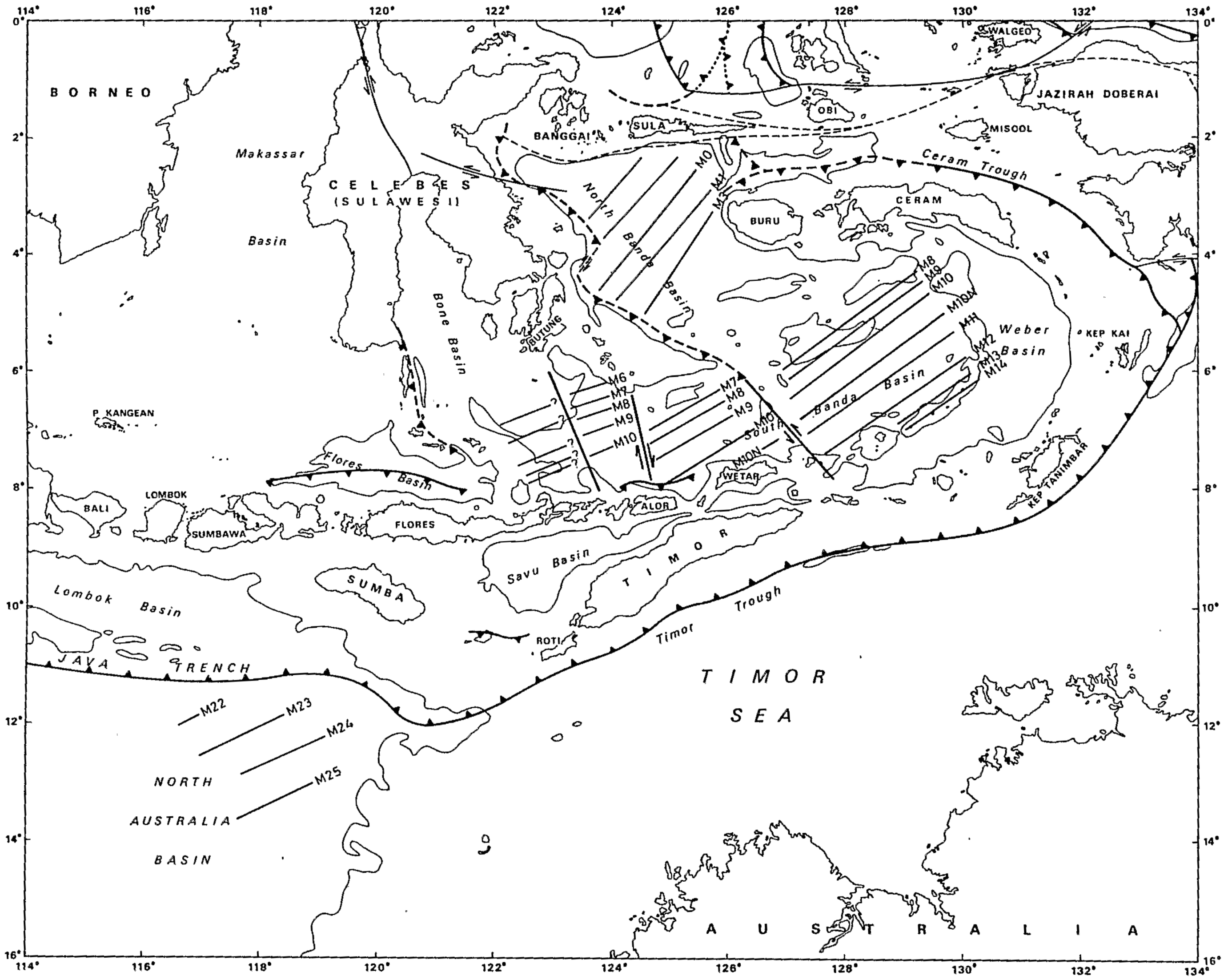

Figure 9

Magnetic lineations in the Banda Sea and Northeast Indian Ocean.

Linéations magnétiques dans la mer de Banda et le nord-est de l'Océan Indien.

sediments are east on profile 303 and west on profile 308; moreover profile 308 displays the broken appearance of the basement which is covered by a sedimentary layer in concordance.

As far as the origin of the crust of the Banda Sea is concerned, this can be inferred from the comparison of the age and the orientation of its magnetic lineations with those of the northeast part of the Indian Ocean (Fig. 9). The existence of magnetic anomalies M10 to M25 forming sections of lineations limited by numerous faults oriented between NW-SE and NNW-SSE have been showed by Heitzler *et al.* (1978) in this region of the Indian Ocean located at the south of the Java trench and called Argo Abyssal Plain, or North Australian Plateau, or Eastern Wharton Basin. The age of these anomalies, forming lineations oriented N55 to 82°E, increases from north to south. This similitary in age and orientation between magnetic lineations of the Banda Sea and those of the Northeast Indian Ocean permits us to suggest a common origin of the crusts of these two oceanic basins, part of which disappeared in the subduction zone of Java-Timor which has been active since the Miocene.

Furthermore, these magnetic lineations can be related to those having the same age and the same orientation in the Northwest Pacific Basin (Hayes, Taylor, 1978). It can therefore be concluded that the crust of the Banda Sea originated as the Northeast Indian Ocean and Northwest Pacific Ocean in the eastern Tethys Sea from a Mesozoic spreading centre which has then disappeared in subductions under Asia (Hilde *et al.*, 1977). North-south transform faults have separated the Indian and Pacific crusts (Ben Avraham, 1978), after which the Java-Timor subduction has trapped the crust of the Banda Sea during the Miocene.

Acknowledgements

The authors are indebted to R. Decourt and F. Jamet who assembled the data and to J.-Y. Collot, J. Daniel and J. Récy for reviewing the paper.

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