APPLICATION OF REMOTE SENSING TECHNIQUES IN PETROLEUM EXPLORATION : THE INDONESIAN EXPERIENCE

By : B. Situmorang

ABSTRACT

Since the seventies, remote sensing data have been widely used in petroleum exploration in Indonesia. These include Landsat, Spot and Radar imageries, apart from the conventional aerial photographs. Examples from Nias Island, East Kalimantan Basin and Irian Jaya, will be presented to show the extensive application of remote sensing techniques in general geological mapping and hydrocarbon exploration.

With the land area of ± $2x10^6$ km^2 which consists of 17000 islands, and sea area of $5,1x10^6$ km^2 (including the EEZ), Indonesia is the largest archipelagic state in the world. Within the archipelago, 60 Tertiary sedimentary basins have been recognized both onshore and offshore. Some 36 of those basins have been explored, 14 of which produced hydrocarbons, 7 exhibited hydrocarbon indications, and 15 appear to be without any discoveries. The remaining 24 sedimentary basins are still unexplored.

Like many other tropical countries, most of the land areas of Indonesia are covered by the thick tropical forest, amounting to $144x10^6$ ha, constituting 74% of Indonesia's total land area. This and thick cloud cover have contributed to the difficulties in observing the general geology by the use of the conventional aerial photographs alone.

Since the launching of Landsat and SPOT, geological mapping and mineral exploration can be implemented in a more efficient way. Less time is needed to interpret a vast land area, which in turn permits cost and time reduction, although ground check is still necessary to confirm the geological interpretation. With the introduction of Radar, cloud cover can now be neglected, however image processing technology has not yet fully developed as in the optical system. Furthermore, Radar imagery is usually expensive compared to Landsat and Spot data.

JERS-1 which will be launched in the early 1992 appears to have some advantages over Landsat and SPOT, especially for Indonesia. Those are:

1. *Higher spatial resolution, i.e. 18mx18m on SAR and 18mx24m on the optical censor, will permit more detailed mapping as in the case of SPOT.*
2. *The availability of a long wavelength SAR (L band) will permit penetration of cloud cover and also dense vegetation which used to hamper optical remote sensing interpretation in some areas of Indonesia, such as Kalimantan and Irian Jaya.*
3. *Stereoscopic capability off JERS-1 (as in SPOT) will be very useful in structural interpretation. This will enable us to recognize regional structural framework of basinal areas.*
4. *Short wave infrared bands will enable the differentiation of clay minerals, which are very useful in studying the hydrothermal alteration zones.*

It appears that various advantages that have been provided by Landsat, Spot and Radar are integrated in JERS-1. With the setting up of the Image Processing Laboratory for Oil and Gas Study at Lemigas which is funded by the Government of Japan, we shall be able to develop image processing and analytical techniques in order to obtain an optimum geological information for hydrocarbon exploration.

INTRODUCTION

Indonesia is the largest archipelagic state in the world, situated between 94°–114° East longitude and 6°–11° South latitude. The archipelago consists of a land area of ± $2x10^6$ km^2 in the form of more than 17000 islands, and a sea area of $5,1x10^6$ km^2 (including the EEZ), spread over the equator with horizontal distance approximately equal to the distance between the west and east coasts of the USA (Fig. 1).

Within this vast region, 60 Tertiary sedimentary basins have been recognized both onshore and offshore (Fig. 2). Some 36 of those basins have been explored, 14 of which produced hydrocarbons, 7 only exhibited hydrocarbon indications, and 15 appeared to be without any discoveries. The other 24 sedimentary basins remain unexplored.

Most of the land areas of Indonesia are covered by the thick tropical forest, amounting to $144x10^6$ ha, or constitute 74% of Indonesia's total land area. This and thick cloud cover have contributed to the difficulties in implementing conventional geological survey, not to mention other factors such as mountainous and swampy terrain which make field work even more difficult.

One important aspect which has to be considered in exploration for hydrocarbon is the availability of database, e.g. geologic maps (Table 1). The most detailed geologic maps are on 1:100,000 scale, and only available for 22% of Jawa. For other islands, the largest scale is 1:250,000 which is available for Sumatra (65%), Kalimantan (0,02%), Sulawesi (41%), Nusantenggara (47%), Maluku (18%) and Irian Jaya (11 %). The other region are mapped only in terms of reconnaissance stage and/or have not been mapped at all yet.

It is then clear that the main constraints of hydrocarbon exploration in Indonesia are: vast and mountainous nature of the region, and the lack of database. As will be seen in the following discussions, remote sensing techniques appear to be an interesting alternative, especially at the beginning of the exploration.

Remote Sensing in Petroleum Exploration

Since the seventies, remote sensing data have been widely used in petroleum exploration in Indonesia. The data include aerial photograph, Landsat, Spot, and Radar (SLAR and SAR) imageries. Integration of those data with other geological and geophysical data has enabled us to unravel the complex geology of various basinal areas of Indonesia, which are believed to be formed by active convergence of three lithospheric plates, the Indian-Australian, the Pacific and the Eurasian plates (Fig. 3).

The following examples illustrate the application of remote sensing techniques in Indonesia :

Irian Jaya

The results of various remote sensing studies of Irian Jaya (Fig. 4) have been extensively published, a.o. in the Proceedings of the Indonesian Petroleum Association (IPA) and in the Bulletin of the American Association of Petroleum Geologists (AAPG).

Froidevaux (1977) has mapped the Salawati area by using Radar imagery which was then combined with geological and geophysical data. The results form the basis of palaeogeographic interpretation and evaluation of hydrocarbon prospects in the Salawati area, especially within the Miocene reefal limestones.

Using the SIR-A imagery, Sabins (1983) has mapped the region which included northwest Vogelkop, Southeast Vogelkop, Sarera Bay and Mimika-Eilanden Plain (Fig. 5). Six terrain categories can be differentiated which nicely correspond to carbonate rocks, elastic rocks, volcanic rocks, melange complexes, alluvial and coastal deposits and metamorphic rocks. Distribution of those terrains appears to be in line with geological data. Sabins (1983) further identified the major tectonic elements of Vogelkop region, i.e. the Tamrau Mountains, Sorong Fault Zone, Kemum Block, Bintuni Basin and Lengguru Fold Belt (Fig. 6). A belt of metamorphic and melange terrain has also been identified in the area of Sarera Bay-Paniai Lake and Central Range-Mimika-Eilanden Plain (Fig. 7). The good spatial resolution of SIR-A (38m) has made the identification of individual structures such as faults and folds possible.

Another aerial photograph and Landsat imagery interpretation was made by Dow and Hartono (1984), from which they were able to determine the structural geological framework of northeast Irian Jaya. Evidently the results are correlatable with seismicity of the region.

The hypothesis for the formation of Lengguru Fold Belt has been put forward by Dow et al. (1985) based on the interpretation of Landsat imagery and aerial photograph.

More recent photogeological study on the Mamberamo and Podena area was made by Waschsmuth and Kunst (1986). Three terrains have been recognized, based on texture and tonal pattern. These data have been influential in synthesizing the wrench fault tectonics of northern part of Irian Jaya.

East Kalimantan

SLAR and SAR imageries have been used in geological research in the East Kutai Basin of East Kalimantan (Wirayadi, 1986) (Fig.8). Four terrain categories can be recognized, i.e. melange, clastic, karst and plain terrains (Fig. 9). Integration with geological data has resulted in differentiation of eight Radar rock units which can be correlated with the existing stratigraphic units (Fig. 10). Oblique illumination produced by Radar can form an excellent image of relief which is very useful in structural interpretation. Wirayadi (1986) has been able to identify 466 lineaments and 85 folds. The main trends of those lineaments are N 50° – 70° E and N 50° - 70° W in the basement complexes, N 60° – 70° E and N 60° – 70° W in transgressive rocks, and N 50° – 70° E and N 50° – 60° W in the regressive sedimentary sequences.

Folds appear to be dominated by tight anticlines and broad synclines. This geometry is due to diapirism and gravity sliding.

Nias Island

Nias island forms part of the Sunda forearc ridge of the active continental margin developed through the collision between the Indian-Australian plate and the Eurasian plate (Fig. 11). The island flanks the forearc basin (Sibolga basin) where some exploration work for hydrocarbons has been carried out in the seventies. Recently, LEMIGAS Basin Study Group has carried out geological fieldwork in this island, combined with gravity survey and remote sensing studies.

In remote sensing studies, the data used are Landsat MSS with highly correlated bands and therefore no distribution of any spectral signatures. Hence, although wide flexibility on data manipulation is possible through digital image processing, image enhancement and information extraction will not produce spectral data that can be used for lithology discrimination. The maximum result is structural information through edge enhancement analysis (Husen, 1989).

The edges that have been identified are mainly linear geological features. The digital convolution method of directional edge enhancement, i.e. the Sobel vertical filter appears to be an effective detector for the NW-SE and NE-SW trending lineaments. Ideally, the digital gradient is perpendicular to the optimum edge enhancement, nevertheless, lineaments which form an oblique angle with digital gradient can also be detected (Fig. 12).

Further attempts were to apply GIS in its simples form (Figs. 13, 14). Ground check was then made on the Nias Island, and the location of extensional zones can be identified (Situmorang et al., in press) (Fig. 15).

Constraints on the Application of Remote Sensing Techniques in Indonesia

Although remote sensing data have been used in exploration for hydrocarbons in Indonesia, geological information derived from this technique has not been extensively applied. Two main constraints exist, i.e. the dense tropical forest and cloud cover, and sophisticated utilization technology which used to be difficult to develop without the assistance from industrial countries.

As mentioned earlier, most of the land areas of Indonesia are covered by thick tropical forest. The field of geobotany could be developed in Indonesia; however, it could be hindered by the problems of utilization technology and platform system either spatial, spectral or radiometric. Therefore, prediction of underlying lithology based on the type and pattern of distribution of vegetation to some extent is still impossible.

With hot temperature and high humidity, most of the Indonesian region is also covered by cloud all the year round. To overcome this condition, application of Radar is the only alternative. However, its image processing technology has not been developed as on the optical system, and the analysis can only be done visually. Apart from that, Radar imageries are relatively expensive. Since most of the data are acquired from the aircraft, Radar system has only been applied in some parts of Indonesia.

From the foregoing discussions, it appears that the most serious constraint for a country like Indonesia is the technology. At the moment, Indonesia is still at the early stage of the application of visible spectrum. More efforts are needed for the establishment of other remote sensing techniques such as the application of thermal spectrum and microwave. Another important factor is the computer facilities. Almost all available hard and soft wares in Indonesia are imported from various industrial countries, which are often incompatible.

Indonesian Remote Sensing Institutions

Various institutions which are involved in remote sensing activities can be grouped into 4 groups as follows (Gastellu-Etchegorry, 1988):

National Remote Sensing Agencies

- LAPAN, the National Institute for Aeronautics and Space. Apart from carrying out research and development in aeronautics, LAPAN is also acting as Landsat and NOAA/GMS receiving station.
- BAKOSURTANAL, the Coordinating Agency for Survey and Mapping, with Dipix system at its remote sensing unit.

Research Institutions and Universities

- PUSPICS, Remote Sensing Laboratory of Bakosurtanal and Gadjah Mada University. This is a training centre for the application and development of remote sensing techniques, with the facilities for digital analysis (IBM).
- Faculty of Geography, Gadjah Mada University, where Remote Sensing is taught as a special subject.

- o Research Centre for Environmental Study (PPLH), Gadjah Mada University.
- o Department of Soil Science, Bogor Institute of Agriculture (IPB), with capabilities for digital analysis (IBM).
- o Department of Electronics Engineering, University of Indonesia, where hardware for remote sensing is being developed..
- o Research and Development Centre for Geotechnology of the Indonesian Institute of Sciences (Puslitbang Geoteknologi-LIPI); involved in research on digital analysis for geological investigation.
- o Institute of Ecology, Padjadjaran University, Bandung.
- o BIOTROP-SEAMEO, International Centre for Biological Studies. This unit develops the application of remote sensing for studying the vegetation, with IBM digital processing facilities.
- o PPPG, Geological Research and Development Centre, Bandung. This centre is involved in the development of application of remote sensing for environmental geology, mineral exploration and volçanology.
- o Soil Research Centre, Centre for Agricultural Research.
- o Research and Development Centre for Oil and Gas Technology "LEMIGAS". The Image Processing Laboratory for Oil and Gas Study is being developed through technical assistance from JICA/Government of Japan. Facilities available are depicted in Table 2.

Other Government Agencies

- o BPPT, Remote Sensing Program, the Agency for the Assessment and Application of Technology. The facilities available include IBM-PC/XT/AT/386, CITRA-88 image processing system, SUN-Mycrosystem, IBM-3090 with LARSYS and CITRA-88 softwares, and ERDAS-GOULD System.
- o PUSDATA, Centre for Digital Remote Sensing Analysis, Ministry of Public Works. A large remote sensing digital analysis system is available at this centre.
- o Management Program, Ministry of Forestry. The unit is responsible for nation-wide forest inventories and monitoring.
- o BPS, Central Bureau of Statistics. This agency is mainly involved in the application of remote sensing for agricultural data collection.

Private Companies

Various private companies are engaged in the field of remote sensing, such as PT Nusantara Systems International (NSI), PT Indo Georeka Nusantara, PT EXSA International and PT Adi Karto.

It is clear that a wide range of activities in remote sensing has been implemented by various institute and government agencies, apart from commercial endeavor by private companies. Undoubtedly, those activities will continue to develop, in line with the Indonesian national development plan.

Possible Application of JERS-1 in Indonesia

The available information indicates that JERS-1 which will be launched in early 1922 appears to have some advantages compared with Landsat and SPOT (Table 3). Those are :

1. Higher spatial resolution, i.e. 18mx18m on SAR and 18mx24m on OPS, with which a more detailed mapping as in the case of SPOT can be carried out.
2. The availability of a long wavelength SAR (L band) will permit penetration of cloud cover and also dense vegetation which used to hamper optical remote sensing interpretation in some areas of Indonesia, e.g. Kalimantan and Irian Jaya.

3. Stereoscopic capability of JERS-1 (as in SPOT) will be very useful in structural interpretation. This will enable the recognition of structural framework of basinal areas.
4. Short wave infrared bands will enable the differentiation of clay minerals, which are very useful in studying the hydrothermal alteration zones.

Various advantages that have been provided by Landsat, Spot and Radar appear to be integrated in JERS-1. Accordingly, through the setting up of the Image Processing Laboratory for Oil and Gas Study at Lemigas, there is an opportunity to develop image processing and other analytical techniques, so that optimum geological information for hydrocarbon exploration can be obtained.

Concluding Remarks

There is no doubt that remote sensing will significantly contribute to more efficient exploration campaigns, especially in a region such as Indonesia. A need for specific technology e.g. platform system and utilization technology is obvious due to the occurrence of dense tropical forest and cloud cover.

With the launching of the forthcoming JERS-1 various remote sensing institutions are now in a position to integrate their efforts in order to maximize its application in exploration for hydrocarbons and minerals in Indonesia. A close link should be maintained between the Image Processing Laboratory for Oil and Gas Study at Lemigas and corresponding agencies in Japan such as ERSDAC. Joint research should be considered not only in terms of field investigations but also in developing image processing and other application techniques. Several capabilities of Landsat, SPOT and Radar system which are integrated in JERS-1 will be of immense value for development of hydrocarbon resources of Indonesia.

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APPENDIX

Table 1 : Published Geologic Maps of Indonesia (Source: GRDC, 1990)

Area	Scale	Geologic Map	Preliminary Map
Jawa and Madura	1:100,000	22%	78%
Sumatra	1:250,000	65%	35%
Kalimantan	1:250,000	2%	35%
Sulawesi	1:250,000	41%	3%
Nusa Tenggara Timur	1:250,000	47%	11%
Maluku	1:250,000	18%	9%
Irian Jaya	1:250,000	11%	31%

Table 2 : HARDWARE FACILITIES AT IMAGE PROCESSING LABORATORY PPPTMGB "LEMIGAS"

UPS	:	30 kVA		
Computer	:	MICROVAX 3900		
		Circle time	:	33 Mhz
		Instruc. vel	:	3.2–4 MIPS (Mega Instruction per Second)
		Memory	:	Physical : 4 MB
		Virtual	:	32 MB
Peripheral	:	RA90 Magnetic Disc (1.2 GB x 2)		
		TK70 Mini Cassete (296 MB/Tape)		
		YU81 Plus MT Drive (6250,1600 BPI)		
		VT382 Console Terminal		
Options	:	RS-232C Interface x 8 ch.		
		IEQ-11 (IEEE488, GPIB) Interface x 2 ch		
		DRV11WA 16 bits Parralel Interface x 2 ch		
		LAser Printer LO3'S		
		VT382 User terminal x 3 ch		
Image Processor		VICOM IP9000 Unit 9516		
		Memory 2048 x 2048 x 8 bits		x 4
		RGB Monitor (1024 x 1024)		x 1
		Track bail		
Film Recorder		Optronics C-1300		
Color Printer		FUJIX Pictrography 2000		
Color Scanner		SHARP JX-600		
CCD Camera System		SONY DXC-3000		
		SONY CCU-M3 Control unit		
		JVC Video Color Monitor		
Terra-Mar SYSTEM (MICROIMAGE)				X 2
		RGB monitor		
		Monitor Zenith data system		
		Magnetic drive		
		Mouse		

Table 3 : CHARACTERISTICS OF SELECTED SATELLITE REMOTE SENSING SYSTEM

		LANDSAT (1 - 5)		S P O T (1 - 2)		J E R S -1	
		Multi Spectral Scanner (MSS)	Thematic Mapper (TM)	Multi Spectral (MS)	Panchromatic (PAN)	Optical Sensor (OPS)	Synthetic Apperture Radar (S A R)
Spectral Bands (micrometer)	Visible	0.5 - 0.6 0.6 - 0.7	0.45 - 0.52 0.52 - 0.60 0.63 - 0.74	0.51 - 0.59 0.61 - 0.68	0.51 - 0.73	0.52 - 0.60 0.63 - 0.69	
	Near Infrared	0.7 - 0.8 0.8 - 1.1	0.76 - 0.90	0.79 - 0.89		0.76 - 0.86 0.76 - 0.86 (stereo)	
	Short Wave Infrared		1.55 - 1.75 2.08 - 2.35			1.60 - 1.71 2.01 - 2.12 2.13 - 2.25 2.27 - 2.40	
	Thermal Infrared		10.50 - 12.50				
	Micro Wave						240,000 (L band)
SWATH WIDTH (km)		185	185	60	60	75	75
I F O V (m)		80	30 120 (thermal)	20	10	18.3x24	18

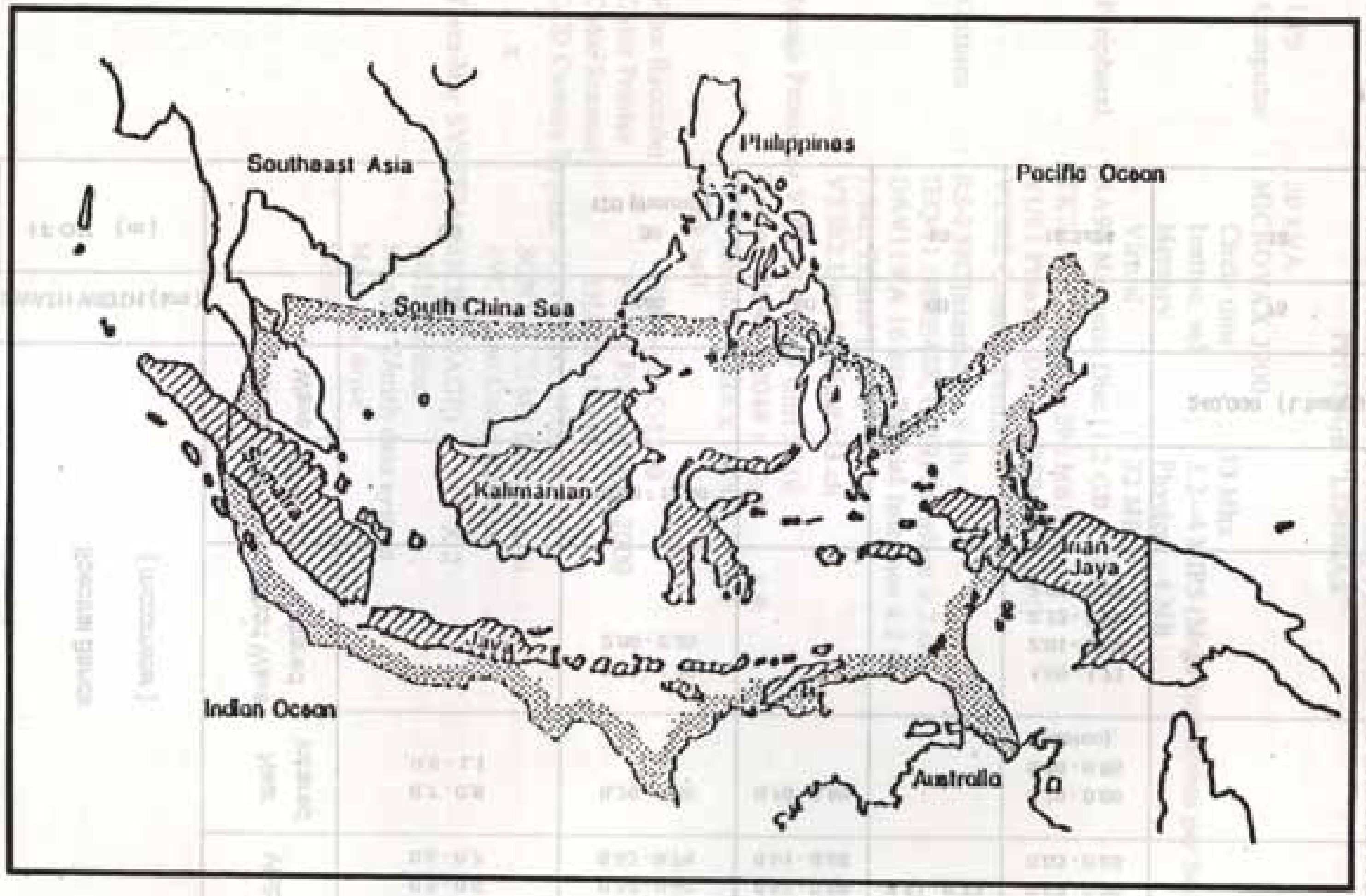

Fig. 1. Comparison of Indonesian archipelago with continental U.S.A. (from Fletcher & Soeparjadi, 1976).

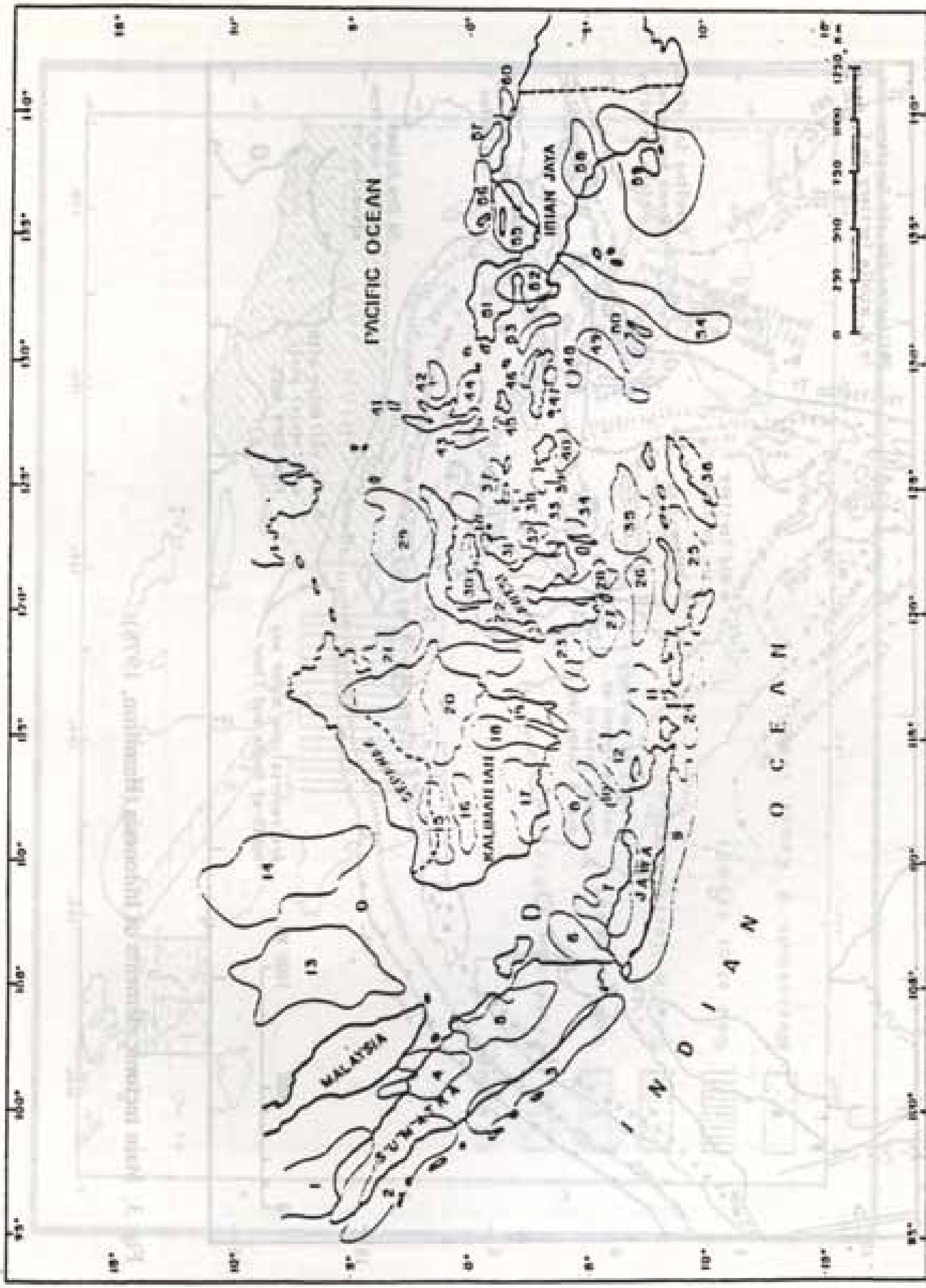

Fig. 2. Sedimentary basins of Indonesia (Suardy & Taruno, 1985).

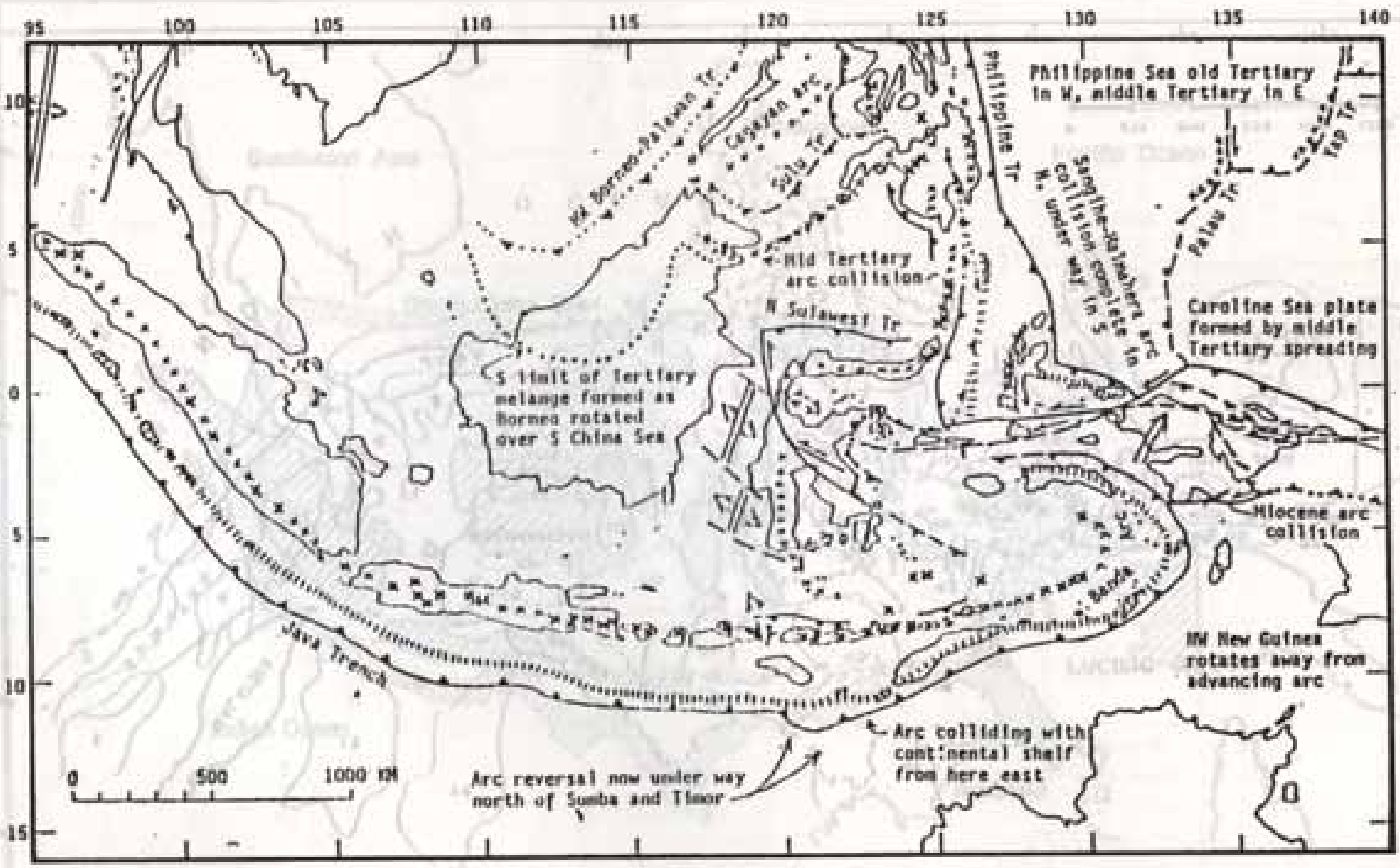

Fig. 3. Main tectonic elements of Indonesia (Hamilton, 1978).

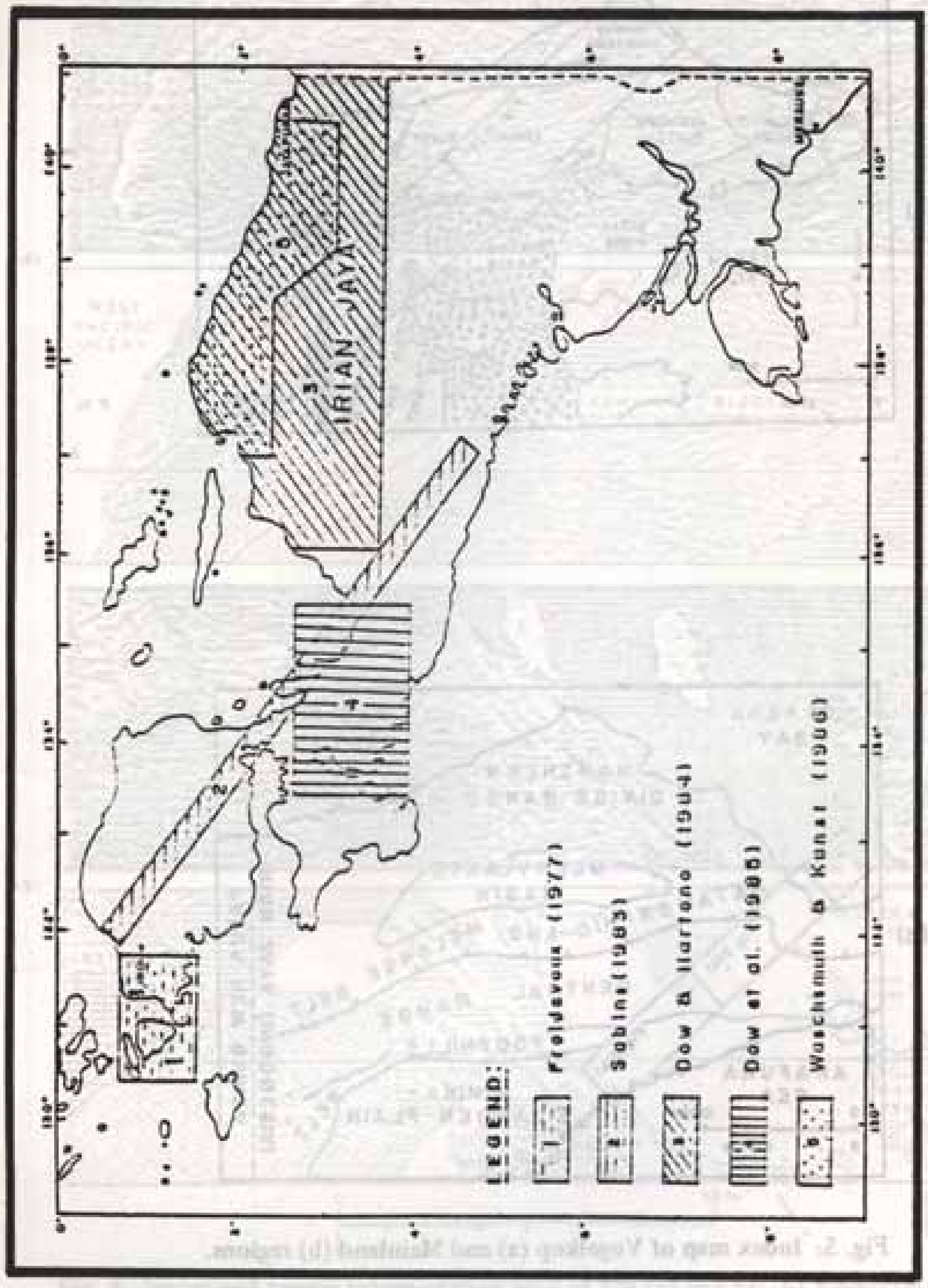

Fig. 4. Irian Jaya : Location of remote sensing studies.

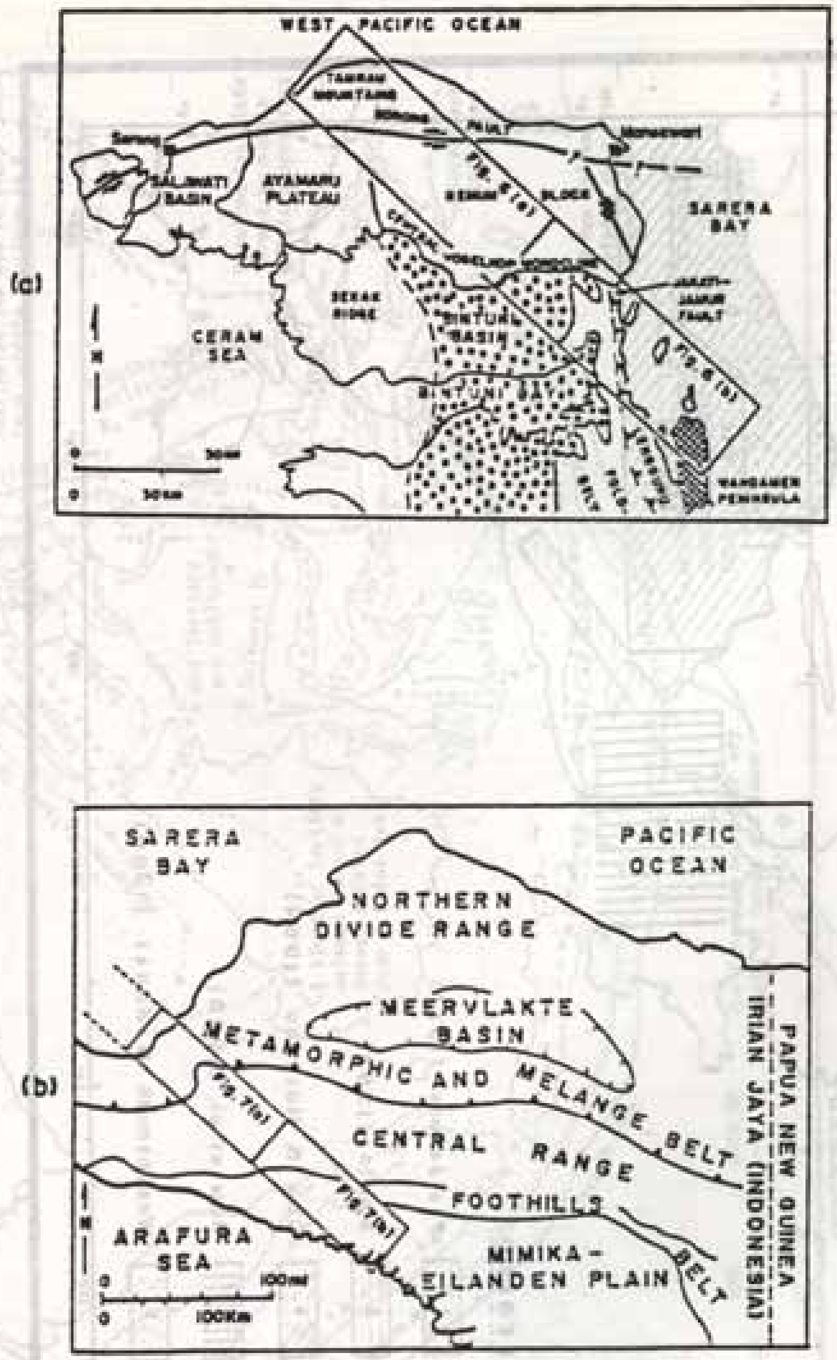

Fig. 5. Index map of Vogelkop (a) and Mainland (b) regions.

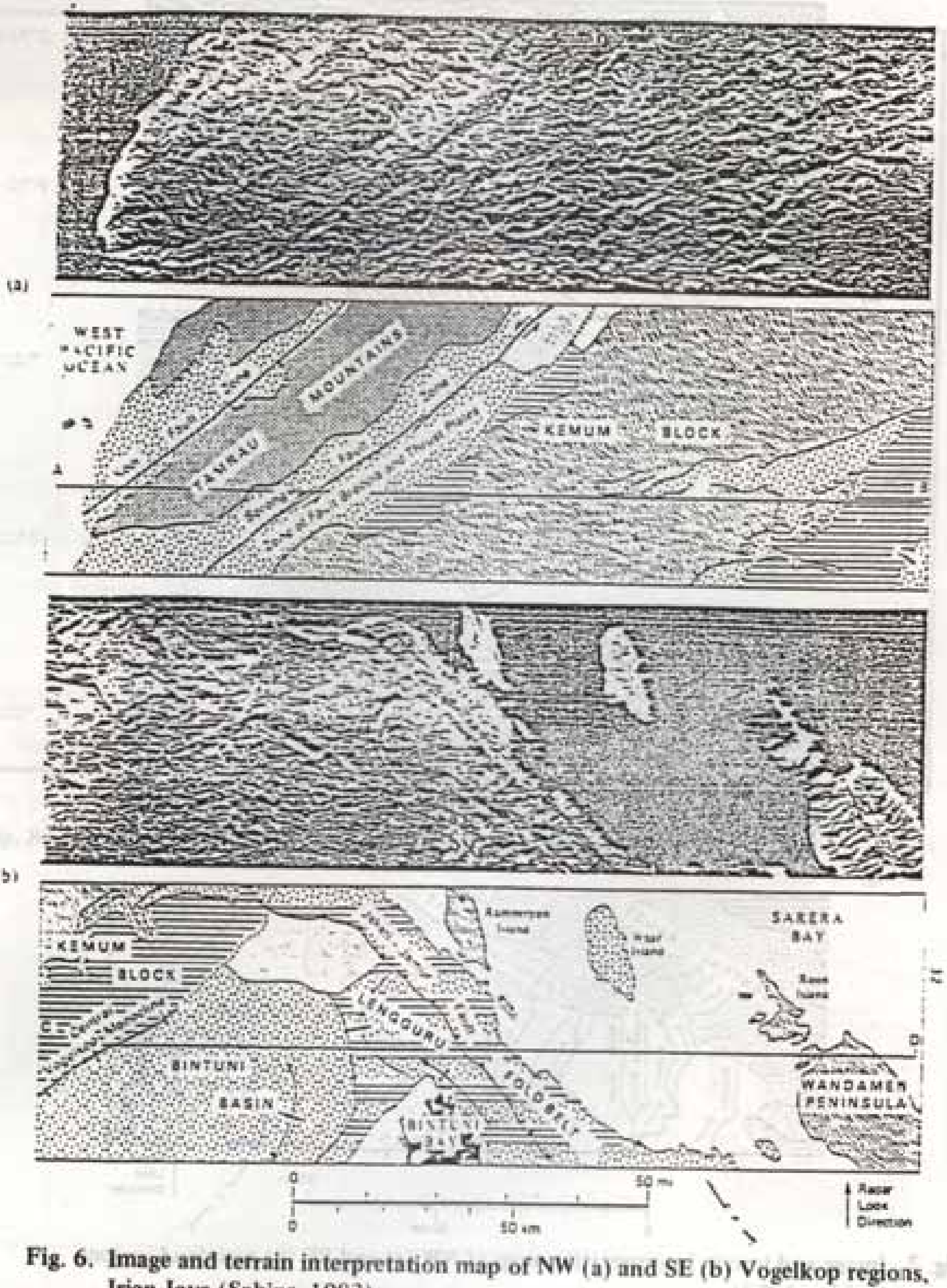

Fig. 6. Image and terrain interpretation map of NW (a) and SE (b) Vogelkop regions, Irian Jaya (Sabins, 1983).

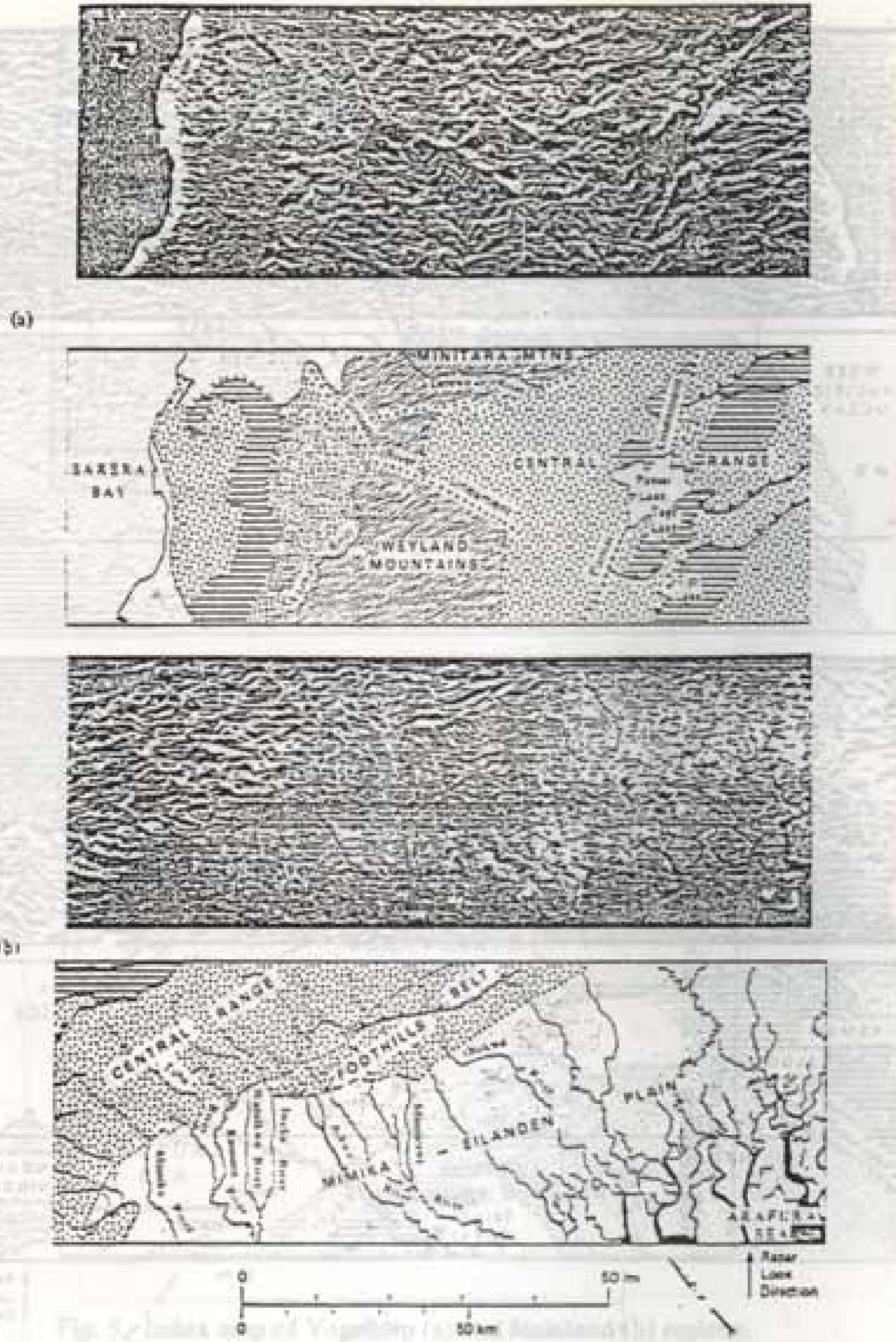

Fig. 7. Image and terrain interpretation map of NW (a) and SE (b) mainland regions (Sabins, 1983).

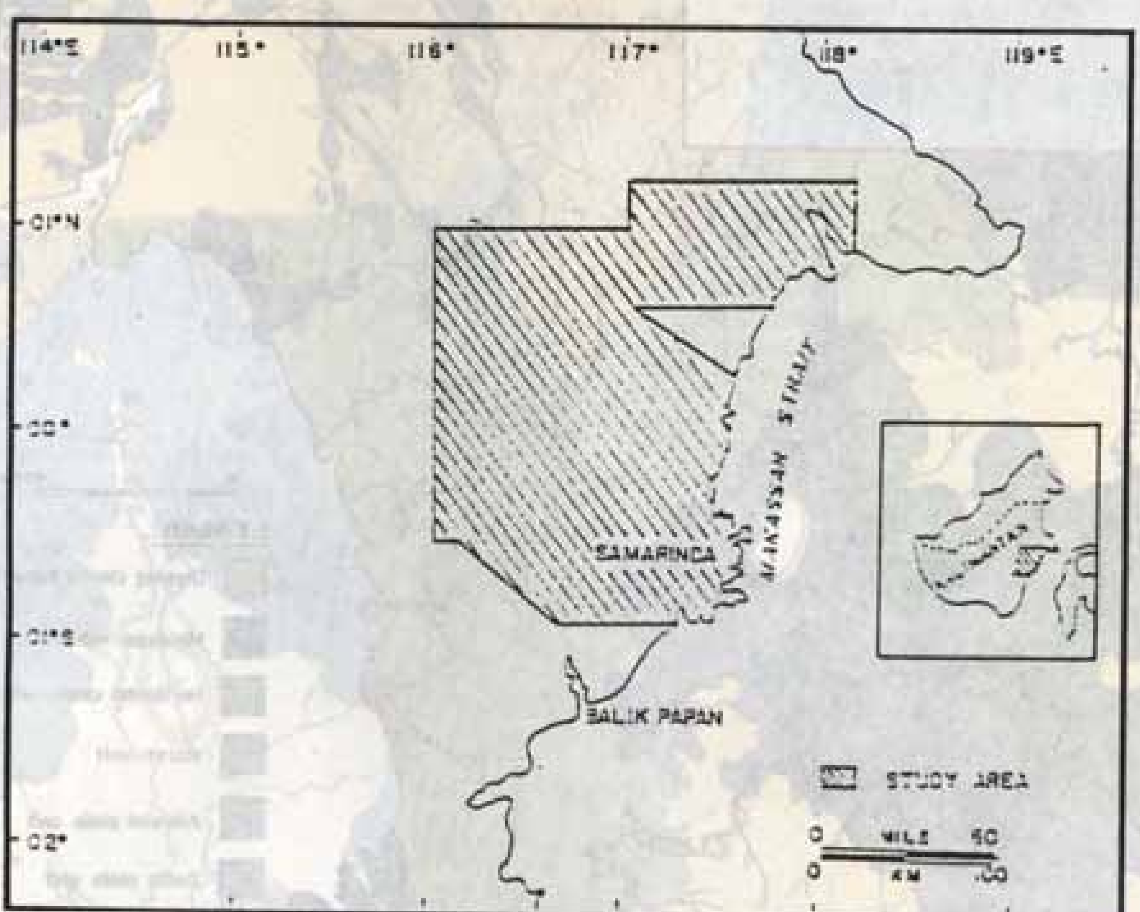

Fig. 8. Location map of East Kutei Basin, East Kalimantan.

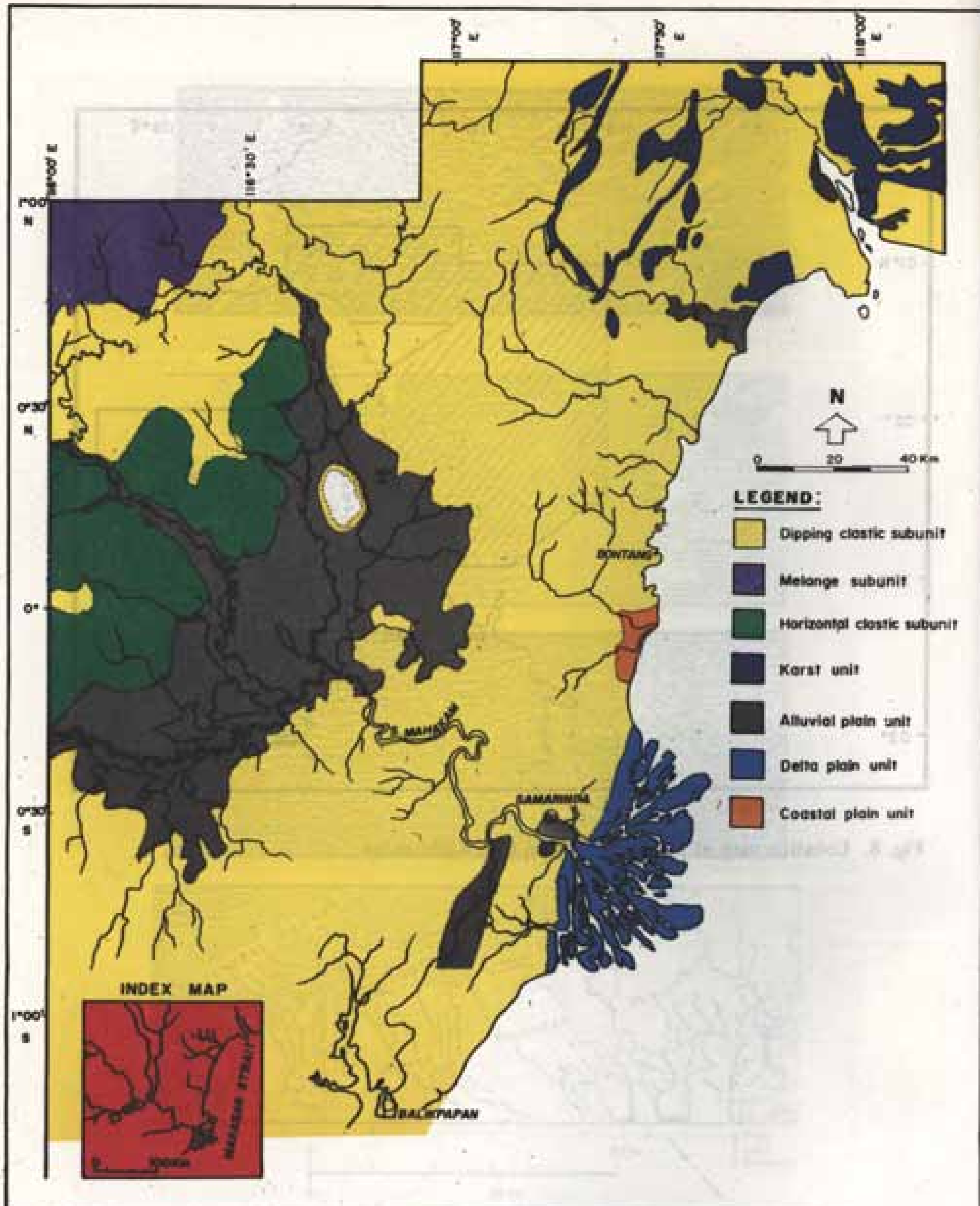

Fig. 9. Morphologic unit map of East Kutei Basin (Wirayadi, 1986).

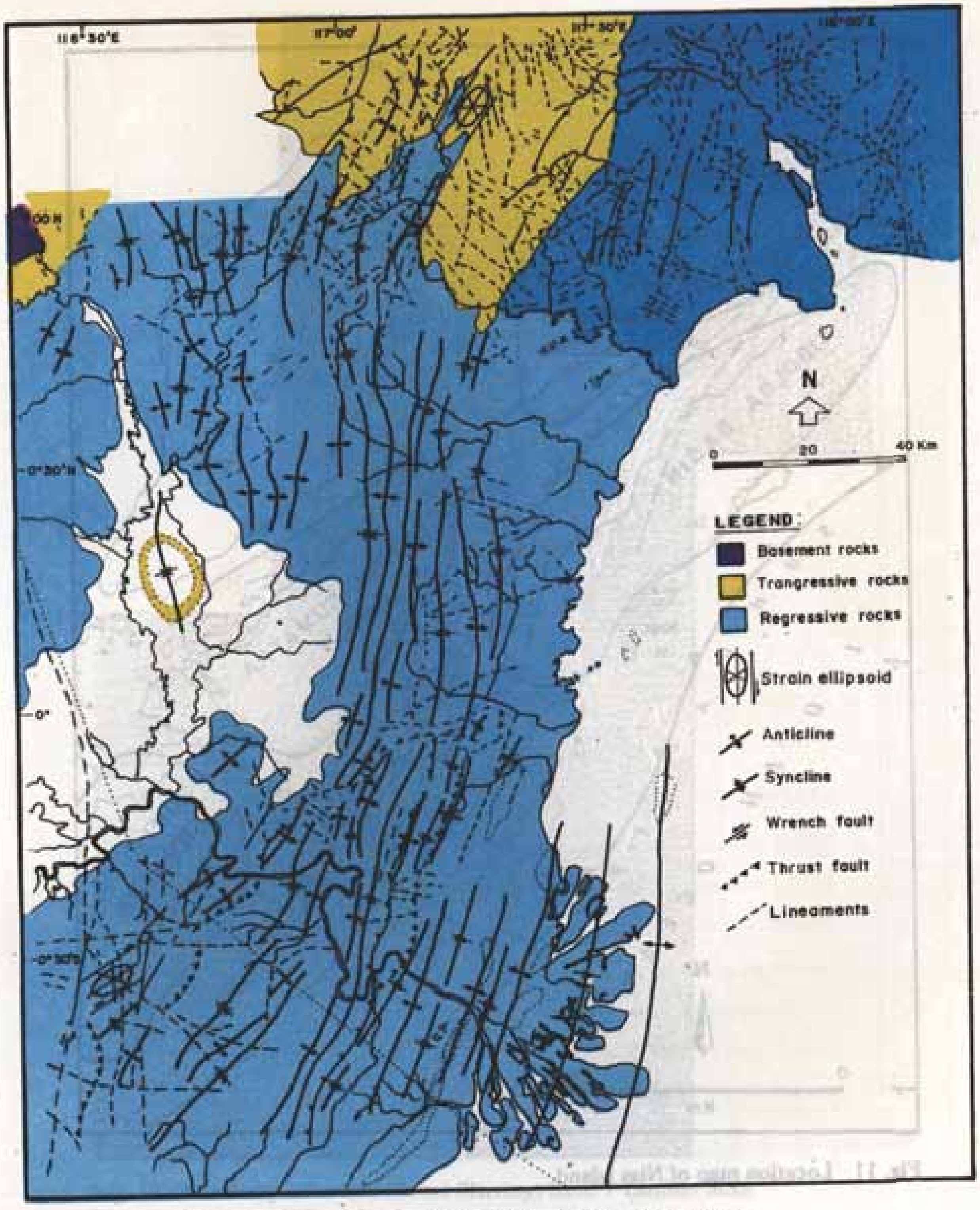

Fig. 10. Geological sketch map of East Kutei Basin (Wirayadi, 1986).

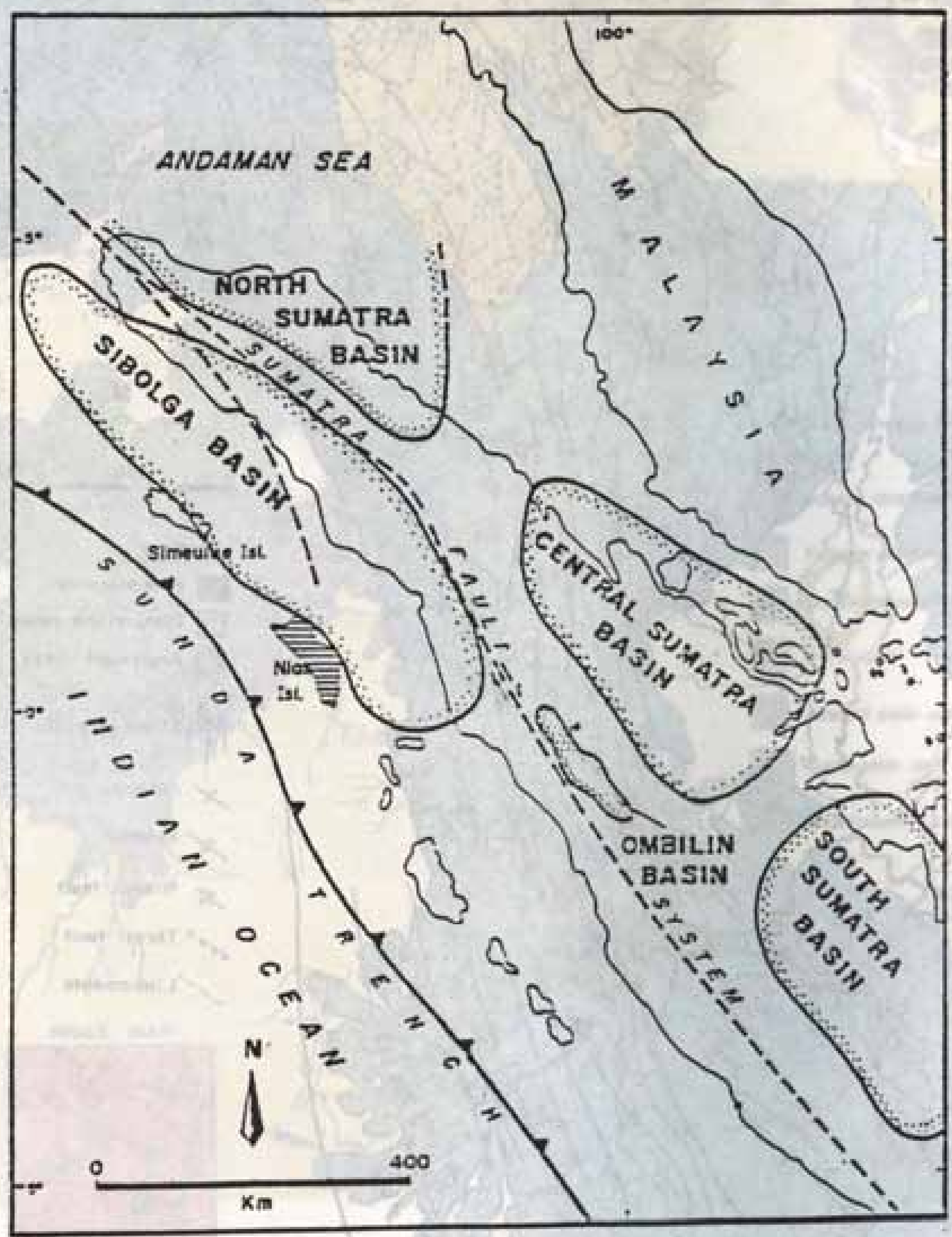

Fig. 11. Location map of Nias Island.

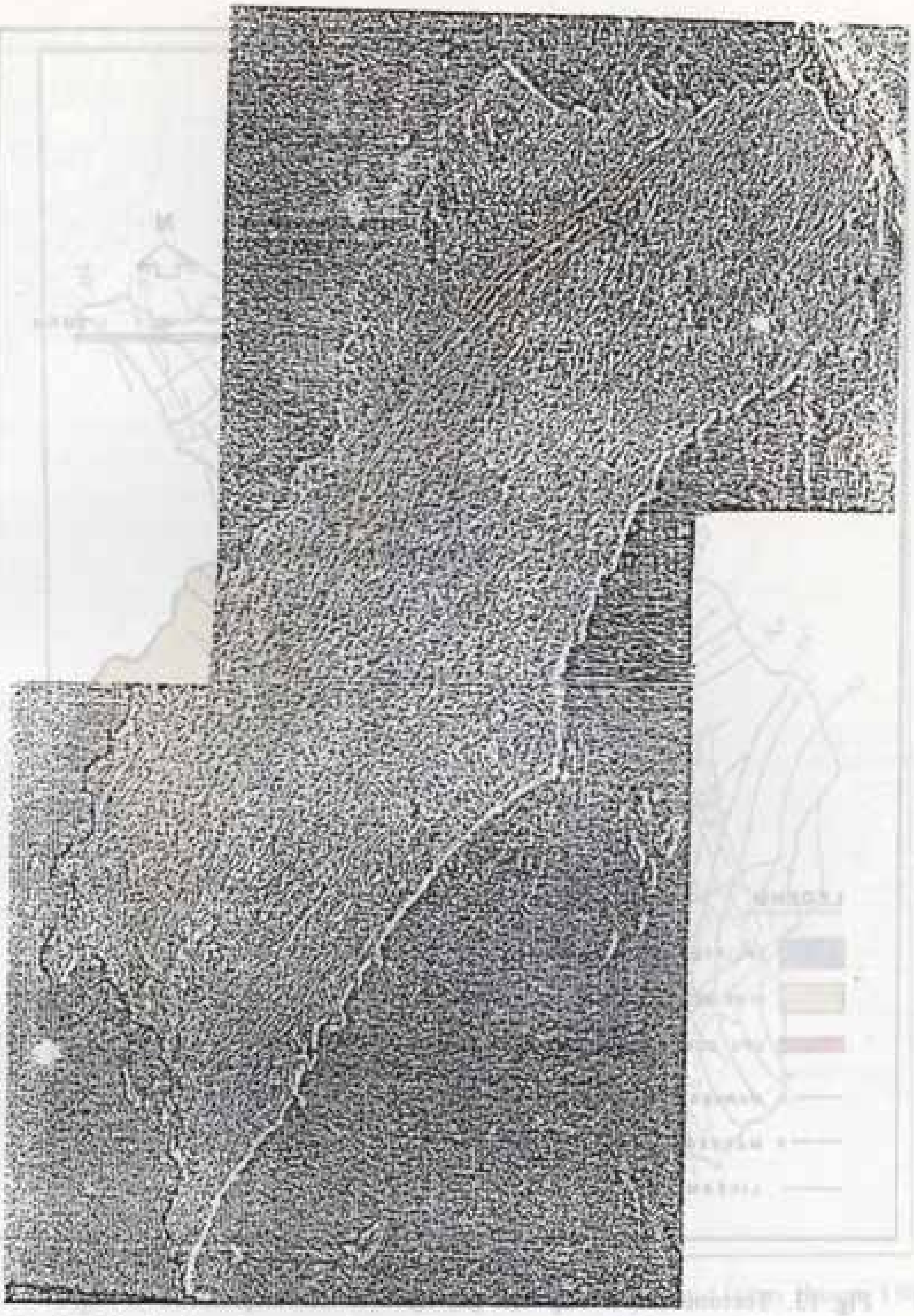

Fig. 12. Vertically enhanced (Sobel filtering) band 7 Landsat MSS imagery of Nias island.

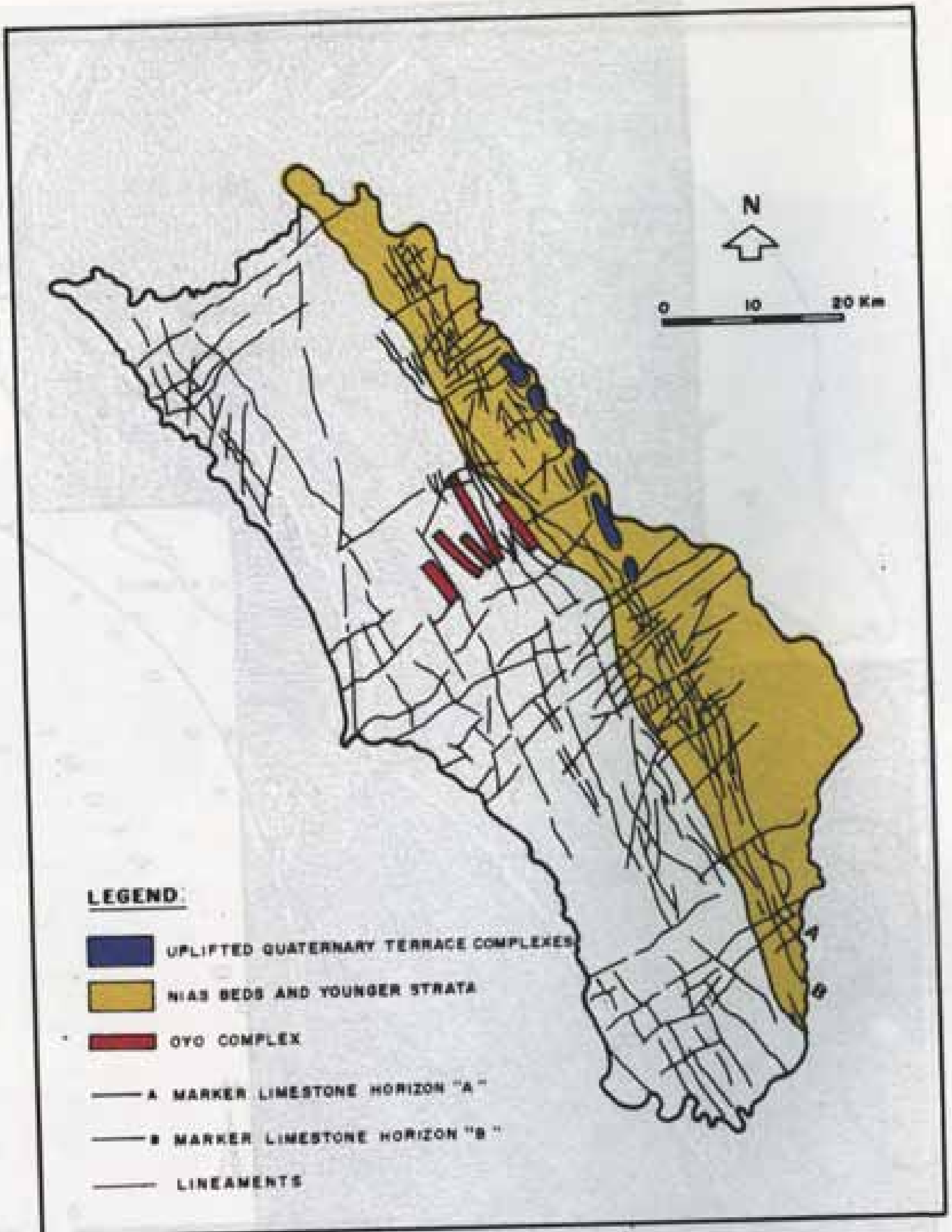

Fig. 13. Tectonic fabric map with geological sketch map of Nias Island (Husen, 1989).

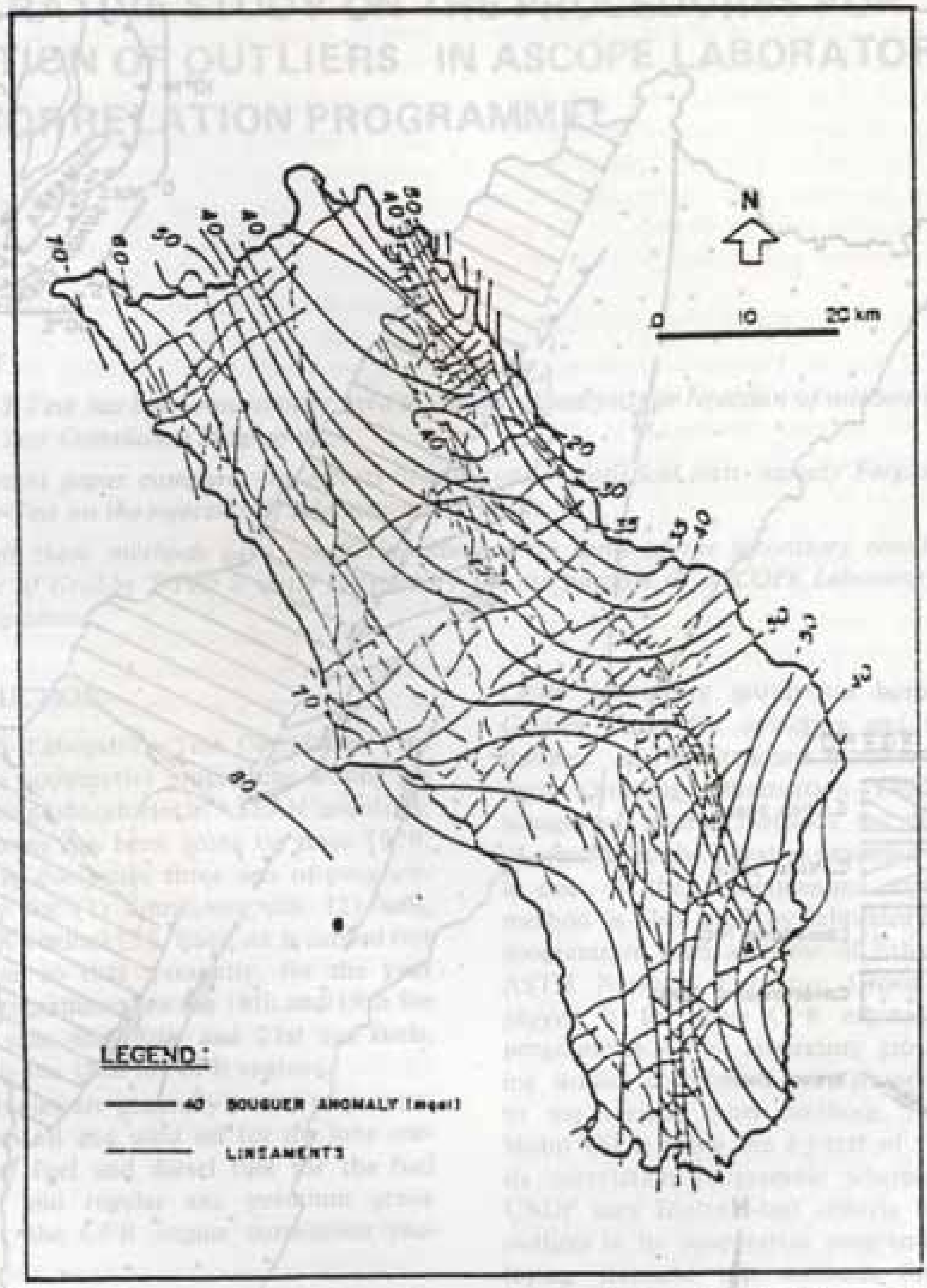

Fig. 14. Tectonic fabric map with gravity map, Nias Island (after Husen, 1989).

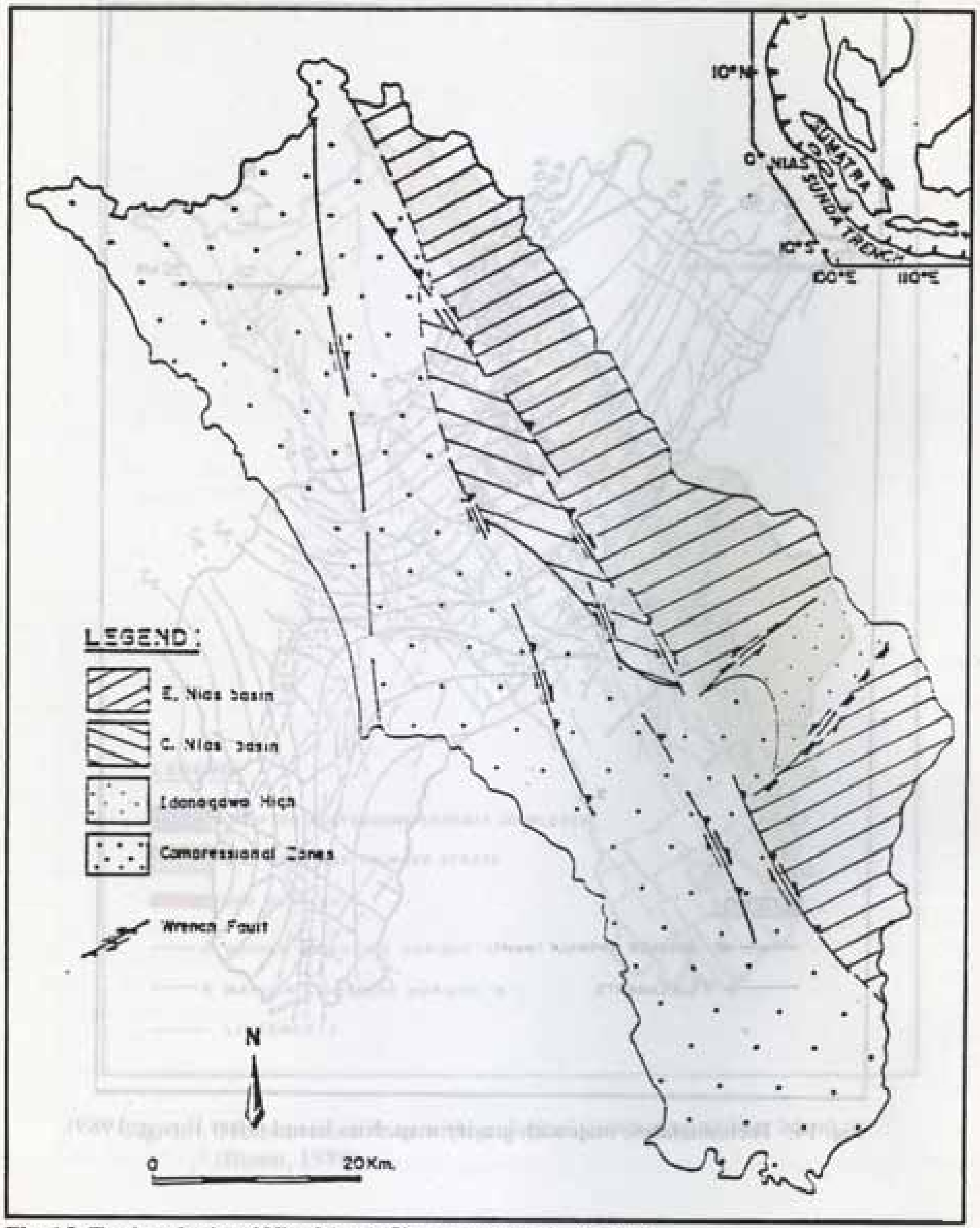

Fig. 15. Tertiary basin of Nias Island (Situmorang et al., in press).