Shock structures in Peninsular Malaysia: evidence from Kedah and Pahang

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Abstract: Evidence of geology, morphology and gravity anomalies demonstrate that the double Mahsuri Rings in Langkawi are impact structures. Each of the partially superimposed rings is 2.4 km across, with centres at 0.6 km distance apart and depths of 107 m (eastern ring) and 45 m. From these rings in the southwest direction are two more circular structures of progressively smaller size: Temoyong and Tepor structures. Together the four structures probably represent the product of serial impacts of extraterrestrial projectiles arriving from the southwest. The impact event was post-granite of Gunung Raya (whose age is Triassic-Jurassic) if the topography was exhumed, but could be of Neogene age if the present landscape was never buried. The Paloh craters at the Pahang-Terengganu border are associated with vein quartz containing planar deformations features and display mosaicism. At Beserah near Kuantan, 35 km southeast from Bukit Paloh, quartz megacrysts of partially weathered granite show naturally etched cleavage. It is not yet clear if the Paloh impact craters are in any way related to the shocked-metamorphose granitoids in the Kuantan area.

Abstrak: Ciri geologi, morfologi dan anomali graviti menandakan gelang kembar sekitar Makam Mahsuri ujud akibat hentaman benda langit. Setiap gelang bergaris-tengah 2.4 km dan pusatnya terletak 0.6 km pada arah 280°–110°. Gelang sebelah timur berkedalaman 107 meter manakala yang di sebelah baratnya mencapai kedalaman 45 meter. Dari Gegelang Mahsuri ke arah barat daya didapati dua gelang lain yang bersaiz semakin kecil, iaitu Temoyong dan Tepor. Keempat struktur dicadangkan mewakili suatu siri hentaman oleh sekumpulan bendalangit yang datang dari arah barat daya. Hentaman terjadi selepas terobosan granitoid Gunung Raya, iaitu lepas Trias-Jura jika landskap gegelang pernah tertimbus dan tersingkap semula. Jika topografi tidak pernah dilindungi oleh sedimen muda, kejadian hentaman boleh lebih muda daripada Neogen. Kawah-kawah Paloh di sempadan negeri Pahang-Terengganu bersekutu dengan kuarza telerang yang memiliki ira halus (PDF) serta pemadaman mosaik. Di Beserah berhampiran Kuantan, 35 km ke sebelah tenggara Bukit Paloh, didapati megakris kuarza daripada granit separa terluluhawa memiliki ira terukir semulajadi. Setakat ini masih kurang jelas sama ada kawah-kawah hentaman Paloh mempunyai kaitan dengan fitur hentaman yang dipamerkan oleh kuarza dalam granit di kawasan Kuantan.

INTRODUCTION

The synoptic view provided by satellite images has enabled ready recognition of large arcuate and circular structures. Foo (1976) was among the first researchers in the country who by using Landsat images mapped such structures in the northwestern part of Peninsular Malaysia. As of to date some 40 large arcuate to circular patterns have been identified in Peninsular Malaysia. Suggestions or interpretations of their origins have also been listed in Tjia (2001). These circular and arcuate patterns range from partial to complete tonal features, and may occur as single, paired, multiple landscapes or multi-concentric rings. Sisik in Johor (04°48'N. 105°50'E.) displays at least 9 concentric part-rings of about 8-km diameter. Double to quadruple multi-concentric rings are more common, however. Recognisable ring diameters range between 2 km and 10 km. The two exceptions of size are in Kelantan where the Taku (05°22'N, 102°08'E) and the Aring (04°52'N, 102°15'E) multi-rings are 25 km and 20 km across, respectively. The Aring multi-ring is hosted by the Triassic Telong Formation and is associated with radial drainage centred about a 210-m high hill (see map by Aw, 1978).

Large, arcuate and circular features may represent varied origins. Volcanic craters and especially calderas are large circular landforms. Igneous rocks in the form of stocks and bosses or as shallow intrusive bodies often have circular plans. Salt domes, mud diapirs and kimberlite pipes also show up as rounded map forms. Domes, basins and brachy-branched folds of layered rocks outcrop as arcuate or circular forms. Collapse depressions in limestone areas, or sinkholes and dolines, may have rounded plans. Rounded artefacts by Man comprise bomb craters, surface mines and other types of excavations. Due to the fact that the Earth's surface is constantly reworked through weathering, denudational and depositional processes, volcanism and other diastrophic activities, the number of recognisable depressions formed by impacting extraterrestrial bodies is very small compared to that seen at the Moon's surface which is free from all the earlier mentioned terrestrial disturbances. Throughout the world fewer than 170 impact structures are known, but the list is growing. A few of these structures do not exhibit the telltale morphology but have been identified on the occurrence of shock-metamorphic features that include high-pressure/low-temperature minerals (stishovite, coesite among the silica group; diamond from coal), diaplectic, suevite breccia, shatter cones, and microscopic features such as PDFs (planar deformation features in the form of sets of cleavages in quartz and other minerals that under "normal" conditions are absent) and patchy extinction or mosaicism. It is widely understood that PDFs in quartz are evidence *par excellence* for shock metamorphism, that is, extremely high pressure associated with relatively low temperature.

The study of shock metamorphic features and identification of impact sites in Malaysia is not merely of academic interest. In a small way the local study contributes to the world inventory of impact sites, knowledge of which could be useful in formulating measures against collisions with Near-Earth Objects (NEOs) in the foreseeable future. In the Precambrian shields of Siberia and Canada, impacts have produced commercial diamonds and nickel alloys. Impact structures and associated breccias are good hydrocarbon plays. In North America alone over a billion barrels of hydrocarbons have already been extracted from such structures (Buthman, 1997). The Chicxulub structure in the Yucatan Peninsula region, Mexico, is considered by many to represent the impact site of the extraterrestrial projectile that brought about the demise of dinosaurs at the Cretaceous-Tertiary boundary. In the mid-1990s it is also the site of a daily production of 2.1 million barrels of oil and 1.4 billion cubic feet of gas. For the region, exploration for hydrocarbons has been computed at 86 per cent success rate (Donofrio, 1997).

In the past two years a study on suspected impact structures in Malaysia resulted in providing strong evidence for the association of circular morphological expressions with shock- metamorphic features in Langkawi, Kedah and in northeastern Pahang. Most of the evidence for Langkawi has been presented separately by Abdul Rahim Samsudin *et al.* (2001) and Tjia (2001). The results will now be combined with additional findings that lead to the interpretation of serial impacts similar to what was observed for the Jupiter-Shoemake/Levy 9 encounter in 1974. The petrographic evidence for the Bukit Paloh craters of Pahang has not been published. Table 1 lists the circular/arcuate landforms in Kedah and Pahang. These large features were identified on Landsat TM images of the early 1990s in combination with regional and "district memoir" maps at 1:500 000 and larger scales published by the Geological Survey of Malaysia.

MAHSURI RINGS, PULAU LANGKAWI, KEDAH

The satellite image shows a somewhat irregular, oval hill-topography enclosing the area of the Mahsuri* tomb in south-central Langkawi Island (Fig. 1). The host rock belongs to the Carboniferous Singa Formation, while the interior part consist of flat paddy fields. Initially a single ring was perceived (see Tjia, 2001). Abdul Rahim Samsudin *et al.* (2001), however, found from gravity survey two depressions with centres located 600 metres apart along an almost E-W line. Two partially superimposed rings, called the Mahsuri Rings, each of 2.4 km diameter, fit the plan of hill-topography (Fig. 1). Since the year 2000, several field surveys were conducted to collect suitable rock samples and examine the bedding attitudes of the Singa beds. On Jones' (1978) geological map, from southwestern Langkawi onward, the Singa beds strike regionally Northwest and bend to a northerly strike beyond the Gunung Raya pluton (Fig. 2). Dips are mainly moderate to SE and East with few exceptions near faults. Significant deflections in strike and dip were measured in the vicinity of the Mahsuri Rings (Fig. 2). Interestingly, almost all Singa dip directions in the area of the rings are toward the geologically younger Gunung Raya granitic pluton.

Further examination of the satellite image and several runs of aerial photographs of average 1:30,000 scale turned up two more circular structures, named Temoyong and Pulau Tepor rings (Fig. 1).

The Mahsuri Rings are each 2.4 km in diameter and partially superimposed with their centres about 600 metres apart in 280°–110° direction (Figs. 1 and 2). The partial rings consist of an arcuate hilly range complex that is breached on its Northwestern quadrant. The hilly terrain consists of Carboniferous Singa strata, while to ring interior is flat paddy land. Gravity modelling suggests two depressions to underlie the rings; the eastern ring is 107 m deep and the western ring is shallower with 45 m depth (Abdul Rahim Samsudin *et al.*, 2001). Relief and tonal patterns of aerial photographs distinctly display the rounded forms that have subsequently been named as Mahsuri Rings. The most significant evidence for impact-origin of these rings consists of planar deformation features and extinction mosaicism in vein quartz (Fig. 3). Koeberl *et al.* (1997) published a recent review of microscopic features associated with shock (impact). French (1972), another proponent of impact structures on Earth contributed an earlier review. The quartz was extracted from a dyke-sill

* According to legend, Mahsuri was a beautiful maiden who lived in the islands some 200 years ago. Wrongly accused of adultery, Mahsuri was sentenced to death. At her execution, she bled white blood, indicating her purity and innocence, while Mahsuri put a curse on the well-being of Langkawi that would last for seven generations. Soon after hear death Langkawi was invaded and languished as a backwater until only recently when the spell expired. Mahsuri's tomb is located at the intersection of the similarly named rings.

Table 1. Identification on Landsat Thematic Mapper (1990s), Geological Survey of Malaysia regional map (1985, 1988) and various geological maps published as district memoirs, SPOT satellite images for SE Johor, and field studies in various parts of the Peninsula.

Name Geographic Location	Coordinates	Description	Host(s) Rock	Remarks
Padang Serai Ring Chain Kedah	05° 30' N. 100° 35' E.	Arcuate-ring structures aligned N-S; chain is 15 km long, individual structures of 3-4 km diameter	Mainly in Triassic Semanggol Formation	
Swettenham Structure Kedah-Pahang-Perak	04° 35'N. 101° 30' E.	Multi- (part) rings Diameter ~ 20 km	Mainly 218 Ma (Late Triassic) granitoid and Lower Palaeozoic roof pendants	
Bukit Koi Chain Ring Pahang	04° 32' N. 102° 07' E.	Multi-rings (≥ 3). Oval NNW-SSE Long axis 6 km Short axis 3.5 km	In Permian volcanics	Volcanic centres?
Kerum Chain Ring Pahang	04° 15' N. 102° 41' E.	NW-SE chain of 3 double rings Diameter 2.5-3 km each	In Jurassic-Cretaceous Tembeling Formation	Volcanic centres?
Chenor Rings Pahang	03° 40' N. 102° 37' E.	Series of part double rings, each of ~ 2 km diameter	Triassic Semantan Formation and Permian metasedimentary rocks	Volcanic centres?
Maran Structures Pahang	03° 30' N. 102° 42' E.	NNW-SSE oval, multi-rings Long radius 9 km Short radius 6.5 km	In Triassic-Jurassic and Jurassic-Cretaceous sediments	
Paloh Rings Terengganu-Pahang	04° 60' N. 103° 05' E.	Larger ring elongated N-S ~ 4 km, 3.5 km E-W Smaller satellite ring ~ 1 km across	Part in Carboniferous formation, part in 243 Ma (Early Triassic) granitoid	Probable impact Detailed description in the text; Figures 10a & 10b
Gelugor North of Bt. Chondong, Pahang	03° 36' N. 102° 55' E.	Double rings Diameter 3 km	Permian metasedimentary rocks	
Kertau NE of Bt. Bertangga, Pahang	03° 18' N. 102° 44' E.	Double ring Diameter ~ 2 km	Jurassic-Cretaceous Bertangga Formation	Probable impact
Bukit Ibam Rings Pahang	03° 11' N. 102° 58' E.	Two double rings with diameters of 0.8 km and 3 lm	In Permian metasedimentary rocks, intermediate and ultrabasic igneous rocks	Intrusive complex?
Cherai Rings Pahang	02° 51' N. 103° 02' E.	Double rings Diameters ~ 3 km each	Jurassic-Cretaceous sediments	
Teriang SW of Temerloh, Pahang	03° 14' N. 102° 20' E.	Multi-rings (≥ 3); NW-SE oval Long axis 4.5 km Short axis 3 km	Triassic Semantan Formation	
Mahsuri Ring-1 P. Langkawi, Kedah	06° 21' N. 99° 47' E.	Part circular, 2.4 km diameter; NW-side open	Carbo-Permian Singa Formation	Details in text Impact structure, PDFs in vein quartz
Mahsuri Ring-2 P. Langkawi, Kedah	06° 20' N. 99° 46' E.	Part circular, part superposed on Mahsuri Ring-1, 2.4 km diameter	Carbo-Permian Singa Formation	Details in text Impact structure, PDFS in vein quartz
Temoyong Ring P. Langkawi southwest	06° 10' N. 99° 43' E.	Double ring Diameter 0.8 km	Carbo-Permian Singa Formation	Part of impact series with Mahsuri Rings
Tepor Structure P. Tepor, Langkawi	06° 10' N. 99° 42' E.	Half-ring open to north Radius 0.5 km; highest elevation of rim 83 m	Carbo-Permian Singa Formation	Part of impact series with Mahsuri Rings

stockwork intruded into tuffaceous Singa sandstones outcropping in a small excavation where Sungai Batu Asah crosses the main road between Kuah and the "Book Village". Bedding strikes between N010°E and N030°E and dips are 10 degrees or less eastward. The lower part of the stockwork crops out as a one-metre wide vertical dyke trending sub-parallel to bedding strike. Upward from ground level, the dyke becomes progressively thinner and branches off treelike into several levels of sills. The quartz sills are ~40 cm thick in the lower part and become thinner towards the upper part of the stockwork. The quartz is massive-looking but in hand specimen it acquires a rhomboidal blocky appearance due to various parallel fracture sets. Thin sections of other vein quartz specimens from the same locality are in Tjia (*in press*).

The satellite image and vertical aerial photographs also show the presence of two other circular morphologies in Langkawi: Temoyong (~1 km diameter) and Tepor (0.7 km across) rings (Fig. 1). The Tepor Ring forms Pulau Tepor, whose southern half suggests a part-crater topography. The target rocks of both these rings are of the Singa Formation.

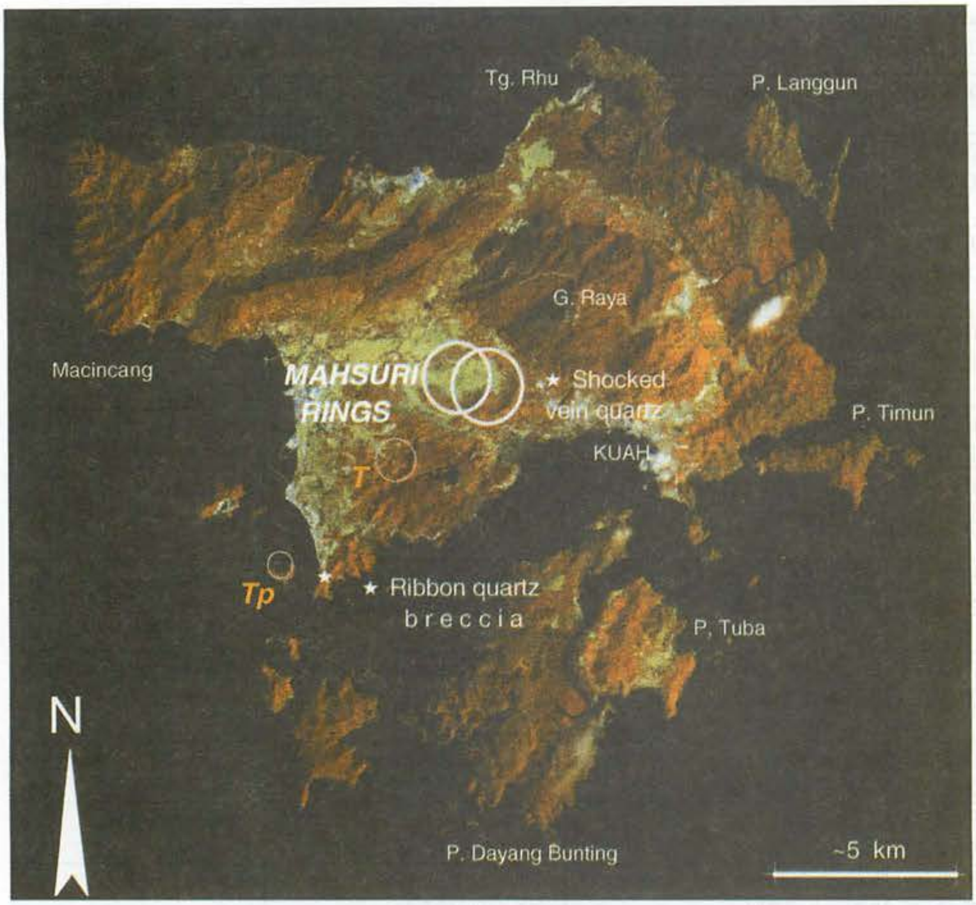

Figure 1. Probable serial impact rings: Tepor (Tp) - Temorong (T) - double Mahsuri Rings on Landsat image. Asterisks are locations of quartz with PDFs and Pulau Tokong Jepun.

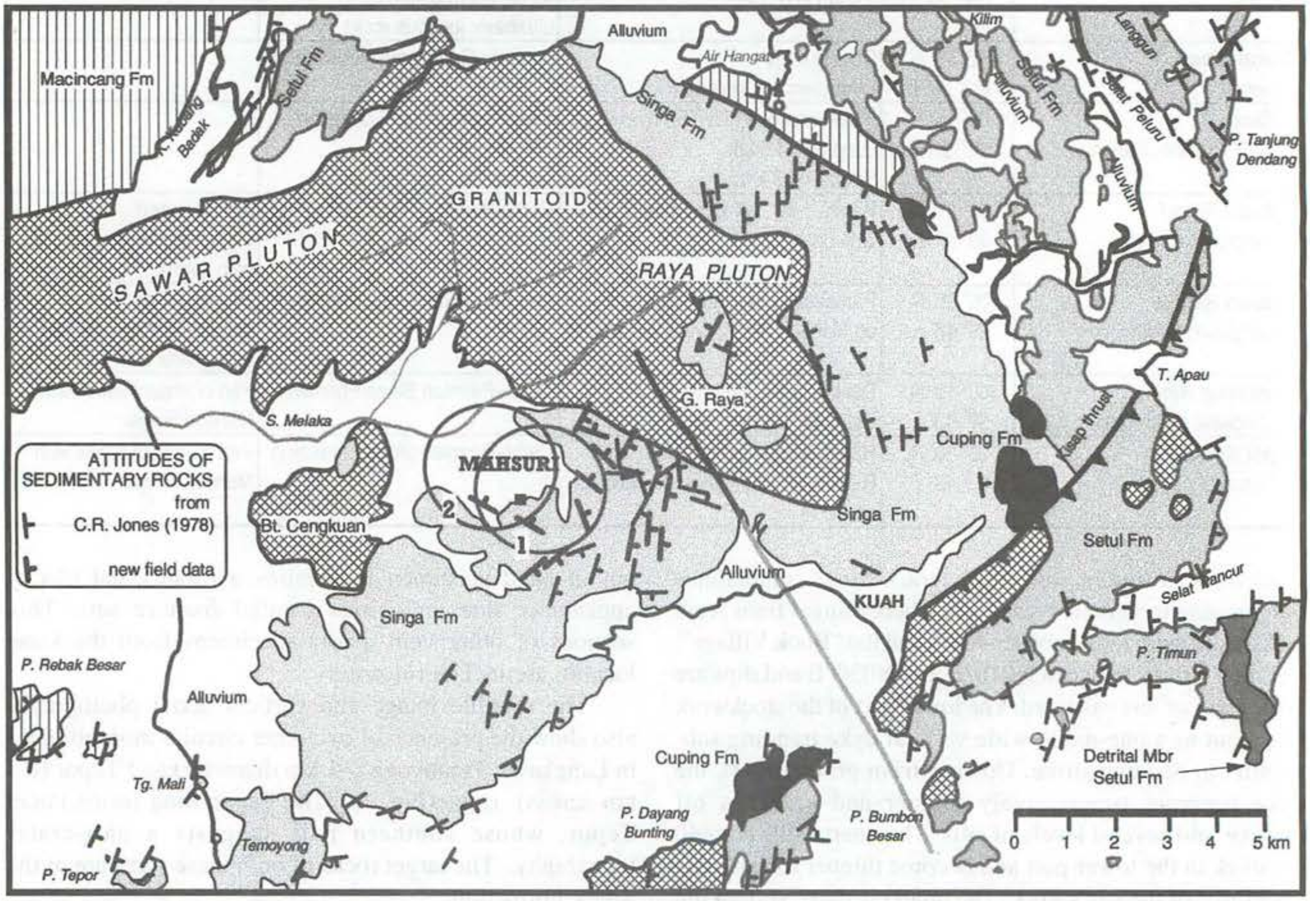

Figure 2. Geological map of central Langkawi island after Jones (1978) with additions. Note the partially superimposed Mahsuri Rings.

Petrographic evidence of shock metamorphism in the southwest of Pulau Langkawi is provided by vein quartz hosted by dark coloured phyllite of the Singa Formation outcropping at the road pass towards Porto Malai. The quartz veins are relatively small, being about 1 to 1.5 m long and each less than 10 cm wide. Figure 4 is a thin section of the vein quartz seen under crossed nicols. NE and NW trending cleavage sets are distinct. From Tokong Jepun in the general area of the Temoyong and Tepor rings a loose block of quartzitic breccia was collected (see Figure 9b in Tjia, 2001). The breccia consists of unusual clast forms. The monolithic fragments are flattish prisms a few centimetres long and about a centimetre wide. No shock metamorphic features, however, were seen in thin sections of its quartz grains.

The progressive decrease in ring size in southwest direction is intriguing. We suggest that the four rings represent one flight of extraterrestrial projectiles that impacted almost simultaneously. The heavier mass of the larger objects produced the longer flight paths or in other words, the flight arrived from the Southwest.

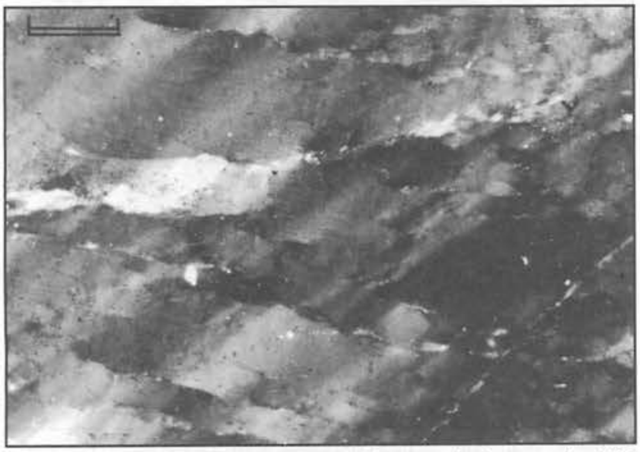

Figure 3. Patchy extinction (mosaicism) and cleavage in ESE direction are evidence for shock metamorphism. Thin section of vein quartz cut from a sill-dyke stock work in Carboniferous Singa beds, Sungai Batu Asah, Pulau Langkawi. Part-polarised light. Bar is 100 microns.

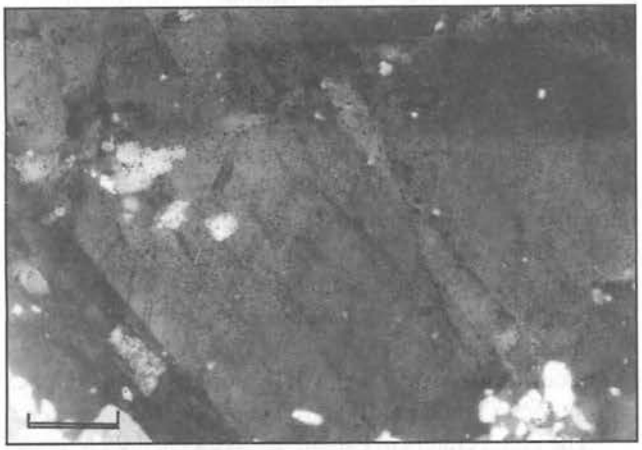

Figure 4. PDFs in NW and NE directions, the NE cleavage being closer spaced. Vein quartz in dark coloured phyllite of the Singa Formation at Porto Malai, SW Langkawi. Part crossed nicols. Bar is 200 microns.

The impact time is problematic. At the Mahsuri Rings the Singa beds dip into the Triassic-Jurassic Gunung Raya pluton but outward from the ring centres. The ring-like topography of all the four rings of Langkawi are still recognisable. The relatively fast weathering and denudation rates of the humid tropics imply that subaerial exposure of the topography has probably only been since the Neogene. However, the Mahsuri Rings could have been exhumed impact structures, in which case the impact time was at any time since the granite emplacement.

PALOH RINGS OR PALOH CRATERS, PAHANG

An ring-like depression straddles the Terengganu-Pahang state boundary in the east coast of Peninsular Malaysia (Figs. 5 and 6). Bukit Paloh (623 m) figures prominently in a landscape of rolling low hills. Bukit Paloh is the highest point on the high topography encircling the depression that will be referred to as Paloh Ring-1. On its SW rim is a smaller rounded depression about a kilometre across (Paloh Ring 2). Paloh Ring-1 is 3.5 km across. The regional geological map of Peninsular Malaysia shows that the south half of the greater ring consists of felsic igneous rock whose mica K/Ar age is 243 million years or Scythian (Geological Survey of Malaysia, 1985). The north half of the ring is underlain by undivided Carboniferous metasedimentary rocks. The larger ring is halved by a N-S lineament along which runs a tributary of Sungai Cherul. Up to the present time we have managed only one field survey that covered the eastern foothills of

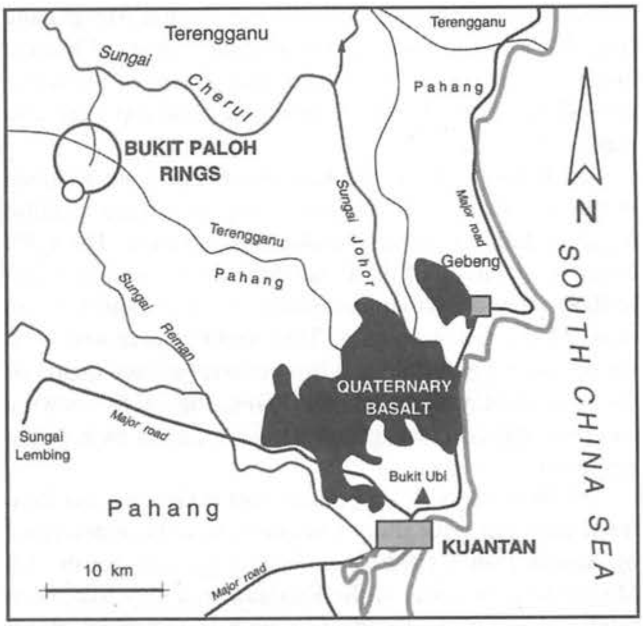

Figure 5. Location of Bukit Paloh Rings on the Pahang-Terengganu border and Beserah granite with PDFs in its quartz grains (see figure 8).

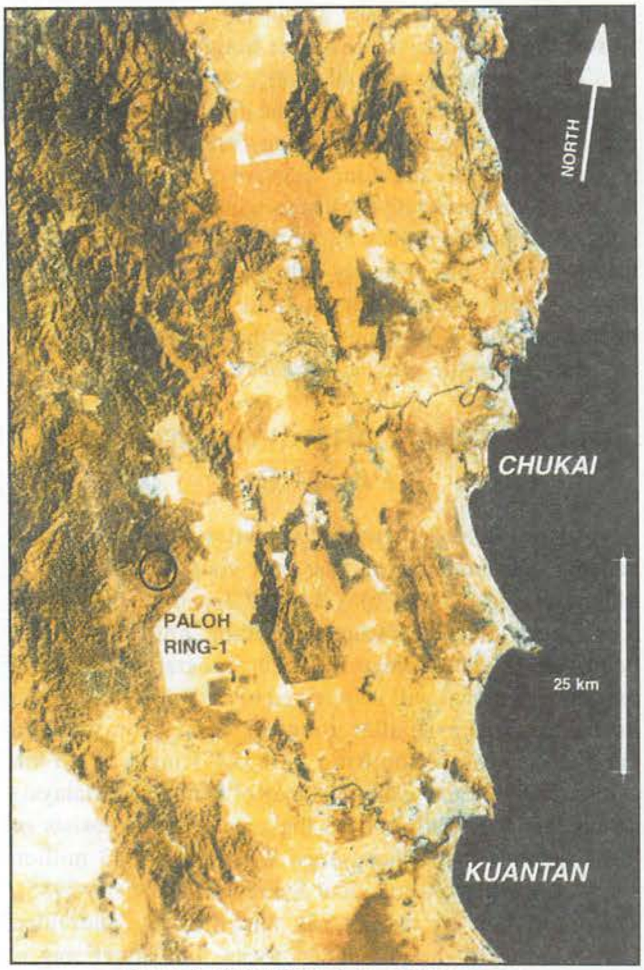

Figure 6. Paloh Ring-1 on satellite image.

Bukit Paloh. Indication for shock metamorphism was provided by vein quartz occurring in tuffaceous metasedimentary rocks in the upper Sungai Mengkuang (Fig. 7). PDFs in thin sections of quartz clasts of breccia blocks and boulders of Sungai Mengkuang a kilometre downstream from the above mentioned outcrop were also seen.

At Beserah on the old East-coast road from Kuantan northward toward Terengganu crop out huge granitic boulders and grus in an abandoned excavation. The U/Pb isochron on zircon of the Beserah granitoid indicates 263 million years (Sakmarian-Asselian). The boulders are cores of the granite pluton. Thin sections prepared from the weathered granitoid and from coarse-grained quartz of the grus display unmistakable PDFs. Figure 8 shows a naturally etched cleavage set across a quartz twin in the granitoid.

PDFs in quartz from granitic soil at Gebeng and from fresh granitoid at the Bukit Ubi quarry have been described by Anizan Isahak (1990) who also suggested that the 1.8 Ma old basaltic lavas of the Kuantan area may have been produced as result of impact by an extraterrestrial object in the area. Further study is needed to determine if a connection exists between the Paloh Craters and shock-

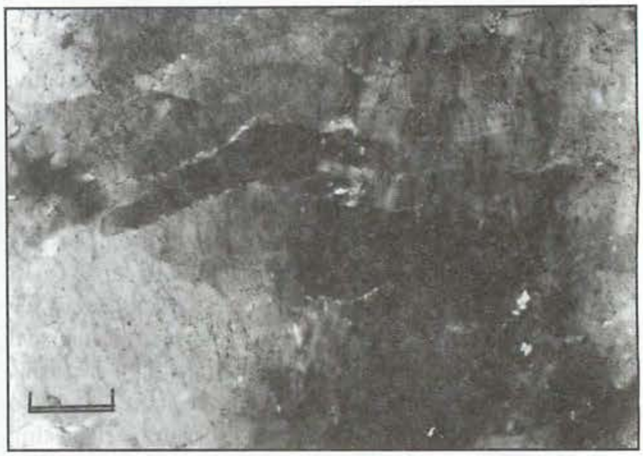

Figure 7. Shock metamorphism manifests as at least 4 cleavage sets (NW, NNE, NE and ENE) and mosaicism caused by patchy extinction in a thin section of quartz cut from a vein in ?Carboniferous metasedimentary rocks. Eastern foot of Bukit Paloh, upper Sungai Mengkuang, Pahang. Part-polarised light. Bar is 200 microns.

Figure 8. Naturally etched cleavages across a megacrystic quartz twin in partially weathered granite at Beserah near Kuantan, Pahang. Thin section under crossed nicols. Bar is 200 microns.

metamorphic features of the Kuantan area (Bukit Ubi, Gebeng and Beserah) that are some 35 km apart.

CONCLUSIONS

Morphology, gravity anomalies and PDFs in vein quartz strongly suggest that the double Mahsuri Rings are of impact origin. The Mahsuri-Temoyong-Tepor rings may have been produced by serial impacts of extraterrestrial objects arriving from the Southwest. If the ring topography had been exhumed, the impact event occurred post-granite of Gunung Raya. In the case that the impacts hit the currently exposed landscape, the still recognisable impact morphologies could hardly have been older than Neogene.

The Paloh craters in Pahang are associated with shock-metamorphic features in quartz veins and quartz breccia. Additional evidence of PDFs in quartz of old (pre-Tertiary) granitoids in the Kuantan area demonstrates the existence of a shock-metamorphic event whose relationship with the Paloh craters needs further study.

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REFERENCES

ABDUL RAHIM SAMSUDIN, UMAR HAMZAH, TJIA, H.D. & LIM, C.H., 2001. Gravity investigation of a "suspect" meteorite impact crater in Langkawi island, Malaysia. *Persidangan Kebangsaan Warisan Geologi Malaysia 2001, Buku program dan abstrak*, 26-27.

ANIZAN ISAHAK, 1990. An impact origin for the Late Cenozoic basalt volcanism in Kuantan Pahang. *Sains Malaysiana, 19(1)*, 65-73.

AW, P.C., 1978. [Sungai Aring, Geological sheet 46 and part of sheet 58]. Geological Survey of Malaysia, Ipoh. Scale 1:63,360.

BUTHMAN, D.B., 1997. Global hydrocarbon potential of impact structures. *Oklahoma Geological Survey, Circular 100*, 83-99.

DONOFRIO, R.R., 1997. Survey of hydrocarbon-producing impact structures in North America: exploration results to date and potential for discovery in Precambrian basement rock. *Oklahoma Geological Survey, Circular 100*, 17-29.

FOO, K.Y., 1976. Interpretation of Landsat-imagery of the Third East Asia IDOE Transect across Malaysia. *Geological Survey of Malaysia, Annual Report for 1976*, 183-192.

FRENCH, B.M., 1972. Shock-metamorphic features in the Sudbury structure, Ontario: a review. *Geological Association of Canada Special Paper 10*, 19-28.

GEOLOGICAL SURVEY OF MALAYSIA, 1985. *Geological map of Peninsular Malaysia, 8th edition*. Geological Survey of Malaysia, Ipoh, 2 sheets, scale 1:500 000.

GEOLOGICAL SURVEY OF MALAYSIA, 1988. *Mineral distribution map of Peninsular Malaysia, 8th edition*. Geological Survey of Malaysia, Ipoh, 2 sheets, scale 1:500 000.

JONES, C.R., 1978. Geology and mineral resources of Perlis, North Kedah and the Langkawi Islands. Geological Survey of Malaysia, *District Memoir 17*, 257p; geological map scale 1:63,360 published in 1966.

KOEBERL, CHR., REIMOLD, W.U., BRANDT, D., DALLMEYER, R.D. & POWELL, R.A., 1997. Target rocks and breccias from Ames impact structure, Oklahoma: petrology, mineralogy, geochemistry and age. *Oklahoma Geological Survey, Circular 100*, 169-198.

TJIA, H.D., 2001. Impact structures in Malaysia: recognition and implications. *Warisan Geologi 4 "Pemetaan Geowarisan dan Pencirian Geotapak"*, Lestari, U.K.M., Bangi, 221-262.

TJIA, H.D., *in press*. The Mahsuri Rings in Langkawi. *Warisan Geologi 5*, Lestari, U.K.M., Bangi.