GEOLOGICAL SURVEY OF MALAYSIA

GEOLOGICAL INTERPRETATION OF SHUTTLE IMAGING RADAR SWATH DATA-TAKE 35/36 OVER WEST MALAYSIA

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INTRODUCTION

Hunting Geology and Geophysics Limited are pleased to present the results of the contract order (reference MP.KB: E/0005/RM) dated 7th October, 1982, from the Geological Survey of Malaysia.

The Shuttle imaging radar SIR-A provides a useful synoptic view of a part of the eastern Malay Peninsula independent of cloud cover. Geological interpretation for structure and general lithologies are appropriate although lithological discrimination of the forested surface is only possible indirectly by interpretation of morphology and internal structure.

SIR-A master positive film was made available to Hunting Geology and Geophysics Limited, in their capacity as Joint Official Observers of the SIR-A investigation (with the Royal Aircraft Establishment, Farnborough, UK), by the Jet Propulsion Laboratory, Pasadena, USA, who are managers of NASA's Shuttle scientific programme. The film, at a nominal scale of 1:500,000 was used to prepare inter-negatives, from which x 2 enlargement paper prints were made for interpretational purposes.

SIR-A Data-Take 35/36 has a track of about 200 km over the Malay Peninsula and is 50 km wide resulting in approximately 10,000 square kilometres of radar imagery of parts of Trengganu and Kelantan provinces. (Figure 1).

The prints of nominal 1:250,000 scale, were interpreted for geology by Dr K.N. Downing, with the guidance of Dr G.M. Lawrence and Dr P. Martin-Kaye, and under the overall supervision of Mr W.A. Willox, Director for Geology.

THE SIR-A SYSTEM

The Shuttle imaging radar was the most substantial of several experiments on-board the second flight of NASA's Shuttle Columbia, launched 12th November, 1981. The main characteristics of the SIR-A are presented in Table 1 and the side-looking attitude of earth inspection in Figure 2. The transmitted signal was an L-band 23 cm frequency synthetic aperture radar beamed from a fixed-antenna on-board the Shuttle orbiting at an average height of 259 km above the earth. The angle of inspection from the horizontal (the depression angle) of the radar beam was nominally 47° varying about 3° across the 50 km wide swath. The beam was directed from the southwest for the swath over the Malayan Peninsula; that is, from the side of the image which has regularly-spaced white dots. These dots represent each second of the Shuttle's flight.

The scale of the imagery in the range direction is not constant. The imagery is slant range corrected so that the scale nearest the radar illumination (i.e. near range) is smaller than for the image furthest from the illumination (i.e. far range). We did not have maps with sufficient detail to check the geometric fidelity of the SIR-A image. Jet Propulsion Laboratory claim that at centre swath of x 2 enlargements the scale is 1:250,000 ±3 per cent, across and along track. The along track scale is 1:250,000 ±3 per cent across the whole swath. In the far range, the range scale is 1:243,000 ±2 per cent and 1:258,000 ±2 per cent in the near range.

BASIC IMAGE CHARACTERISTICS AND INTERPRETATION METHOD

Radar images are described by the variation of shape, texture and tone which they exhibit. The interpretation of shape is usually contextual; texture is resolved at three levels: the most important is macrotexture, which contains the prime geographic data content of

FIGURE 1

LOCATION MAP

SHOWING SIR-A SWATH 35/36 AND DISTRIBUTION OF GRANITE IN WEST MALAYSIA

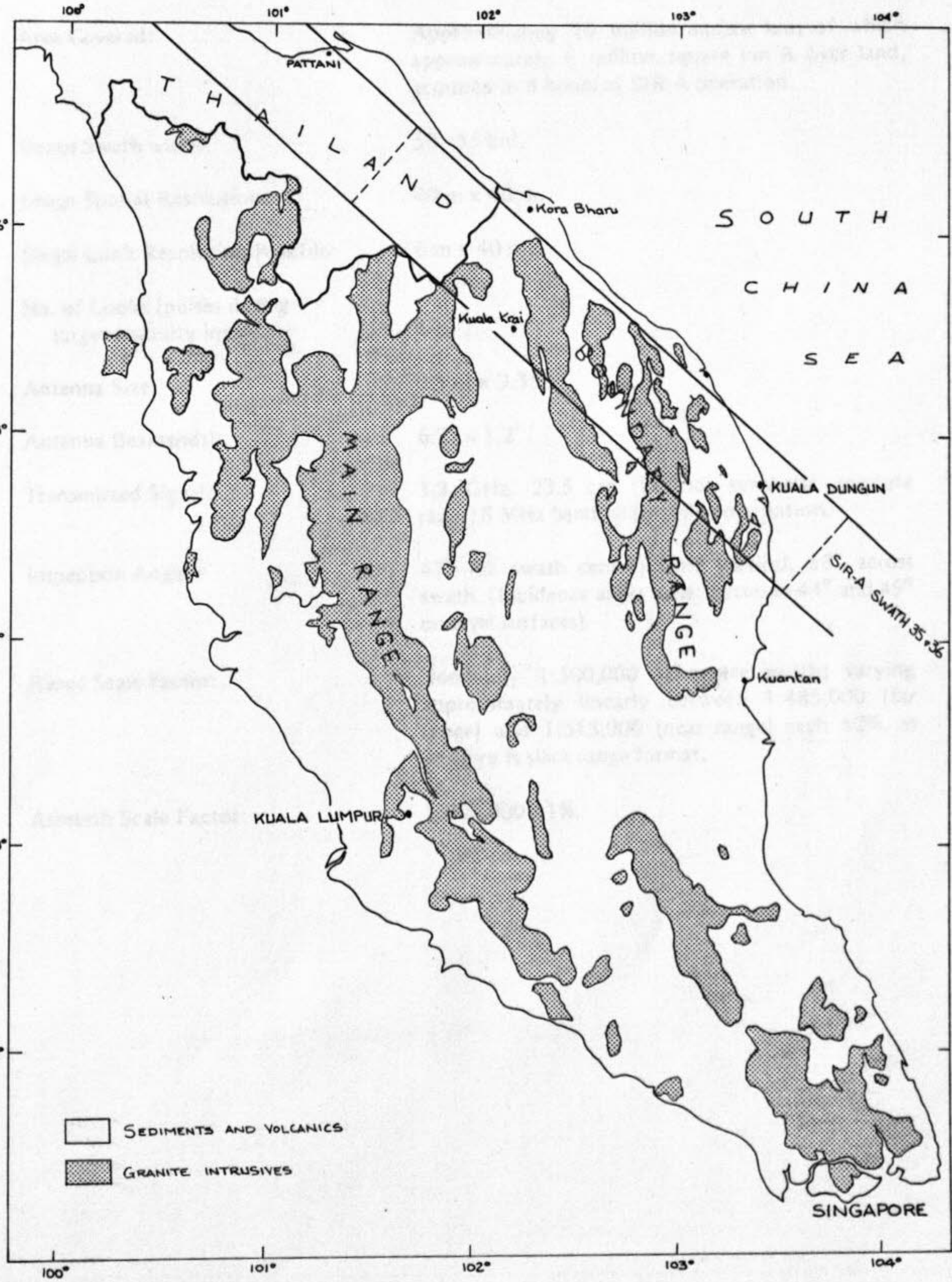

TABLE 1 MAIN CHARACTERISTICS OF NASA's SHUTTLE IMAGING RADAR (SIR-A)

Orbit:	Circular; 257 - 266 km height; 38° inclination.
Area Covered:	Approximately 10 million square km; of which approximately 6 million square km is over land, acquired in 8 hours of SIR-A operation.
Image Swath width:	50 - 55 km.
Image Spatial Resolution:	40 m x 40 m.
Single Look Resolution Possible:	6 m x 40 m.
No. of Looks (pulses during target visibility interval):	4 to 7.
Antenna Size:	2.1 m x 9.35 m.
Antenna Beamwidth:	6.2° x 1.2°.
Transmitted Signal:	1.3 GHz, 23.5 cm (L-band) synthetic aperture radar; 6 MHz band width; HH polarisation.
Inspection Angle:	47° (at swath centre) from vertical, ±3° across swath. (Incidence angle varies between 44° and 49° on level surfaces).
Range Scale Factor:	Nominally 1:500,000 at centre swath; varying approximately linearly between 1:485,000 (far range) and 1:515,000 (near range) each ±2%, as imagery is slant range format.
Azimuth Scale Factor:	1:500,000 ±1%.

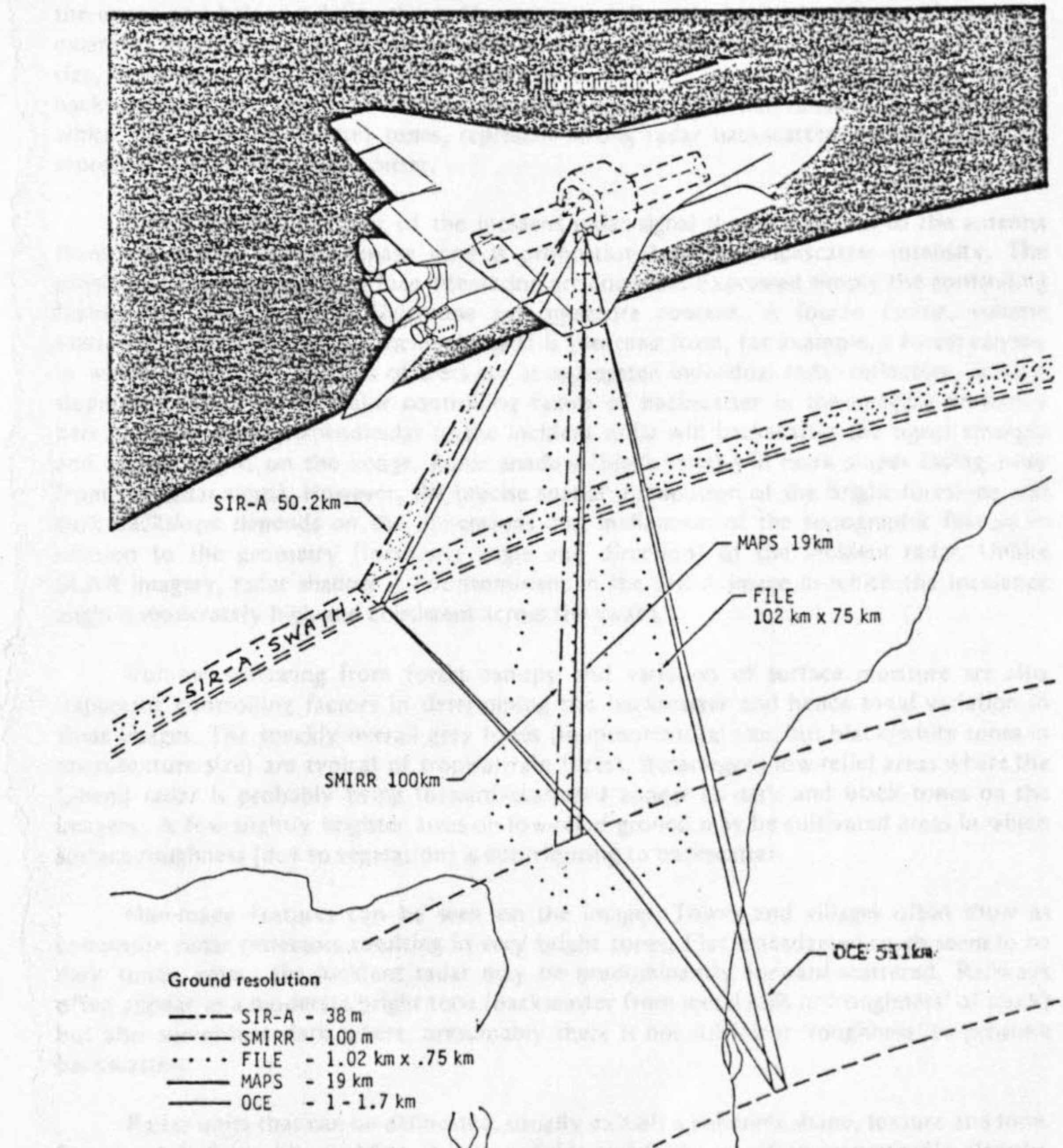

FIGURE 2 The Shuttle attitude during SIR-A acquisition

the image and helps to define shape. Mesotexture defines the internal structure of units, for example, that determined by topographic variation; microtexture of a few to a single pixel size, is, in the case of the imagery presented here, made up of radar speckle, a random backscattering phenomenon. Texture is recognised by its tonal variation from black to white. The brightest (white) tones, represent strong radar backscatter, whilst dark tones represent low (or zero) backscatter.

Backscatter is that part of the incident radar signal that is returned to the antenna from the earth's surface. Image tone is proportional to the backscatter intensity. The physics of the radar signal-surface interaction are complex. Expressed simply the controlling factors are surface slope, roughness and moisture content. A fourth factor, volume scattering, describes how the incident signal is returned from, for example, a forest canopy in which leaves and branches of trees act as aggregated individual radar reflectors. Surface slope/topography is the major controlling factor of backscatter in the imagery presented here. A steep slope perpendicular to the incident radar will backscatter the signal strongly and appear bright on the image. Radar shadow (black tone) will mark slopes facing away from the radar signal. However, the precise spatial distribution of the bright foreslope and dark backslope depends on the dimensions and inclination of the topographic feature in relation to the geometry (incidence angle and direction) of the incident radar. Unlike SLAR imagery, radar shadow is not prominent in the SIR-A image in which the incidence angle is moderately high and consistent across the swath.

Volume scattering from forest canopy and variation of surface moisture are also important controlling factors in determining the backscatter and hence tonal variation in these images. The speckly overall grey tones (in mesotextural size, but black/white tones in microtexture size) are typical of tropical rain forest. Waterlogged low-relief areas where the L-band radar is probably being forward-scattered appear as dark and black tones on the imagery. A few slightly brighter areas on low-relief ground may be cultivated areas in which surface roughness (due to vegetation) is contributing to backscatter.

Man-made features can be seen on the images. Towns and villages often show as composite radar reflectors resulting in very bright tones. Flat macadamed roads seem to be dark tones, where the incident radar may be predominantly forward-scattered. Railways often appear as a moderate bright tone (backscatter from metal rails or 'roughness' of track) but also sometimes dark where, presumably there is not sufficient 'roughness' to provoke backscatter.

Radar units that can be delineated, usually exhibit a coherent shape, texture and tone. Structural features like bedding, foliation, folds and faults are often recognisable directly. Lithologic and stratigraphic correlations can be established using data on the ground, or, as in this study, using information from published maps and literature. The main reference work used in this study was the 1:1,000,000 scale geological map presented by Gobbett (1972).

INTERPRETATION - GEOLOGY AND STRATIGRAPHIC/LITHOLOGIC CORRELATIONS

Plate 1 presents the results of the interpretation at a nominal 1:250,000 scale.

Interpretation of the Malay Peninsula Swath

Geology and Radar Correlations

A list of radar units, their major features and attempted geological correlations is given in Table 2. Clarification of the correlations is made below. Most of the geological information comes from Gobbett and Hutchison (1973) and the 1:1,000,000 geological map (Gobbett 1972).

The oldest unit of the surveyed area comprises the high grade (amphibolite facies), Palaeozoic Taku Schist and associated gneisses and migmatites. The Schists (229.1 to 229.8, top) consist of quartz biotite schists, often containing kyanite and locally sillimanite and andalusite, are grouped as LP_T on the interpretation and are surprisingly free of foliation trends (229.5 top) in comparison to some of the overlying metasediments. The migmatites and gneisses of this unit are reported to lie in the metamorphic foliation of the metasediments. However the interpreted outcrop of these gneisses seen on the SIR-A swath (LP_g) (229 to 229.2 top) cross-cuts the strike of the metasediments and has similar features to the later granite outcrops (G). The LP_g unit does, however, exhibit a more rounded terrain and probably represents older gneisses and migmatites.

The schist and gneisses of the Taku Schist unit exhibit the highest grade metamorphism seen on the Malay Peninsular. All the other pre-Upper Triassic units identified contain greenschist or at maximum epidote amphibolite facies mineralogies.

A unit thought to be a low grade equivalent of the Taku Schist is exposed in the northwestern part of the SIR-A swath (227.3 top). This unit, LP_p, which displays marked foliation or bedding traces, consists of deep water shales and mudstones followed by poorly graded rapidly deposited arkoses associated with volcanic, pyroclastic and ophiolitic rocks. This sequence possibly represents a eugeosynclinal deposit of a rapidly infilled sedimentary basin or may represent a melange (Hamilton 1979).

The Lower Palaeozoic units in the study area are overlain, with apparent conformity by Upper Palaeozoic metasediments and volcanics. These units are mapped as UP_q and UP_p on Plate 1, q and p denoting quartzitic and pelitic units respectively. UP_q represents the more resistant members of the Upper Palaeozoic formation which comprise acid to intermediate pyroclastics and lavas and quartzitic metasediments. The radar features of these units vary according to elevation. However the characteristics of well developed dissection accompanied by well defined bedding traces is diagnostic. The UP_p (232 to 233) unit is interpreted as representing pelites and calc pelites which are interbedded with UP_q. The radar characteristics of UP_p are similar to those of UP_q but UP_p displays markedly lower relief in comparison with adjacent UP_q horizons. In upland terrain the division of these units is probably not observed on the imagery. It is thought that the areas marked as UP_q in the upland areas will also contain pelitic horizons. The Permian and Lower Triassic units identified on the interpretation (P_p and P_c) represent sediments and volcanics similar to those of the Upper Palaeozoics and described above. However the radar characteristics of these units are very different from those of the underlying Upper Palaeozoic rocks (Table 2). The Permian unit (228.5 to 230) displays a much subdued topography and structural grain in comparison to the UP formations, this may be a reflection of a superficial cover masking solid geology or it may indicate different Permian lithologies as yet not described in the literature.

The Lower Triassic units of the study area represent the youngest sedimentary 'rocks'

TABLE 2 SUMMARY OF INTERPRETED RADAR GEOLOGIC UNITS AND PROPOSED CORRELATIONS

Unit	Image characteristics	Inferred topography	Internal structure	Inferred geological correlations	Possible associated mineralisation
Qa_1	High tone contrast, no dissection some linear features (233.2 and 232.8)	Flat low lying terrain	Linear features - possibly coastal dune or strand-line traces	Coastal dune & littoral deposits	Heavy mineral placer deposits ?
Qa	High tone contrast, no dissection	Flat - featureless terrain low lying	None	Quaternary alluvium - in places, not distinguished from Qa_1	Secondary alluvial mineral deposits, where associated with granites
Na	Low contrast, no dissection, slightly darker	Flat terrain with some subtly-expressed features	Very weak linear features (232.5 middle)	Alluvium, possibly older than Qa. Where some internal structure is seen, possible basement features	Same as Qa
Pp	High tone contrast producing mottled effect, poorly dissected	Low-relief terrain with weak relief	None	Permian & L. Triassic pelitic sediments	
Pp_1	Darker toned than Pp				
Pc	Moderate tone contrast and dissection	Low-relief terrain with moderate relief	None	Permian & L. Triassic limestones or volcanics	Some scarn mineralisation at granite limestone contacts?
APq	Moderate contrast, finely dissected (230.6 top)	Moderate to high-relief terrain, moderate to good relief	Some linear features probably bedding traces. Some faulting (231.1 top)	More resistant U. Palaeozoic metasediments & volcanics. (Quartzites, acid to intermediate lavas & pyroclastics)	Some gold mineralisation associated with volcanics but unknown in study area
APp	Low to moderate contrast, finely dissected (finer UPq)	Low-relief terrain with moderate relief	Some weak linear features - bedding or foliation	U. Palaeozoic pelites & calc-pelites. May be inseparable from UPq in upland areas	
LPp	High contrast, finely dissected, similar to UPq	High relief upland terrain	Linear features similar to UPq but not so well defined	L. Palaeozoic metapelites & arenites of greenschist facies	
LP_T	High contrast, fine dissection (229.5 top)	Moderate relief	Bedding or foliation traces of variable intensity	L. Palaeozoic metasediments of Amphibplite facies Taku Schists	
G	Moderate contrast, coarse dissection	Moderate to high relief in generally upland terrain	Extensive fracture traces. Some weak foliation	Granites, U. Carboniferous to Cenozoic	Hydrothermal mineralisation associated with faults. Pegmatite mineralisation
G_1	Finer dissection than G	Lower relief than G	Non visible probably fractured		
G_2	Low contrast no dissection	Flat intermontane basins	None	Weathered or altered granite	Kaolin in altered granite? residual and colluvial/alluvial tungsten or tin
LPq	Less sharp contrast than G but similar dissection	Similar terrain to G but more rounded hills	Extensive fracture traces	L. Palaeozoic migmatites & gneisses members of Taku Schists	

covered by the SIR-A swath. During the Middle and Upper Triassic the Malay Peninsula underwent a tectonic event which involved deformation, granite intrusion, greenschist and amphibolite facies metamorphism and considerable uplift. Although younger continental sediments are recorded on the Peninsula, none of these deposits are covered by the SIR-A swath.

Granite intrusion occurred in Malaya from the Upper Carboniferous through to the Tertiary when large volumes of felsic plutonic rocks were emplaced in the Palaeozoic metasediments of the Peninsula. The most voluminous rock type identified on the SIR-A imagery is granite. Although the radar characteristics of the granite outcrops vary slightly (see Table 2), correlation with the geological map is good and these units can be mapped with some confidence.

Whilst most of the tin-bearing granites of the Main Range to the east of the present study area are probably Triassic or younger it is thought from radiometric evidence that the granites of the Boundary Range, in the study area, are Upper Carboniferous in age. (Snelling 1965, 1967, Anon 1966, Hutchison and Snelling 1977).

All the mapped units on the interpretation exhibit, to some extent, low lying areas which probably contain superficial cover deposits. Larger areas of this cover have been delineated as Na and Qa and probably represent alluvial deposits. Tonal variation in these flat lying areas are very marked and probably represent variation in moisture content of what is presumably generally waterlogged ground.

Interpretation - Structure

The sedimentary and volcanic rocks of the Palaeozoic Geosyncline underwent an orogenic event during the latter stages of the Triassic period. This tectonism can be recognised in the isoclinal structures which trend south southeast and the greenschist and amphibolite facies mineralogies which are preserved in the rocks of the study area. Although the fold structures preserved dip steeply to the east the intense nature of the deformation, especially in the Taku schists, may imply that these folds may have originally been flat-lying structures. This would result in crustal thickening which could account for the regional metamorphism of the Palaeozoic strata.

Due to the isoclinal nature of the Triassic fold structures no closures can be identified on the SIR-A imagery. Bedding and foliation traces however can be clearly identified in most of the Palaeozoic units, these traces define the strike of the fold belt clearly.

It is notable that the granitic bodies of the study area are sub-parallel to the regional strike of the fold belt and also that the SIR-A imagery does indicate a local foliation in some of the bodies. This foliation also parallels the regional strike. Though the literature does not mention the occurrence of a foliation within the Boundary Range intrusives the SIR-A evidence supports the radiometric evidence of a pre-orogenic, hence pre-Upper Triassic age, for the granites in the study area.

Post Triassic deformation is restricted to the development of a well defined fault and fracture pattern which is apparent throughout the whole of the Malay Peninsula. This fracturing, which is related to a regional sinistral-sense wrench fault system is clearly defined on the SIR-A imagery, especially across the granitic bodies.

The regional strike and fracture trends are also reflected in the magnetic data. The southeastern end of the study area (232.1 to swath end) has been surveyed by an airborne magnetometer survey (Agocs and Paton 1959). The major magnetic gradients from this survey have been superimposed on the SIR-A interpretation, to illustrate the relationship between magnetic gradients and basement structure, and in particular fracture trends.

Interpretation - Mineralisation

The known primary mineralisation in the Malay Peninsula is related to the numerous granite bodies. Pegmatitic and hydrothermal mineral deposits are the most important occurrences of primary mineralisation. Although the Main Range granite belt forms the core of the main metallogenic province of the Peninsula, several sizeable tin and other metal deposits have been identified and worked on the flanks of the Boundary Range granites (see interpretation). Hydrothermal deposits form the largest number of primary deposits of the Malayan Tin Province. The SIR-A imagery indicates possible targets for geochemical and geological investigation. The fractures cutting the granites and marginal metasediments may be a focus for late stage hydrothermal fluids. Investigation of the fractures, fracture intersections and surrounding zones as identified on the SIR-A interpretation is recommended.

The small areas of subdued relief within the granite mountains (G_2 on Plate 1, 230 middle and 231.2) may be an indication of less resistant lithologies in these areas. They may represent zones of altered granite for example, and hence might contain kaolin deposits or residual base metal deposits like tungsten or tin. However the nature of these zones is unclear on the imagery and field checking is required to determine the nature of these areas.

Summary

Although the area covered by the SIR-A swath is restricted some major geological features can be identified on the imagery which may not be apparent on other imagery. The usefulness of conventional air photographs and Landsat data in often cloud-covered terrains is restricted whilst side-looking radar (SLAR) imagery suffers from the problem of excessive shadow areas in mountainous terrains. The high flight altitude of the Space Shuttle combined with the moderate angle of the radar signal, reduces the shadow effect in mountainous terrains. It is likely that the interpretation of the Malay Peninsula swath has identified features which were previously un-mapped.

Structural features, especially faults and fractures are readily visible on SIR-A imagery, and could become focii for ground checking and mineral prospecting.

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