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Hydrocarbon prospect mapping using balanced cross-sections and gravity modelling, Onin and Kumawa Peninsulas, Irian Jaya, Indonesia

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Abstract: Exploration field geology mapping and acquisition of gravity data has been conducted on approximately 650 line kilometres of 26 surveyed traverse lines across the Onin and Kumawa Peninsulas of western Irian Jaya. Karstified New Guinea Limestone with a maximum thickness of 2,150 m is the predominant surface outcrop, and precludes use of seismic. However, integrated use of field geology data, balanced cross-sections, and gravity modelling has enabled us to identify two giant hydrocarbon prospects.

The Onin and Kumawa Peninsulas lie at the margin of Jurassic age faulting associated with the Australian Northwest Shelf. Jurassic rift sands of the Lower Kembelangan Formation are the primary reservoir target. During the Plio-Pleistocene, collision of the Australian plate and the Banda Arc inverted sections of the rift system, including the Onin and Kumawa Peninsulas.

A better understanding of the regional structure was gained by integrating the Mobil Oil gravity data (of 1992) and that collected by Shell Oil (in the 1950's) in the structurally less deformed Bomberai region east of Onin and Kumawa. Bouguer reduction was carried out using 2.4 g/cm^3 density, GRS 1967 and IGSN 1971. A sequence of gravity maps were generated, including Bouguer, regional, residual, downward continued, and second derivative. Spectral analyses indicate that basement is about 3 km depth at Onin and about 6 km in the Bomberai area. The Bomberai and Onin-Kumawa regions are separated from one another by a steep gravity gradient which has a SE-NW strike direction. This gravity gradient may represent a change of lithology.

Prospect definition was obtained by evaluating traverse profile data. Balanced cross-sections were constructed, using detailed biostratigraphy to determine formation thicknesses and amount of fault offsets. Where possible, onshore balanced section profiles were tied to offshore seismic profiles and wells. Two dimensional forward gravity models were calculated, using formation densities from well data. The calculated profiles were then compared to profile observed values.

Differences between calculated and observed profiles were resolved by adhering to the exploration model, which required that the main thickness changes would be in the Lower Kembelangan Formation rift section. Density values for the seven formations were held constant.

Constraining the variables to one (Lower Kembelangan thickness) in the gravity profile modelling maintains credibility of the technique. Errors inherent in the structural maps derived from the cross-sections are likely to be vertical shift which would be approximately constant across the prospects. The interactive work between geologists and geophysicists was effective in producing a logical representation of subsurface geology, which in turn allowed selection of drill sites with some degree of confidence. Subsequent to completing the modelling, offshore seismic data across the western plunge of the Onin Peninsula was obtained. The structural style demonstrated in the modelling and the seismic data are comparable. This enhances our confidence in the modelling results.

INTRODUCTION

The Onin and Kumawa Peninsulas are located in the western portion of Irian Jaya, south of Kepala Burung or the Bird's Head, Indonesia (Figs. 1 and 2). The search for hydrocarbon occurrences in Kepala Burung has long been conducted by many oil companies (Visser and Hermes, 1962). Oil and gas are produced in the Tertiary basin of Salawati, a structural depression in the western part of Kepala Burung. It is thought oil has been migrated from the Mesozoic-Paleozoic formation into the Miocene Kais Formation (Samuel *et al.*, 1990). Although drillings in this basin have never reached the Pre-Tertiary rock formation, many oil workers have postulated this formation might be the source rock

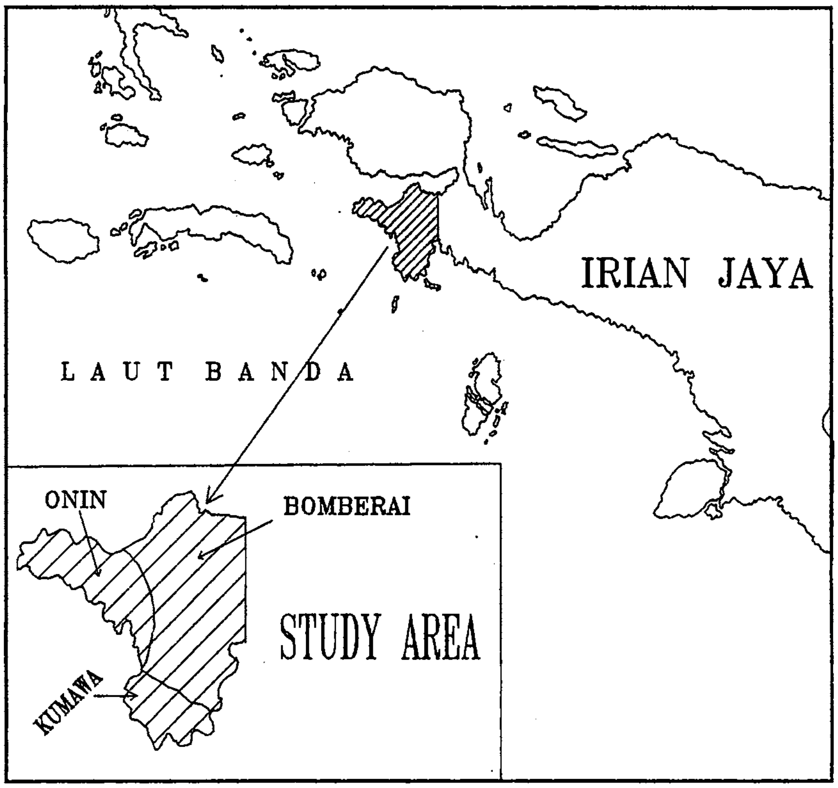


Figure 1. Map of study location.

of hydrocarbon accumulation. Departing from this thought, geological and gravity traverses were made in Onin and Kumawa peninsulas with the target to determine the depth and the configuration of the Mesozoic-Palaeozoic rock layers. Surface geological mapping and gravity readings across the peninsulas were conducted (Fig. 3). Sections and maps were generated to model the subsurface geology. A 2-D modelling programme of the software packages LCT and ISM mapping were used. Balanced cross section was applied to produce reasonable and logical gravity models.

The Onin peninsula is dominated by thrusted and broadly folded limestone sheet being developed into the Onin Main Anticline. Small anticlines in the west and north are also present. A number of easterly trending fractures disrupted the numerous anticlines and synclines. The Mesozoic and Cainozoic sediments are mainly calcareous in the lower part with steeply dipping Neogene terrigenous clastic detritus.

The dominant structural feature in the Kumawa Peninsula is the Kumawa Anticline. It is characterised by an extensive array of superficial horst and graben in the fractured crestal region. Eocene reef core material has been exposed in the crestal horst (Robinson *et al.*, 1988).

This paper deals with determining depth of subsurface structural features that is making use of existed data such as drilling logs and seismic data in the surrounding offshore region, surface geology and gravity data to identify drilling sites for hydrocarbon prospects.

GEOLOGICAL SETTING

The Onin and Kumawa Peninsulas lie on the present-day northwest margin of the Australian continental plate. These two peninsulas together with the Bomberai region is known as the Babo Block. During the Permo-Triassic period the region was undergoing crustal thinning and downwarping associated with extension forces. This extension leads to continental breakup and movement of the Indian block away from the Australian northwest shelf and curves northwards between Seram and Babo, with Seram lying on the western margin of the rift the Onin and Kumawa Peninsulas on the eastern margin (Fig. 4). Several oil discoveries have been made in the rift system, including the Challis and Jabiru fields in the Vulcan rift and more recently the Oseil wildcat on Seram.

The collision of the Banda Arc at 5-3 MYBP is interpreted as causing a foreland bulge, inverting many of the Triassic-Early Jurassic rift grabens, and reactivating many of the graben system extension faults. Based on current data, Onin is the largest inversion structure along the trend. The Kumawa Anticlinorium, on the other hand, is characterised by horst and graven in the fractured

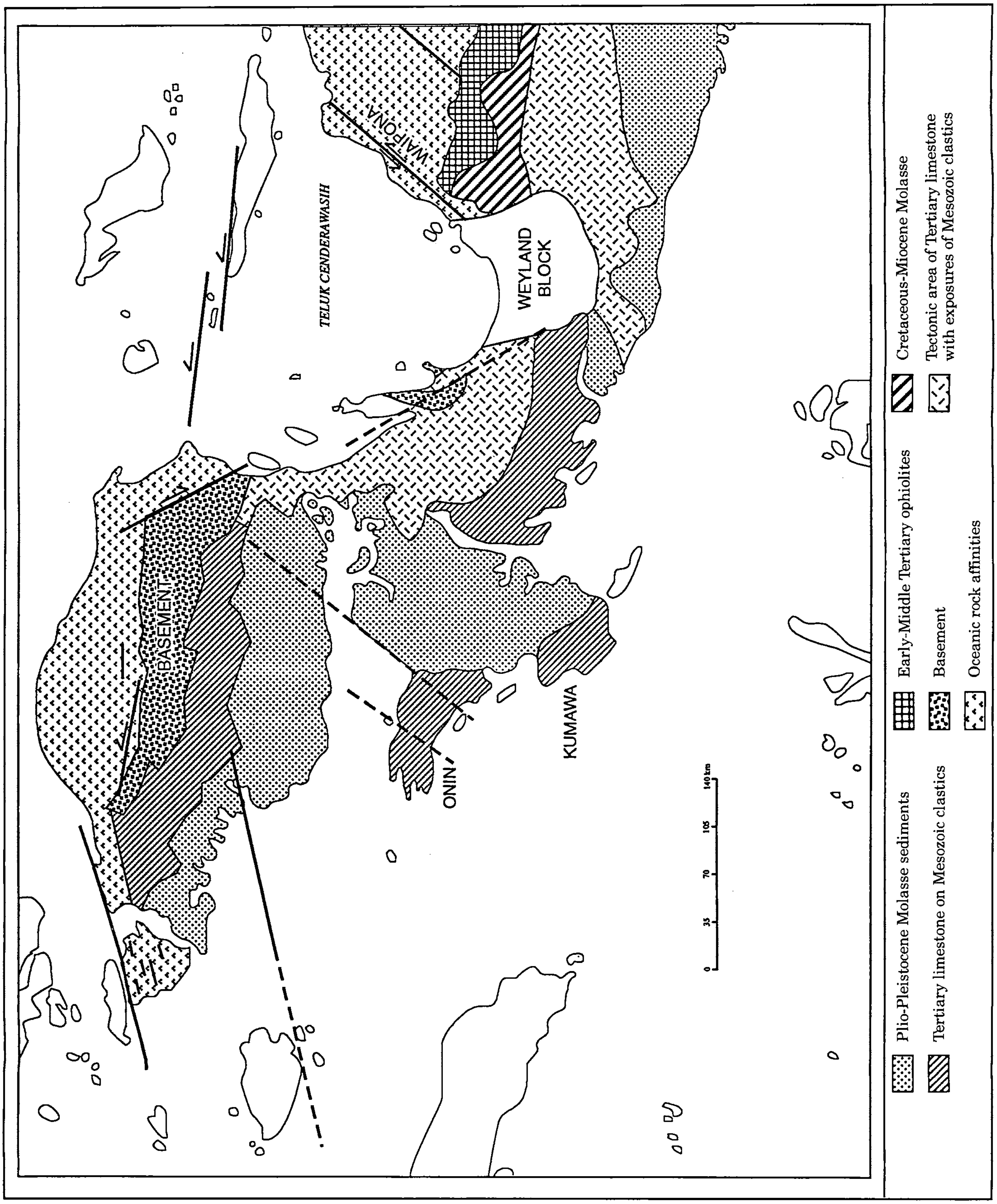


Figure 2. Geological sketch map of Western Irian Jaya.

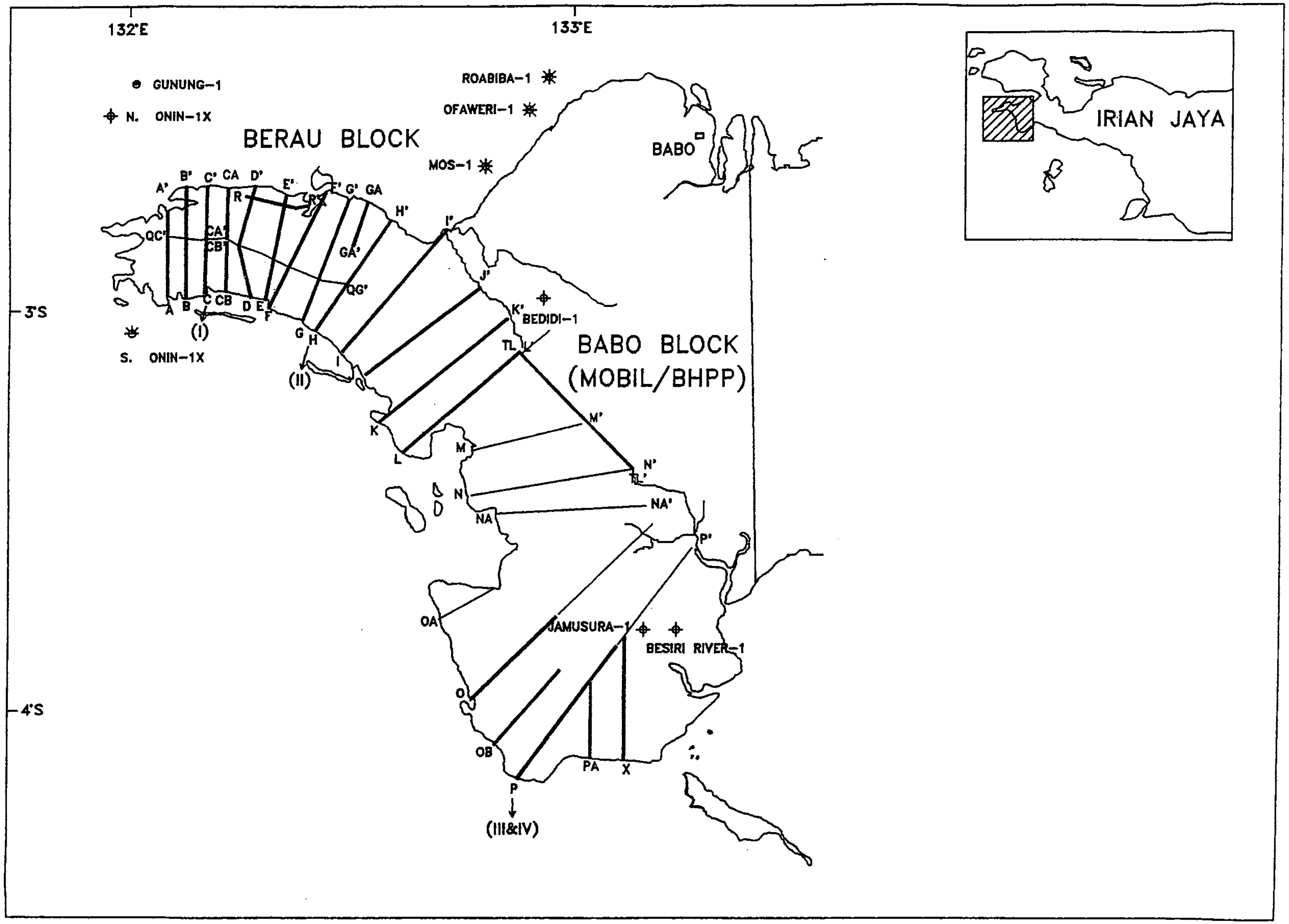


Figure 3. Map of gravity and geology traverses in the Onin and Kumawa Peninsulas. The traverses across the peninsulas are 26 in number and some are along the coastal regions with the following specifications.

Geology		Gravity and magnetics	
land	= 705 km	land	= 948 km
coastal	= 573 km	coastal/river	= 675 km

Station interval for gravity and magnetics ~ 100 m. Position and topographic surveys were conducted respectively by GPS and theodolite methods. Traverses C-C', H-H' and P-P' or I, II and III are described in this paper (Figs. 8, 9, 10 and 11).

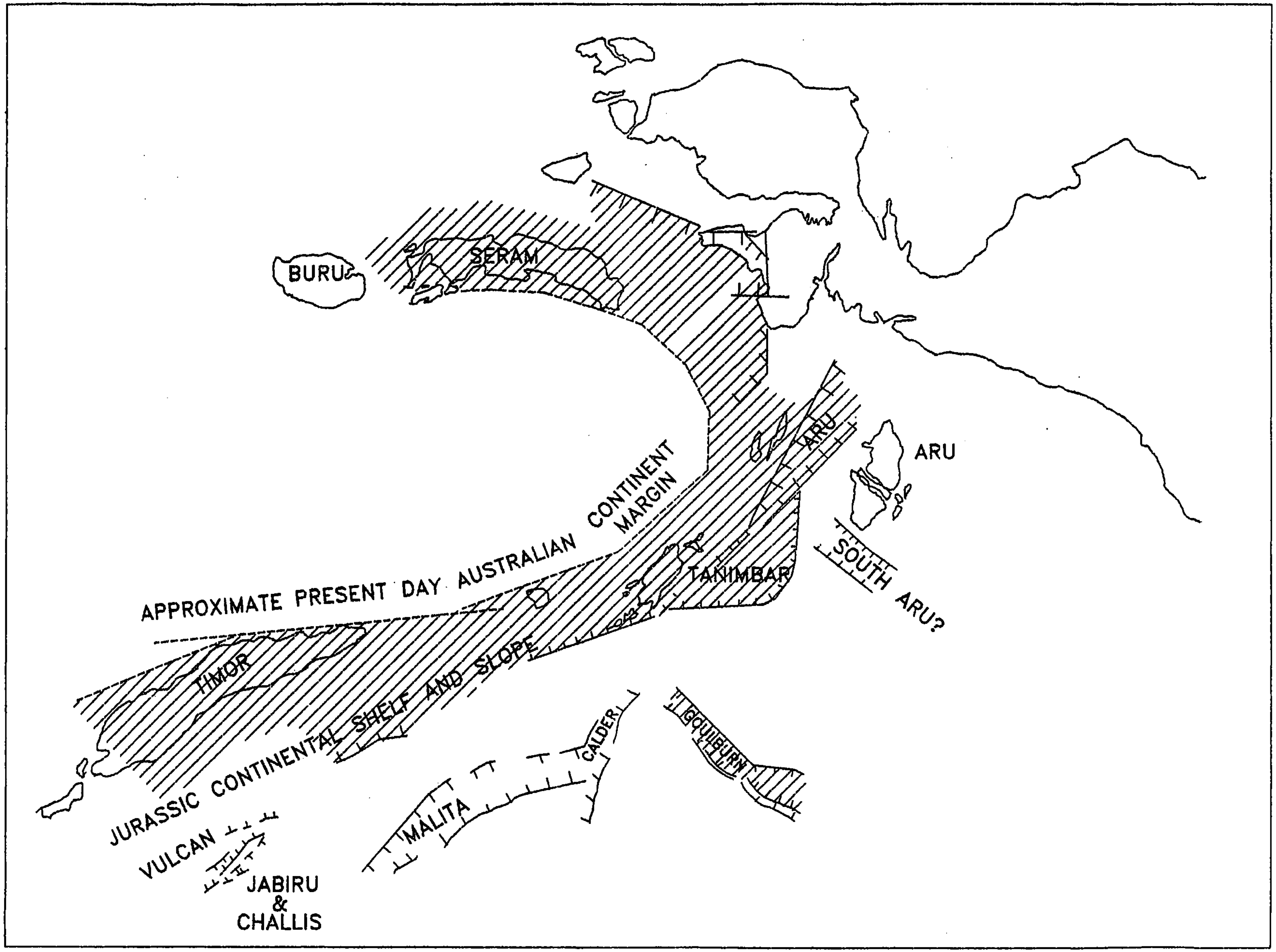


Figure 4. Australian northwest shelf, Triassic-Jurassic rifting. The Australian continental margin is indicated by hatched lines, direction of teeth indicates rifting.

crestal region. In the crestal area, Eocene reef material is exposed and is surrounded by graven containing Miocene reef limestone (Robinson *et al.*, 1988). Further movement may have taken place on the Tarera Aiduna Fault Zone causing an increase in arching and crestal fracturing in the Kumawa anticline. Compaction may have been accentuated of the rigid reef core of the Kumawa Reef Complex. An earlier tectonic event at 19 MYBP is indicated by Apatite Fission Track Analysis (AFTA), but the effects of that event are poorly understood.

The Babo region is presently divisible into three distinct tectonic regimes. These are the Triassic-Jurassic platform, the adjacent rift basin, and the Pliocene Bintuni Embayment. The interface between the rift and platform lies underneath the Onin Peninsula, with the platform to the north and east (including the Kumawa Peninsula) and the rift to the west and south. The Onin Peninsula represents inverted grabens immediately within the rift. The Bintuni Embayment is the foreland basin to the southwest verging Lengguru thrust foldbelt, the Pliocene inversion of another Triassic-Jurassic rift system which lies along the Australian continent northern margin.

A brief stratigraphy of the region could be mentioned as the following (Fig. 5): Sandstones, shales, and limestones of the Permo-Triassic Aifam and Tipuma Formations were deposited in fluvial, nearshore and shallow marine environments. These beds, particularly the coals, are mixed oil and gas source beds. The Lower Kembelangan Group was deposited in the active rift environment. Sands are more common in the initial stages (Jurassic) while shales were predominant as rifting waned (Early Cretaceous). Regionally, the Lower Kembelangan is extremely variable in thickness, and we estimate 900–1,300 m are present at West Onin. Sands in this interval are the primary reservoir target. The Late Cretaceous Upper Kembelangan Group (Jass, Piniya and Simora) predominantly comprises post-rift shales and siltstones with some carbonates, and constitutes the main reservoir seal. Despite surface erosion of up to 1,200 m, the outcrop across the Onin and Kumawa Peninsulas is Tertiary New Guinea Limestone (NGL). The NGL principally consists of platform and pelagic limestones, with interbedded Palaeocene and Eocene Baham Formation sands and limestone at West Onin. At Kumawa, the NGL is a platform limestone. The transition from pelagic to platform limestones roughly follows the Mesozoic rift margin. The NGL was deposited regionally to a thickness of 1,500–2,000 m, and was overlain by up to 2,000 m of Late Miocene-Pleistocene deeper water shales and molasse deposits of the Klasafet and Steenkool Formations, respectively. Farther east in the Bintuni Embayment, the Steenkool Formation is over 4,000 m thick.

FIELD EXPLORATION AND DATA ACQUISITION PROGRAMME

The primary objective of the study was to generate predictive subsurface structural maps to identify drillable hydrocarbon prospects. A secondary objective was to more closely evaluate the regional setting of those prospects.

Soon after acquiring the block in August 1990, exploration commenced with SAR (Synthetic Aperture Radar) survey acquisition over the entire area. No source, reservoir, or seal rocks are exposed on the block, and none of these have been drilled within 60 km of the identified structural culminations. Earlier seismic surveys across intensely karsted surface thick limestone surface rocks in Papua New Guinea provided no subsurface information. Similarly, marine seismic surveys conducted by Mobil Oil in regions with karsted limestone exposed at the sea floor provided little or no subsurface information. Therefore, it was decided that a seismic survey across the Onin and Kumawa Peninsulas would be difficult and costly due to the terrain, dense tropical rain forest, and lack of road access, and would not add to our subsurface understanding.

Heavy vegetation and relatively uniform surface lithologies in the limestone add difficulties and impair detailed mapping with SAR.

Instead, a field programme was conducted by surveyors to acquire high quality topographic survey data at 25 m intervals on long traverses across the Onin and Kumawa anticlinorium (Fig. 3). These survey data were obtained, using satellite navigation (GPS) and theodolite surveys. Then, precisely located structural, biostratigraphic, gravity, and magnetic data were collected along the traverses as well as along coastal areas and river banks. All data were entered into a computer data base in the field as the programme was in progress. Except for gravity distant terrain corrections, the initial data processing and interpretation were also done in the field.

Geophysics

Seismic data are available in Bomberai and also in the offshore region of Onin. A Bouguer gravity map of the Bomberai region obtained by the Dutch Shell in the fifties (Visser and Hermes, 1962) are also available to the authors. A small number of gravity base stations were established by the Geological Research and Development Centre (GRDC) — Bureau of Mineral Resources (BMR) joint research programme in 1978. The subsurface geology was obtained from drilling in Bomberai and in the nearby offshore region. An aeromagnetic survey in Onin was reported. No other geophysics was carried out in Onin and Kumawa since then until a comprehensive gravity data acquisition was made in 1992 on approximately 650 line kilometres of 26 surveyed traverses of about 5 km spacing and 100 m station interval across Onin and Kumawa. The readings were reduced to Bouguer anomalies using 2.4 g/cm^3 Nettleton density. Terrain correction was done for the near zones B and C and also for the distant zone from 925 m outwards reaching a maximum value of 0.92 mgal or 9.2 μms^{-2}. Fluctuations of Bouguer values reaching some 50 μms^{-2} are caused by the rugged topographic features that are constituted by hard and dense rock of the New Guinea Limestone Group. The Bouguer values along the profiles shows a systematic culmination in Onin that coincides with the crestal region. This feature may indicate a basement high of high density protruding beneath the crestal axis of the peninsula. Circular and lenticular anomaly patterns as indicated in the Bouguer anomaly map of East Onin of the order of 800 μms^{-2} extends southeast towards Kumawa forming a gravity ridge and culminates up to 1,420 μms^{-2} at the southeastern edge of the peninsula (Fig. 6). A few drillings in Bomberai have penetrated the upper Kembelangan, and some have just reached the Baham Formation (4,000 m) of the New Guinea Limestone Group.

GENERATION OF CROSS-SECTION

It was necessary to define a useful age-based stratigraphic sequence in the limestone, for regional mapping and section construction. Then, thicknesses of surface traverse exposed formations and units (basically within the NGL) were determined by integrating biostratigraphic markers with structural data, and then calculated using both a True Stratigraphic Thickness computer programme and graphically through building kink cross sections. An initial estimation of thicknesses of not exposed pre-Tertiary formations along traverses was gained from regional wells and limited offshore seismic data.

Cross sections were made on a stepwise basis, with kink sections being constructed initially, then layer cake balanced cross sections, and finally modified balanced section accommodated the gravity traverse data.

Kink section construction

Age boundaries, identified from outcrop data, were combined with structural data were used to

SYMBOL	BENTHIC BIOZONE/UNIT		FORMATION	GROUP
Tk			Klasafet Fm.	
Tml	Miocene Limestone	Upper Tf Lower Tf Upper Te		New Guinea Limestone Group (NGL)
Tol	Oligocene Limestone	Lower Te Td Tc		
Tel	Eocene Limestone	Tb Ta3		
Teb	Eocene Baham	Ta3		
Tpb	Paleocene Baham	P6–P9	Baham Formation	
Simora Jass			Simora Fm. Jass Fm.	Upper Kembelangan Group
Lower Kembelangan				Lower Kembelangan Group
Tipuma Aifam			Tipuma Fm. Alfam Fm.	Pre Kembelangan Units
Basement				

Figure 5. Stratigraphic nomenclature for the Babo geological cross-section and maps.

determine the fold geometry using the kink fold projection technique. Sequential kink cross sections were linked and the surface geology map was made, with the intervals filled using SAR imagery (Fig. 7).

After integration of surface dips, palaeontology, and fold geometry into kink sections, an additional check on the fold constructions was provided by tying adjacent traverses together on the surface geologic map. Information such as age unit contacts and field-defined fold axes were transferred directly from cross sections to a 1:100,000 scale map and integrated with the SAR image. The process of constructing a geological map necessitated a number of minor changes to the kink sections (fault positions, thickness adjustments), but the end result was an internally consistent map and set of surface kink sections on which to base the subsurface interpretation.

Balanced cross sections with integrated (layer-cake) stratigraphy

The initial kink sections provide the guide for projecting fold geometry to depth. The stratigraphy

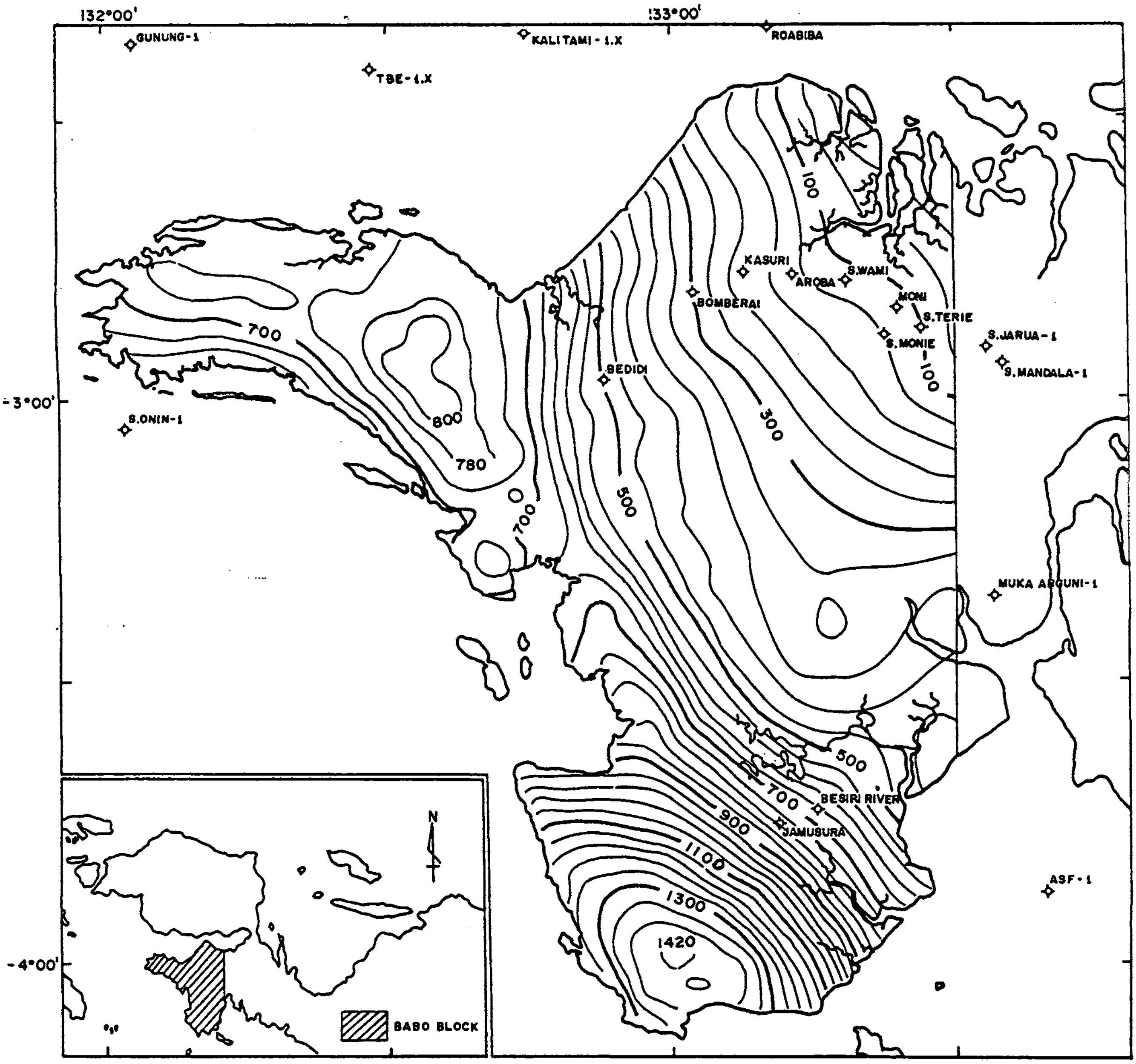


Figure 6. Bouguer anomaly map of the Babo Block. The Kumawa Peninsula is characterised by high values in the order of 1,400 μms^{-2}. These anomalies are most likely caused by compacted basement. Towards the north and northeast the anomalies are regularly decreasing and being marked by a northwest-southeast trending steep gradient inferred being the western margin of the Bintuni embayment. The Onin Peninsula is represented by two closed anomalies in the order of 700 μms^{-2}, an expression of the Onin Main anticline.

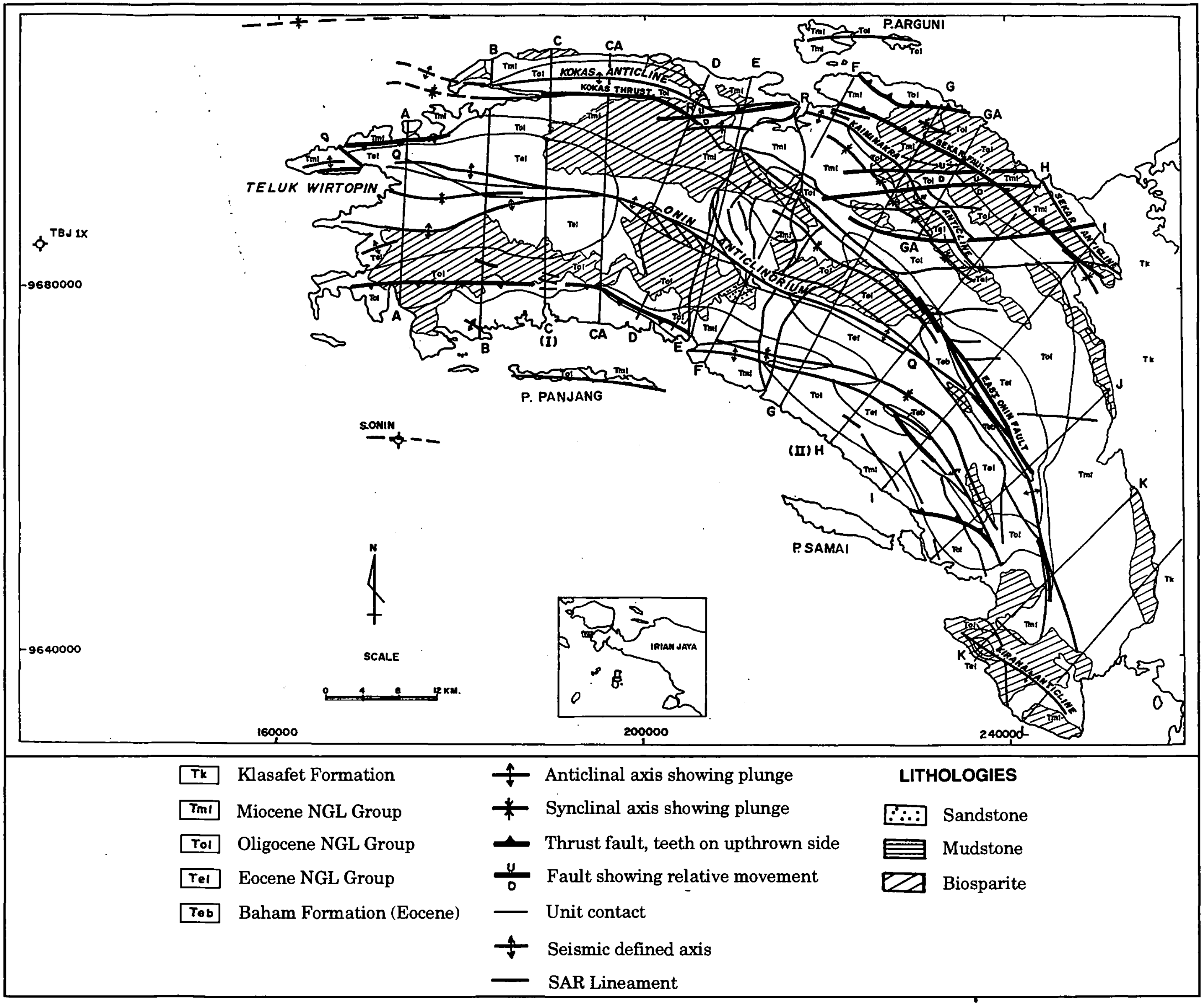


Figure 7a. Geological map of Onin compiled from surface geological mapping and SAR.

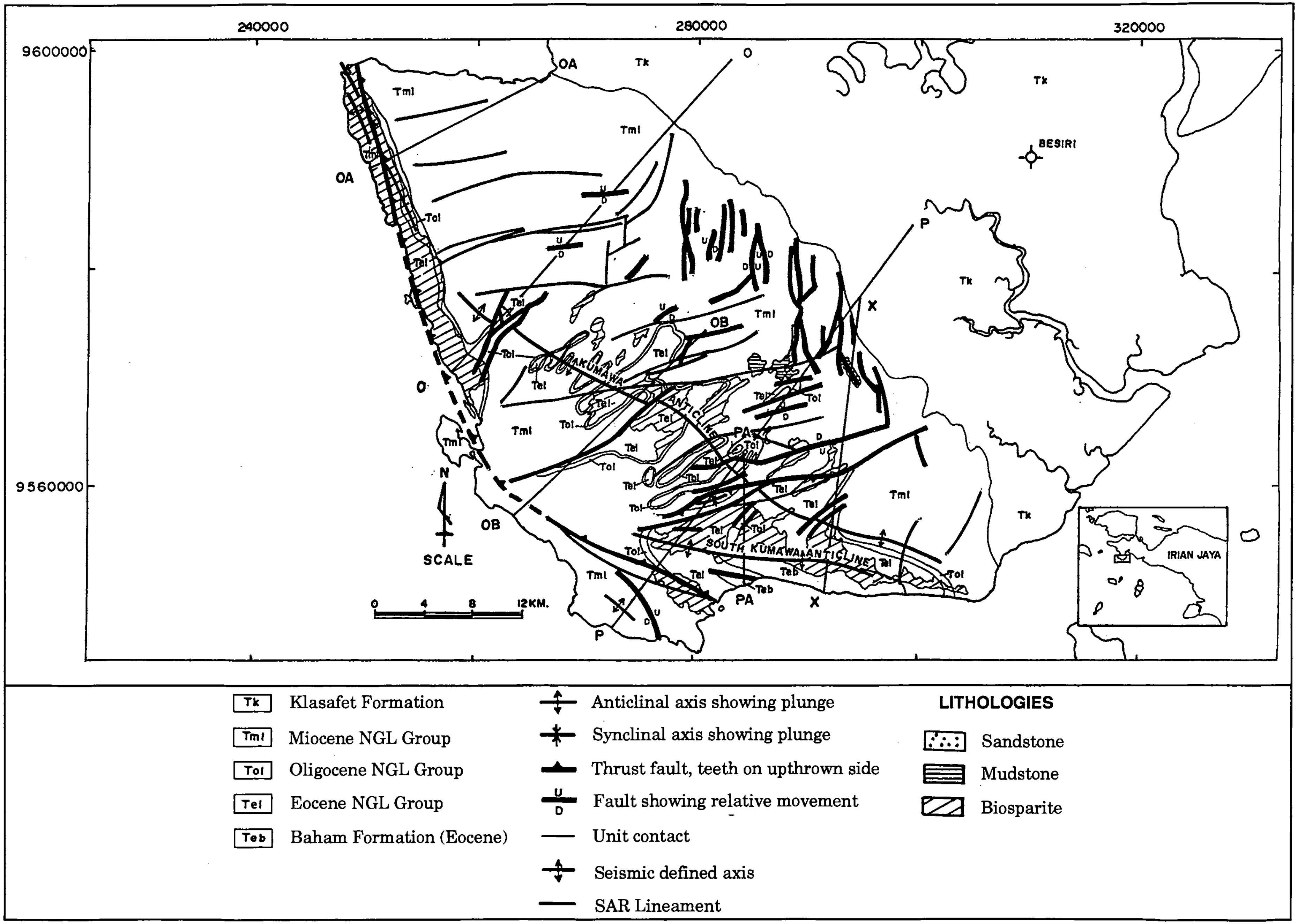


Figure 7b. Geological map of Kumawa compiled from surface geological mapping and SAR.

and thickness of formations below exposures were derived from surface exposures and adjacent wells. The limestone units included: Miocene Limestone (Tml), Oligocene Limestone (Tol), Eocene Limestone (Tel), Eocene Baham Formation (Teb) and Palaeocene Baham Formation (Tpb). There are a number of thickness variations in these units across the Onin Peninsula, although thicknesses for most units remain relatively constant. Initial thicknesses of pre-Tertiary units were estimated from Bintuni Bay seismic data and wells in the area. The pre-Tertiary divisions that have been used in the cross sections below the Palaeocene Baham are: Simora Limestone, Jass Formation, Lower Kembelangan Group, Tipuma-Aifam Group and Basement. Best estimates for thickness of these divisions were made and input into the cross sections as a layer cake section, offset only by faults which cut the surface. These data were then used to construct formation thickness within each section, but not necessarily between sections. Differences in stratigraphic thickness between cross sections was required by surface data and regional changes indicated in offshore wells and seismic.

Gravity modelling and cross section modification

The main purpose of the line gravity modelling was to determine the structural geometry of the pre-Tertiary units. Modelling was done on all traverses using surface gravity data input into the 2D MOD forward gravity programme of the LCT Incorporation, Dallas U.S.A. Three sections of these, two in Onin and one in Kumawa are presented in this paper (Figs. 8, 9 and 10). Rock densities were derived from regional well petrophysical log data, and were kept constant across the study area. The background density of 2.40 g/cm^3, which is the density for reducing the raw gravity data to the Bouguer values, was used in the modelling stage. Because gravity modelling provides non-unique solutions for structural interpretations, we constrained our modelling by assuming that deposition of the Lower Kembelangan Group was controlled by pre-Tertiary normal faults associated with rifting. All other units were kept at relatively constant thickness and with geometries at depth constrained by projection of surface measurements.

This limited number of variables to one, thickness of the target rift interval, and it is consistent with the marked variation in Lower Kembelangan thicknesses from wells and observations from the limited seismic data available.

The line gravity modelling consisted of three steps. The first step involved generating gravity models of the cross sections with the simple layer-cake stratigraphic interpretations. The following layers were grouped together because of their similar density: Klasafet and Steenkool Formation (ρ = 2.20); Miocene and Oligocene Limestone (ρ = 2.50); Eocene Limestone, Eocene and Palaeocene Baham, and Simora (ρ = 2.65); Jass (ρ = 2.50); Lower Kembelangan (ρ = 2.40); Tipuma-Aifam (ρ = 2.57); and Basement (ρ = 2.67). The densities of lithologies which are present above water table were modified to account for air-filled porosity compared to water-filled porosity below watertable (Nettleton, 1983). A calculation of Oligocene-Miocene Limestone above water table resulted in a figure of 2.37 g/cm^3, whereas below water table for Onin being 2.61 and for Kumawa 2.58 g/cm^3.

The second step required modifying the cross sections to make the slope changes of the calculated gravity coincident with the observed gravity data. The modifications were made by introducing normal faults that lower the basement with consequent thickening of the Lower Kembelangan. Initially, these were limited to faults which cut the surface, and were assumed to be reactivated manifestations of earlier rift faults. Subsequently, addition fault, blind at the surface, were introduced to make observed and predicted gravity gradients parallel. For example, on the initial gravity model of cross section I (Fig. 8) the observed gravity profile is relatively flat between 10 and 14 km and drops down at a constant slope between 0 to 10 km. The calculated gravity from the cross section is relatively flat between 12 and 14 km but has a lower value than the observed curve. Between 0 and 12 km the calculated gravity curve drops down but a more gentle slope than the observed curve. In order to steepen the slope of the calculated curve a series of normal faults were put in between 0 and 12 km that thicken the Lower Kembelangan and drop the level of basement. A result of the second phase was to identify the location of pre-Tertiary normal faults that did not reach the surface or had been reactivated as compressional reverse faults that may or may not have cut the surface. The resulting calculated and observed gravity curves had coincident shape but varied in magnitude.

The third and final step involved a uniform uplifting or down-dropping of the basement along the cross section so that the observed and calculated models had coincident shape and magnitudes. The gravity modelling of the northern portion of cross section I between 19 and 26 km provides a good example of this phase in the process. Both the observed and calculated curves have similar shape over this portion of the cross section but the calculated gravity is too low by about 5 mgal. By uniformly thinning and raising the base of the Lower Kembelangan by about 600 m the curves become coincident. The structural thinning is accomplished across normal faults at about 19 km.

Several profiles across the Kumawa Peninsula presented a problem in that observed gravity values are so much higher on most of Kumawa than Onin. It was necessary to raise basement considerably on nearly all sections in order to fit the calculated to the observed gravity. In most cases, particularly eastern Kumawa, this required removal of not only Lower Kembelangan but also Jass Formation and even Tipuma-Aifam Group, leaving Simora Limestone sitting directly on basement. Removal of section was confined to the pre-Tertiary because the NGL is relatively well constrained by surface data.

An alternative solution for Kumawa was to assume that the predominant underlying basement is fundamentally different than the basement underlying Onin. To test that hypothesis, a sensitivity model was made, with basement density increased from 2.67 g/cm^3 to 2.73 g/cm^3 (Fig. 11). This value falls within the acceptable range of known basement densities for the region, and is the minimum value which allows Lower Kembelangan to appear in the cross section. An additional justification to increase basement density comes from satellite free air gravity map, which shows a high gravity trend in the order of 60 mgal beneath Kumawa extending offshore to the south,

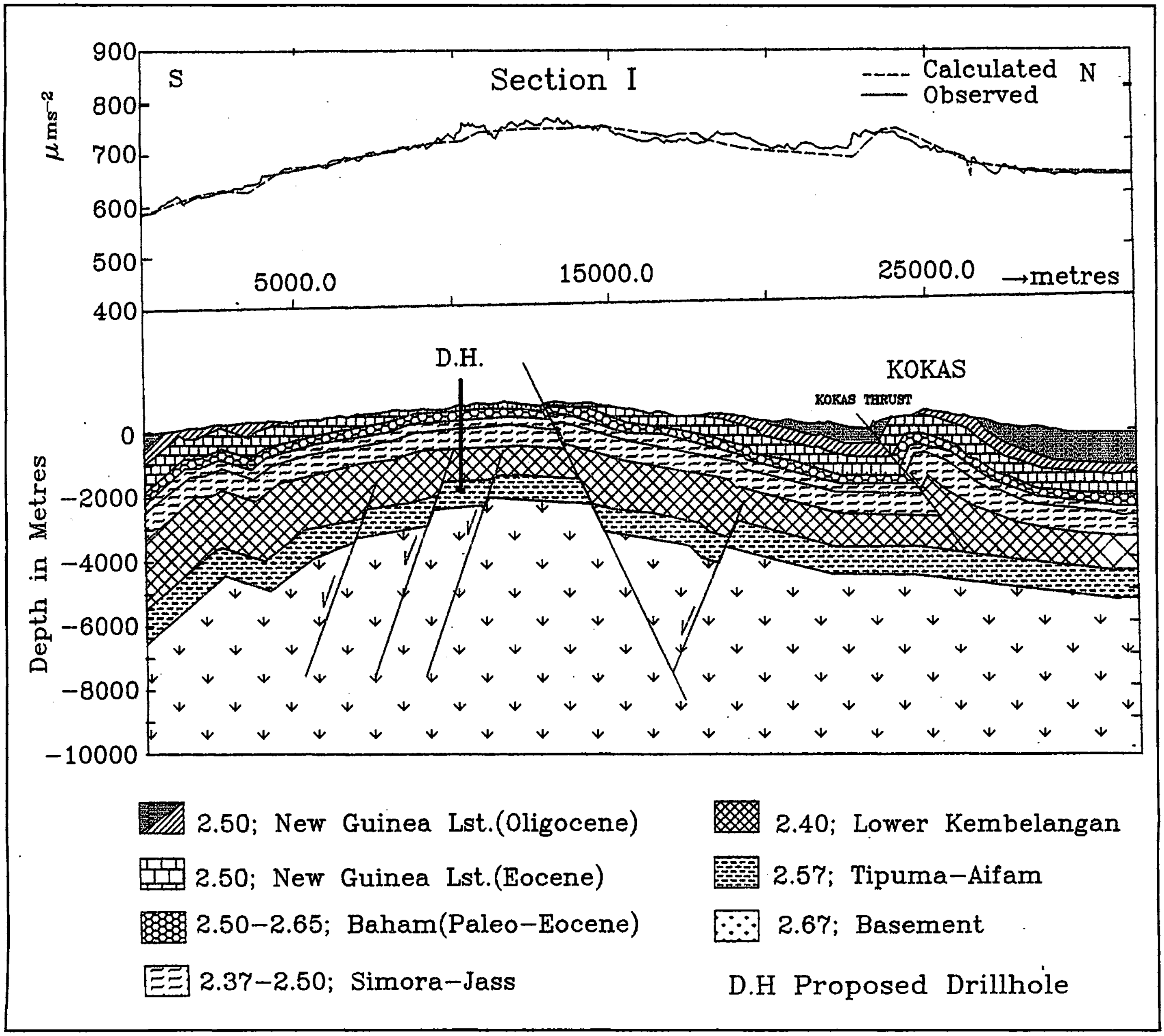


Figure 8. Section I, gravity model across west Onin aided by balanced geological section. Density (g/cm^3) distribution: 2.50; NGL (Tml, Tol, Tel), 2.50–2.65; Baham Fm. (Teb, Tpb), 2.37–2.50; Simora-Jass, Upper Kembelangan, 2.40; Lower Kembelangan, 2.57; Tipuma-Aifam Fm., 2.67; Basement. A drilling site (D.H.) is proposed at the crest of the anticline reaching depth of about 3,000 km. The Kokas thrust is shown at the right end of the profile that is expressed by culmination of Bouguer values of about 600 μms^{-2}.

but does not continue across to Onin.

The method of this alternative approach was to work directly from the cross section and gravity profiles modelled with the 2.67 g/cm³ basement density. The cross sections were left unchanged and the only adjustment was to replace the 2.67 g/cm³ basement density with the higher value on the gravity profiles. This had the effect of uniformly raising the calculated gravity curve above the observe curve. The next step was to lower this 'new' basement by adding stratigraphic section until the curves matched. Stratigraphic section was added to the cross section in the reverse order to which it had been removed from the 2.67 g/cm³ basement density models. Tipuma-Aifam was added first, followed by Jass and finally Lower Kembelangan. This allowed full sequences of Tipuma-Aifam and Jass to appear in the cross sections as well as a thin Lower Kembelangan over the crest of Kumawa anticline.

The above alternative modelling was applied to all portions in Kumawa, except in the northern most part where the observed Bouguer values are similar to Onin (Fig. 6). A good match between observed and calculated Bouguer gravity curves was achieved for this part of Kumawa with a basement density of 2.67 g/cm³ with only adjustments to the Lower Kembelangan thickness, in much the same way as Onin. This suggests that if the alternative model is valid, a change in density occurs to the south of cross section OA. The break between these two basement types has been

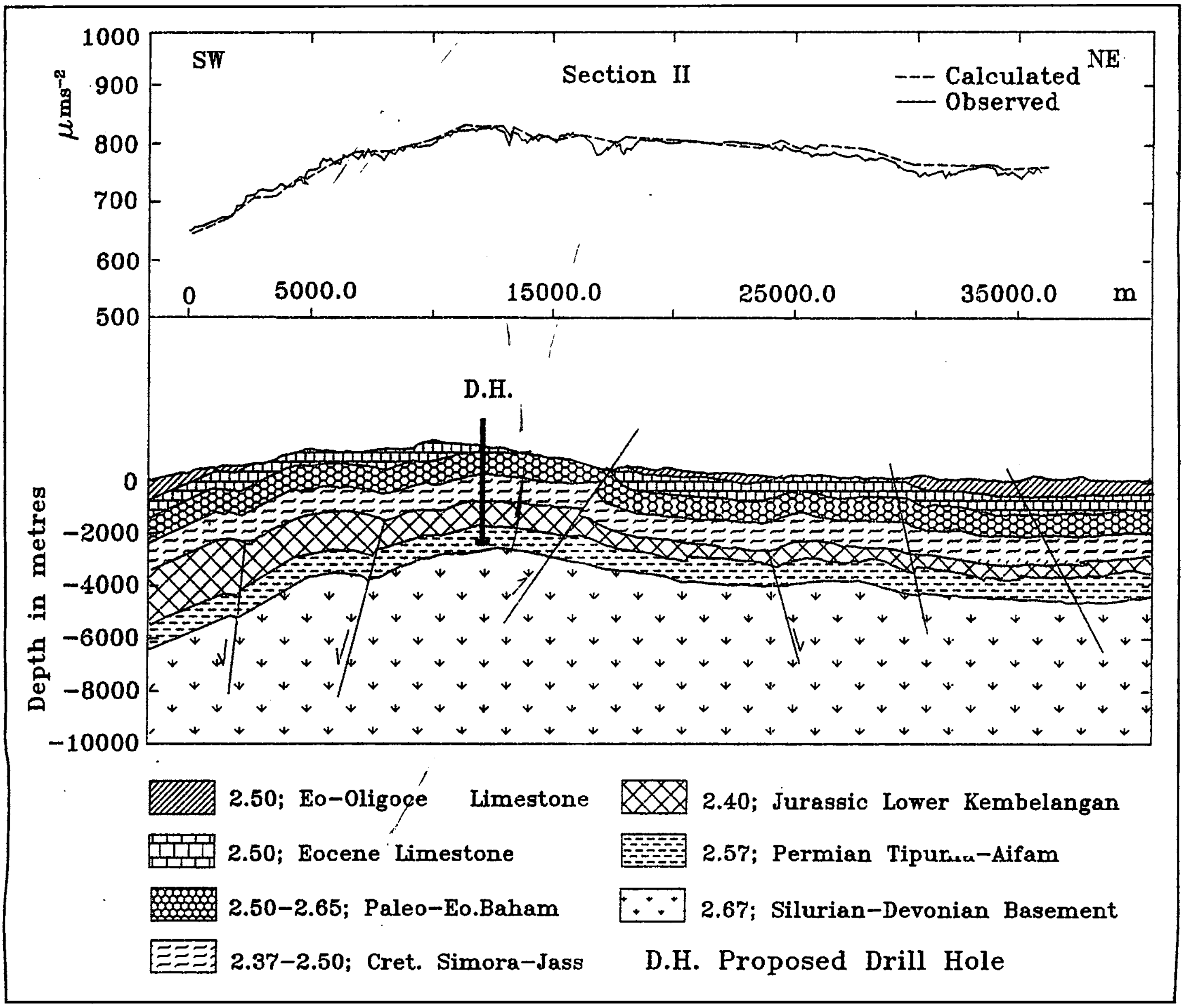


Figure 9. Section II, gravity model across east Onin aided by balanced geological section. Density (g/cm³) distribution: 2.50; NGL (Tml, Tol, Tel), 2.50–2.65; Baham Fm. (Teb, Tpb), 2.37–2.50; Simora-Jass, Upper Kembelangan, 2.40; Lower Kembelangan, 2.57; Tipuma-Aifam Fm., 2.67; Basement. A drilling site (D.H.) is proposed at the crest of the anticline reaching depth of about 3,000 km.

interpreted to trend approximately east-west (Fig. 12).

GRAVITY BASED REGIONAL INTERPRETATION

The gravity models across West Onin, East Onin and Kumawa as shown on Figures 8, 9 and 10 show a chronological stratification of all layers. The culmination at the central part of the section is inferred being a doming up of the basement rock forming an anticlinal structure that is regarded being potential for hydrocarbon deposition. In order to have a regional geological appreciation of the region qualitatively, several maps were generated from the calculated gravity values along the 26 traverses. The minimum curvature of Briggs (1974) was used for the gridding and contouring. Such maps are Bouguer anomaly map, residual and regional gravity maps, derivative maps and depth to the high-density basement rock.

The gravity anomaly comprises two components. These are the gravity expression of the high-density basement and the gravity effect of the sedimentary sequences above the basement. The separation of these two components was achieved by firstly computing the gravitational attraction of the basement rock and then the sedimentary sequences. The gravity effect of the high-density basement rock is considered to be the regional gravity anomaly (Fig. 13), whereas the residual gravity anomaly (Fig. 14) is represented by the gravity expression of

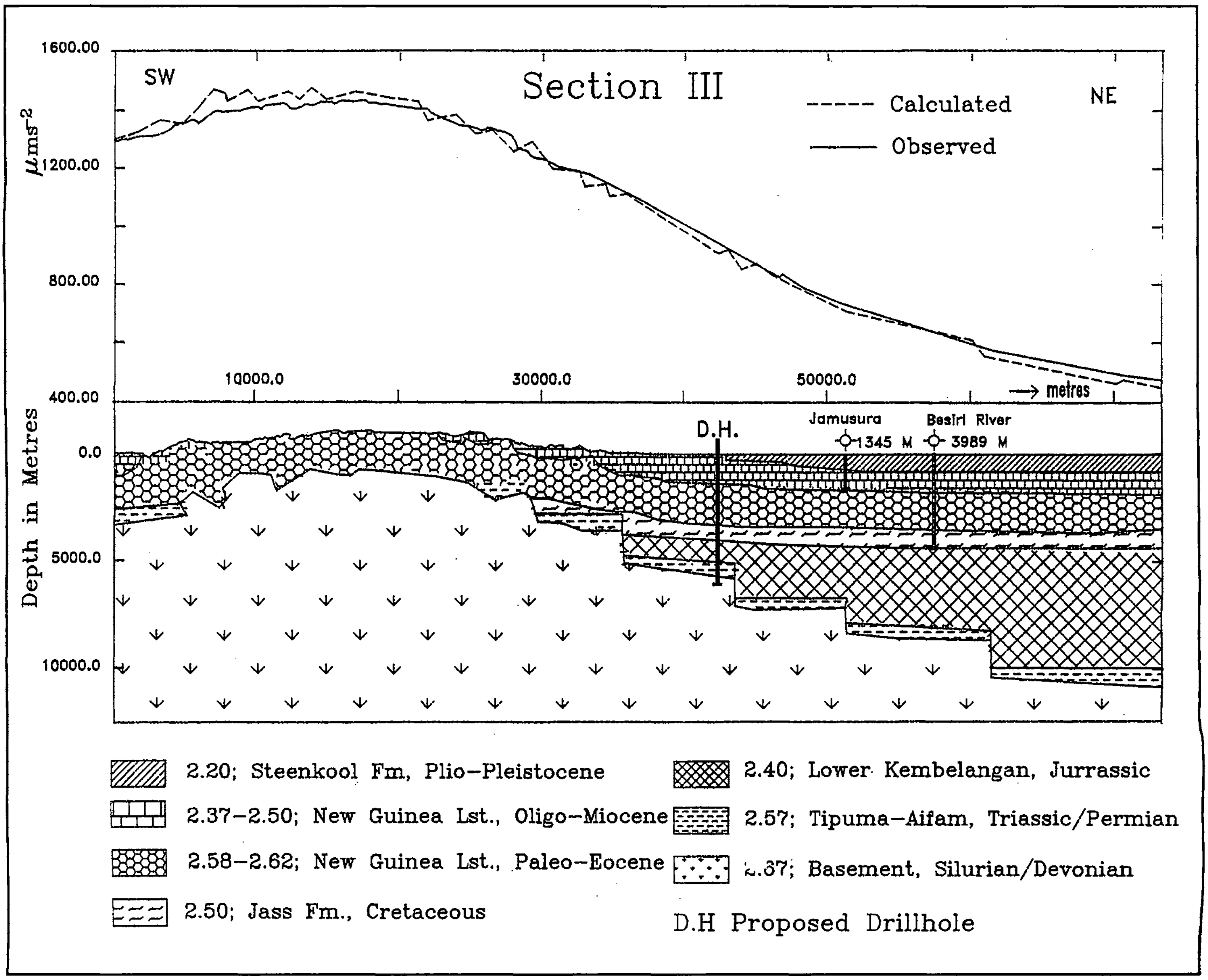


Figure 10. Section III, gravity model across Kumawa aided by balanced geological section. Density (g/cm^3) distribution: 2.20; Steenkool Fm. (Plio-Pleistocene), 2.37–2.50, NGL (Tml, Tol), 2.58–2.62; NGL (Tel, Teb, Tpb), 2.50; Jass Fm. (Upper Kembelangan), 2.40; Lower Kembelangan, 2.57; Tipuma-Aifam Fm., 2.67; Basement. Jamusura and Besiri river are existing drilling sites. No indication of hydrocarbon are encountered. D.H. is a proposed drilling site reaching at an approximate depth of 5,000 m. The Tipuma-Aifam Formation and the Kembelangan Group are not present on top of the crestal region.

the sedimentary column above the basement. A Bouguer anomaly map was then produced from the modelled gravity values (Fig. 15). Structural configuration maps of the basement rock of 2.67 g/cm^3 density and the sedimentary sequence above the basement as shown on maps of Figures 16 and 17 show complicated patterns on the basement. A NE-SW lateral fault separates East from West Onin, that may be interpreted as the axis of the clockwise rotation of West Onin mentioned earlier in this paper. A merging of the 1992 Onin and Kumawa data and the data of the Bomberai region collected by the Dutch Shell Company in the fifties was made to produce a Bouguer anomaly map of the Babo Block (Fig. 6).

The Bouguer anomaly map of Onin (Fig. 15) shows major features with values of the order of 600 to 820 μms^{-2}. Closed and circular patterns with ascending values towards the centre are inferred being expression of structures related to hydrocarbon accumulation. The circular patterns in East and West Onin are very dominant in the regional gravity indicating a doming up of the basement rock that comprise, respectively, areas of about 1,200 sq km and 600 sq km. These two anomaly features are separated by a gravity lineation of southwest-northeast direction probably representing a fault with lateral movement that extends far offshore in the northeast. This fault might be connected with a possible clockwise rotation of East Onin. A series of faults mostly striking northwest-southeast may act as avenues

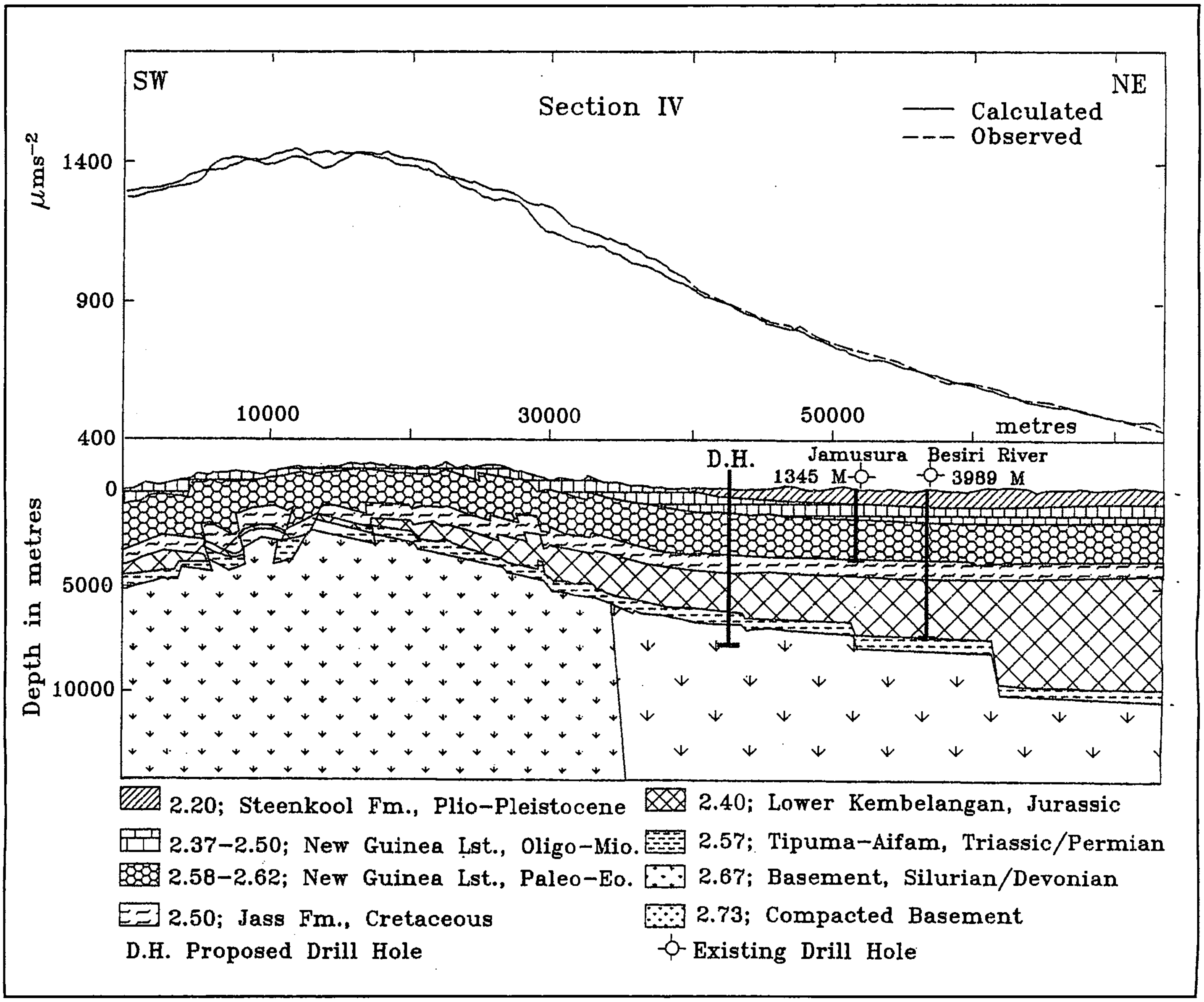


Figure 11. Section IV, an alternative gravity model and balanced geological for Section III. Basement density 2.73 g/cm^3 at the southern portion of the profile. At a distance of about 35 km a fault is interpreted to mark a density boundary between 2.73 in the south and 2.67 in the north. The Tipuma-Aifam Formation (density 2.57) appears on the crestal region. Density distribution refers to Figure 10 (Section III).

for a migration of hydrocarbon sources. The doming up of the basement rock at the crestal region of West and East Onin is due to compression resulted from the northward movement of the Australian plate. A part of the area between Onin and Kumawa is covered by anomalies in the order of 400 μms^{-2} in the north and northeast and increasing up to 700 μms^{-2} in the south. The basement of Onin and Kumawa and the area in between with a density of 2.67 g/cm^3 is the Kemum Formation of Silurian/Devonian age. This basement rock forms a ridge as indicated in West Onin and extends southeast towards Kumawa. In the area between the two peninsulas this ridge continues offshore (Fig. 18).

A plate tectonic interpretation of Onin and the western portion of Irian Jaya is illustrated in Figure 19. The northern margin of the Australian Plate underlies the whole region. Beneath Onin and Kepala Burung the plate thickens considerably forming the root of the land mass of the Kepala

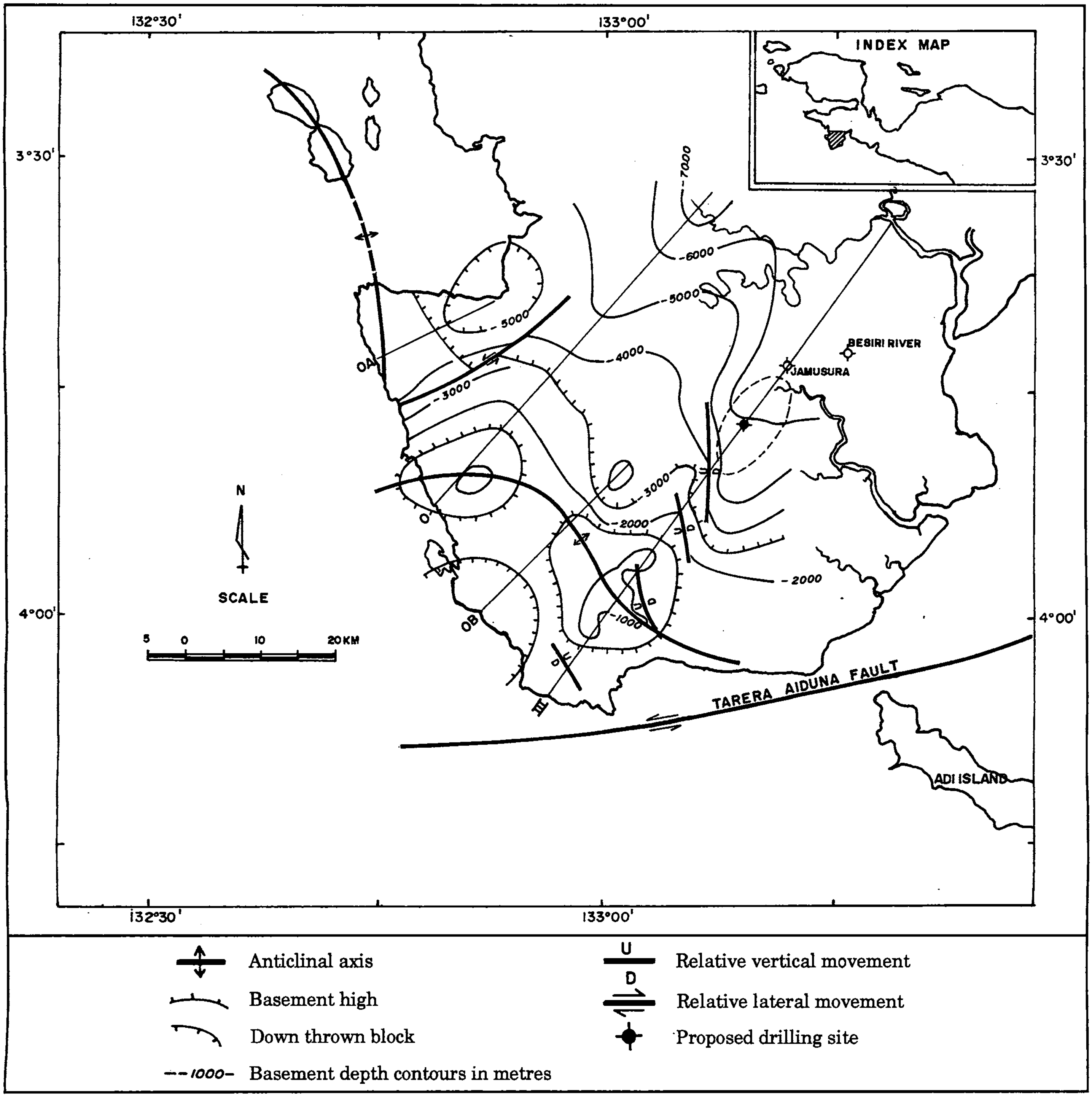
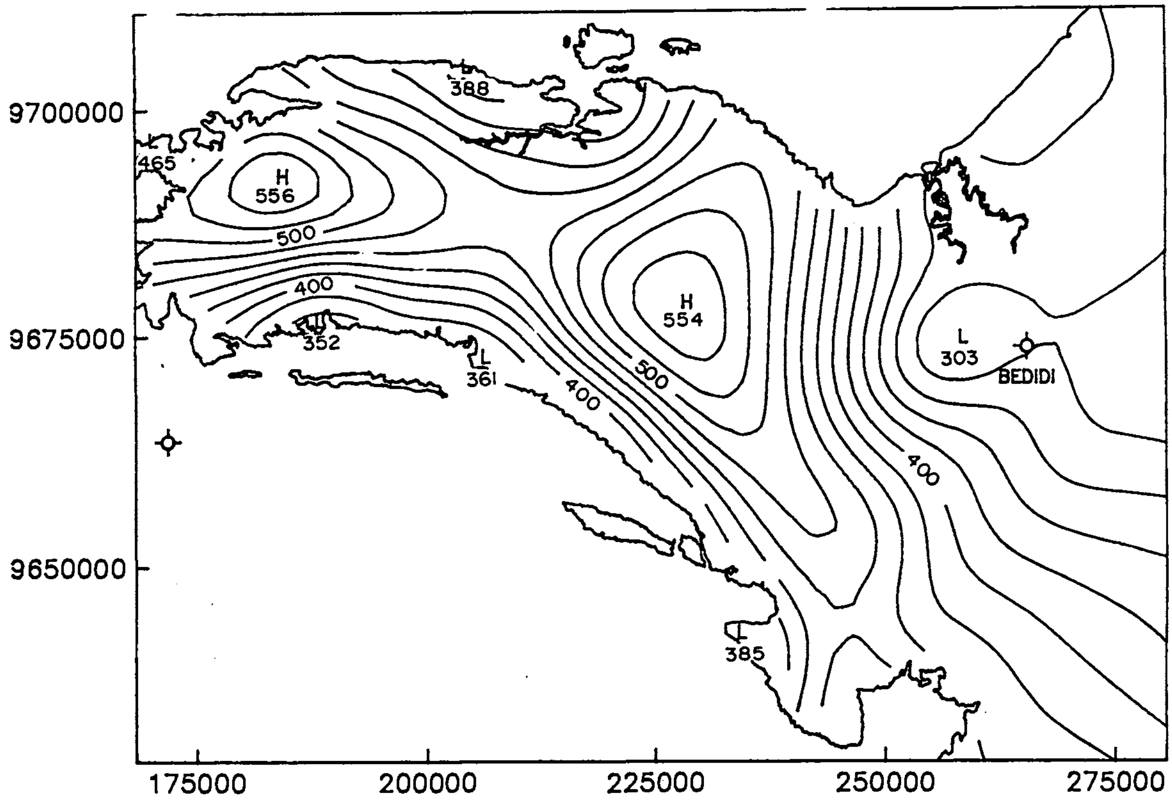


Figure 12. Structural configuration map of the top of 2.67 g/cm³ basement density of Kumawa. Contour lines are in metres. The 3,000 m contour line may be interpreted as a NW-SE fault trace separating the 2.67 in the north from the 2.73 g/cm³ density basement rock in the south. Jamusura and Besiri River are existing drill holes (Figs. 10 and 11).

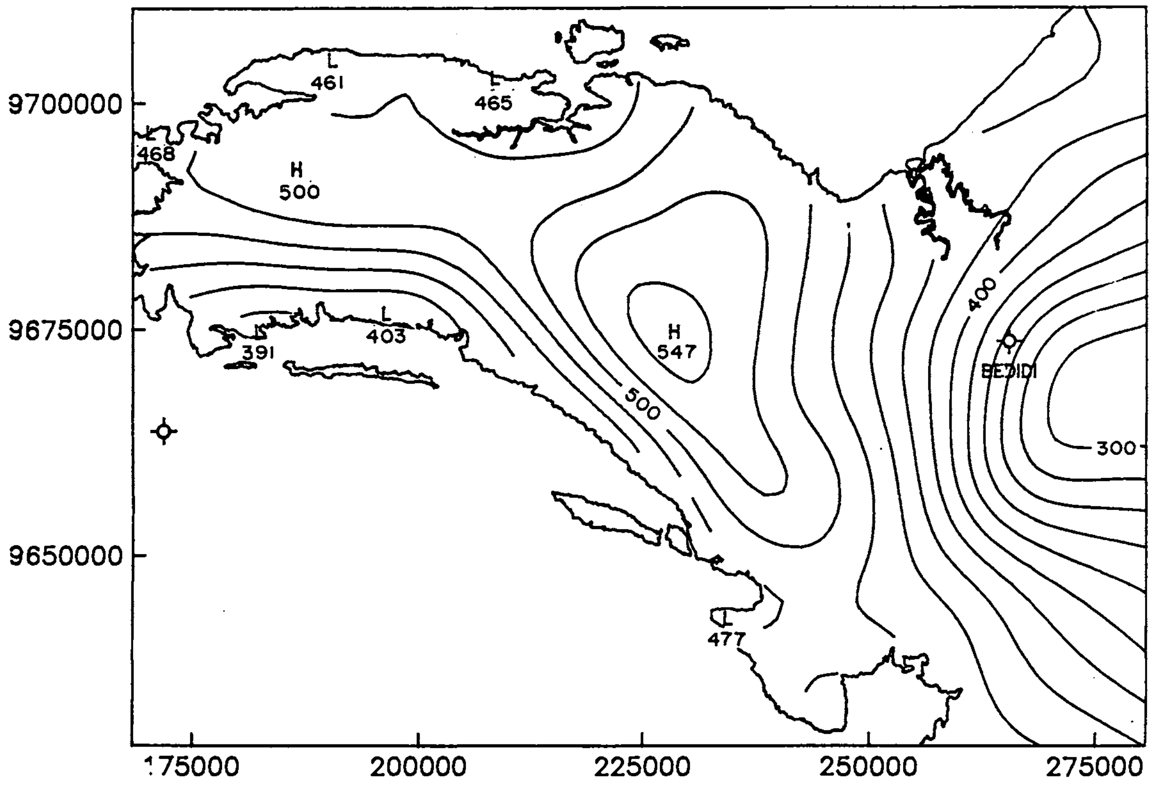
Fig. **REGIONAL GRAVITY ANOMALY MAP; ONIN**



The two closed anomaly patterns are more pronounced, indicating structural features at a greater depth.

Figure 13. Regional gravity map of Onin representing the gravity effect of the basement rock of 2.67 g/cm³ density. High lenticular anomalies of the order of 550 µms⁻² are expression of a doming up of the basement rock.

Fig. **RESIDUAL BOUGUER ANOMALY MAP; ONIN**



The anomaly features are expressions of sedimentary sequences above the basement rock of 2.67 g/cm³ density.

Figure 14. Residual gravity map of Onin representing the sedimentary sequence above the basement rock. The Onin anticlines are expressed by high anomalies of the order of 540 µms⁻².

Burung region. An interaction of the Australian Continental Plate and the Pacific Plate in the north resulted in an amalgamation of the continental and oceanic material mostly along the Sorong Fault Zone (Dow and Sukamto, 1984; Dow *et al.*, 1986).

In the south, the left-lateral Tarera-Aiduna Fault may extend far to the west towards the Seram Trough passing the Kumawa area (Fig. 2). Because of stresses generated in the Banda Arc, further movement may have taken place on the Tarera-Aiduna Fault resulting in an increase in the arching and crestal fracturing in the Kumawa Anticline that may result in the compaction of the rock formation in Kumawa with high Bouguer anomaly values in the order of 1,400 μms^{-2}.

An interpretation of the structures on the basement rock of 2.67 g/cm^3 density in Onin (Fig. 16) shows faulted crestal regions that must have been the result of generation of stresses originating from the northward movement of the Australian Mobile Belt. This pattern continues upwards but is less extensive in the sedimentary sequence (Fig. 17). Figure 20 is a cartoon expression of the development of the doming up of Onin and its relation to the Lengguru Fold Belt to the east. The formation of the Lengguru Fold Belt was the result of a push of the oceanic crust beneath the Cenderawasih Bay in late Cainozoic after the deposition of the Miocene Limestone Group, whereas the culmination of Onin Peninsula along its axis was partly caused by the thick load of the Mesozoic clastics and Tertiary carbonates of the Lengguru Fold Belt in the east and partly by the northeastwards moving Australian continental plate. The Bomberai embayment seems to be undeformed at the surface, but deformation occurs at a depth of about 5 km as shown by the spectral analysis generated depth-map (Fig. 21).

The position of Onin and Kumawa peninsulas as related to the whole western portion of Irian Jaya must have an important geological meaning as the geophysical features are quite different from Bomberai next to the east. These two regions are separated by a steep gravity gradient of 10 μms^{-2}/km along a north-northwest–south-southeast lineation (Fig. 6). This gradient could be inferred being the western boundary of the Bintuni Basin in the northeast with its very low gravity anomalies

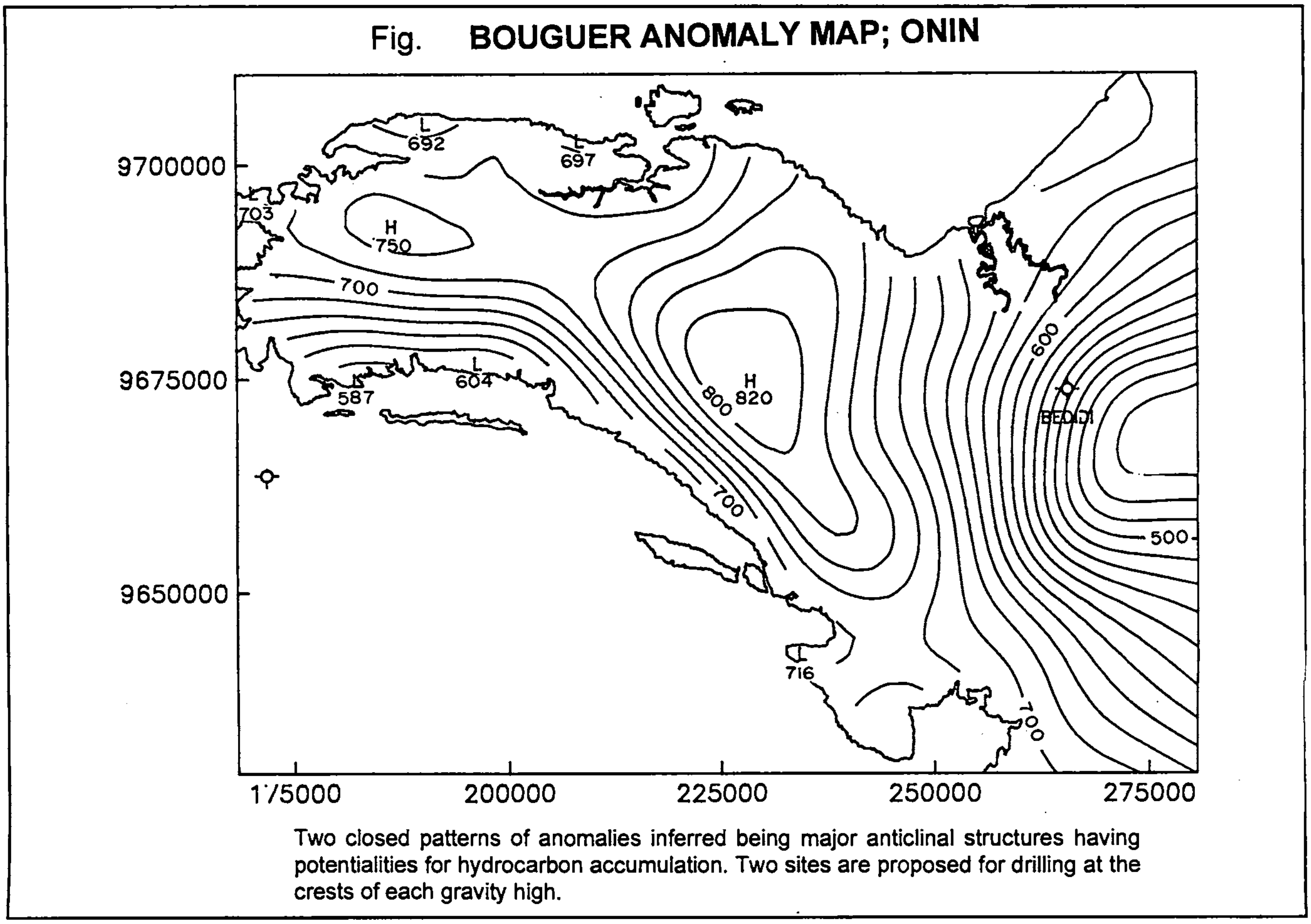


Figure 15. Bouguer anomaly map of Onin. The Bouguer values are reduced using 2.40 g/cm^3 density. Lenticular anomalies of 800 μms^{-2} are expressions of the Onin anticlines. Contour intervals are 25 μms^{-2}.

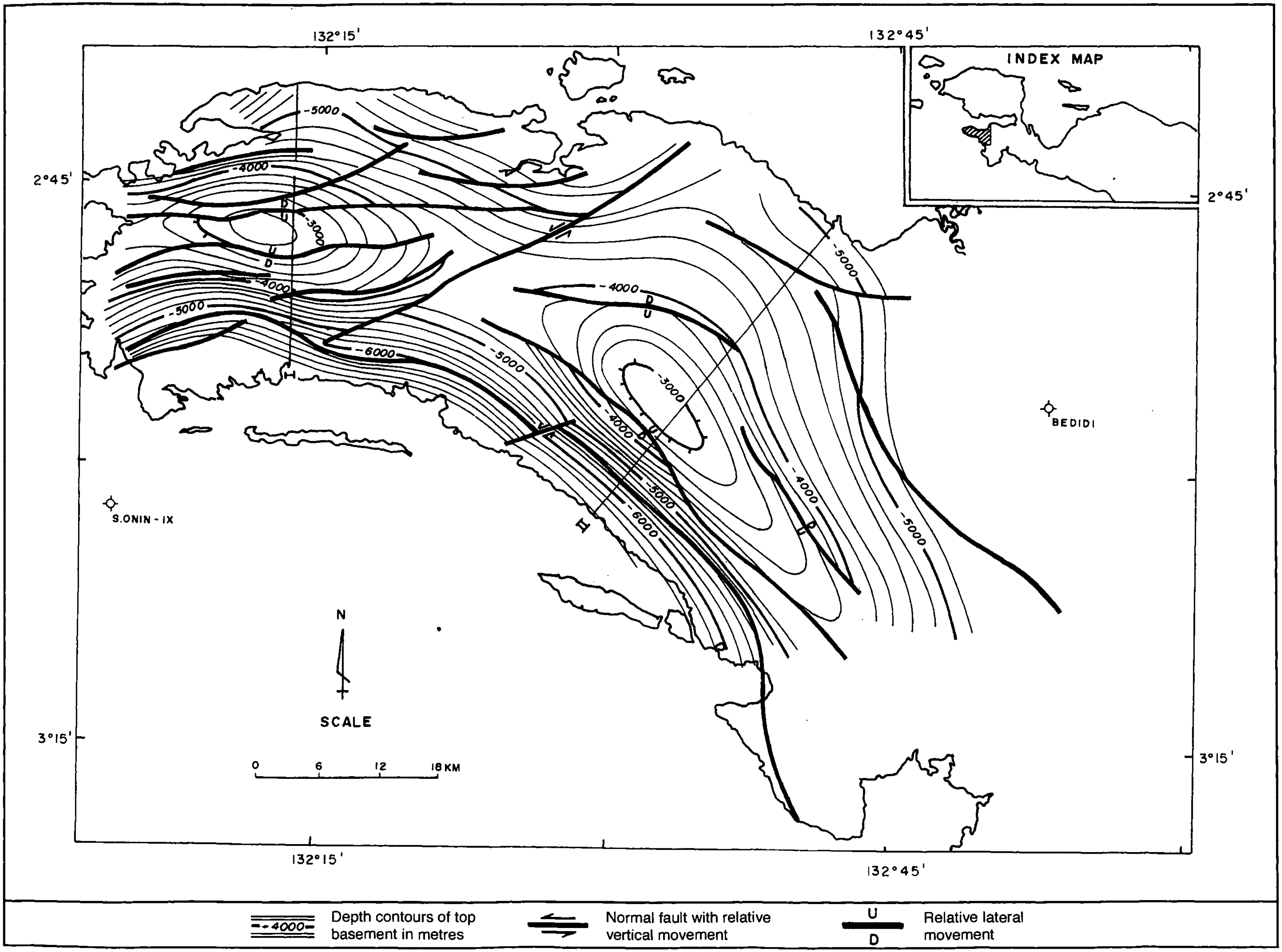


Figure 16. Structural configuration map of the top of 2.67 g/cm^3 density basement rock of Onin. Contour lines are in metres. Structural highs are observed in west and east Onin. An expected lateral fault separates features in the west from the east. The steep gradient along the coast line in the south marks a rapid change of depth.

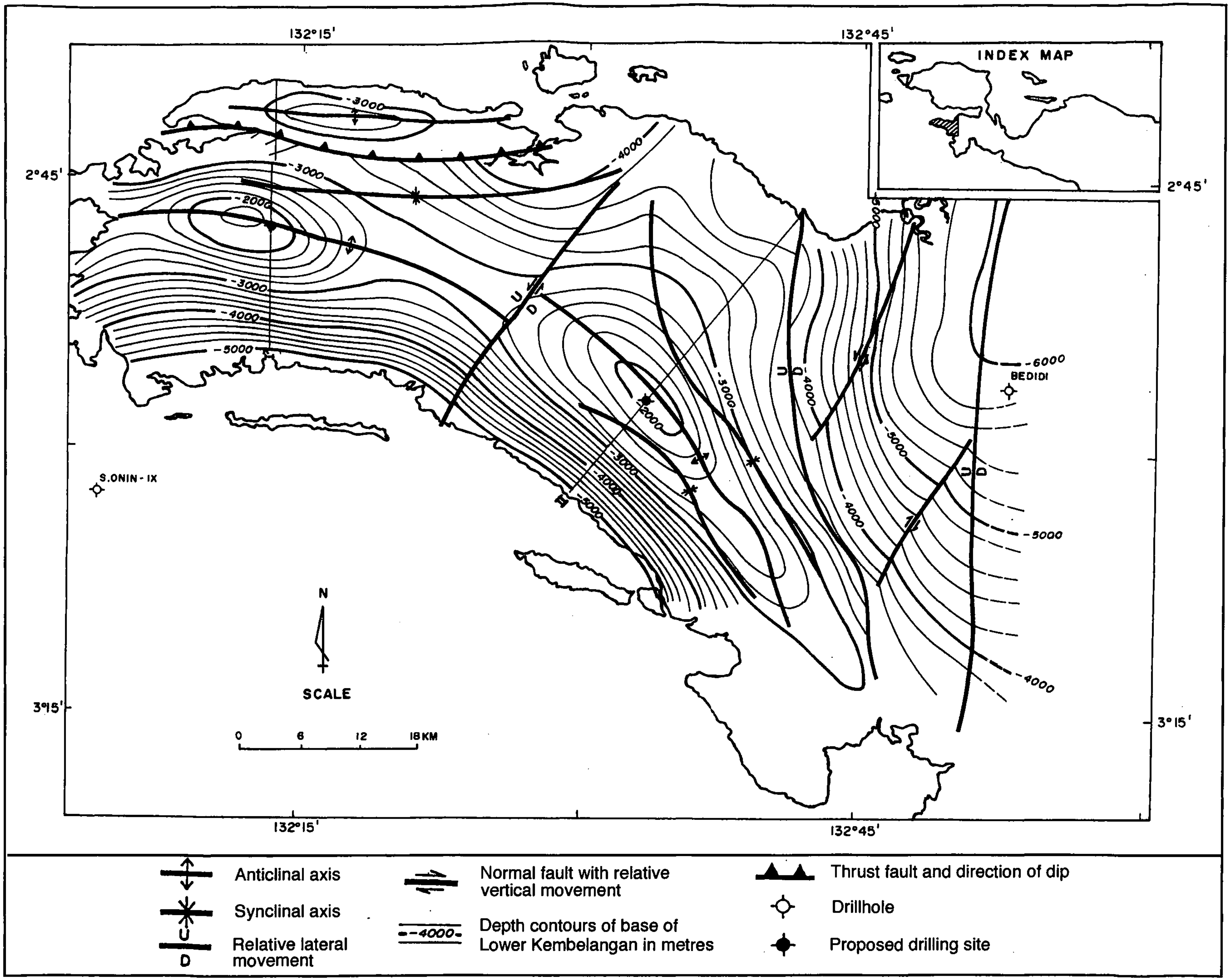


Figure 17. Structural configuration map of the sedimentary sequence above 2.67 g/cm³ density of Onin. Contour lines are in metres. Structural highs are interpreted as the Onin anticlines. Thrust fault is observed in West Onin known as the Kokas Thrust. A northeast-southwest lateral fault may be the upward continuation of the fault in the basement rock mentioned in Figure 16.

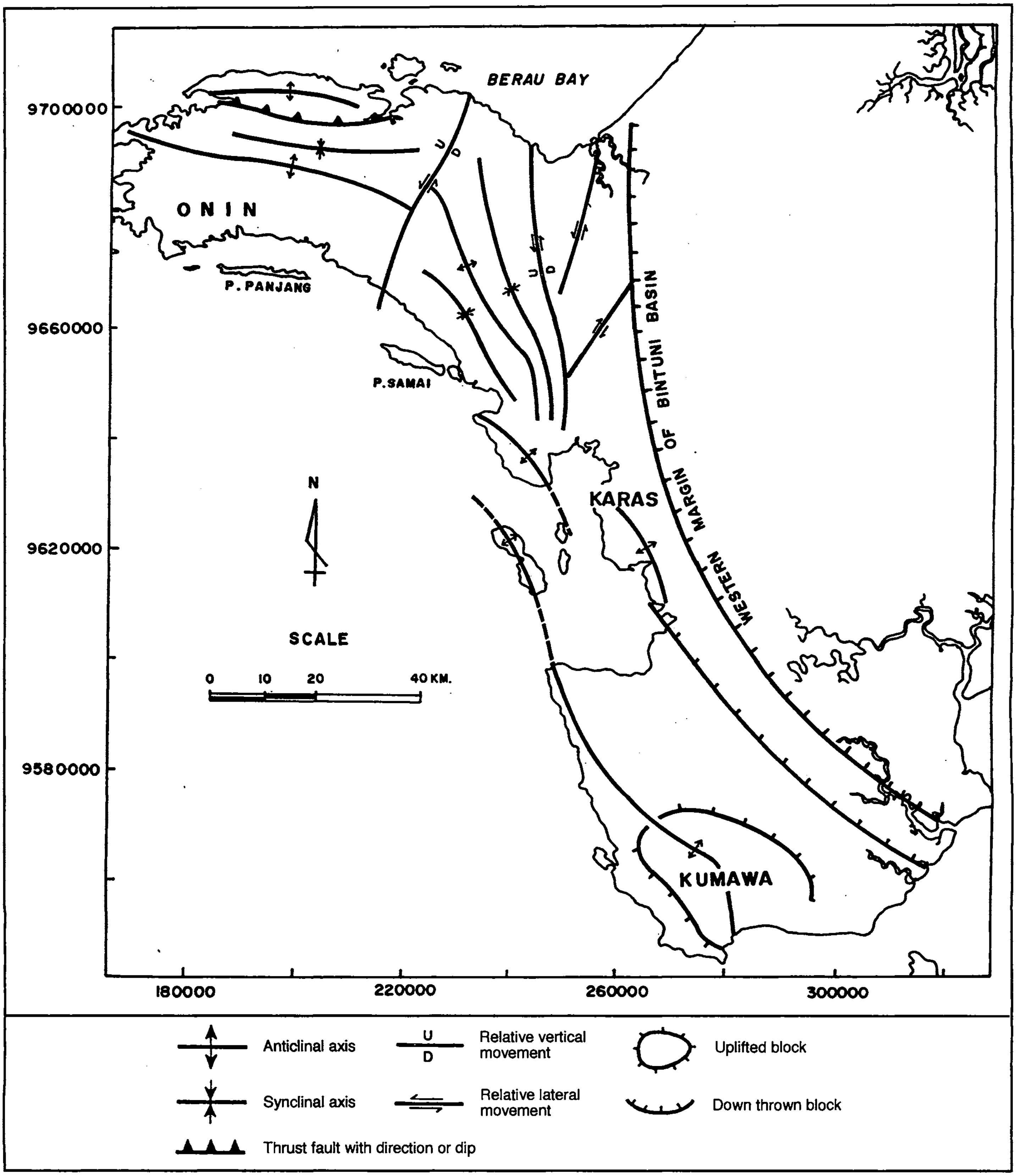


Figure 18. Generalised structural pattern of Onin and Kumawa. Structural lineation beneath Onin and Kumawa is inferred to occur in the offshore portion between the two peninsulas.

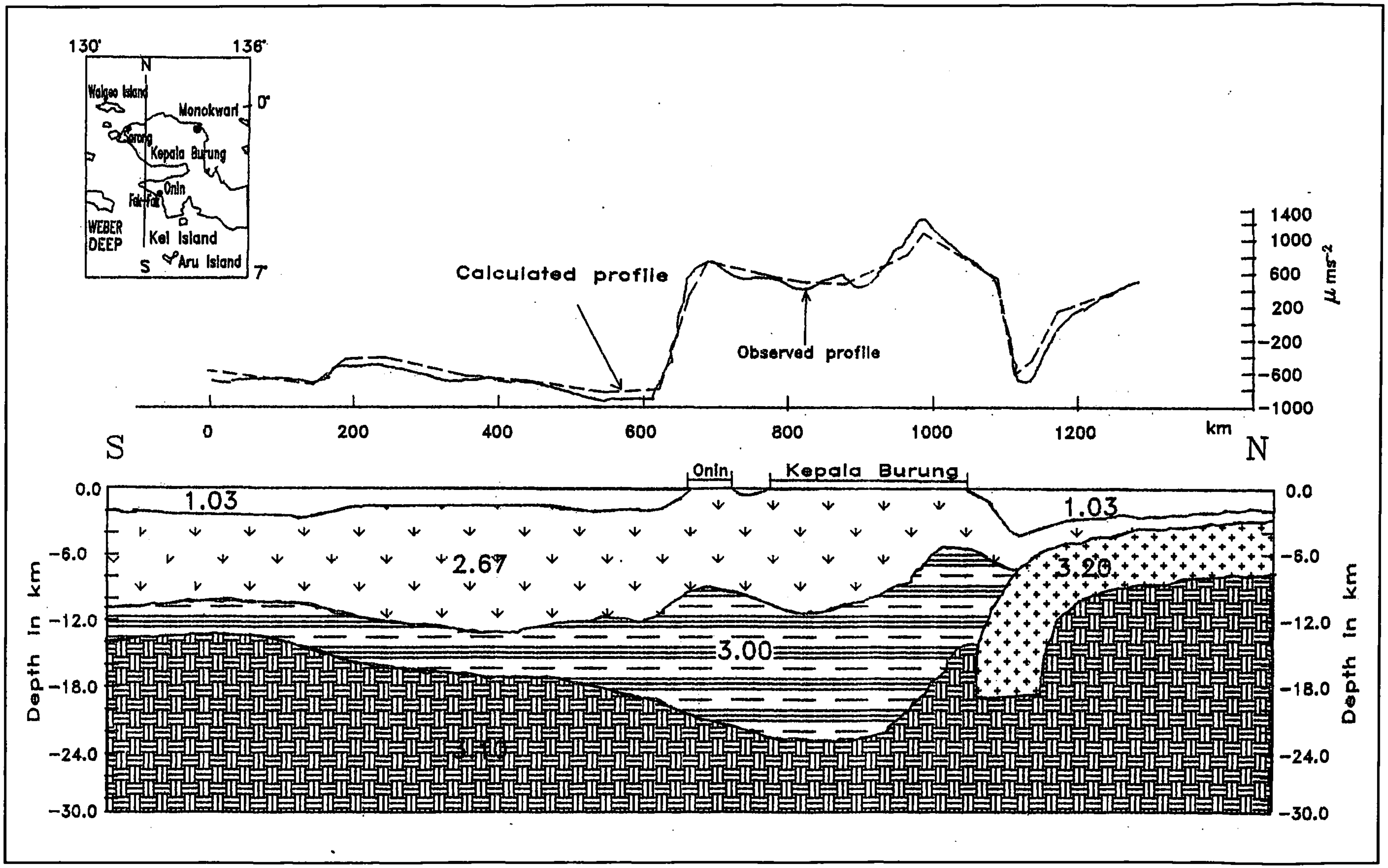


Figure 19. A south-north regional interpretation gravity profile. The section is 1,300 km long starting from east of Weber Deep to Onin and Kepala Burung, Irian Jaya. Free-air values on sea, Bouguer on land. Free-air taken from Bowin *et al.* (1982), Onin Bouguer values from Untung *et al.* (1992) and Kepala Burung from Dow *et al.* (1986). 1.03 is density of sea water, 2.67 is average density of upper crust, 3.00 is density of lower crust, 3.10 is mantle rock density, 3.20 is density of oceanic crust.

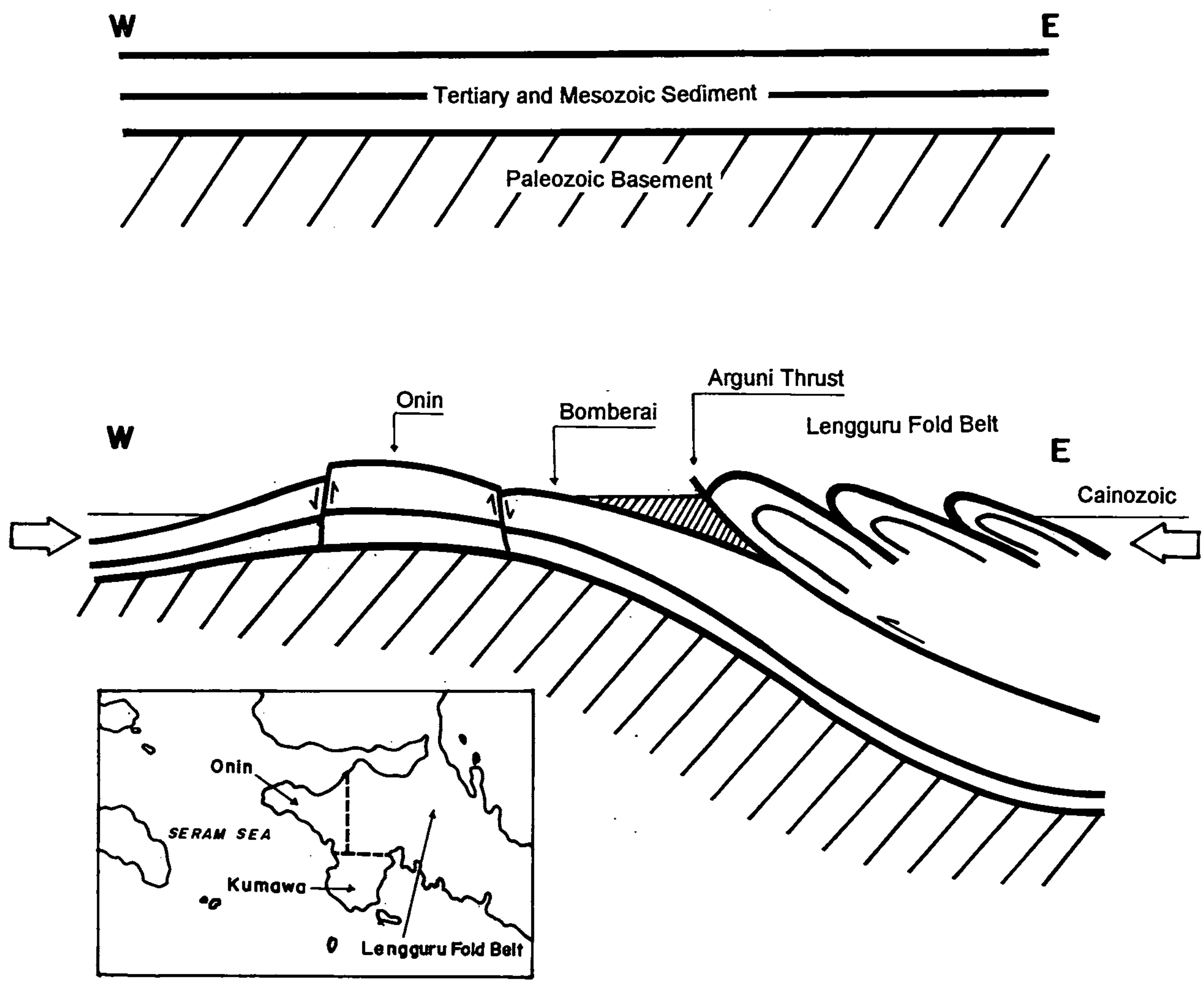


Figure 20. Cartoon expression of the development of Onin Peninsula and the Lengguru Fold Belt. The formation of the Lengguru Fold Belt was the result of a push of the oceanic plate beneath the Cenderawasih Bay in late Cainozoic after the deposition of the New Guinea Limestone Group. The culmination and fracturing of Onin Peninsula was partly because of the loading of the Mesozoic clastics and Tertiary carbonates in the Lengguru Fold Belt and partly of the northeastward push of the Australian continental plate.

(Untung, 1982, 1987). The Bintuni Basin is a north-south structural depression filled by about 6,000 m thick Tertiary sediments (Pigram and Sukanta, 1982; Untung, 1982). In the west it is bounded by Sekak Ridge and by Onin and Kumawa in the south. The Sekak ridge is separated by the Bintuni Bay from the Onin peninsula. The similarity of the gravity features in Sekak Ridge, Onin and Kumawa suggests these regions must be underlain by a basement rock having the same density. So far no oil discovery in the Bintuni Basin has been reported. The steep gravity gradient to the east of Onin as mentioned earlier separates the peninsula from the Bomberai landmass with its regular decreasing trend towards the east approaching a minimum value of –300 μms^{-2} in the Lengguru foldbelt. Further east in the Cenderawasih Bay the gravity values become higher (approaching 1,000 μms^{-2}) that is inferred being expression of the occurrence of an oceanic crust of high density. Figure 22 shows a gravity mathematical model, of the cartoon expression of Figure 20, across Onin, Bomberai

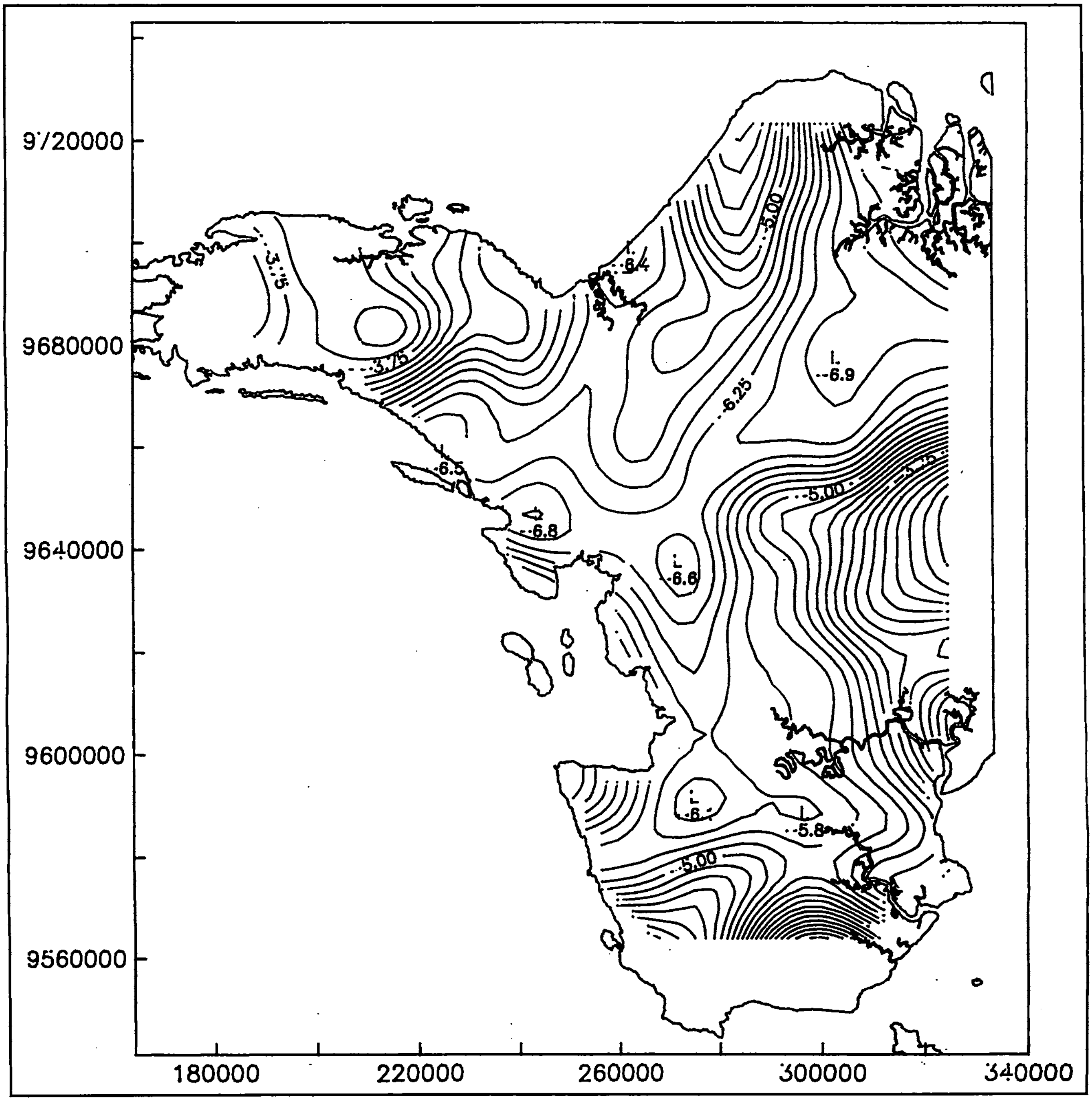


Figure 21. Depth of the high density rock formation in kilometres of the Babo Block. The depths of the high density rock formation are calculated using spectral analysis technique. Contour lines are in kilometres with 250 metres interval. Structural deformation in Bomberai is observed at a great depth. A channel-like structure trending northeast-southwest at an average depth of 6.5 km filled by thick pile sediments separates Onin from Kumawa and Bomberai region.

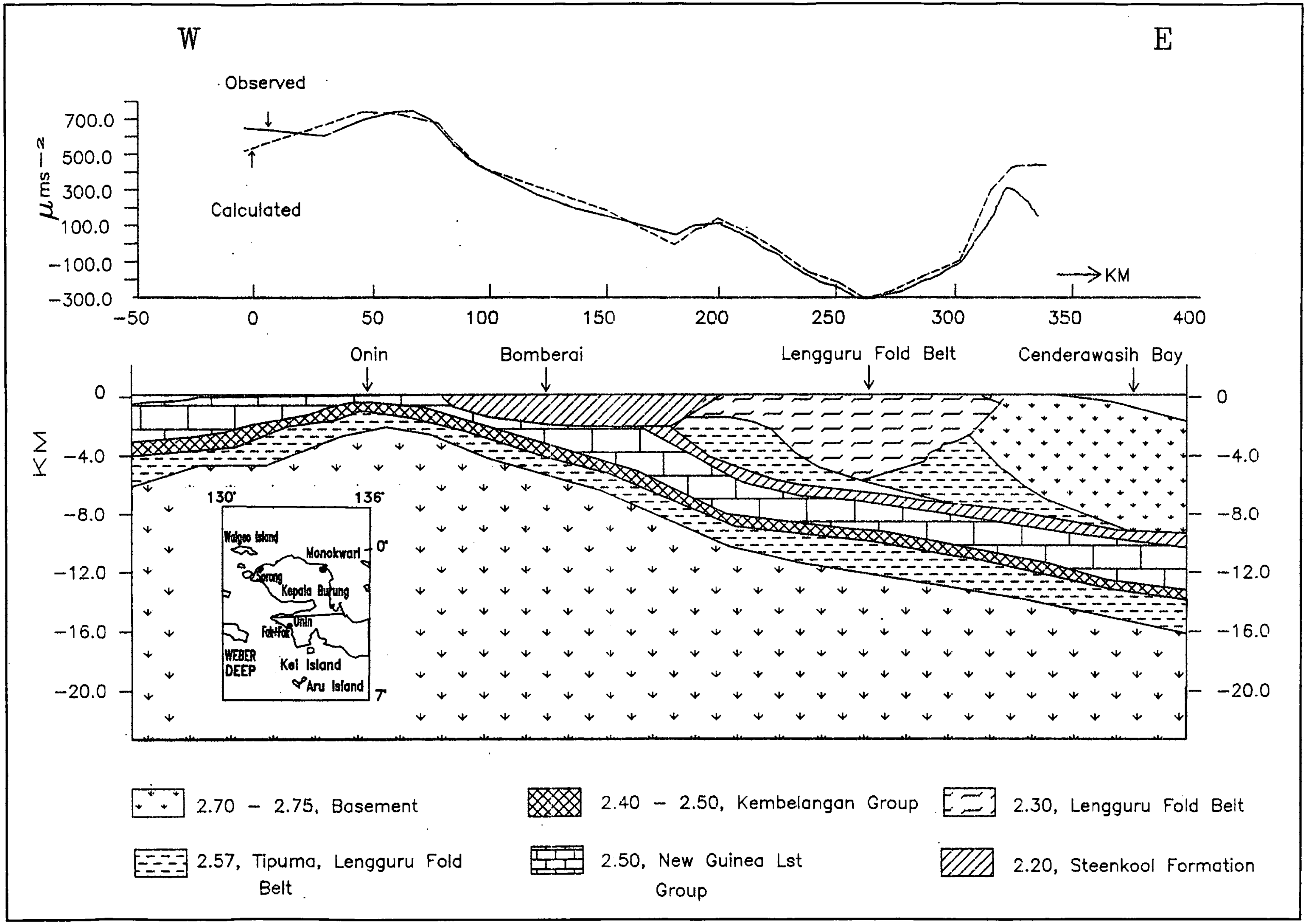


Figure 22. An east-west gravity model of 450 km long across Onin-Bomberai and Lengguru Fold Belt. Density (g/cm^3) distribution: 2.70–2.75; basement rock, 2.57; Tipuma-Aifam. These rock formations are thrusted and folded in the Lengguru Fold Belt, 2.40–2.50; Kembelangan Group also thrusted and folded in the Lengguru Fold Belt, 2.50; New Guinea Limestone (NGL) Group, 2.30; the Lengguru Fold Belt constituted of Tertiary as well as Mesozoic rock formations. 2.20; Steenkool Fm of Plio-Pleistocene.

and the Lengguru Fold Belt that is interpreted as a thrusting of the older sedimentary sequence towards the west. This thrusting, however, does not affect the surface sedimentary sequence of the Bomberai embayment. While Bomberai is completely undisturbed, Onin and Kumawa are upwarped gently resulted in an anticlinorium structure that may have potentialities of hydrocarbon accumulations (Figs. 8 and 9). The gravity models across Kumawa (Figs. 10 and 11) may lead to a dual interpretation of the structure of the peninsula. However, assuming the model of Figure 11 is acceptable, a west-east lithology break of the basement rock must have happened about the centre of Kumawa.

If it is proven that oil occurrences in the Salawati Basin came from the pre-Tertiary formation as has been mentioned earlier, it is most likely the older formations in the Onin and Kumawa peninsulas may be a rich source rock. The geological and gravity models (Figs. 8, 9 and 10) show a nice deposition of these older formation at the crestal regions. There are, however, possibilities that the expected oil bearing layers become thinner at the crest or even are not there, then oil might occur at the flanks of the anticlines. As the regions have experienced deformation, block faultings are encountered at many places, so that oil may have already migrated or leaked along the fractures.

CONCLUSIONS

1. An interactive approach between gravity modelling and balance section technique gives an optimum and reliable picture of the subsurface geology configuration.
2. In a karstified and rugged terrain covered by dense limestone such as the Onin and Kumawa Peninsulas, where seismic will not give a good answer about the subsurface geology, gravity survey accompanied by a detailed geological mapping resulted in a much better understanding on the regional structure and enabled the authors to identify two major hydrocarbon prospects.
3. Onin and Kumawa Peninsulas are inverted rift system. The Jurassic rift sands of the Lower Kembelangan located at about 1,500 m depth below the surface topography in West Onin and at about 2,000 m in East Onin are the primary targets.

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