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The use of SAR imagery for hydrocarbon exploration in Sarawak

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Abstract: Side Looking Airborne Radar (SLAR) has been widely used in hydrocarbon exploration recently. However the use of Synthetic Aperture Radar (SAR) has greatly improved the problem of aperture restriction caused by the limited antenna length in the use of real aperture SLAR.

A SAR survey of Block SK-12, onshore Sarawak, Malaysia, resulted in strip prints of SAR imagery for each flight line at a scale of 1:100,000. Computer processed mosaics in three sheets were produced at the same scale for plotting geological and cultural interpretations of the SAR data.

The geological interpretation and lineament analysis resulted in more detailed information than available from the published maps of the Geological Survey of Malaysia whilst the cultural interpretation included the identification of forest type and land use.

Areas of structural interest identified from the geological interpretation are now being surveyed from the ground. The cultural interpretation is used as a guide for accessibility for both geological field crews and seismic crews and was used in the planning of the seismic programme.

INTRODUCTION OF SAR

Radar is an active remote sensing system, which supplies its own illumination. Side Looking Airborne Radar (SLAR) utilises a narrow beam of pulsed microwave energy transmitted out to the side of the aircraft. This radar beam sweeps across the surface of the earth with the forward motion of the aircraft. The reflected radar signals within this narrow beam are recorded on photographic film. This resultant strip of imagery has many of the characteristics of an aerial photograph and the interpretation of radar imagery is guided by the same basic principles which apply - in the interpretation of aerial photography.

Synthetic Aperture Radar (SAR) is an improved system of SLAR. Previously, in the use of real aperture SLAR, the resolution of the radar imagery greatly depended upon the beamwidth of the pulsed microwave energy. Since the beamwidth is the inverse of the antenna aperture, it is restricted by the antenna length. The use of SAR greatly improved the problem of aperture restriction caused by the limited antenna length.

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Compared with aerial photography, the advantages of SLAR are its ability to be operated both day and night due to its own illumination and the cloud penetration capability of radar which allows an almost complete disregard of climatic conditions. The most important advantage for geological interpretation using SLAR imagery is that the SLAR imagery can enhance topographic features which are controlled by geological elements.

In any SLAR Survey, two of the most important parameters are look direction and correct depression angles. These two elements are directly related to the amount of information that will be available from the imagery. For geological interpretation, the most desirable look direction is usually determined by studying the topographic and structural trends in the survey area. An important rule of thumb is to look neither exactly parallel with nor perpendicular to the topographic trend. Either direction may cause the loss of a significant amount of information because of too much radar shadow which influences the structural enhancing effect. On the other hand, the selection and control of depression angles can determine the amount of "radar shadow" that will appear in the image. Shadows are extremely important in revealing subtle geologic structural features which can be missed if the selected depression angle is too steep. A rule to follow in choosing the depression angel is to use a low angle (10 - 15 degrees) for flat-lying terrain to enhance topographic detail and a steeper angle, usually less than 35 degrees, in mountainous terrain to reduce the amount of data lost to shadowing.

ELEMENTS IN SLAR IMAGERY INTERPRETATION

SLAR imagery interpretation is the process of examining images for the purpose of identifying features and judging their significance.

Six importance elements are applied in SLAR imagery interpretation. They are:

1. ***The size of objects***

   This is one of the most important elements for object identification. The - imagery scale and the effects of vertical exaggeration must be known in order to determine the size of objects and comprehend their significance.

2. ***Shape or form of objects***

   Many geological features have typical shapes or morphologies which may vary under different environmental conditions. Recognition of basic forms (for example volcanic cones, badlands, hogbacks and numerous other features) requires very little effort.

3. ***Shadows***

   These can either enhance or obscure scene depending on the depression angle selected. In regions of varying relief the depression angle must be selected carefully. However, radar shadowing is the key to detecting subtle geological features in areas of low relief.

4. ***Tone***

Tone is the degree of brightness or darkness observed on an image. Tonal variations on radar imagery are a function of topography, surface roughness, depression angle and the complex dielectric properties of the reflecting materials. On radar imagery, tone ranges from black to bright white depending on the reflected energy from the surface of objects.

5. ***Texture***

This is the visual expression of roughness or smoothness of the imaged surface. Texture usually results from lithology, vegetation, structure of topography of combinations of these. In some cases, textural changes are expressed by tonal contrasts related to soil moisture difference, land use or some other factor. Areas are described as fine, medium or coarse-textured or as smooth or rough-textured.

6. ***Pattern***

Pattern on an image is a regular and characteristic arrangement of tones or textures which depict the respective spacing of elements in an imaged scene. Pattern may be critical in determining one outcrop area from another, regardless of wether the area a natural or cultural pattern.

Pattern variation, formed either by natural or cultural factors, may permit the interpreter to predict subsurface lithology and structure of may assist in geological interpretation.

A SAR SURVEY IN BLOCK SK-12 ONSHORE SARAWAK

A SAR Survey was conducted over the central and eastern parts of Block SK-12, onshore Sarawak (Figure 1) during February 1989. The data were acquired in order to map surface geology (including structure, stratigraphy and lineament analysis) and cultural information, (such as land cover, access and trafficability) to assist in planning and conducting the exploration programme for hydrocarbons.

The surveyed area is topographically diverse in the north and northwest. The structural trend is NE-ESE at the western margin. Therefore, the flight lines were designed with an east-west orientation and the look direction was to the south. The depression angles selected were 28° for the average near-range angle and 12° for the average far-range angle.

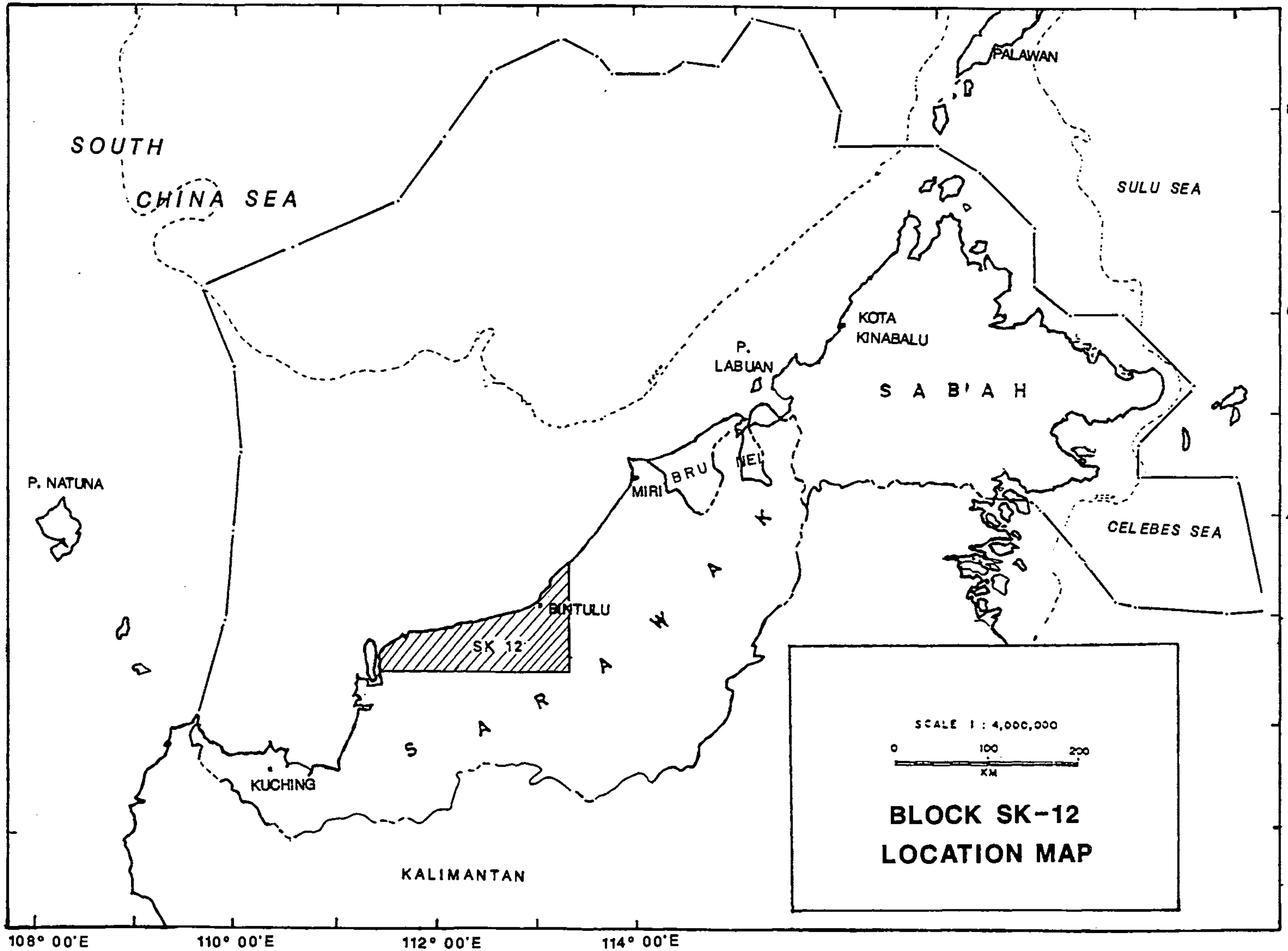


Figure 1: Block SK–12 location map.

The aircraft flew at an altitude of 8540 m (28000 ft) above sea level, with a flight line spacing of 10 km. The image swath is 23 km. This resulted in 60% of sidelap for each strip so allowing stereoscopic interpretation.

The data acquisition resulted in strip prints of SAR imagery for each flight line at a scale of 1:100,000. Computer processed mosaic were also produced at the same scale (Figure 2). All the interpretations were performed on strip prints using a streoscopic viewer and then plotted on translucent film overlaid on the mosaics.

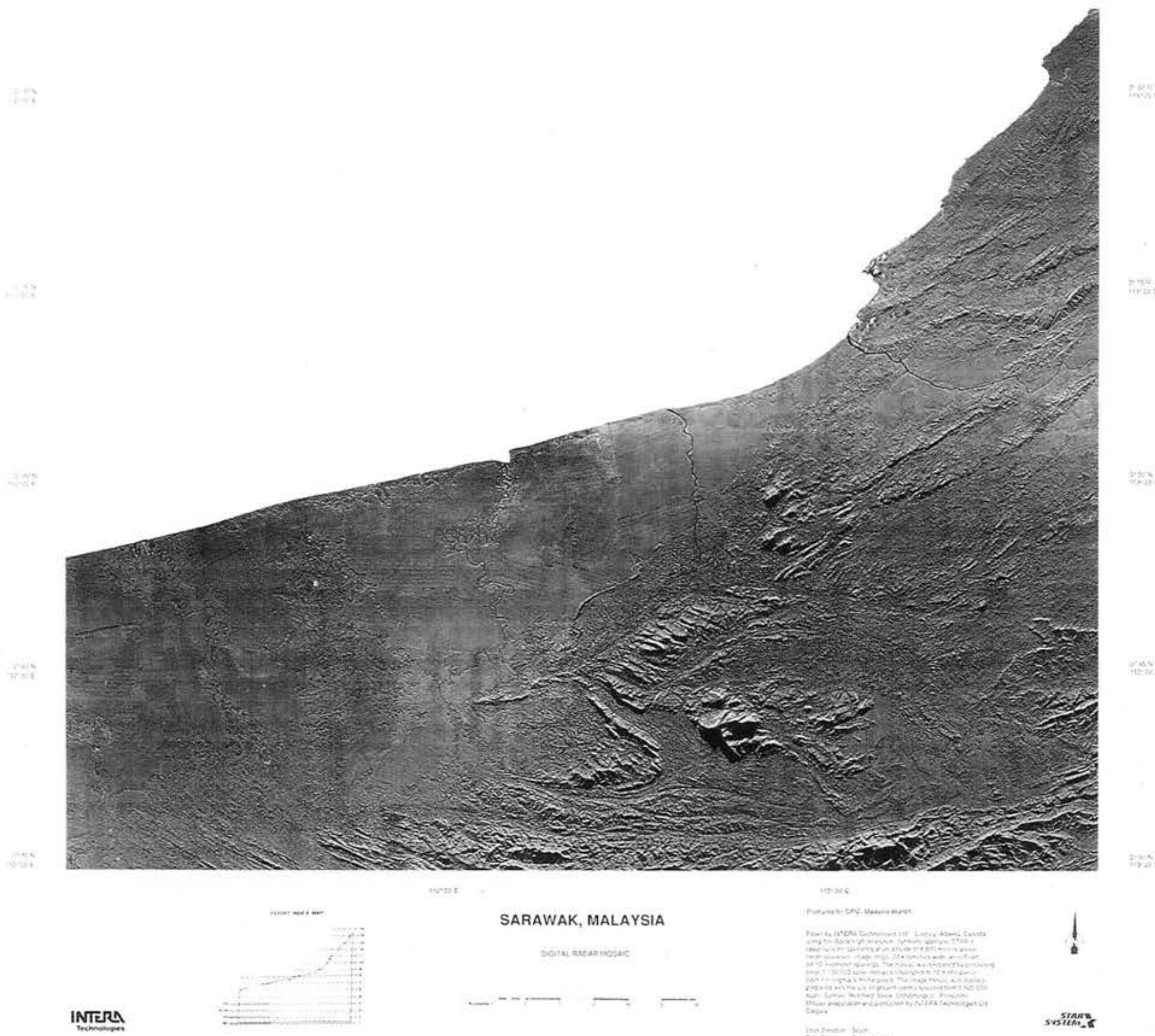


Figure 2: Digital radar mosaic, Sarawak.

INTERPRETATION-STRATIGRAPHIC DISCRIMINATION

Discrimination of stratigraphic units on the Block SK-12 SAR imagery is moderately difficult. most of the rocks outcropping in this area are near shore sediments, their sedimentary environments ranging from coastal plain to inner neritic. Facies changes occurred, frequently resulting in a lack of sufficient marker beds which could be used over the whole area. The Biban Sandstone Member of the Nyalau Formation is usable in part of the area, as it forms a relatively resistant cap over mountains and plateaux in the central portion of the project area.

Referring to stratigraphic data available prior to the SAR survey, fifteen mapable units were identified on the three radargeologic map sheets. They were selected with respect to formations and member beds already identified in the literature available . The discrimination of these units was based on stratigraphic differentiation related to their resistance, drainage, texture, fracturing and various erosional characteristics.

Table 1 shows the stratigraphic units used in the interpretation, their brief lithological description and their age.

INTERPRETATION-STRUCTURE

Structural interpretation from SAR imagery (Figures 3, 4, 5) shows a series of complicated structure patterns. More detailed data can be obtained compared with the geological maps published by the Geological Survey of Malaysia.

The project area lies within parts of four geological provinces: the Rajang Accretionary Prism, the Tatau Province, the Balingian Province and the Tinjar Province (Figure 6). These were well-defined in the available reports. The Rajang Accretionary Prism and Tatau Province may be ignored from the view point of hydrocarbon exploration because the sedimentary sequence over the basement is relatively thin.

The Balingian Province, located in the western central portion of the surveyed area, is of geologic interest because of its higher potential for hydrocarbon exploration. The very low relief of the flat, featureless coastal plain sediments makes the SAR imagery extremely difficult to interpret. However, outcrops of the Liang, Begrih and Balingian Formations in the western half of the province provided some geological features for interpretation.

Two obvious fault lines can be interpreted but the Teres Bakau Anticline, shown on the Geological Map of Malaysia, could not be identified on the SAR imagery. It is possible that the dips are too subtle to be visible on the imagery. One of the main faults may be related to the anticline. A solution will probably not be found on the radar imagery but the data interpreted may prove valuable in future exploration modelling.

Table 1: Stratigraphic Unit Used in Block SK-12

EPOCH	ROCK UNITS	SERIES	LITHOLOGY
QUATERNARY	Alluvium	Recent	Alluvium and coastal plain sediments.
	Liang Formation	Pliocene-Pleistocene	Poorly consolidated sand, clay and gravely sand and abundant lignite.
TERTIARY	Begrih Formation	Miocene-Pliocene	Basal conglomerate, sand stone and clay
	Begrih Formation Sandstone Member	Miocene-Pliocene	Sandstone and conglomerate.
	Balingian Formation	Oligocene-Miocene	Sandstone, clay-shales, minor conglomerates oand abudant lignites.
	Nyalau Formation Setap Shale Member	Oligocene-Miocene	Shales and Mudstone.
	Nyalau Formation Kakus Formation	Oligocene-Miocene	Sandstone, siltstone, shale, mudstone and lignite.
	Nyalau Formation Undifferentiated	Oligocene-Miocene	Sandstone, shale, mudstone, limestone, Lignite with marlstone and siltstone.
	Nyalau Formation Biban Member	Oligocene-Miocene	Indurated well-bedded sandstone with subordinate argillaceous or silty intercalations.
	Buan Formation	Oligocene	Finely laminated shales with monor medium-grained sandstones.
	Tatau Formation	Eocene-Oligocene	Sandstone, siltstone, shale, limestone intercalated marl and locally developed conglomerate.
	Tatau Formation Arip Volcanics Member	Eocene-Oligocene	Confinental volcanics and conglomerates.
	Belaga Formation Bawang Member	Eocene	Bathyal Shales.
	Belaga Formation Metah Member	Eocene	Submetamophic or semimetamorphic shale with greywacke and subgreywacke.
CRETACEOUS	Mersing Volcanics	Cretaceous	Gabbro, diabase, basalt and spilite

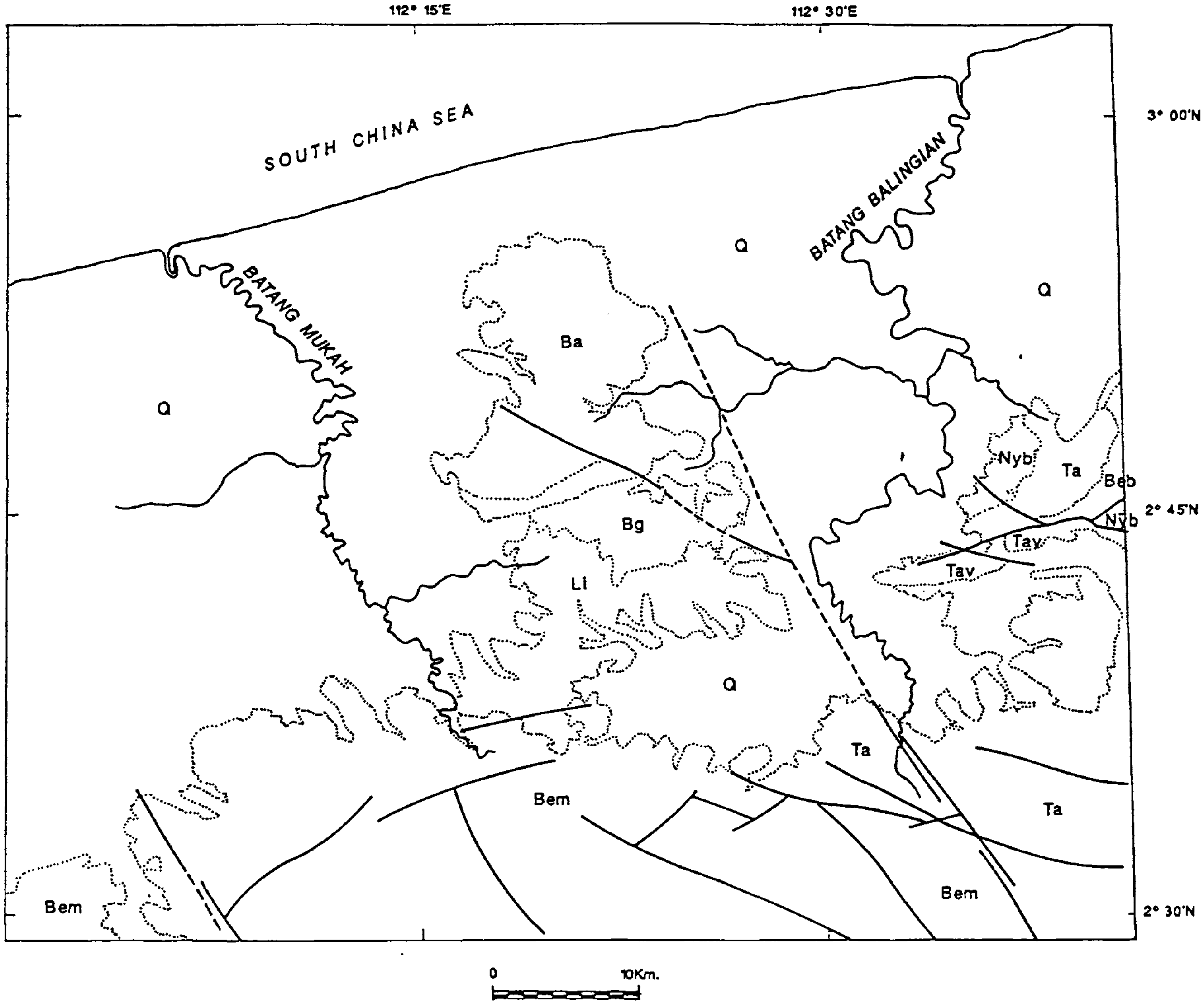


Figure 3: Geological interpretation map – Balingian area. (Ba Balingian Formation, Bab Belaga Formation Bawang Member, Bem Belaga Formation Metah Member, Bg Begrih Formation Sandstone Member, Li Liang Formation, Nyb Nyalau Formation Biban Member, Q Alluvium & Coastal Plain, Ta Tatau Formation, Tav Tatau Formation Arip Volcanics Member).

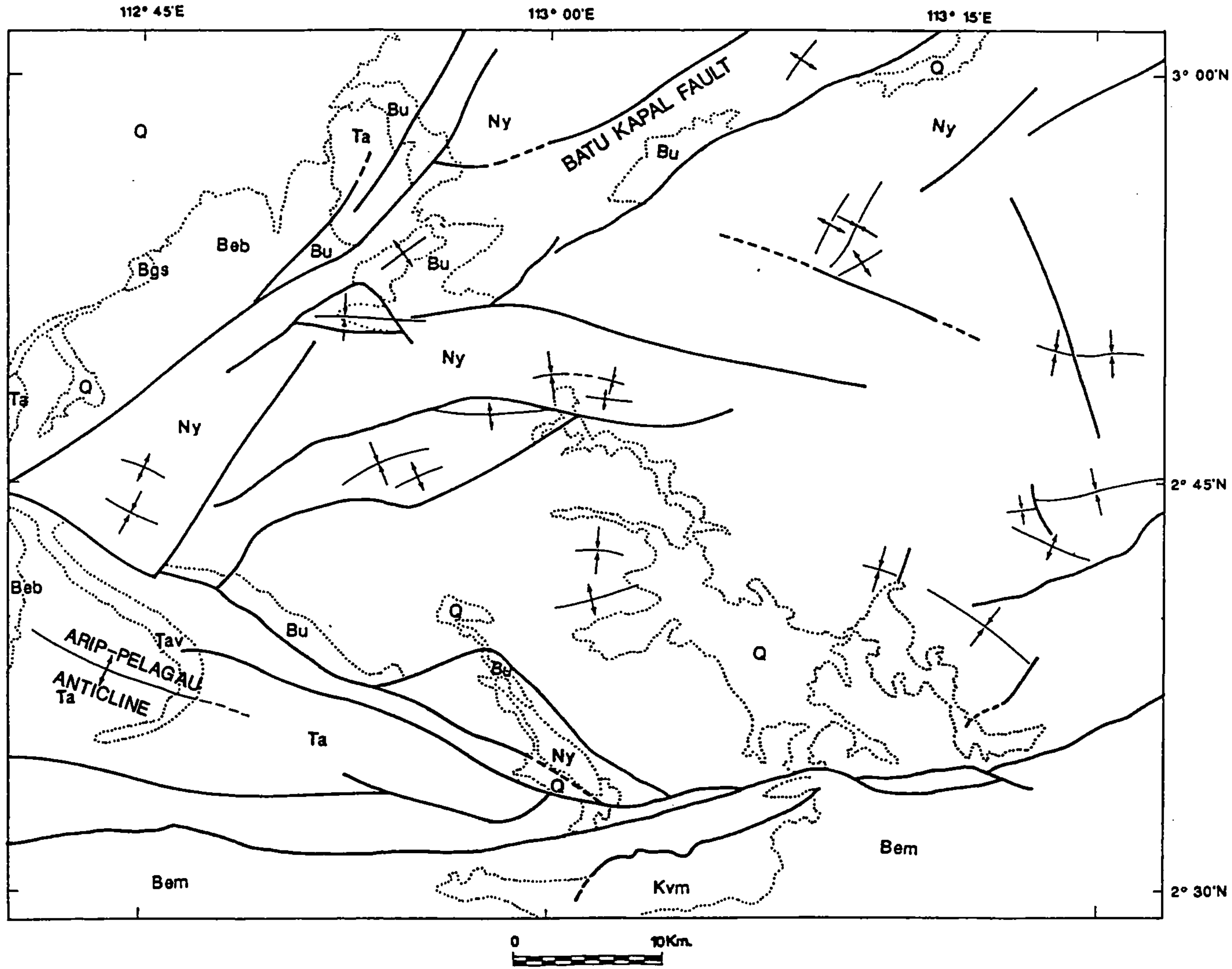


Figure 4: Geological interpretation map – Tatau area.(Beb Belaga Formation Bawang Member, Bem Belaga Formation Metah Member, Bgs Begrih Formation Sandstone Member, Bu Buan Formation, Kvm Mersing, Ny Nyalau Formation, Q Alluvium & Coastal Plain, Ta Tatau Formation).

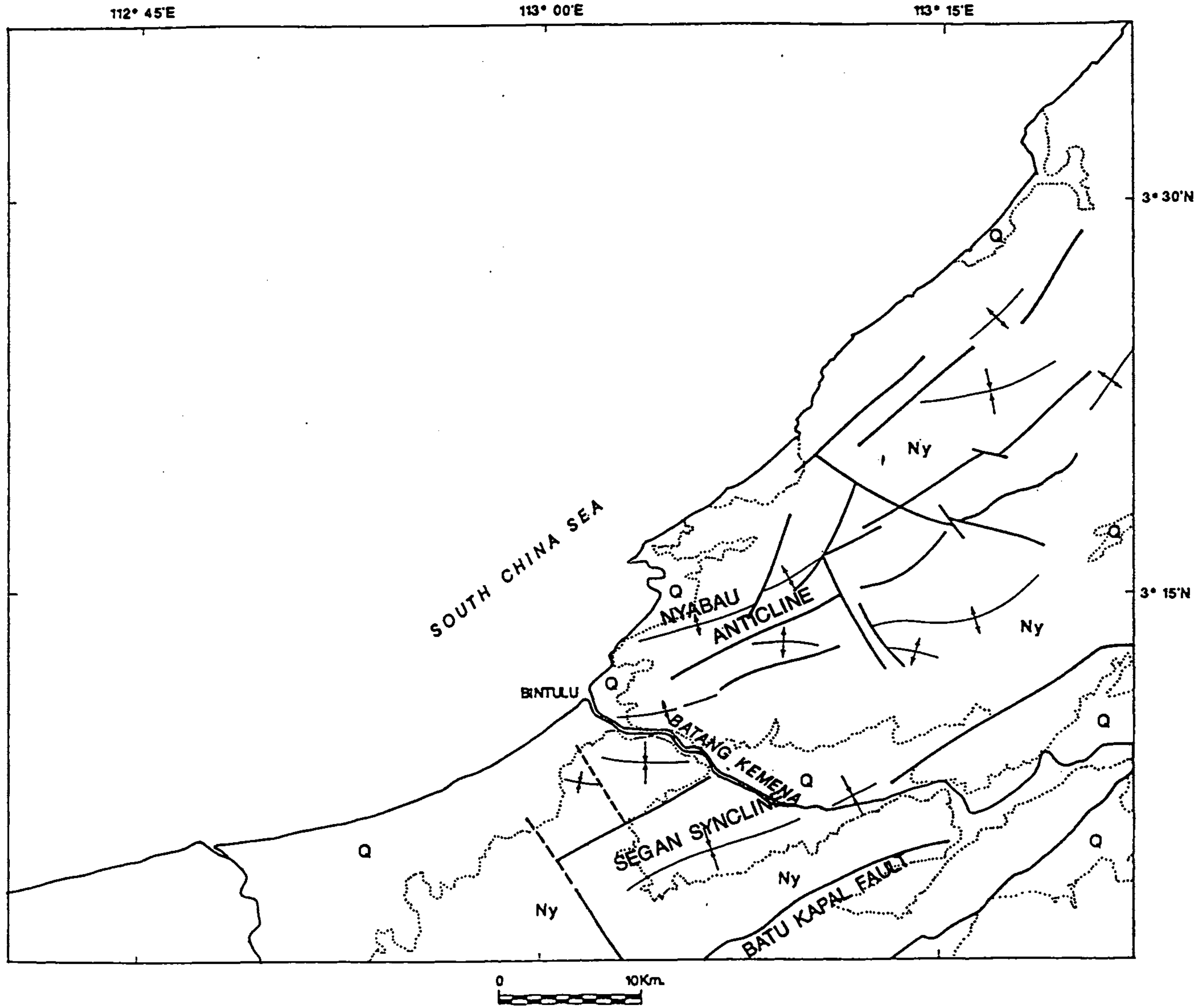


Figure 5: Geological interpretation map – Bintulu area (Ny Nyalau Formation, Q Alluvium & Coastal Plain).

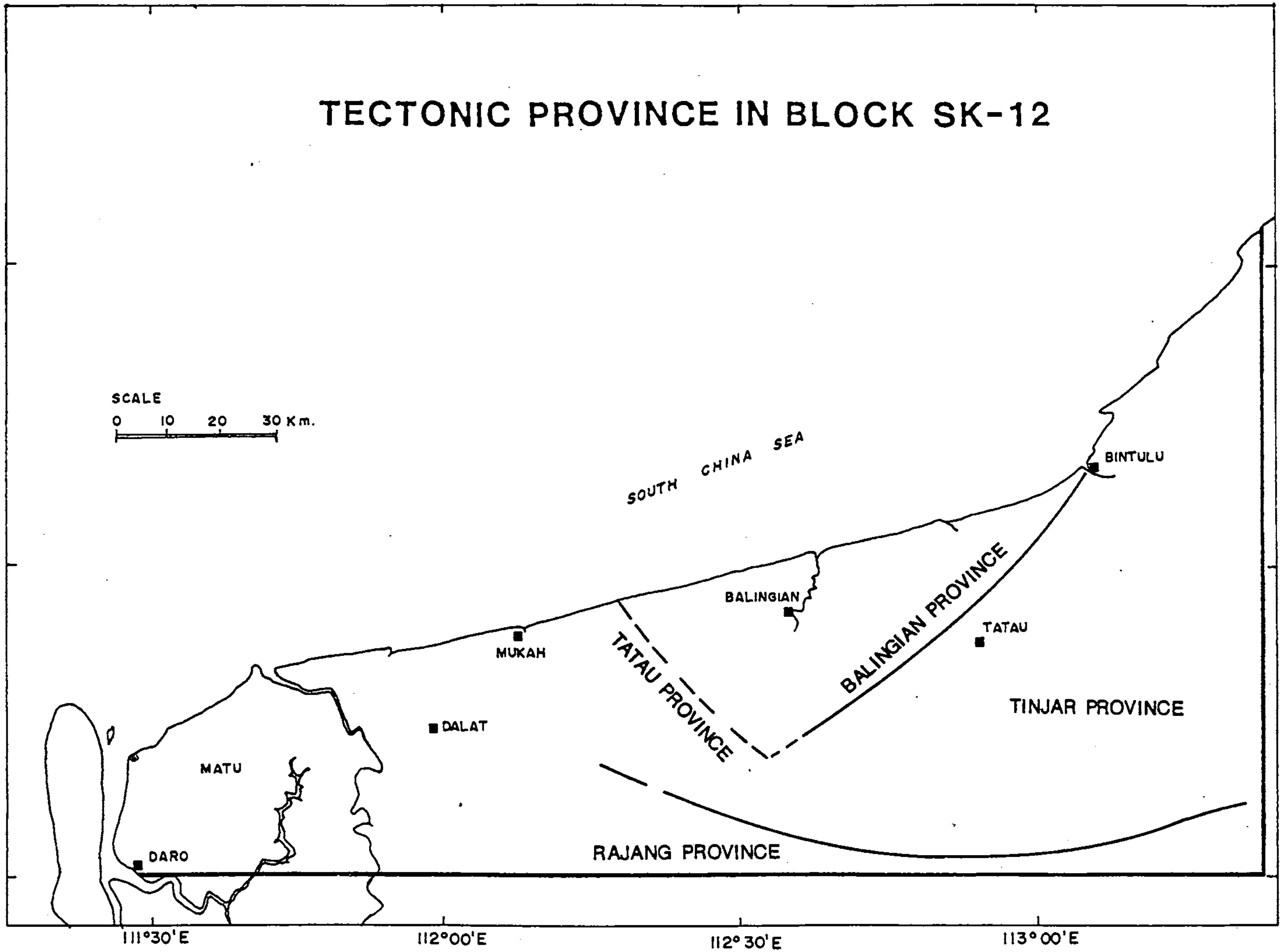


Figure 6: Tectonic province in Block SK-12.

The Tinjar Province, located in the east and south-eastern portion of the surveyed area, is the province with the most prominent structural features. A variety of faults, anticlines and synclines were mapped from SAR imagery. The Batu Kapal fault, a major fault with NE-SW trend in the central north portion of the province, displays vertical offset with the relative motion being up to the north.The southern part of the exhibited except for the Arip-Pelagau Anticline which shows a fairly complete anticlinal structure although both flanks are bound by faults.

To the north of the Batu Kapal fault there is a series of anticline-syncline-fault structural patterns with a mainly NE-SW trend. The Segan Syncline lies in a broad valley along Batang Kemana and is the main synclinal structure in the block north of the Batu Kapal fault. To the north of the Segan Syncline, the structure rises gradually, with some local undulation, until the Nyabau Anticline.The Nyabau Anticline is a main anticlinal structure, although its continuation to the northeast may not be so well identified because of the interception of faults. However, the basic anticlinal structure pattern is certain.

INTERPRETATION-LINEAMENT ANALYSIS

The term "lineament" is used to describe alignments of vegetation, soil tone, stream courses, topographic scarps, saddles and sags or, more frequently, combinations thereof. These alignments are basically controlled by geological factors, mainly joints, fractures and faults. They are observed either directly in exposed rocks, or indirectly as surface traces in overlying materials, In practice, joints are of little value as they are intraformational features and do not extend to significant depth, thus thier patterns do not provide any clues to the structural style or tectonism of an area. Local lineaments, which are limited to individual structures, are related to fairly simple and well understood forces and are eliminated also.

Regional lineaments are used in the analysis and are on a much larger scale. They are widely spaced, are usually organized in well-defined patterns and are seen to transect a wide variety of structures and lithologies of all ages, with little or no change in azimuth indicating that they are near vertical with depth. It has been widely observed that the major fracture pattern in basement rocks appears to propagate upward to the surface through considerable thicknesses of younger rocks.

The causative mechanism for regional lineaments is so far uncertain and is still being debated by geologists. However, the following possible causative mechanisms have been cited: (1) earth rotation, (2) plate tectonics and associated uplift, (3) global shear forces, (4) tensile forces due to earth tides, and (5) partial melting (thinning) of the earth's curst over large magma chambers which creates lateral subsidence and extensional fractures above or flanking the chamber, etc.

Fractures that extend to great depths are known to significantly increase the permeability and porosity of the rocks they penetrate. Therefore, lineaments can act as conduits for migrating fluids, form fractured reservoirs or traps. Figures 7, 8, 9 are Lineaments Mapping for the three sheets of imagery mosaic.

To determine the regional stress directions which produced the deformation in the surveyed area, a rose diagram and histogram for all the well-defined lineaments were prepared for the purpose of analysis. Figure 10 shows the rose diagram and histogram for the whole area.

The regional compressive forces deduced from the rose diagram and orientation of fold axes in the surveyed area are in a general north-south direction. Referring to the idealized strain-ellipse in Figure 11 and comparing it to the folds and fractures in the surveyed area, the four lineament sets are most likely to correspond to the following.

(i) N26°E - Principal stress direction and trend of normal faults.

(ii) N29°W - Right lateral shears

(iii) N61°E - Left lateral shears

(iv) N70°W - Trend of major fold axes and thrust of reverse faults.

CULTURAL INTERPRETATION

The purpose of the cultural interpretation was to map the land cover, terrain, hydrology and access information directly from the SAR imagery and confirmed by ground truthing. The area interpreted occupied 28% of the whole surveyed area, mainly in the low relief swampy area of the Balingian Province. One set of forest and land cover maps and one set of physiography/terrain maps (Figures 12, 13, 14) were produced in three sheets each to overlay the SAR mosaics.

Seismic trafficability was deduced based on a combination of all the information contained on the interpretation maps. All land cover and terrain/physiography categories were characterised and then subjectively ranked and analised in terms of their respective limitations to seismic trafficability.

Two categories of terrain type directly affect tranfficability in the proposed seismic survey area. The alluvial plains which are associated with the major and some secondary revers in the area are usually covered by reverine vegetatin and old channels, such as meander scars and oxbow lakes are present. Soils are muddy, clay, silt, sand and gravels with layer peat. Seasonal to permanent inudation can be expecteed in these areas making access (except by boat) and seismic trafficability very difficult.

The coastal plain, comprises the level to undulating area from the sea shore to the inland ridged and mountainous terrain. The level to slightly undulating

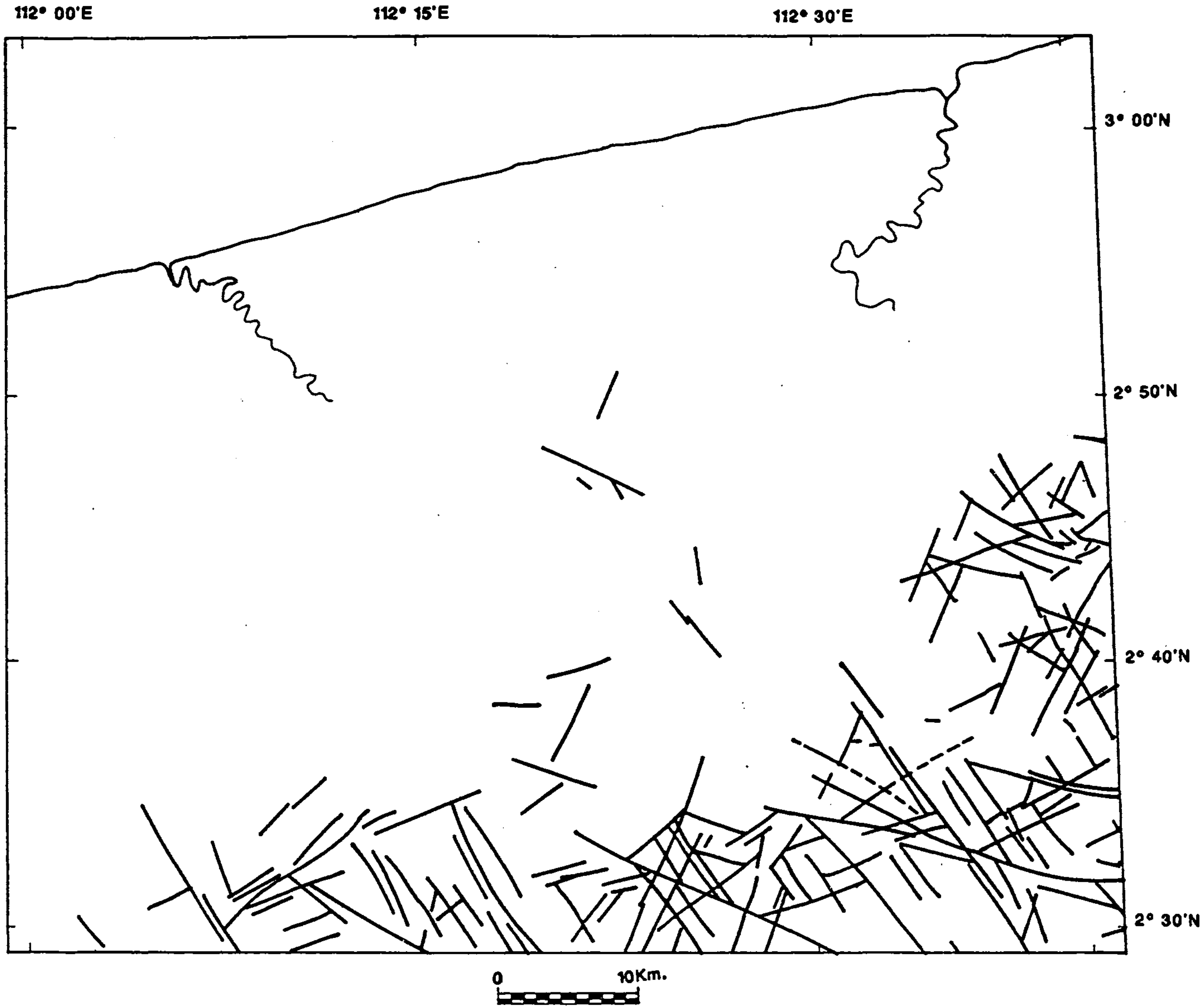


Figure 7: Lineament interpretation overlay – Balingian area.

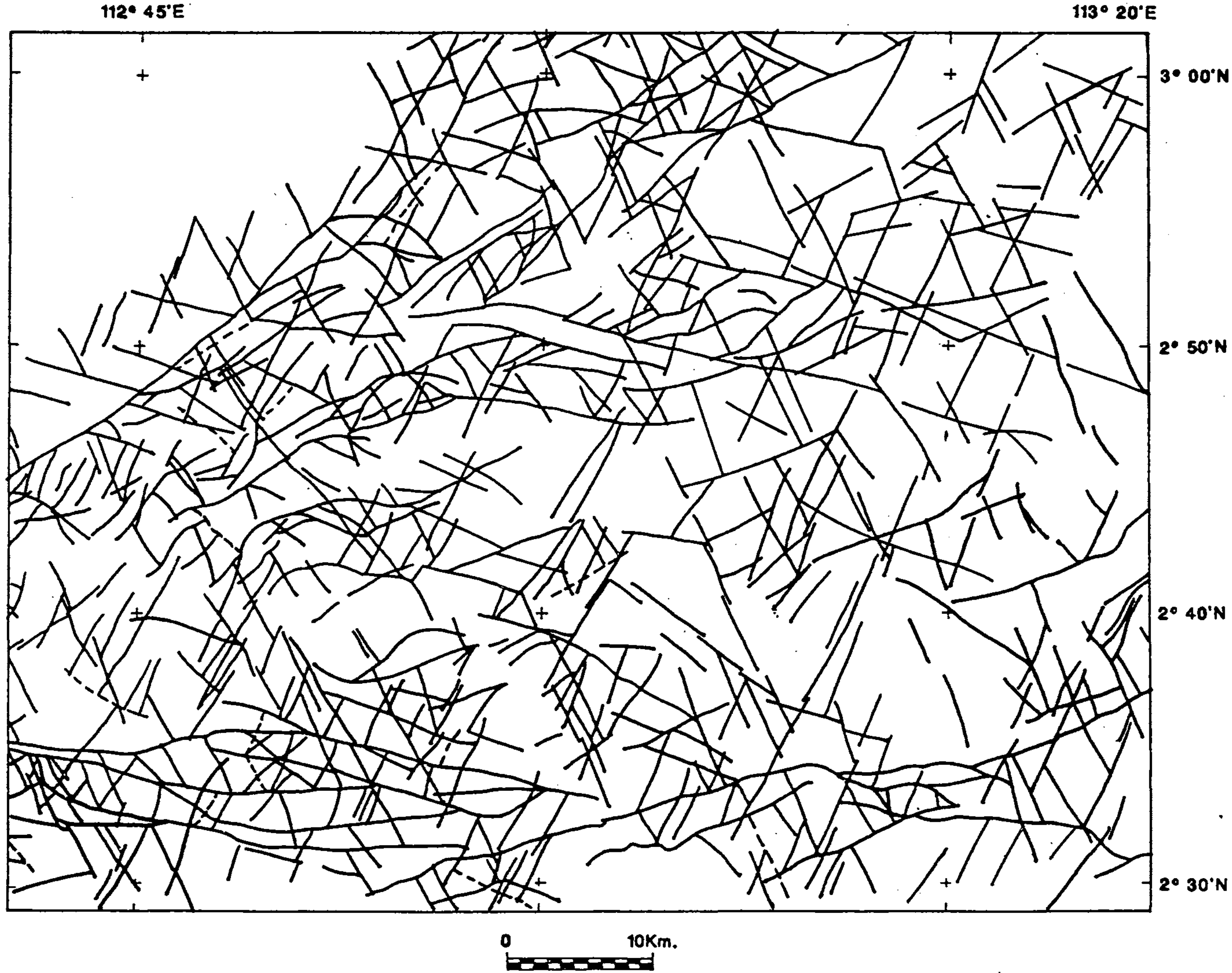


Figure 8: Lineament interpretation overlay – Tatau area.

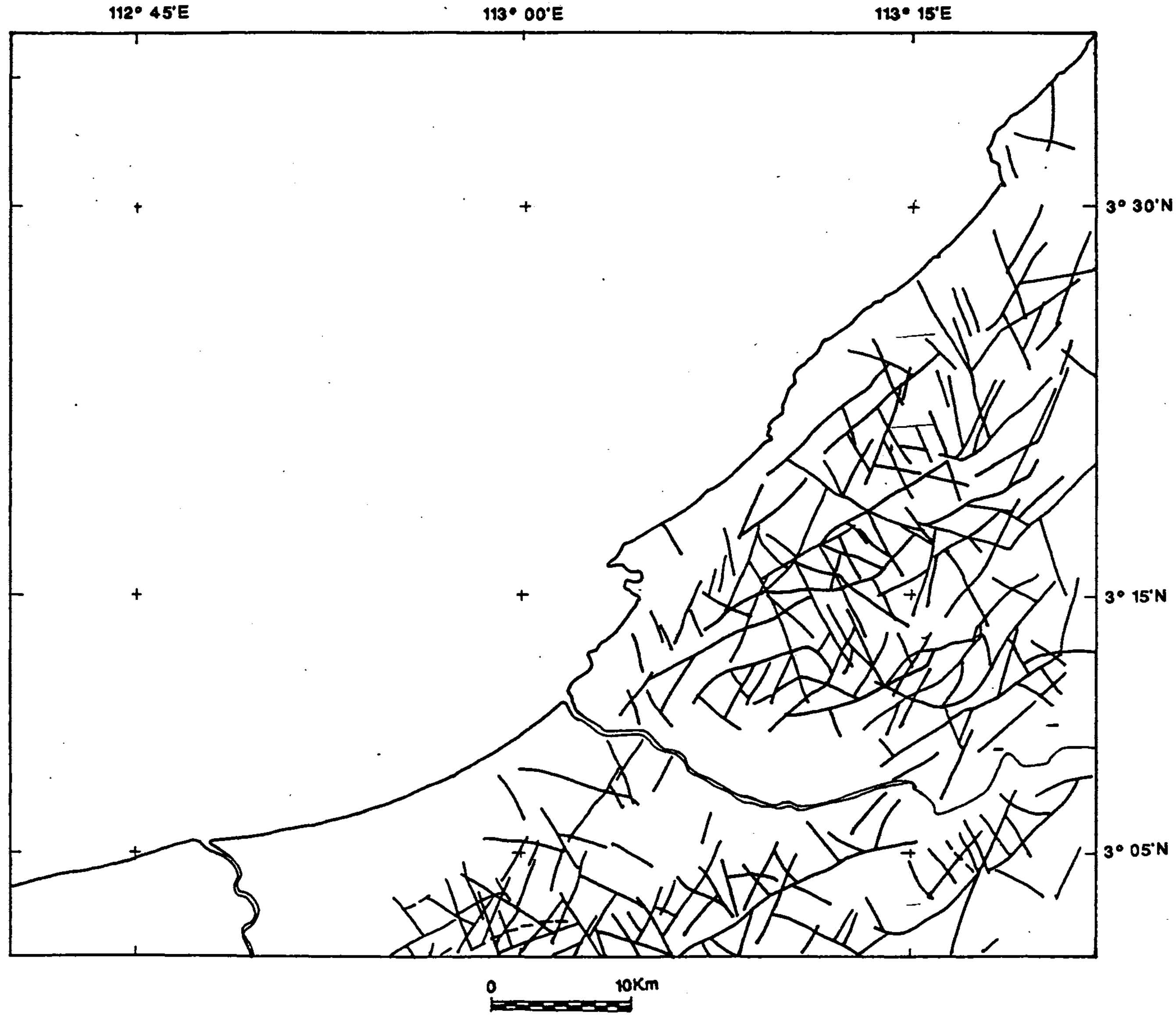
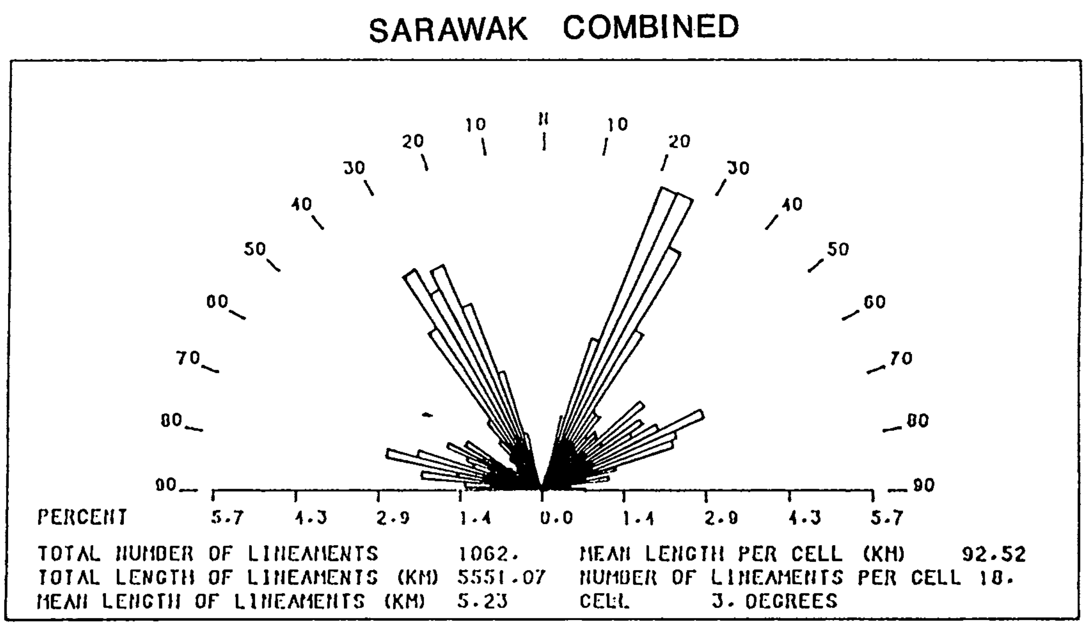


Figure 9: Lineament interpretation overlay – Bintulu area.



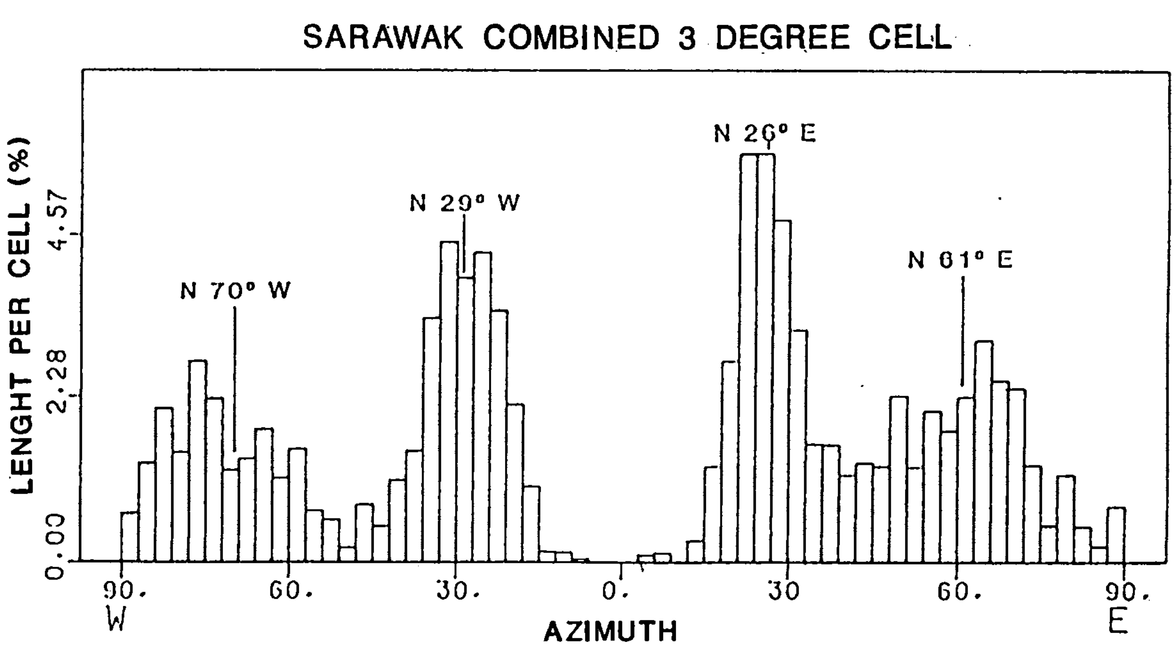


Figure 10: Rose Diagram and Histogram for Sheets A, B and C (Combined)

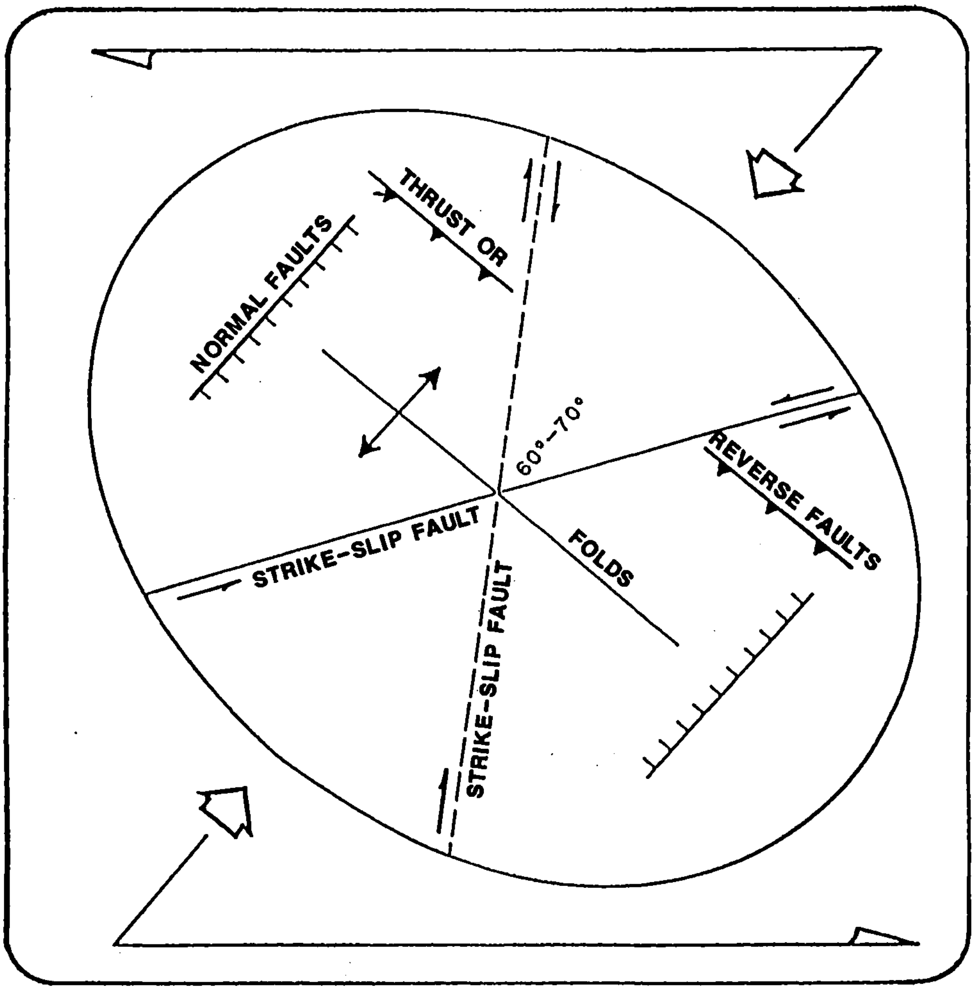


Figure 11: Strain Ellipse Diagram

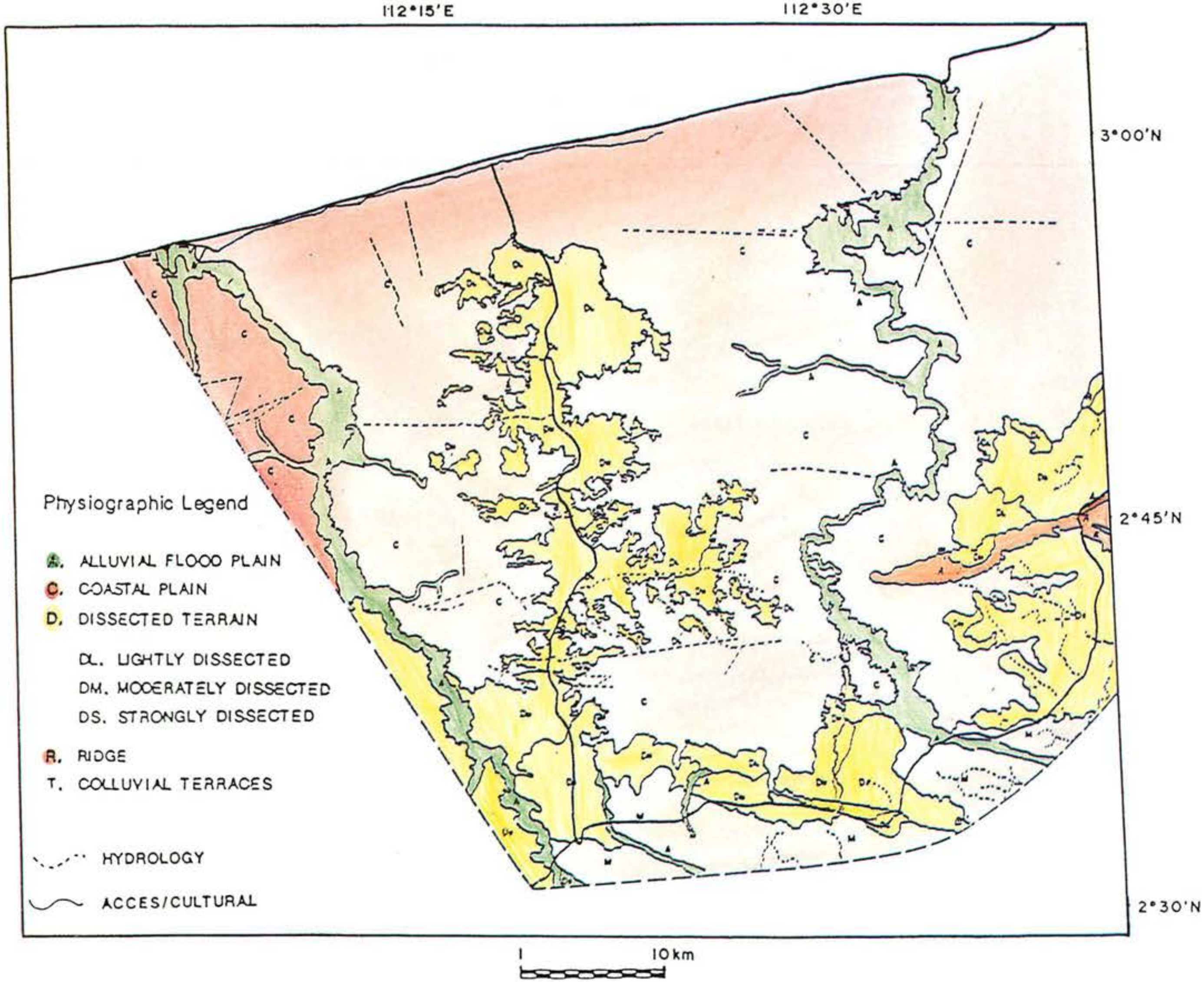


Figure 12: Physiography/terrain map – Balingian area.

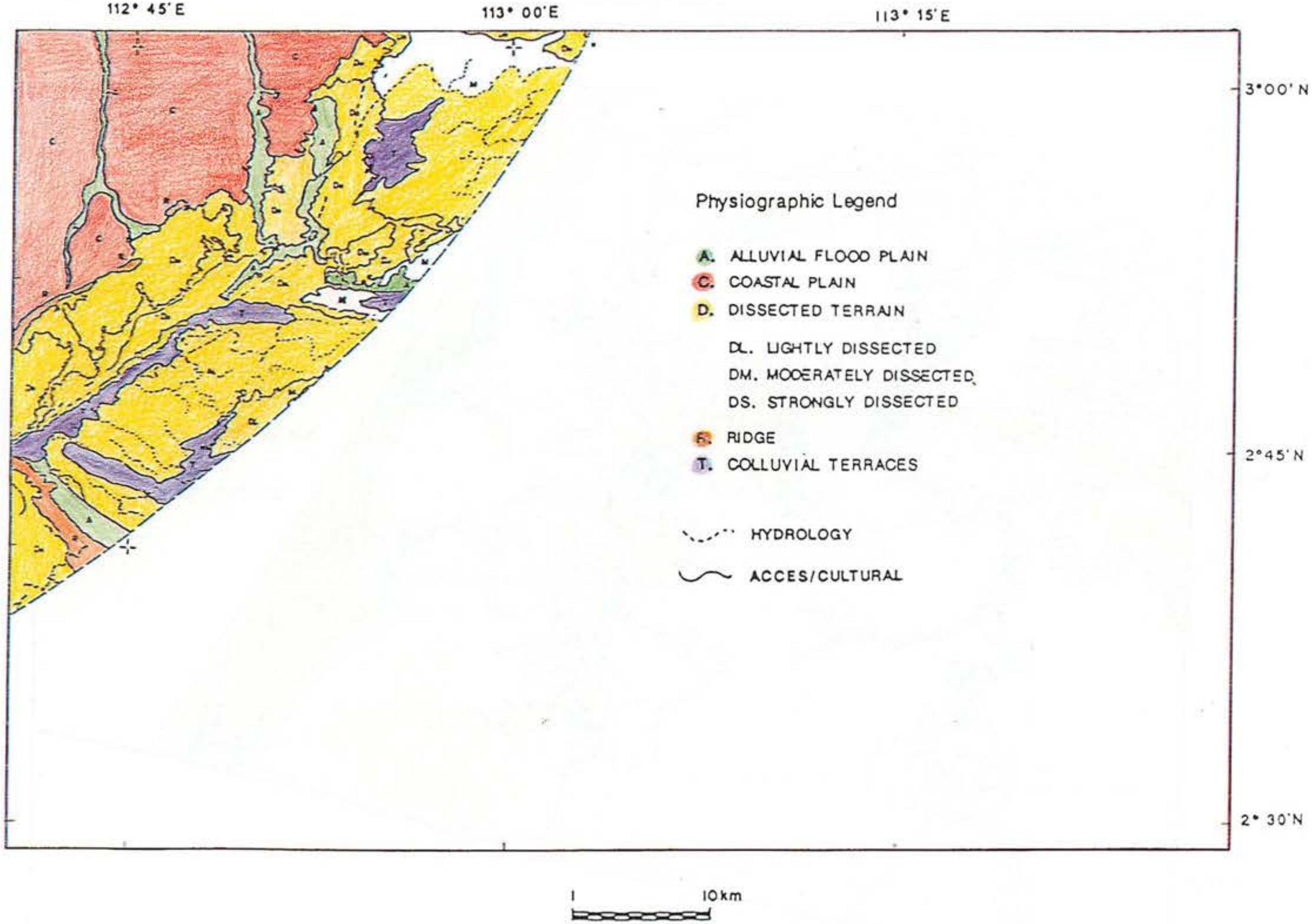


Figure 13: Physiography/terrain map – Tatau area.

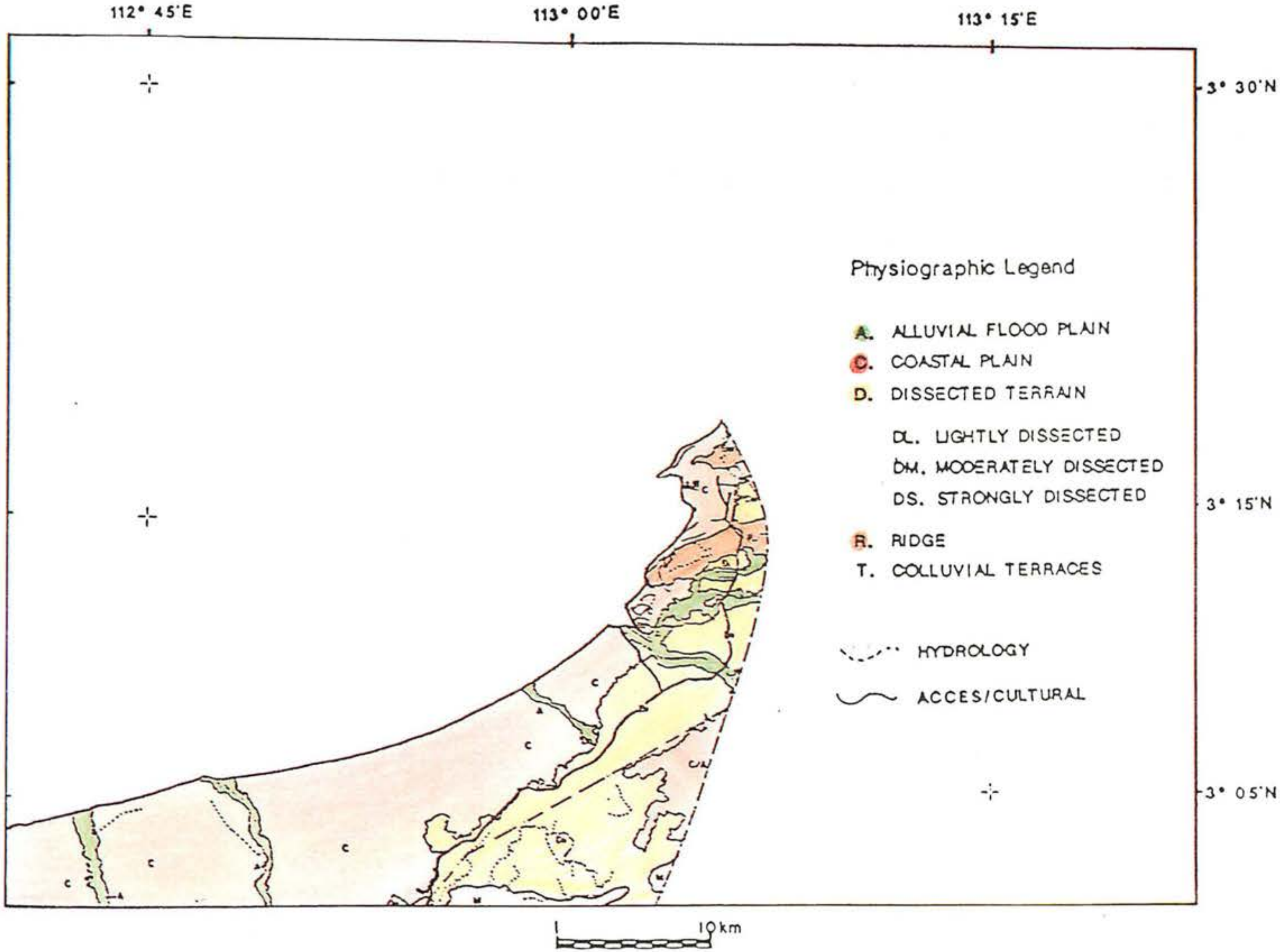


Figure 14: Physiography/terrain map – Bintulu area.

nature of this area makes it favourable for road and seismic line clearing. However, the deep organic peat soils and periodic to permanent inundation in local areas present some problems.

The cultural interpretation is being used in conjunction with the geologic interpretation of the SAR imagery as guide for accessibility and trafficability for both field geology and seismic crews. It is also used in the planning of the seismic programme in order make the seismic field opertions more efficient and cost-effective.

CONCLUSION

The SAR survey of Block SK-12 onshore Sarawak has been valuable for hydrocarbon exploration. Since most parts of the block are covered by secondary jungle, there is poor accessibility for field operations and previous studies contain limited information.

The interpretations from SAR imagery provide useful guidelines for field operations. The geological interpretation depicts the outline of the structural patterns, regional structural trends and more detailed geological than that available from old reports. These data are invaluable for the planning and conducting of the field geological servey in an area of poor outcrops. In addition, the cultural interpretation combined with the geological interpretation, is used as a guide for the planning of the seismic programme, resulting in a field seismic operation which is more efficient and cost-effective.

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