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Since its establishment in 1967, the Geological Society of Malaysia has been a major contributor to the advancement of knowledge in geoscience at national and regional levels.

Bulletin 59 is a collection of 15 papers based on basic, applied and policy research on geoscience. The first five articles are thematic papers presented at the 48th CCOP Annual Session held from 5-8 November 2012 in Langkawi, Malaysia and the other papers were papers presented at the National Geoscience Conference and the Petroleum Geology Conference and Exhibition.

I would like to thank guest editors, Dr. Antony J. Reedman & Dr. Nguyen Thi Minh Ngoc for editing the CCOP manuscripts. I am also grateful to all the authors for their contributions, the reviewers for making time to improve the contributions and the organising committee of the conferences for facilitating publication of the papers.

T.F. Ng
Editor
### GLOSSARY

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<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barat</td>
<td>B</td>
<td>west</td>
</tr>
<tr>
<td>Baratdaya</td>
<td>BD</td>
<td>southwest</td>
</tr>
<tr>
<td>Baratlaut</td>
<td>BL</td>
<td>northwest</td>
</tr>
<tr>
<td>Batu</td>
<td></td>
<td>stone</td>
</tr>
<tr>
<td>Batuan</td>
<td></td>
<td>rock</td>
</tr>
<tr>
<td>Besar</td>
<td></td>
<td>large</td>
</tr>
<tr>
<td>Bukit</td>
<td>Bt</td>
<td>hill</td>
</tr>
<tr>
<td>Genting</td>
<td>Gtg</td>
<td>pass</td>
</tr>
<tr>
<td>Gunung</td>
<td>G</td>
<td>mountain</td>
</tr>
<tr>
<td>Jalan</td>
<td>Jln</td>
<td>road, street</td>
</tr>
<tr>
<td>Kampung</td>
<td>Kg</td>
<td>village</td>
</tr>
<tr>
<td>Kecil</td>
<td></td>
<td>small</td>
</tr>
<tr>
<td>Kuala</td>
<td>K</td>
<td>mouth of river</td>
</tr>
<tr>
<td>Laut</td>
<td></td>
<td>sea</td>
</tr>
<tr>
<td>Permatang</td>
<td>Ptg</td>
<td>sandy ridge along coast</td>
</tr>
<tr>
<td>Pulau</td>
<td>P</td>
<td>island</td>
</tr>
<tr>
<td>Selat</td>
<td></td>
<td>strait</td>
</tr>
<tr>
<td>Selatan</td>
<td>S</td>
<td>south</td>
</tr>
<tr>
<td>Semenanjung</td>
<td></td>
<td>peninsula</td>
</tr>
<tr>
<td>Sungai</td>
<td>S, Sg</td>
<td>river</td>
</tr>
<tr>
<td>Tanjung</td>
<td>Tg</td>
<td>cape</td>
</tr>
<tr>
<td>Tasik</td>
<td></td>
<td>lake</td>
</tr>
<tr>
<td>Teluk</td>
<td>T, Tlk</td>
<td>bay</td>
</tr>
<tr>
<td>Tenggara</td>
<td>TG</td>
<td>southeast</td>
</tr>
<tr>
<td>Timur</td>
<td>T</td>
<td>east</td>
</tr>
<tr>
<td>Timurlaut</td>
<td>TL</td>
<td>southwest</td>
</tr>
<tr>
<td>Utara</td>
<td>U</td>
<td>north</td>
</tr>
</tbody>
</table>
The geological heritage values and potential geotourism development of the beaches in Northern Sabah, Malaysia

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Abstract: A study was carried out on 13 beaches in Northern Sabah, Malaysia to identify their geological heritage values and geotourism potential. Northern Sabah has some of the finest beaches in Sabah and most of them are still undisturbed and in pristine condition. However, with the increasing demand for tourism facilities, considerable development is currently being undertaken in the coastal areas and the impact upon the beaches is considerable. The natural geomorphologic processes may be disrupted and the beaches in the area might be degraded and damaged. The main attractions of the beaches are their beautiful landscape. The geological heritage values usually go unnoticed and unappreciated due to lack of awareness and information. By unraveling and explaining their hidden natural qualities, the attractions of the beaches could be enhanced. This study has identified the scientific values of the beaches such as the composition, morphology and sources of the beach sediments. Black sand comprising mainly chromite was found at Marasimsim Beach and pink sand comprising mainly garnet was found at a pocket beach in Tanjung Simpang Mengayau. The study also revealed that several of the beaches in the area have aesthetic and cultural value as well as their obvious recreational value. Such aspects could be explained to visitors so that they can appreciate the importance of conservation. Geotourism could be developed and promoted on some of the beaches together with steps to ensure the sustainability and to protect these beach environments. The promotion of beach geotourism could be carried out together with other potential geotourism sites in Northern Sabah. The study on beaches for geotourism development is an innovative way to add-value to their existing aesthetic attractions and to enhance and sustain the tourism industry in the State.

Keywords: geological heritage, geotourism, beach, Sabah

INTRODUCTION

Beaches are one of the most important landscape assets for the tourism industry in Sabah. For instance, nearly all the highly rated hotels in Sabah are built near beaches such as the Nexus Karambunai Resort, Shangri-La Rasa Ria Resort and Shangri-La Tanjung Aru Resort. Northern Sabah has some of the finest beaches in Sabah, especially in the western part of the Kudat Peninsula. The beaches in this area stretch from Teringkai, located south of the Kudat Peninsula to Kosuhui just south of Tanjung Simpang Mengayau (popularly known as the Tip of Borneo). Beaches can also be found at the eastern side of the Kudat Peninsula and at the western part of the Bengkoka Peninsula.

Beaches are formed where there is a sufficient supply of sediment and suitable sites for accumulation. Beaches are often associated with fishing, recreation and scientific research such as studies on geomorphology, coastal environmental and global sea level change. Beaches lure visitors because of their sandy nature and beautiful landscape. By unraveling more of their hidden natural qualities, the attractions could be enhanced. Most of the beaches in the study area are still undisturbed and in pristine condition. However, with the increasing demand for tourism facilities, developments is now being carried in the coastal areas and the impact upon the beaches are greater now than ever. The natural geomorphologic processes could be disrupted and the beaches in the area might be degraded and damaged.

The main attraction of a beach is because of its sandy nature. Visitors naturally shun muddy or rocky beaches. The supplies of sand to a beach area are from various sources such as from the hinterland, coastal rocky outcrops and from the seabed. Disruption at the source or of the transport medium could alter the nature of a beach. Therefore, this study is timely and the outcome of this study could be used as a guide for sustainable development along coastal areas in Northern Sabah.

Each beach has its own heritage value. The value which is usually appreciated by the public is the aesthetic value while the other values such as the scientific values usually go unnoticed and unappreciated due to lack of awareness and information. The scientific values of beaches could be conveyed to the general public so that they can appreciate its importance. Visitors to beaches could thereby gain some knowledge concerning the history of the formation of these important landscapes of the earth.

Beach landscape is one of the youngest landscapes compared to many other types of landscape. The coastal areas are very dynamic and among the factors that form beach landscapes are sea level changes, tides, wave actions, rock types and geological structures. Visitors have to be made aware of the geomorphologic processes and geological features that shape and control the formation of beaches so that they can appreciate and protect them.

Presented at 48th CCOP Annual Session
LOCATION OF STUDY AREA

The study area is located mainly in the Kudat Peninsula, Northern Sabah. A total of thirteen beaches were involved in the study (Figure 1). They are Kampung Kuala Tajau, Sampaping, Tanjung Simpang Mengayau, Kosuhui, Pongugadan, Bawang Jamal, Kulambu, Loro Kecil, Kamihang, Sikuati, Torongkongan, Teluk Agal and Marasimsim Beach (Figures 2 and 3).

OBJECTIVES AND METHODOLOGY

The objectives of the study are to identify the geological heritage values and the geotourism potential of the beaches in Northern Sabah. This includes the study of the physical characteristics and composition of the beach sand and the beach landscape itself.

Beach sediment samples were collected for grain size, compositional and morphological analyses. Two types of samples were collected at each sampling site, one which is nearer to the sea (foreshore) and the other nearer to the land (backshore). Samples were also collected whenever coloured sediments were encountered. The beach sand samples were collected up to 10 cm deep using a small plastic scope and the amount of sample collected was at least 300 g. A duplicate sample was collected at each beach for quality control of the sampling procedure. All samples were washed with fresh water, air-dried and thoroughly dispersed before sieving. The amount of sample used for dry sieving was about 250 g. A mechanical riffle splitter was used to split samples before sieving. Sieve with sizes of 2.0, 1.0, 0.5, 0.25, 0.125 and 0.0625 mm were used and set up in order of decreasing mesh size. The results obtained from the sieve analysis were treated statistically using the Folk and Ward (1957) method.

The statistical parameters calculated in phi (Φ) units were mean particle size, standard deviation (sorting), skewness and kurtosis. Semi-quantitative estimation (QME) analysis was also carried out on selected beach sediment samples. The characteristics of the beach and its surrounding landscapes such as the profile, slope, width, rock outcrops, erosional features and vegetation were also recorded.

GEOLOGICAL SETTING

The oldest rocks in Northern Sabah, the basement rocks are consist of ophiolite and associated sedimentary rocks such as sandstone, mudstone and chert. These are overlain by sedimentary rocks comprising the Crocker, Kudat, South Banggi and Bongaya Formations together with minor mélange and Quaternary deposits of alluvium, terrace sand and gravel. The geological map of Northern Sabah is shown in Figure 4.

RESULTS

Two types of beach are observed in the study area; the linear type and pocket type respectively. Linear beaches are generally straight or slightly curved while pocket beaches are small interruptions of rocky shores. For the purpose of this study, pocket beaches are those less than 500 m in length. The characteristics of the beach sediments in the study area range from fine to coarse grained and poorly sorted to very well sorted. The summary of the landscapes and physical characteristics of the beach sediments in Northern Sabah is shown in Table 1.

According to King (1972), fine-grained sediments form beaches with a smooth profile. The beaches with fine-grained and well-sorted sediments are Kampung Kuala Tajau, Kosuhui, Bawang Jamal, Kulambu, Loro Kecil, Sikuati, Torongkongan, Teluk Agal and Marasimsim Beach (Figures 2 and 3).
Kamihang, Sikuati, Teluk Agal and Torongkongan. The occurrence of black sand was found at Marasimsim Beach and Torongkongan Beach (Figure 5). The black sand at the Marasimsim Beach comprises mainly chromite (39-83%) which originated from the ultrabasic rocks in the hinterland. The patches of black sand at the Torongkongan Beach comprise mainly zircon (39%) and chromite (35%) which probably derived from the ultrabasic rocks and basalt at Tanjung Bangau located just north of the Sikuati Beach (Figure 6). Pink sand was found at Tanjung Simpang Mengayau pocket beach (Figure 7). The QME analysis carried out on the pink sand shows it consists mostly of garnet (73%) with minor amounts of ilmenite, chromite, pyroxene, iron oxide, zircon, rutile, leucoxene and other minerals. The garnet sand is medium grained and moderately well sorted. The colour of the garnet is various shades of pink (Figure 8). The grains are subangular to rounded and mostly spherical in shape due to attrition. The source of the garnet is not known with certainty but probably was derived from the reworking of older sediments.

**EVALUATION OF THE GEOLOGICAL HERITAGE OF BEACHES**

The evaluation of the geological heritage of beaches is carried out based on scientific, aesthetic, recreational, cultural and ecological values (Table 2). The geological heritage values that are present in beaches usually go unnoticed and unappreciated by visitors. These values should be conveyed to the beach users and the general public so that they can appreciate their importance. Based on the evaluation, several beaches such as the Kosuhui, Kulambu, Loro Kecil, Torongkongan and Marasimsim Beach have scientific, aesthetic, recreational and cultural values.

**GEOTOURISM POTENTIAL**

The target groups identified for geotourism development include amateur and professional geoscientists, school and university students, academics and teachers, ecotourism participants, landscape photographers, artists, historians, those interested in the physical natural wonders of the earth and ordinary tourists (Joyce, 2006). With these in mind, the geotourism potential of beaches is evaluated as based on research, educational and recreational activities. The geotourism potential of the beaches in Northern Sabah is shown in Table 3. Beaches such as the Tanjung Simpang Mengayau, Kulambu, Loro Kecil, Torongkongan and Marasimsim Beach have scientific, aesthetic, recreational and cultural values and therefore have high potential for geotourism.
Table 1: Summary of the landscape and physical characteristics of the beach sediments in Northern Sabah, Malaysia.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Beach</th>
<th>Type of Beach/Other Features Near Beach</th>
<th>Beach Sediment Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grain Size and Sorting</td>
</tr>
<tr>
<td>1</td>
<td>Kampung Kuala Tajau</td>
<td>Linear</td>
<td>Sandy sediment (fine-grained, moderately well-sorted)</td>
</tr>
<tr>
<td>2</td>
<td>Sampaping</td>
<td>Linear/Remnant cliffs</td>
<td>Sandy sediment (fine-grained, moderately well-sorted to poorly sorted)</td>
</tr>
<tr>
<td>3</td>
<td>Tanjung Simpang Mengayau</td>
<td>Pocket/Cliffs, faults, sea caves</td>
<td>Sandy to pebbly sediment (coarse-grained, moderately well-sorted), pink sand (garnet).</td>
</tr>
<tr>
<td>4</td>
<td>Kosuhi</td>
<td>Extensive linear</td>
<td>Sandy sediment (fine-to medium-grained, moderately well-sorted to very well-sorted).</td>
</tr>
<tr>
<td>5</td>
<td>Pongugadan</td>
<td>Pocket/Cliffs, karren-like feature</td>
<td>Sandy sediment (medium- to very coarse-grained, moderately well-sorted to poorly sorted).</td>
</tr>
<tr>
<td>6</td>
<td>Bawang Jamal</td>
<td>Linear</td>
<td>Sandy sediment (fine-to medium-grained, moderately well-sorted to very well-sorted).</td>
</tr>
<tr>
<td>7</td>
<td>Kulambu</td>
<td>Linear/Remnant cliff, remnant island (Pulau Kulambu), tombolo</td>
<td>Sandy sediment (fine-grained, moderately well-sorted to well-sorted).</td>
</tr>
<tr>
<td>8</td>
<td>Loro Kecil</td>
<td>Embayed pocket/Cliffs</td>
<td>Sandy sediment (fine-to very fine-grained, moderately well-sorted to well-sorted).</td>
</tr>
<tr>
<td>9</td>
<td>Kamihang</td>
<td>Embayed pocket</td>
<td>Sandy sediment (fine-to very fine-grained, moderately well-sorted to poorly sorted).</td>
</tr>
<tr>
<td>10</td>
<td>Sikuati</td>
<td>Extensive linear/Terrace beach</td>
<td>Sandy sediment (fine-to medium-grained, moderately well-sorted to very well-sorted).</td>
</tr>
<tr>
<td>11</td>
<td>Torongkongan</td>
<td>Extensive linear/Remnant cliffs, rocky shore</td>
<td>Sandy sediment (fine-to medium-grained, moderately well-sorted). Black sandy patch (chromite, zircon).</td>
</tr>
<tr>
<td>12</td>
<td>Teluk Agal</td>
<td>Embayed pocket/Cliffs</td>
<td>Sandy sediment (fine-to medium-grained, moderately well-sorted to very well-sorted).</td>
</tr>
<tr>
<td>13</td>
<td>Marasimsim</td>
<td>Linear</td>
<td>Sandy to pebbly sediment (medium-to very coarse-grained, poorly sorted), black sand (chromite).</td>
</tr>
</tbody>
</table>

Figure 7: A patch of pink beach sand at Tanjung Simpang Mengayau comprising mainly garnet.

Figure 8: Garnet grains of various shades of pink that give the pink colour to the beach sand at Tanjung Simpang Mengayau.
### Table 2: The evaluation of the geological heritage of the beaches in Northern Sabah, Malaysia.

<table>
<thead>
<tr>
<th>Name of Beach</th>
<th>Main Geological Heritage Resources</th>
<th>Evaluation of Geological Heritage Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampung Kuala Tajau</td>
<td>Linear beach, sandy sediment (fine-grained, moderately sorted to well-sorted)</td>
<td>Depositional history, coastal processes and source of beach sediment. Attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Sampaping</td>
<td>Linear beach, sandy sediment (fine-to-coarse-grained, moderately sorted to poorly sorted), remnant cliffs.</td>
<td>Depositional and erosional history, coastal processes and source of beach sediment. Attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Tanjung Simpang Mengayau</td>
<td>Pocket beach, sandy to pebbly sediment (coarse-grained, moderately well-sorted), cliffs, faults, sea caves.</td>
<td>Depositional and erosional history, coastal processes and source of pink sediment. Scenic embayment, attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Kosuhi</td>
<td>Linear beach, extensive sandy sediment (fine-to-medium-grained, moderately well-sorted to well-sorted), cliffs, karren-like feature.</td>
<td>Depositional and erosional history and coastal processes. Attractive landscape. Beach recreation. Probably visited by Ferdinand Magellan’s Fleet in the 16th Century. Support coastal biodiversity</td>
</tr>
<tr>
<td>Pongugadan</td>
<td>Pocket beach, sandy sediment (medium-to-very coarse-grained, moderately well-sorted to poorly sorted), cliffs, karren-like feature.</td>
<td>Depositional and erosional history and coastal processes. Attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Bawang Jamal</td>
<td>Linear beach, sandy sediment (fine-to-medium-grained, moderately well-sorted to very well-sorted).</td>
<td>Depositional history and coastal processes. Attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Kulambu</td>
<td>Linear beach, sandy sediment (fine-grained, moderately well-sorted to well-sorted), remnant cliff, remnant island (Pulau Kulambu), tombolo, pocket beach.</td>
<td>Rare tombolo, depositional and erosional history and coastal processes. Picturesque landscape. Beach recreation. The name Kulambu derived a from local story. Support coastal biodiversity</td>
</tr>
<tr>
<td>Loro Kecil</td>
<td>Embayed pocket beach, sandy sediment (fine-to-very fine-grained, moderately well-sorted to well-sorted), cliff.</td>
<td>Depositional and erosional history and coastal processes. Scenic embayment, attractive landscape. Beach recreation. Ship wreck site. Treasure hunting site. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Kamihang</td>
<td>Embayed pocket beach, sandy sediment (fine-to-very fine-grained, well-sorted to poorly sorted).</td>
<td>Depositional and erosional history and coastal processes. Scenic embayment, attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Sikuati</td>
<td>Linear beach, extensive sandy sediment (fine-to-medium-grained, moderately well-sorted to very well-sorted), terrace beach.</td>
<td>Depositional history and sea level changes. Attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Torongkon-gan</td>
<td>Linear beach, extensive sandy sediment (fine-to-medium-grained, moderately sorted to moderately well-sorted), black sandy patch (chromite, zircon), remnant cliff, rocky shore.</td>
<td>Depositional and erosional history, coastal processes and source of black sediment. Attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Teluk Agal</td>
<td>Embayed pocket beach, sandy sediment (fine-to-medium-grained, moderately well-sorted to very well-sorted), cliff.</td>
<td>Depositional and erosional history and coastal processes. Scenic embayment, attractive landscape. Beach recreation. Supports coastal biodiversity</td>
</tr>
<tr>
<td>Marasimsim</td>
<td>Linear beach, sandy to pebbly sediment (medium-to-very coarse-grained, poorly sorted), black sand (chromite).</td>
<td>Depositional and erosional history, coastal processes and source of black sediment. Modest landscape. Beach recreation. Historic mineral exploration site. Support coastal biodiversity</td>
</tr>
</tbody>
</table>
CONCLUSION

The study has unraveled the geological heritage values of beaches based on scientific, aesthetic, recreational and cultural values. The scientific values of beaches such as the composition, morphology and sources of the beach sediments have been identified. The occurrence of other geomorphologic and geological features at or near beaches such as remnant cliffs, faults, sea caves, tombolo and remnant island enhances the aesthetic values and attractiveness of beaches and therefore are appealing to visitors. These features also enhance the scientific value of the beaches. Any unregulated development, such as sand extraction along coastal areas, will affect the beaches of Northern Sabah.

It is recommended that the beaches of Northern Sabah to be conserved so as to protect the beautiful landscapes. Geotourism could be promoted on some of the beaches such as Tanjung Simpang Mengayau, Kulambu, Loro Kecil, Torongkongan and Marasimsim. The development of geotourism will ensure the sustainability and protection of the beaches. The promotion of beach geotourism could be carried out together with that at other potential geotourism sites such as the Tanjung Simpang Mengayau (Tip of Borneo) and the Kampung Minyak oil seeps. The study of beaches for geotourism development is an innovative way to add-value to their existing aesthetic attraction in order to enhance and sustain the tourism industry in the State.

Table 3: Evaluation of the geotourism potential of the beaches in Northern Sabah, Malaysia.

<table>
<thead>
<tr>
<th>Name of Beach</th>
<th>Main Geological Heritage Resources</th>
<th>Evaluation of Geotourism Potential</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampung Kuala Tajau</td>
<td>Linear beach, sandy sediment.</td>
<td>Education on coastal erosional and depositional processes.</td>
<td>Suitable for various beach recreational activities.</td>
</tr>
<tr>
<td>Sampaping</td>
<td>Linear beach, sandy sediment, remnant cliffs.</td>
<td>Education on coastal erosional and depositional processes.</td>
<td>Suitable for various beach recreational activities.</td>
</tr>
<tr>
<td>Tanjung Simpang Mengayau</td>
<td>Pocket beach, sandy to pebbly sediment, unique pink sand (garnet).</td>
<td>Research on formation of various coastal features and processes, source of pink sand.</td>
<td>Suitable for various beach recreational activities.</td>
</tr>
<tr>
<td>Kosuhi</td>
<td>Linear beach, extensive sandy sediment.</td>
<td>Education on coastal erosional and depositional processes.</td>
<td>Suitable for various beach recreational activities.</td>
</tr>
<tr>
<td>Pongugadan</td>
<td>Pocket beach, sandy sediment, cliffs, karren-like feature.</td>
<td>Education on coastal erosional and depositional processes.</td>
<td>Suitable for various beach recreational activities.</td>
</tr>
<tr>
<td>Bawang Jamal</td>
<td>Linear beach, sandy sediment.</td>
<td>Education on coastal erosional and depositional processes.</td>
<td>Suitable for various beach recreational activities.</td>
</tr>
<tr>
<td>Kulambu</td>
<td>Linear beach, sandy sediment, remnant island (Pulau Kulambu), tombolo, pocket beach.</td>
<td>Research on formation of various coastal features and processes.</td>
<td>Suitable for various beach recreational activities.</td>
</tr>
<tr>
<td>Loro Kecil</td>
<td>Embayed beach, sandy sediment, cliff.</td>
<td>Research on formation of embayed beach.</td>
<td>Education on coastal erosional and depositional processes.</td>
</tr>
<tr>
<td>Kamihang</td>
<td>Embayed beach, sandy sediment, cliff.</td>
<td>-</td>
<td>Education on coastal erosional and depositional processes.</td>
</tr>
<tr>
<td>Sikuati</td>
<td>Linear beach, extensive sandy sediment, terrace beach.</td>
<td>Research on terrace beach.</td>
<td>Education on coastal erosional and depositional processes.</td>
</tr>
<tr>
<td>Torongkongan</td>
<td>Linear beach, extensive sandy sediment, black sandy patch (chromite, zircon), remnant cliff, rocky shore.</td>
<td>Research on formation of various coastal features and processes, source of black sand.</td>
<td>Education on coastal erosional and depositional processes.</td>
</tr>
<tr>
<td>Teluk Agal</td>
<td>Embayed beach, sandy sediment, cliff.</td>
<td>-</td>
<td>Education on coastal erosional and depositional processes.</td>
</tr>
<tr>
<td>Marasimsim</td>
<td>Linear beach, sandy to pebbly sediment, unique black sand (chromite).</td>
<td>Research on formation of various coastal features and processes, source of black sand.</td>
<td>Education on coastal erosional and depositional processes.</td>
</tr>
</tbody>
</table>

It is recommended that the beaches of Northern Sabah to be conserved so as to protect the beautiful landscapes. Geotourism could be promoted on some of the beaches such as Tanjung Simpang Mengayau, Kulambu, Loro Kecil, Torongkongan and Marasimsim. The development of geotourism will ensure the sustainability and protection of the beaches. The promotion of beach geotourism could be carried out together with that at other potential geotourism sites such as the Tanjung Simpang Mengayau (Tip of Borneo) and the Kampung Minyak oil seeps. The study of beaches for geotourism development is an innovative way to add-value to their existing aesthetic attraction in order to enhance and sustain the tourism industry in the State.
REFERENCES

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ASEAN Mineral Resources Information System using FOSS and OGC-based standards

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Abstract: Highly accessible mineral resources information encourages investment and more sustainable utilization of mineral resources. The Geological Survey of Japan, AIST developed the web based ASEAN Mineral Resources Information System using Free and Open Source Software (FOSS) and the Open Geospatial Consortium (OGC) standards. The use of FOSS and OGC compliant standards aims to make the mineral resources information system cost efficient, interoperable and user friendly. The developed system is composed of 3 modules which are the Database, Web Services and the Web Portal. The Database module is mainly PostGIS, a PostGreSQL open source object-relational database management system software. It supports simple features defined by OGC and simple Sequential Query Language (SQL). The Database module is a distributed database system comprising the individual mineral resources database of each country in the ASEAN region. It also includes the database of the geological map of East Asia and some ASTER and ALOS satellite images of the Geological Survey of Japan. The Web Service module is composed of the Web Processing Service (WPS) and Web Map Service (WMS). WPS handles the database maintenance and queries, including the data upload and download. WMS provides remote access to the mineral resources databases. It generates map images to be displayed on the Web Portal module. The Web Portal Module provides the web based Graphic User Interface (GUI) of the developed information system. It could also display map images provided by the Web Services module. The portal is named the ASOMM WebGIS system. This project aims to make mineral resources information in the ASEAN region easily available for use by policy makers, investors and the general public.

Keywords: Mineral Resources Information System, database, ASEAN

INTRODUCTION
The mineral sector has always been considered to be an engine for greater economic growth and social progress in the ASEAN region. Minerals in the region account for a relatively large shares of world reserves (Short et al., 2005). Easily accessible information about mineral resources enhances trade and investment in the sector. It also encourages environmentally sound and socially responsible mineral development practices and optimum utilization of mineral resources. A public that is well informed about this important resource will also discourage corruption.

As the economic integration of the ASEAN region progresses, unimpairment of capital and know-how across the region should be guaranteed. This requires the creation of an information infrastructure that facilitates unhindered and efficient sharing of information. This project focuses on the creation of an information infrastructure that promotes sharing of information about mineral resources across the region, an initiative of the ASEAN Senior Officials Meeting on Minerals (ASOMM). The project involves the use of internationally accepted standards and cost efficient software. Specifically, this project is aimed at creating the web based ASEAN mineral resources information system using Free and Open Source Software (FOSS) and Open Geospatial Consortium Standards (OGC). OGC standards are technical documents that detail interfaces or encodings into their products and services (OGC, 2012a). The use of OGC standards and FOSS makes this information system cost efficient and interoperable. The develop system was also designed to be very accessible and easy to use. The ultimate objective of this project is to create an information technology platform for easy sharing and access of mineral resources information among ASEAN countries. Successful implementation of this project will make mineral resources information easily available for use by policy makers, investors and the general public.

ASEAN MINERAL RESOURCES INFORMATION SYSTEM
The ASEAN Mineral Resources Information System is a complete web-based system for storing, sharing and viewing mineral resources information in the ASEAN region. The system was developed following the application development guidelines of GeoGrid, National Institute of Advanced Industrial Science and Technology (AIST) which are as follows:
1) user-friendly
2) cost efficient
3) interoperable.

The system is composed of 3 modules which are the Database, Web Services and the Web Portal as shown in Figure 1.
DATABASE MODULE

The database module is mainly a PostGIS database system. PostGIS is PostGreSQL open source object-relational database management system software that supports simple features defined by OGC, and simple feature Sequential Query Language (SQL). PostGIS supports simple and complex spatial queries, functionalities that are very important for handling mineral resources related information. The database maintenance and queries are initiated by Web Processing Service requests from the Web Services Module. The database module of the ASEAN Mineral Resources Information System is a distributed database system consisting of the individual mineral resource databases of the countries in the ASEAN region. The composite database also includes the geological map of East Asia and some ASTER and ALOS satellite images databases of the Geological Survey of Japan (Figure 2). Mineral resources information from individual databases is served as Web Map Service s, which receives requests from the Web Services module.

WEB SERVICES MODULE

Web Service Module follows the Open Geospatial Consortium standards (OGC). The module is composed mainly of the Web Processing Service and the Web Map Service (WMS). It receives requests from the Web Portal module, processes the requests and implements them on the Database Module. The WPS handles the database maintenance and queries, including the data upload and download. The WPS component of this module is mostly implemented using PHP scripts. WMS is a standard protocol that provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases (OGC, 2012b). WMS provides map images online generated by mapserver software, in response to a GetMap request, using a GIS database (Figure 2). WMS provides remote access to the databases in the Database module, and generates map images for display on the Web Portal module.

WEB PORTAL MODULE

The Web Portal Module provides the web based Graphic User Interface (GUI) of the ASEAN Mineral Resources Information System. The portal is named ASOMM WebGIS system. It provides the interface and forms for the users to upload and download data, query the database and display the maps. Forms are provided for simple and complex spatial queries. Figure 4 shows the main page and main menu of the portal.

The portal uses the open source Openlayers Javascript libraries (OSGeo, 2012) for displaying maps on the site. The map images displayed are generated from the GetMap requests pointed to the WMS servers on the Web Services module. The site could display any kind of geographically referenced data including satellite images. It provides the standard GIS functions for manipulating maps. Figure 5 shows the map display page of the site showing metallic mineral occurrence in ASEAN countries overlaid over the geological map covering East Asia. Database queries could also be performed easily using the site. Figure 6 shows a single mineral query form of ASOMM WebGIS. Query results could be downloaded in ArcGIS shape file or KML formats. Figure 7 shows the downloaded query results in KML format displayed using Google Earth.

SUMMARY

The ASEAN Mineral Resources Information System is a web-based application that provides a cost efficient and
ASEAN Mineral Resources Information System using FOSS and OGC-based standards

Figure 4: The main page of ASOMM WebGIS.

Figure 5: The map display page of the ASOMM WebGIS.

Figure 6: The single mineral query form of ASOMM WebGIS.
easy to use information technology platform for sharing and accessing mineral resources information in the ASEAN region. It is composed of independent modules which are the Database, Web Services and the Web Portal. A series of trial versions are presently being tested with promising results. The database module of the system is currently being updated, mainly the mineral information contents of the database, with the cooperation of the countries in the ASEAN region. The Geological survey of Japan has been conducting a series of training sessions and workshops about FOSS based database system development and Web Services following OGC standards in the ASEAN region. The main objective of these training sessions is to make ASEAN countries acquire skills in creating and maintaining their own databases, and formulate OGC based web services to serve their mineral resource data to ASSOM WebGIS portal. These human resource development activities are also very important for the creation of cheap and user friendly geoinformation platforms where people can access, integrate and analyze a wide array of data sets to make them understand the earth easily and accurately.

REFERENCES

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Geoheritage values of the Dong Van Karst Plateau Geopark: A quantitative geomorphological and topographic analysis

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2General Department of Geology and Minerals of Viet Nam, No. 6, Pham Ngú Lào, Hanoi
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Abstract: The main purpose of this study is to analyse the geomorphological characteristics of the Dong Van Karst Plateau Geopark (DVKPG) in the Ha Giang province of Vietnam. A digital elevation model (DEM) was generated using SPOT5 imagery and elevation and slope maps were then extracted from the DEM. A geological map at the scale of 1:200,000 was constructed and used for analyzing and visualizing the carbonate rock in three dimensions. The results show that there are two types of topographic development in the study area. The first, formed by tectonic movement and affected by major faults, is distributed in a NW–SE direction. The second was formed by exogenous geomorphological processes and influenced by both major and faults. It is distributed mainly in a NE–SW direction. Geological analysis indicates that ten stratigraphic formations crop out in the study area but only six of these have correlations with karst landscapes. Carbonate rocks are mainly distributed in the Dong Van district. They cover an area of 329.7 km² (71.7% of the entire district and 36.5% of study area). In contrast, there is few carbonate rocks in the Quan Ba district. In the case of slope, the slope angels from 15–30° cover about 53.5% of the study area. There are 1261 karst sinkholes in the study area with an average density of 1.4 sinkholes per km².

Keywords: Dong Van, Ha Giang, karst plateau, geopark

INTRODUCTION

The Global Network of National Geoparks was established under the aegis of UNESCO in 2004 aimed at protecting some of the world’s most spectacular and important geological sites. A geopark is defined as a nationally protected area containing a number of geological heritage sites of particular significance, rarity or aesthetic appeal and these heritage sites are developed as part of an integrated concept of conservation, education and sustainable development (UNESCO, 2006). According to Azman et al., (2010), the main objectives of a geopark are (1) protection and conservation, (2) tourism-related infrastructural development and (3) socio-economic development. Therefore scientific studies in these geoparks may present opportunities to understand important events in their geo-history and supply additional information on permanent and protected sites where scientific ideas can be tested for generations to come (Kusky et al., 2010). The main objective of this study was to undertake quantitative analyses of the geomorphology and topography of the geoheritage of the Dong Van karst plateau in the Ha Giang province of Vietnam.

STUDY AREA

The Dong Van karst plateau Geopark (Figure 1) is located in Ha Giang province, in the northwestern part of Vietnam. It covers an area of 2380 km² in four administrative districts: Dong Van (460 km²), Meo Vac (577.6 km²), Yen Minh (785.2 km²), and Quan Ba (557.2 km²). The altitude varies from 174 to 2,265 m.

DATA AND ANALYSIS

Digital elevation model and derivatives

A digital elevation model was generated from SPOT5 satellite imagery with a resolution of 15 m. Based on the DEM, geomorphometric data was extracted using ArcGIS 10.0 software. The elevation map was constructed with elevation seven classes: 100–300 m; 300–600 m; 600–900 m; 900–1200 m; 1200–1500 m; 1500–2000 m and >2000 m. The three elevation classes (600–900 m; 900–1200 m; 1200–1500 m) cover an area of 1,765 km² (74.2% of the study area) and contain impressive landscape characteristics. In contrast, the elevation class >2000 m covers an area of only 3.4 km², distributed mainly in the rear of the plateau. The elevation class of 600–900 m contains terrestrial (non-karstic) landscapes with residual towers and cones on the
slopes, and carren slopes. This elevation class is adjacent to karst areas and terrestrial landscapes make a contrast to surrounding karstic landscapes. For the elevation classes 900-1200 m and 1200-1500 m, karstic landscape features are mainly steep cliffs, cones and towers that are distributed on the top of mountain chains. In order to show the variation of elevation in the DVPKG, three NW trending cross-sections (Figure 3) were constructed.

The slope angle map (Figure 4) was constructed with 7 classes. Characteristics of the slope angle classes are indicated in Table 2.

The areas of steep slope (15°-30°) account for 53.9% of the study area. They are characterised by limestone mountains with non-karst landscapes, stone forests and residual cones on the slopes. The inclined slope (5°-15°) and comparatively steep slope (30°-45°) cover areas that account for around 21.9% and 16.5% of the study area, respectively. The very gradual slopes (0° - 2°) and gradual
slopes (2° - 5°) are mainly located in alluvial flats and terraces along the Mien river. These areas contain karst valleys. Generally, the slope angle map represents a high contrast of landscape within the geoheritage area.

**Geological map**

The geological map (Figure 6) was constructed using the Bao Lac and Ma Quan geological sheet maps at the scale of 1:200,000 and was used for analyzing the distribution of carbonate rocks. Lithological formations in the map were updated using the SPOT5 satellite images. Fieldwork was conducted to verify the results. A total of 10 lithological formations were represented. They are Chang Pung (E, cp), Lutxia (O, lx), Tow Tat (D, tt), Bac Son (C-P, bs), Dong Dang (P, dd), Hong Ngai (T, hn) formations and 2) non-carbonate rock with non-karst landscape. Using DEM, the distributions of different types of rock in correlation with the elevation classes was analysed. Distribution of the carbonate rocks are shown in Figure 7. The carbonate rock covers of 71.7% area of the Dong Van district, but only 19.5 % in the Quan Ba district (Table 3).

In this study, the lithological formations were divided in to 2 groups: 1) carbonate rock with karst landscape including Chang Pung (E, cp), Lutxia (O, lx), Tow Tat (D, tt), Bac Son (C-P, bs), Dong Dang (P, dd), and Hong Ngai (T, hn) formations and 2) non-carbonate rock with non-karst landscape. Using DEM, the distributions of different types of rock in correlation with the elevation classes was analysed. Distribution of the carbonate rocks are shown in Figure 7. The carbonate rock covers of 71.7% area of the Dong Van district, but only 19.5 % in the Quan Ba district (Table 3).

**Table 2.** Characteristics of the slope classes.

<table>
<thead>
<tr>
<th>No.</th>
<th>Elevation classes (m)</th>
<th>Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very gradual (0° - 2°)</td>
<td>31.3</td>
<td>1.32</td>
</tr>
<tr>
<td>2</td>
<td>Gradual (2° - 5°)</td>
<td>92.4</td>
<td>3.88</td>
</tr>
<tr>
<td>3</td>
<td>Inclined (5°-15°)</td>
<td>522.3</td>
<td>21.94</td>
</tr>
<tr>
<td>4</td>
<td>Steep (15°-30°)</td>
<td>1,283.8</td>
<td>53.94</td>
</tr>
<tr>
<td>5</td>
<td>Comparatively steep (30°-45°)</td>
<td>392.5</td>
<td>16.49</td>
</tr>
<tr>
<td>6</td>
<td>Very steep (45°-60°)</td>
<td>56.8</td>
<td>2.39</td>
</tr>
<tr>
<td>7</td>
<td>Abrupt (&gt; 60°)</td>
<td>0.8</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Table 3.** Statistics of carbonate rocks in the study area.

<table>
<thead>
<tr>
<th>No.</th>
<th>District</th>
<th>Area (km²)</th>
<th>%</th>
<th>Areas with carbonate rocks (km²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dong Van</td>
<td>460.0</td>
<td>71.7</td>
<td>329.7</td>
<td>36.5</td>
</tr>
<tr>
<td>2</td>
<td>Meo Vac</td>
<td>577.6</td>
<td>49.7</td>
<td>287.1</td>
<td>31.8</td>
</tr>
<tr>
<td>3</td>
<td>Yen Minh</td>
<td>785.2</td>
<td>22.7</td>
<td>178.2</td>
<td>19.7</td>
</tr>
<tr>
<td>4</td>
<td>Quan Ba</td>
<td>557.2</td>
<td>19.5</td>
<td>108.5</td>
<td>12.0</td>
</tr>
</tbody>
</table>

The carbonate rocks with karst landscape cover an area of 903.5 km², distributed mainly in Dong Van and Meo Vac districts. Carbonate rocks interbedded with non-
Pham Viet Ha, Tran Tan Van, Quach Duc Tin, Ho Huu Hieu, Nguyen Dinh Tuan & Nguyen Quang Hung


carbonate rocks are distributed in the districts of Quan Ba and Yen Minh. These areas are characterized by diversity in landscape, geological history and cave development and therefore represent the geoheritage values of the DVKPG.

Distribution analysis of karst sinkholes and caves

Karst funnels were interpreted by using SPOT5 imagery, DEMs and topographic map. The location and shape of caves were checked and mapped in field surveys by experts from the Vietnam Institute of Geosciences and Mineral Resources (VIGMR) and Belgian colleagues. A total of 1261 karst sinkholes and 62 caves were identified in the study area (Figure 7). An average density of karst sinkholes per 1 km² is 1.4. The distribution of sinkholes and caves in correlates with elevation classes as shown in Table 4.

The elevation class of 1200 – 1500 m has the highest density of sinkholes (58.8%) and a high density of caves (25.8%). The highest density of caves is in the elevation class of 300-600 m. In contrast, there are no caves or sinkholes in the elevation classes of 0-300 m and >2000 m.

Lineament analysis

In order to explore the trend of topographic features in the study area, a lineament analysis was carried out. Using the DEM, eight hillshade maps were created and used to extract lineaments in the study area. This process was carried out using PCI software.

Figure 9 shows positive lineament map of the study area. The positive lineament map represents elevated topography, topographic ridges and tectonic cliffs. In general, the positive lineaments trend NW. This is the direction of trend of fault scarps and lithological boundaries in the study area. This is also the major trend of topographic development and tectonic features in Vietnam.

A negative lineament map that represents topographic features such as valleys, rivers and streams is shown in Figure 10. In general, the density of negative lineaments is higher than that of positive lineaments. The negative lineaments are mainly short and discontinuous and trend in a NE direction. This indicates that the topography was formed by exogenous geomorphological processes (such as slope erosion processes) or formed by a combination of small faults (trending NE) with major faults (trending NW).

The DEM is also used as a basic data layer to show the distribution of geoheritage sites in three dimensions in the study area (Figure 10).

CONCLUSION

In this study, the geoheritage characteristics of the Dong Van Karst Plateau Geopark were investigated through geomorphological quantitative analysis. A digital elevation model, elevation map, slope angle map and geological map were used in the analysis. The results show that the study area mainly lies within the three elevation classes (600-900 m; 900-1200 m; 1200-1600 m) which have special landscape characteristics. There are 10 lithological formations that crop

Table 4: Distribution of sinkholes and caves in correlation with elevation classes.

<table>
<thead>
<tr>
<th>No</th>
<th>Elevation classes (m)</th>
<th>Number of caves</th>
<th>%</th>
<th>Number of sinkholes</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-300</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>300-600</td>
<td>18</td>
<td>29.0</td>
<td>9</td>
<td>0.7</td>
</tr>
<tr>
<td>3</td>
<td>600-900</td>
<td>13</td>
<td>21.0</td>
<td>43</td>
<td>3.4</td>
</tr>
<tr>
<td>4</td>
<td>900-1200</td>
<td>9</td>
<td>14.5</td>
<td>281</td>
<td>22.3</td>
</tr>
<tr>
<td>5</td>
<td>1200-1500</td>
<td>16</td>
<td>25.8</td>
<td>742</td>
<td>58.8</td>
</tr>
<tr>
<td>6</td>
<td>1500-2000</td>
<td>6</td>
<td>9.7</td>
<td>186</td>
<td>14.8</td>
</tr>
<tr>
<td>7</td>
<td>&gt; 2000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 8: Location of karst sinkholes and caves in the studied area.

Figure 9: Positive lineaments map of the studied area.

Figure 10: Negative lineaments map of the studied area.
out in the study area but only six of these were determined as karst landscape-forming areas. Carbonate rocks are mainly distributed in the Dong Van district.

Areas of steep slopes (15° - 30°) cover about 53.5% of the study area and display impressive plateau characteristics. There are 1261 karst sinkholes and 62 caves distributed in the study area. Topography in the study area was influenced by tectonic movement including major faulting and exogenous geomorphological processes.

ACKNOWLEDGEMENT

The authors would like to thank the Vietnam Institute of Geosciences and Mineral Resources (VIGMR) for permission to use the results of the project KC. 08. 20: “Investigating and researching the potential of geoheritage and the prospects for building Geopark in North Vietnam”.

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Geological interpretation based on satellite imagery: Updating geological maps of Indonesia to 1:50,000 map scale

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Abstract: Indonesia is an archipelago comprising over 13,700 islands and a total territory of more than seven million km². Geologically, the earth’s crust in this region displays several special features as a result of the collision of three mega plates, Eurasia, Indiaustralia and Pacific. Inter-related features such as island arcs, volcanic belts, seismic zones, gravity anomaly zones, and deep sea trenches resulted from the collision process.

Knowledge of the regional geology of the entire Indonesian region was greatly advanced by the completion of systematic geological mapping at the scale of 1: 100,000 of Jawa and Madura Islands and at the scale of 1:250,000 on the other islands. A great quantity of data concerning various aspects of geology and geophysics, collected during more than 50 years, has accumulated.

The need for geological information at a larger scale, however, is now increasing. This demand is related to national development programs as well as to Indonesia’s industrial growth. Exploration for energy, mineral and ground water resources, the generation of information for land-use planning and geological hazard mitigation will all benefit from the availability of geological maps at the scale of 1:50,000. Therefore, since 2010 the Geological Agency, Ministry of Energy and Mineral Resources of Republic of Indonesia, has initiated new geological mapping project starting with geological interpretation based on data from satellite imagery combined with existing field data.

The methodology for geological interpretation is based on visual interpretation of remote sensing data of morpho-structural aspects of the imagery combined with field data existing in a GIS environment. Interpretation keys were determined in order to provide guidelines on how to recognize certain geological objects on satellite imagery. Preparation of data including the creation of shaded relief of the digital surface model (DSM) and intensity layer of orthorectified images (ORRI), contour generation, color composite of optical images, drainage pattern generation and fusion of passive and active remotely-sensed images.

Keywords: geological map, remote sensing, Indonesia

BACKGROUND

Indonesia is the largest archipelagic country in the world, which has five major islands and about 300 smaller island groups. Altogether there are more than 13,700 islands. The archipelago is situated at a junction between two oceans, the Pacific and Indian oceans, and bridges two continents, the Asian and Australian continents. Indonesia has a total area of 9.8 million km², of which more than 7.9 million km² is ocean.

From the point of view of earth science, Indonesia has various unique geological phenomena due to its location at the triple junction of three mega-plates: Eurasia, Indiaustralia and Pacific (Figure 1). The involvement of these three mega-plates interaction with each other, has resulted in the formation of double island arcs, K-shaped islands, active volcanic belts, active seismic zones, deep sea trenches and the negative gravity anomalies. Morphologically this condition has resulted in a distinct and varied relief with high mountain belts, deep valleys, and high cliffs. Moreover, due to this complex geological history, Indonesia also has a huge amount of geological resources including oil and gas, coal, gold, diamonds, iron, nickel and other mineral resources such as clay and gem stones. However, the potency of geo-hazards such as earthquakes, landslides, volcanic activity, floods and tsunami are also a major concern.

The knowledge of the regional geology of the entire Indonesian region has been greatly advanced following the completion of systematic geological mapping in 1995. Much data concerning all aspects of geology and geophysics has been acquired during more than 50 years of geological mapping. From the compiled geological data, it is possible to perceive the distribution of various kinds of rock units ranging in age from Palaeozoic, through Mesozoic to Cenozoic. The rock units consist of sedimentary, carbonate, and volcanic rocks which are subdivided into broad groups based on their ages, respectively; Quaternary, Tertiary, and Pre-Tertiary ages. In addition, based on the rock lithology and origin, some rocks are grouped into plutonic, ophiolite, metamorphic and mélange rocks (Figure 2).

DEVELOPMENT OF GEOLOGICAL INFORMATION

The Center for Geological Survey, one of the units of the Geological Agency of the Ministry of Energy and Mineral Resources, continues its activities in mapping and research on various aspects of geology and geophysics in the entire Indonesian region, which originally was initiated...
in 1850 by previous research institutions. The results of the research, investigation and mapping have become national assets represented by all the the geological and geophysical data which are collected in the Geological Museum and Library within the Center for Geological Survey of the Geological Agency that was established in 1979.

The above activities in mapping and research of many aspects of geology and geophysics were diversified and reinvigorated with the commencement of the Indonesian Five Year Development Plan in 1969. Systematic mapping which initially was only applied to geology and geophysics, were later been applied to construct other thematic maps, such as seismotectonics, geomorphology, and Quaternary geology. The research in aspects of geology and geophysics also includes topics such as paleontology, sedimentology, petrology, geochemistry, gravity, paleo-magnetics, radiometric dating, rock physics, and structural geology.

Indonesia has now succeeded in the completion of systematic geological mapping at the scale of 1:100,000 in Jawa and Madura Island and 1:250,000 in the islands outside Jawa and Madura together with the 1:1,000,000 map of the entire Indonesian region. Based on these systematic maps, geological and thematic maps at the scale of 1:5,000,000 have been compiled.

The need of geological information in Indonesia at a larger scale is now increasing. This demand is related to national development programs as well to Indonesia’s industrial growth. Exploration for energy, mineral and ground water resources, information required to aid land use planning and geological hazard avoidance and mitigation are all issues that argue for the development of geological maps at the scale of at least 1:50,000. In order to answer this demand, the Geological Agency as an Institution that is responsible for geological survey, has been conducting geological mapping program, which is planned to last from year 2010 until 2025. This program was initiated employing geological interpretation based on satellite imagery combined with field data collected during from previous work. Later on, validation will be conducted with ground truth in addition to stratigraphic study and the collection of new field data.

**Table 1**: The extent of geologic units on land (1,925,814 km²), calculated using grid by Handoko (Sukamto, 2000).

<table>
<thead>
<tr>
<th>No.</th>
<th>GEOLOGICAL UNIT</th>
<th>EXTENT (± km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Quaternary sediments</td>
<td>570,798</td>
</tr>
<tr>
<td>2</td>
<td>Quaternary carbonates</td>
<td>15,811</td>
</tr>
<tr>
<td>3</td>
<td>Quaternary volcanics</td>
<td>140,860</td>
</tr>
<tr>
<td>4</td>
<td>Tertiary sediments</td>
<td>474,513</td>
</tr>
<tr>
<td>5</td>
<td>Tertiary carbonates</td>
<td>119,877</td>
</tr>
<tr>
<td>6</td>
<td>Tertiary volcanics</td>
<td>118,349</td>
</tr>
<tr>
<td>7</td>
<td>Tertiary-Cretaceous Sediments</td>
<td>98,229</td>
</tr>
<tr>
<td>8</td>
<td>Mesozoic sediments</td>
<td>99,901</td>
</tr>
<tr>
<td>9</td>
<td>Mesozoic carbonates</td>
<td>18,344</td>
</tr>
<tr>
<td>10</td>
<td>Mesozoic volcanics</td>
<td>21,204</td>
</tr>
<tr>
<td>11</td>
<td>Paleozoic rocks</td>
<td>45,783</td>
</tr>
<tr>
<td>12</td>
<td>Metamorphic rocks</td>
<td>82,247</td>
</tr>
<tr>
<td>13</td>
<td>Plutonic rocks</td>
<td>66,442</td>
</tr>
<tr>
<td>14</td>
<td>Melange rocks</td>
<td>31,115</td>
</tr>
<tr>
<td>15</td>
<td>Ophiolitic rocks</td>
<td>36,970</td>
</tr>
</tbody>
</table>

The extent of geologic units on land which covers an area of 1,952,814 km². The extent of each geologic unit is measured on the basis of the distribution of the unit which appears on the Geological Map of Indonesia at scale 1:5,000,000 (GRDC, 1992). The extent of each geologic unit of Quaternary, Tertiary, Mesozoic and Paleozoic age is shown in Table 1; including geologic units based on their rock association: metamorphic rocks, plutonic rocks, mélange rocks and ophiolitic rocks. This summary information about the geological units, based on the geological eras, is introduced here to give an insight into the potential for mineral and energy resources as well for geohazards that possibly may occur within each geological unit.

The distribution of these various geological units may be used in evaluating the veracity of the opinion that Indonesia remains well endowed with mineral and energy resources. Peat deposits, for example, have been estimated to be over...
2 m thick over a total area of 88,015 km² in Sumatera, Kalimantan and Papua (Soedradjat et al., 1991) in areas (±570,798 km²) underlain by Quaternary sedimentary rocks. Coal which originally was estimated to have a reserve of ±32.1 billion tons (Soedradjat et al., 1991), later rising to an estimated ±36.34 billion tons (Suhala & Yoesoef, 1995), is found in Tertiary sedimentary rocks, which have an areal extent of ±474,513 km². Tertiary sedimentary rocks can also be used to re-evaluate sedimentary basins that may contain hydrocarbon reserves. Quaternary, Tertiary and Mesozoic carbonate rocks as potential raw material for Portland cement and other industries are of very great extent (±154,032 km²). Limestone layers may attain thickness of hundreds of meters, so that when the average thickness is estimated at only 100 m, the limestone would have a reserve of at least 39.28 trillion tons (specific weight 2.55). This figure is much higher than the previous estimated reserve of limestone which was only ±20 billion tons (Soedradjat et al., 1991).

Various kinds of geological units of which the extent has been measured above may provide information for the further exploration of various kinds of metallic minerals, industrial minerals, coal and peat, petroleum and natural gas. More intensive prospecting is still needed to explore possible potential resources and this requires the detail provided by geological maps at a larger scale of 1:50,000. Such information on regional geology, which covers the entire Indonesian region is an asset that can be used in further investigation needed for mineral and energy resource evaluation, geohazards and land use planning decisions within a fully self supporting civil society.

**RAPID MAPPING**

In order to accelerate planning and to support national development, the Geological Agency as the institution responsible for national geological survey and mapping, proposed a rapid mapping programme to cover Indonesia’s entire land territory from 2010 until 2025. This programme started with geological mapping based on interpretation of remotely-sensed data combined with existing data in a GIS environment. The programme is categorized as “rapid mapping” because the final target is to complete more than 3700 updated map sheets at the scale of 1:50,000 by 2015. Thereafter, the programme will be continued by a field campaign as a method of verification until 2025. Geological interpretation on the basis of remotely-sensed data combined with the large quantity of geological and geophysical data, which are stored in the Geological Agency can provide a fast and effective way to produce geological maps at the 1:50,000 scale. Combination of an optical dataset (e.g. Landsat ETM, ALOS DAICHI and ASTER) and synthetic aperture radar (e.g. IFSAR, Radarsat-2 and TerraSAR-X) should produce data of outstanding quality for analysing and extracting surface geological phenomena for geological interpretation maps.

The earth’s surface is composed of various lithological units which are reflected in morphological complexity because of the exogenous and endogenous geological processes involved. Morphological features and resultant landforms can be analyzed through field campaigns and also from remotely-sensed data. Interpretation of geological features from remotely-sensed data is aimed to collect geological information for further applications. There are

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*Figure 2:* The geology of Indonesia simplified from the Geological Map of Indonesia, 1:5,000,000 compiled by Geological Agency (GRDC, 1992).
some advantages of using such data as, for example, many remote areas and small islands can be examined quickly and without problems related to accessibility and difficult terrain. Such a rapid mapping program can therefore reduce both time and cost of obtaining detailed initial geological information. However, the program will still need validation in the form of a limited field campaign and the use of specific computer aided tools.

**GEOLOGICAL AND TECHNICAL CHALLENGES**

Development of geological information at larger scales (1:50,000) is a critical issue for the Geological Agency as the institution responsible for systematic national geological survey and mapping in Indonesia. However, resolving this issue involves many practical challenges for the researchers including the huge area of the Indonesian territory, its archipelagic setting, the complexity of its geology and the large number of remote areas involved. As mentioned above, rapidly acquired, remote sensed data can partly resolve some of these challenges.

The quality of the results of image interpretation depends on a number of factors: the interpreter, the image data used, and the guidelines provided. Professional experience, including experience of image interpretation determines the skills of an image-interpreter. A background in geological interpretation is essential in order for the interpreter to extract image features related to geological phenomena. Furthermore, local knowledge, derived from field visits, is required to help in the interpretation. Finally the quality of interpretation guidelines are a large influence, for example standards for the development of Indonesian geologic maps have an important role in ensuring the replicability of work.

Geological interpretation in a tropical terrain is often particularly challenging due to the dense vegetation cover in heterogeneous rain forest and the thickness of weathered soil that renders spectral information for the rock units beneath difficult to recognize. The technical challenge in geological interpretation was how to make the visual interpretation of remotely-sensed data of morpho-structural aspects combine with field data existing in a GIS environment. Interpretation keys needed to be established such as tone/hue, texture, shape, size, pattern, site and association which provide guidelines on how to recognize certain geological objects on satellite imagery. Other aspects used in geological interpretation were landforms, relief, drainage pattern, vegetation and land use.

The aim was to define and delineate the lithology of geological units and recognise geological structures that could be used to analyze and interpret sub-surface conditions and geological relationships. Geological sections relatively crossing or perpendicular to the main geometry of geological structures were made and represented at the surface by contours. Distributions of lithology in the subsurface were interpreted from trends and steepness of slopes as seen on the data images.

Updating geological maps to a larger scale in part focuses on further subdividing the existing mapped geological units by introducing new classes or categories of units. Lineaments, scarp, and land offsets are assigned to geological structures which are categorized as faults, joints, calderas, and bedding traces.

**CRITERIA DATA NEEDED**

The use of remote sensing data for geological application has been applied by the Geological Bureau in Indonesia since the beginning of 1960. In the beginning, the remotely-sensed images were aerial photographs, which were analyzed with stereoscopes to extract information about the surface geology. Advanced technologies have led to the use of better remotely sensed data leading to higher accuracy, precision and detailed graphic and temporal resolution.

Some quality aspects regarding the remotely sensed data that are used during identification of geological features in the Indonesian archipelago are:

1. Technology must take account of the tropical climatic condition in Indonesia.
2. Sensors for data acquisition must cover optical and altitude information.
3. Up-to-date data acquisition and collection are of main concern.
4. Datasets are expected to be processed with the latest technologies in order to achieve a high quality standard of radiometric correction, geometric correction, enhancement, filtering, fusion, and classification.
5. Digital technology will ensure that data is easy to collect, process, duplicate, interpret, analyze, and store.

Several products that can meet acceptable quality standards in geological mapping applications and have been used by The Geological Agency are:

1. **LANDSAT 7 ETM+**; optical satellite observation with orbital height of 705 km, temporal resolution 18 days, swath 185 x 185 km, 7 bands with 30 x 30 m spatial resolutions and 120 m thermal band resolution. Cloud sensitive but having good spectral information for surface geological survey.
   - **ASTER** – Advanced Spaceborne Thermal Emission and Reflection Radiometer; 16 bands of optical earth satellite observation with three sub system of 15 m spatial resolution in visible near infra red (VNIR), 30 m in short wave infra red (SWIR), 90 m spatial resolution in thermal infra red (TIR). This sensor can run oblique scanning to create three dimensional images or create a digital elevation model (DEM).
2. **SRTM** – Shuttle Radar Topography Mission; radar technology with 90 m and 30 m spatial resolutions. Sensors used are C-band and X-band with capabilities of three dimensional representation, cloud penetration, and active sensor which could operate in day and night.
   - **IFSAR** – Interferometry Synthetic Aperture Radar; an airborne radar technology with single-pass mode of acquisition. This sensor produce digital elevation model (DEM) and orthorectified radar image (ORRI). Using X-band technology with 3 cm of wavelength that can penetrate could, haze, dust, rain and night.
IFSAR type II, having spatial resolution of 5 m digital surface model (DSM) with 1 m vertical accuracy and 2 m of horizontal accuracy. Spatial resolution of ORRI product is 1.25 m with 2 m accuracy. IFSAR type I, having spatial resolution of 5 m DSM with 15 – 50 cm vertical accuracy and 1 m of horizontal accuracy. Spatial resolution of ORRI product is 0.625 m with 1 m accuracy.

5. Radarsat-2; Canadian satellite earth observation. Launched in December 2007. Radar technology in orbital height 798 km of sun-synchronous orbit and using C-band and multi polarization of HH, VV, HV and VH. Highest spatial resolution is 1 m in Spotlight Mode, 3 m in Ultra Fine Mode with 100 m position of accuracy.

6. TerraSar-X; German satellite earth observation. Launched in June 2007 and operated since January 2008. Radar technology using X-band and multi polarization of HH, VV, HV and VH. This sensor can operate in day and night and in all weather conditions. TerraSar-X is having 11 days of temporal resolution and 1 m of spatial resolution. There are three modes of data acquisition of TerraSar-X: Spot Light with 1 m of spatial resolution and swath 5 km x 10 km, Strip Map with 3 m of spatial resolution and swath 30 km x 50 km and finally Scan SAR with 18 m of spatial resolution and swath 100 km x 150 km.

**METHODOLOGY**

Geological interpretation based on remotely sensed data required datasets which contain specific information on the earth’s surface. Spectral, altitude and terrain data combined with secondary data regarding morphology, lithology, location of observation, rock units, geochemistry, measurements of strikes and dips and other local attributes comprised the main information used to develop the geological maps. In order to achieve a better performance in interpretation work, it was necessary to develop all information into a database format and process in a GIS environment. Airborne and satellite images, field data, and other secondary data were prepared before geological interpretation started and finally compiled in a preliminary geological map based on remote sensing data interpretation (Figure 3).

**Spatial Data Preparation**

Preparation of data included the creation of shaded relief of the digital surface model (DSM) and intensity layer of orthorectified images (ORRI) taken from satellite radar images which are posted by 50 m to generate contours at a 25 m interval. Data preparation on optical images (Landsat ETM+7) included the creation of orthorectified images and color composites of R/G/B: 4/5/7 in order to highlight geological features in the areas of interest. Image fusion of active and passive satellite imagery was also undertaken in order to create datasets which have both spectral information and highly detailed terrain information. The drainage pattern provides an essential aid in morpho-structural analysis and characterization of landform-lithology in geological interpretation and was derived from the digital surface model data by using particular hydro-enforcement software.

**Development of Existing Data**

A great deal of data from various aspects of geology and geophysics had been accumulated over the previous fifty years. However, development of an inventory of such a great amount of data can be a problem. Data collections which are stored in the library are mostly only available in non-digital format and must be converted into digital data in the form of vector and raster layers together with data attributes.

Building a geological database system referred firstly to broad geological information in particular areas and further pursued into local specific geological information. A database inventory was collected and stored with the information content including information on regional geology, physiography, stratigraphy, geological structures, tectonic setting, and energy and mineral resources. Specific data were stored in vector format in the following hierarchy: project (Prj_ID), map sheet number (sheet_ID), region (region_ID), location number (loc_ID), formation (Fm_ID), symbols (symbol_ID), group (group_ID), class lithology (litho_ID), environment (en_ID), era, period, epoch, fossil, remarks, storage number (sto_ID) and references.

**Figure 3:** Flow chart in updating geological maps of Indonesia to 1:50,000 map scale.
Development of the data base into a GIS environment was necessary in order to support the geological interpretation work and ensure that geological interpretation met a good quality standard and used valid and precise information.

**Geological Interpretation**

Geological interpretation based on satellite images was done by visual interpretation with computer aided software. Specific computer software was used with capabilities of digital image processing, modeling, three dimensional visualization, hydro enforcement, and other visual enhancement techniques. Overlays of various datasets including field data in the form of vector data from previous projects were combined to analyze and develop a preliminary geological map. The interpretation was conducted by overlaying information layers from vector and raster data to extract new detailed geological information.

The method of interpretation was to describe morphological features in a particular area, define the landform genetics, and group into geo-morphological classes. Key elements are shape, pattern, relief, drainage, vegetation and dimension of a particular morphology. Furthermore, other geological features were analyzed on the imagery to differentiate and delineate lithologic units or rock units. Optical satellite images can help to determine relatively younger and older formations or rock units. Combination with high resolution radar images may help to recognize sediments, intrusions, alluvial deposits, metamorphic rocks, and volcanic deposits.

**Validation and Ground Truth**

Ground truth and stratigraphic surveys were undertaken for some area of interest which are believed to be key area in order to validate the geological interpretation results. For this purpose a limited number of objects or areas are selected and visited in the field. The data collected in the field is referred to as ground truth.

Geological interpretation results are inevitably subjective results, therefore it is necessary to validate and cross check the relationships of several ‘interpreted’ formations or rock units in the field. Field identification was also undertaken to collect new authentic data as well as for data validation in order to prove the interpretation results and to check the correlation of rock units or formations in a particular area.

Ground truth investigations were also conducted by visiting areas in which there was ambiguity in the interpretation of results. Furthermore, a more systematic survey was also undertaken by carrying out stratigraphic studies regarding rock formations that have already been interpreted. Survey lines were prepared in order to make new geologic cross sections of the interpretation maps at 1:50,000 scale. The data records that were collected during field survey contain information of station number, date, scale, formation, lithology, thickness, texture, sedimentary structures, composition, fossils, color, strike/dip, sample number, remarks and other descriptive information as thought necessary. All data records were compiled and added as a new information layer in geological interpretation map in order to develop a preliminary geological map at 1:50,000 map scale.

**Digital Layout**

Geological interpretations based on remote sensing data were prepared in a digital map format at 1:50,000 scale. The information includes boundaries of rock units, geological structures, satellite/airborne imagery as base map (both optical and radar data), the geological map at 1:250,000 scale as reference data, topographic map, and legend containing geological symbols (Figure 6).

**UPDATING GEOLOGICAL MAP AT 1:50,000 MAP SCALE**

The project has so far been conducted for two years starting from 2010. Until now it has produced geologic interpretation maps for at least 1700 map sheets. The areas covered areas are Sulawesi, Kalimantan, Bali, Nusa Tenggara and Papua Island. Preparation of the maps in digital layouts was done in 1:50,000 scale. The maps are represented as geological maps based on interpretation of remote sensing data (Figure 4).

In the year 2010 geological interpretation was done for Sulawesi, Bali, and Nusa Tenggara Island with the completion of more than 750 map sheets. The following
year (2011) geological interpretation was done for the island of Kalimantan with the completion of more than 800 map sheets. By mid 2012 the completed geological interpretations have produced more than 200 map sheets which cover Papua Island.

Creation of the larger map scale (1:50,000) divides a sheet of the regional geological map at 1:250,000 scale into 24 sheets of the new geological maps (Figure 5). There are several improvements in the updated geological map of Indonesia regarding detailed information on boundaries of rock units. As compared to the previous geological maps (1:250,000 map scale) rock formations can be divided into several lithological units or rock types. For example, in the new geological interpretation map a sedimentary formation may be subdivided into sandstone, clay and conglomerate/ coarse sandstone. Formations of volcanic rocks may be divided into several classes as lava flows, volcanic breccias, tuffs and lahars. In addition, it may be possible to gain more information on the source of eruption.

Other improvements in geological interpretation at 1:50,000 map scale are the recognition of geological lineaments which appear as minor structures in the imagery.
but could not be found in the field. These were successfully mapped as faults, anticlines and synclines and categorized as new geological information in the interpreted maps. This can be used to describe and to explain the detailed tectonic setting in local areas.

**CONCLUSION**

The methodology for updating existing geological maps to 1:50000 scale has depended on geological interpretation that is based on visual interpretation on remote sensing data, which means that all the interpretation results still need to be validated in the real world. It is therefore necessary to mount a field campaign to cross check the relationships between classes of interpreted rock units and define them based on new and authentic data.

The quality of the result of an image interpretation depends on a number of factors: the interpreter, the image data used, and the guidelines provided. The professional experience and the experience of image interpretation determine the skills of an image-interpreter. Therefore, it is important to define interpretation keys, which provide guidelines on how to recognize certain geological features on satellite imagery and to establish standardization for development of Indonesian geologic maps, thus ensuring the reproducability of the work.

These new geological interpretation maps are not standard geological maps; they are preliminary maps providing guidelines for conducting detailed geological mapping and selecting the priority areas throughout Indonesia in order to accelerate the needs of geological information for national development purposes.

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Global Heritage Stone Resource

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(National Institute of Advanced Industrial Science and Technology)

Abstract: A designation as a Global Heritage Stone Resource (GHSR) provides international recognition of a natural stone resource that has achieved important utilisation in human culture. Stones used for heritage construction and sculptural masterpieces, as well as in utilitarian (yet culturally important) applications, are obvious candidates for the GHSR designation. The GHSR designation is essentially a “world heritage” naming of a stone type. The benefits of the designation include legal definition of an historic stone type, prevention of stone resource depletion, and improved restoration of stone heritage. The GHSR designation may encourage developers of new stone materials to aspire to major projects, international exports, and hence new market opportunities.

The Heritage Stone Task Group (HSTG) was established by the International Union of Geological Sciences (IUGS). The HSTG is also a working party under the Building Stone and Ornamental Rocks Commission of the International Association of Engineering Geology and the Environment (IAEG C-10). The HSTG Board of Management was established in August 2012 at the 34th International Geological Congress. The board is supposed to approve GHSR nominations and promote the designation. Trial nominations are being prepared for Portland Stone and Welsh Slate in the United Kingdom and Podpeč Limestone in Slovenia.

In this paper the Hiroshima-type Granite (Cretaceous), the Koto Rhyolite (Paleogene) and Hakone Andesite (Quaternary), which are some of the most famous building stones for Japanese castles, are introduced as examples for potential GHSR designation. In East and Southeast Asia there will be many stone types with potential to be designated as GHSRs.

Keywords: Global Heritage Stone Resource, heritage building

INTRODUCTION

The Global Heritage Stone Resource (GHSR) designation provides international recognition of a natural stone resource that has achieved important historic utilisation in human culture. Stones used for sculptural masterpieces and in construction of buildings forming an important part of an area’s cultural heritage are obvious candidates for the GHSR designation.

The GHSR designation is essentially a “world heritage” naming of a stone type and the benefits of the designation include legal definition of an historic stone type, prevention of stone resource depletion, and improved restoration of stone heritage. The GHSR designation may also encourage developers of new stone materials to aspire to major projects, international exports, and hence new market opportunities.

THE HERITAGE STONE TASK GROUP

The Heritage Stone Task Group (HSTG) was established by the International Union of Geological Sciences (IUGS). The HSTG is also a working party under the Building Stone and Ornamental Rocks Commission of the International Association of Engineering Geology and the Environment (IAEG C-10). The HSTG Board of Management was established in August 2012 at the 34th International Geological Congress. The board is supposed to approve GHSR nominations and promote the GHSR designation. Currently the Board of Management consists of:

President (ex officio Chair IAEG C-10): Dr Björn Schouenborg (Swedish National Testing and Research Institute, SWEDEN)
Secretary General: Dr Barry J. Cooper (University of South Australia, AUSTRALIA)
Vice President Southern Europe: Professor Dolores Pereira (Institute for Science and Technology Studies, SPAIN)
Vice President Central Europe: Dr Sabina Kramar (Institute for the Protection of Cultural Heritage of Slovenia, SLOVENIA)
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Vice President Africa: Dr Phil Paige-Greene (Infrastructure Engineering CSIR Built Environment, SOUTH AFRICA)
Member: Dr Brian R. Marker (Independent Consultant, UNITED KINGDOM)

Presented at 48th CCOP Annual Session
Trial nominations are being prepared for Portland Stone and Welsh Slate in the United Kingdom and Podpeč Limestone in Slovenia. Table 1 summarises the information called for in seeking citation as a Global Heritage Stone Province.

**POSSIBLE GSRH EXAMPLES IN JAPAN:**

**HISTORY AND GEOLOGY OF STONE WALLS OF SOME TYPICAL JAPANESE CASTLES**

**Osaka Castle**

In 1583, Hideyoshi Toyotomi (1536-1598) began to construct Osaka Castle and the surrounding castle town which is the origin of modern Osaka City, southwest Japan. During his reign, he set up a central administrative network in Osaka, ended the century-long civil wars and established the Toyotomi Government. However, his administration lasted only 15 years and ended with his death. Furthermore, Osaka Castle and town were destroyed by fire in 1615 because of so-called “Osaka Summer War” in which Toyotomi’s allied forces were defeated by Tokugawa’s allied forces. Then the castle was reconstructed between 1620 and 1629 under the rule of the Tokugawa Shogunate.

**Origin of the Osaka Castle stones**

These mainly consist of Cretaceous granite which is widely distributed in southwest Japan, comprising the so-called Hiroshima-type granite, a mainly coarse-grained biotite granite.

The granite building stones, exceeding 500,000 in number, were gathered from various areas including mountainous regions such as the Rokko Mountains.

**Giant stones of the walls of Osaka Castle**

In the walls surrounding the courtyards of the gates of the castle are five stone blocks weighing over 100 tons and 16 blocks weighing more than 50 tons. The largest block is called “Tako-ishi” (“Tako” means octopus and “ishi” means stone in Japanese, Figure 2). Although the front surface of this stone is about 59.43 square meters and it weight is 108...
tons, its thickness is only 70 to 90 cm. This is because of the technical difficulty in cutting and transport (Figure 3) and because the builders wanted to have as wide a surface as possible. Almost all the stone blocks except these huge ones have a depth of between two or three times their width or height.

Hikone Castle

Hikone Castle with its twin moats and chalk-white walls is a hilltop-type castle and has for long been a landmark on the shores of Lake Biwa, the biggest lake in Japan (Figures 4 and 5). It is located in Hikone City, Shiga Prefecture, southwest Japan and is one of the four National Treasure Castles.

History of Hikone Castle

The victory of so-called “the Battle of Sekigahara” in 1600 between Tokugawa and Toyotomi allied forces is one of the most important events in the medieval history of Japan, because it founded the Edo (Tokugawa) Shogunate. On account of his contribution to the victory, Naomasa Ii, one of the Four Guardians of the Tokugawa, was given Sawayama Castle which was built at the beginning of the Kamakura Period (1192-1333) and became the first Lord of the Hikone Domain. His son and successor was permitted by the Tokugawa Shogunate to move the castle to Mt. Hikone because of its convenience and geopolitical importance. In 1604, he commenced the construction and transported much of the mountaintop Sawayama Castle’s stonework and buildings and also the stonework of other nearby old castles so that it is often called “A Recycled Castle” (Figure 6). The castle was completed in 1622.

Geological setting of building stones

The main building stone is from the Koto Rhyolites formed during the igneous activity of the Koto Cauldron (Figures 10 and 11).

Edo Castle

Old Edo castle was built in 15th century. About 130 years later, Ieyasu Tokugawa who unified the nation completely, rebuilt the castle and developed Edo town, one of the

**Figure 2:** “Tako-ishi”

**Figure 3:** Transportation using “Shura”.

**Figure 4:** Castle tower and base stone wall of Hikone Castle.

**Figure 5:** Locality map in and around Hikone Castle.

**Figure 6:** Origin of stones used in Hikone Castle. Many structures such as main keep, towers etc. were taken from other nearby castle because it was necessary to complete the castle as soon as possible in order to monitor the Toyotomi faction after the Battle of Sekigahara. The Hikone Castle stone was taken from the Late Cretaceous-Palaeogene Koto Rhyolite.
biggest town in the world in those days. He enlarged the castle from 1604 to 1635. The castle is now used as the Imperial Palace.

**Edo Castle stones**

Mainly consisting of Quaternary andesite lava, the main quarrying places were several tens to more than 100 km away from Edo such as in Kanagawa and Shizuoka Prefectures.

Manazuru-misaki (“misaki” means peninsula in Japanese) is located 70 km southwestward from Tokyo (in Kanagawa Prefecture) and situated at the northeast end of Izu Peninsula, which is the northern end of Izu-Ogasawara Arc. In this area, Quaternary volcanic products are widely distributed and divided roughly into two groups, that is the Hakone Volcanoes comprising the Hakone Volcano (0.4 Ma to present) and Yugawara Volcano (0.4-0.2 Ma), and the slightly older Usami-Taga Volcanoes. These rock types

**Figure 7:** Stonework of Hikone Castle. Two-storied turret at the gates, which has been repaired many times, especially in 1854. The stone wall of right hand side was made in the original Gobozumi style of stone work. The left side was made by the later Otoshizumi style, because it was destroyed by the earthquake and re-built.

**Figure 8:** Vertical stoneworks, “Tate-ishigaki” in Japanese. “Tate” stands for vertical, and “ishigaki” is stonewall. Vertical stoneworks run from the top to the bottom of a hill to prevent an enemy attack. The top of the stonework is surrounded by a wall with tiles on top.

**Figure 9:** Inner Moat Stonework. Around the lower part of the earthen embankment known as Hachimaki Ishigaki (“Hachimaki” means headband) and Koshimaki Ishigaki (“Koshimaki” means waistband type underwear of women). This type of stonework is rarely seen in the Kansai region, southwest Japan.

**Figure 10:** The Koto Rhyolites consist of welded tuff, pumiceous tuff, silicic pyroclastics including quartz porphyry of the latest Cretaceous to Pleogene.

**Figure 11:** Outcrop and quarry of the Koto Rhyolite.
Figure 12: The keep (left) and stone wall (right) around the moat of Edo Castle.

Figure 13: Structure of the stonewall.

Figure 14: Regular-cut blocks of the stonewall.

Figure 15: Manazuru-misaki Quarry.

Figure 16: Stamped stone block.

Figure 17: Summary of geology in the Atami area including Manazuru peninsula (Oikawa and Ishizuka, 2011).

Figure 18: Index map of three castles.
are mainly olivine-clinopyroxene or olivine-clinopyroxene-orthopyroxene basalt to andesite, and clinopyroxene-orthopyroxene andesite to dacite. Some of them were used as building stones. The typical and famous usage of this stone was to build the stone walls of Edo Castle. Edo is the old name of Tokyo, the capital city of Japan. Edo Castle was built at the beginning of 17th century.

Hon-komatsu Lavas consisting of dacite lava whose K-Ar age is 0.18–0.17 Ma, 0.25 ±0.01 Ma, and Manazuru-misaki Lava consisting of andesite lava and pyroclastics whose K-Ar age is 0.15 ±0.01 Ma, are Hakone Volcanic products, dating from the Middle Pleistocene. Hon-komatsu Lavas are called Hon-komatsu-ishi as the name of building stone, and Manazuru-misaki Lava is called Shin-komatsu-ishi.

FURTHER COMMENT
In the near future, the author proposes to compile and edit a book, “Stone Heritage in East and Southeast Asia”, in cooperation with relevant CCOP Member Countries.

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Middle Permian Radiolarians from the siliceous mudstone block near Pos Blau, Ulu Kelantan and their significance

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Abstract: A large siliceous sedimentary block was exposed in the vicinity Pos Blau, Ulu Kelantan. The block is a part of mélange in the Bentong-Raub Suture Zone. The lower part of the block is composed of ribbon chert and the upper part consists of interbedded siliceous mudstone and tuffaceous mudstone. Five samples from the siliceous mudstone yielded very low number of individuals but fairly high number of species. Fourteen radiolarians taxa were identified. The radiolarians are divided into two assemblage zones namely *Pseudoalbaillella fusiformis* Zone and *Follicucullus monacanthus* Zone indicating Middle Permian age. The occurrence of tuffaceous material in Middle Permian siliceous rock in Peninsular Malaysia was related to volcanic activities as a result of collision between Palaeo-Tethys oceanic crust and the East Malaya terrane. The source of the tuffaceous material was from the East Malaya terrane. The tuffaceous sediments became widespread in Late Permian and Triassic. This indicates the early stage of closing the Palaeo-Tethys.

Keywords: Radiolaria, siliceous mudstone, tuffaceous mudstone, Middle Permian, Palaeo-Tethys

INTRODUCTION

Chert and siliceous mudstone occur as blocks in the mélange of Bentong-Raub Suture Zone. The siliceous rocks yielded Late Devonian, Early Carboniferous and Permian radiolarians. The late Devonian radiolarians were reported from Bentong area (Spiller & Metcalfe, 1995; Spiller, 2002; Basir et al., 2004). Early Carboniferous radiolarians were recorded from Langkap (Spiller & Metcalfe, 1995; Spiller, 2002; Basir & Che Aziz, 1997a). In Pos Blau area, the siliceous sedimentary sequence comprises ribbon chert at the lower part and interbedded siliceous mudstone and tuffaceous mudstone in the upper part. The ribbon chert block yielded well-preserved and high diversity Early Permian radiolarian assemblages belonging to *Pseudoalbaillella lomentaria* and *Pseudoalbaillella scalprata* m. *rhombothoracata* Zones (Spiller & Metcalfe, 1995, Basir & Che Aziz, 1997b; Spiller, 2002). The siliceous and tuffaceous mudstone yielded an early Middle Permian radiolarian assemblage indicating the uppermost part *Pseudoalbaillella longtanensis* – lowermost part of *Pseudoalbaillella globosa* Zones (Spiller & Metcalfe, 1995; Spiller, 2002). Chert and siliceous mudstone represent oceanic sediments. These rocks were folded, faulted and highly deformed. The chert blocks represent the remnant of Palaeo-Tethys.

Recently, twenty two samples of siliceous mudstone were collected from an outcrop of abandoned timber track (Figure 1). The rocks comprise thinly bedded siliceous mudstone interbeds with tuffaceous mudstone and steeply dipping towards southeast. Five samples yielded very low number of individuals but fairly well preserved specimens.

GEOLOGICAL SETTING

The Bentong-Raub suture zone is a belt of mélange consisting of olistromal blocks of oceanic sediments such as chert, siliceous mudstone, tuffaceous mudstone, sandstone, limestone, with minor serpentinite bodies. Some of these rocks are sheared, faulted and embedded in the sheared matrix of mudstone. Tjia & Almashoor (1996) had conducted a detailed mapping of the Bentong-Raub Suture Zone in Southwest Kelantan. The rocks generally strike in a north-south direction and they recorded at least seven tectonic units representing imbricate thrust slices which formed a compressed accretionary prism. They estimated the width of this accretionary prism is at least 18 km. This rock assemblage could be classified as a lithodemic called complex and the most appropriate term is Bentong Complex.

The biggest siliceous sediment block is located at the eastern part of the Bentong-Raub Suture Zone in the
vicinity of Pos Blau. The block extend further south into the oil palm plantation. The size of the block cannot be properly estimated because lacking of outcrop. The chert block exhibits thinly bedded chert interbeds with siliceous mudstone and tuffaceous mudstone. Well bedded ribbon chert is exposed at km 38 Gua Musang-Cameron Highland road.

**DESCRIPTION OF OUTCROP**

The outcrop is located at an abandoned timber track near Pos Blau (4°45’13”N, 101°45’3”E) (Figure 1). The outcrop is approximately 10 m wide consisting of thinly bedded siliceous mudstone interbeds with tuffaceous mudstone. The rocks are highly weathered and steeply dipping towards southeast (Figure 2).

**RESULTS AND DISCUSSION**

Radiolarians and Age

Twenty two samples of siliceous mudstone were collected and only 5 samples yielded quite well-preserved radiolarians. The radiolarians exhibit relatively high specific diversity but low number of individuals. A total of fourteen species radiolarians were identified (Plate 1). Stratigraphic distribution of the species is listed in Figure 3. The radiolarians can be grouped into two assemblage zones i.e. *Pseudoalbaillella fusiformis* Zone and *Follicucullus monacanthus* Zone.

*Pseudoalbaillella fusiformis* Zone

The zone is characterized by the occurrence of *Pseudoalbaillella fusiformis* (Holdsworth and Jones) (Pl. 1, figs. 1,2,3), *Pseudoalbaillella globosa* Ishiga and Imoto (Pl. 1, figs. 4,5,6), *Albaillella cf. asymmetrica* Ishiga and Imoto (Pl.1, fig 7), *Pseudoalbaillella cf. longtanensis* (Sheng and Wang) (Pl.1, fig. 8), *Pseudoalbaillella convexa* Rudenko and Panasenko (Pl. 1, fig. 9), *Pseudoalbaillella cf. longicornis* Ishiga and Imoto (Pl. 1, fig. 10), and *Pseudoalbaillella aidentis* Nishimura and Ishiga (Pl. 1, fig. 11). This zone was proposed by Zhang Ning et al. (2010). The lower
Middle Permian radiolarians from the siliceous mudstone block near Pos Blau, Ulu Kelantan and their significance

Plate 1: Middle Permian radiolarians from Pos Blau, Kelantan. Scale bar is indicated in the parenthesis.
boundary of the zone is based on the first occurrence of *Pseudoalbaillella fusiformis*. This zone is equivalent to the top part of the *Pseudoalbaillella globosa* Zone (Ishiga, 1991) indicative an age of late Raordian, early Middle Permian. The assemblage is recorded from samples BC 18 to BC 20.

**Follicucullus monacanthus Zone**

The zone is marked by the occurrence of zonal marker *Follicucullus monacanthus* (Pl. 1, figs. 12, 13) which restricted to the zone. Other species found are *Latentibifistula asperspongiosa* Sashida and Tonishi (Pl. 1 fig. 14), *Latentibifistula* sp. (Pl. 1, Fig.15), *Hegleria mammilla* Sheng and Wang (Pl. 1, fig. 16), *Gustefana obliqueannulata* Kozur (Pl. 1, fig. 17), *Ruzhenecvispongus girtyi* Nazarov and Ormiston (Pl. 1, fig. 18) and *Latentifistula* sp. (Pl. 1, fig. 19). The assemblage is obtained from samples BC21 and BC22. This assemblage suggests Wordian age, middle Middle Permian.

*Pseudoalbaillella* fusiformis, *Pseudoalbaillella* convexa, *Pseudoalbaillella cf. longicornis*, *Hegleria mammilla*, and *Latentifistula* sp. occur in both zones.

Spiller & Metcalfe (1995) and Spiller (2002) were also discovered *Pseudoalbaillella* cf. *longicornis*, *Pseudoalbaillella* fusiformis, *pseudaloabaillella longtanensis* and *Albaillella asymmetrica* from the tuffaceous argillite and chert near Pos Blau, Kelantan. They assigned the assemblage to the uppermost part *Pseudoalbaillella longtanensis* – lowermost part of *Pseudoalbaillella globosa* Zones. The zone is older than the present material.

**Occurrence of Middle Permian Radiolarians in Peninsular Malaysia**

Middle Permian radiolarians were also reported from the siliceous sediment from Jengka area, Central Pahang (Basir et al., 1995), Kuala Ketil and Pokok Sena, Kedah (Sashida et al., 1995; Basir et al., 2005; Basir, 2008)(Figure 4). Nine species radiolarians were identified i.e. *Entactinia itsukaicheniensis*, *Entactinia* sp., *Hegleria mammilla*, *Hegleria* sp., *Copycyntra* sp., *Copiellintra* sp., *Follicucullus monacanthus*, *Follicucullus japonicus* and *Pseudoalbaillella globosa*. This assemblage was previously assigned to the *Follicucullus japonicus* Zone of Ishiga (1991). *Follicucullus japonicus* Ishiga (1991) is a junior synonym of *Follicucullus porrectus* Rudenko (1984). The assemblage is now included in the *Follicucullus monacanthus* Zone.

In the Western Belt of Peninsular Malaysia, Middle Permian Radiolarians were reported mainly from the Semanggol Formation at Bukit Yoi, Pokok Sena, Kedah (Basir, 2008) and from Bukit Kukus, Kuala Ketil area, south Kedah (Basir et al., 2005). Middle Permian Radiolarians from Bukit Yoi comprise *Pseudoalbaillella globosa* together with *Pseudoalbaillella yanaharenensis*, *Pseudoalbaillella fusiformis*, *Pseudoalbaillella cf. longicornis*, *Latentifistula texana*, *Raciditor inflata*, *Pseudoalbaillella* sp. and *Ishigaum* sp. This assemblage is indicating Roardian in age. Middle Permian *Follicucullus monacanthus* Zone was also reported from Bukit Barak, near Pokok Sena, Kedah (Sashida et al., 1995). In Kuala Ketil area, south Kedah two Middle Permian radiolarians zones were recognized namely *Follicucullus monacanthus* and *Follicucullus porrectus* Zones (Basir et al., 2005). The zones contain very low number of species.

The most common feature shared by the Middle Permian siliceous sediments from the three areas namely Jengka, Pahang; Pos Blau, Kelantan; Bukit Yoi, and Bukit Kukus, Kedah is the occurrence of tuffaceous sediments interbedded with siliceous mudstone. The tuffaceous mudstone was reported from Jengka (Basir et al., 1995), Bukit Kukus (Basir et al., 2005), Bukit Yoi (Basir, 2008) and Pos Blau (Spiller & Metaclfe, 1995; Spiller, 2002). Middle Permian tuffaceous material was also recorded from Northern Johor (Sone et al., 2003) and Bera, south Pahang (Sone & Leman, 2005). This suggests that tuffaceous material was quite widespread in the Middle Permian of Peninsular Malaysia. At Bukit Kukus, Kedah the tuffaceous material was found below the *Pseudoalbaillella scalprata rhombothoracata* Zone in Early Permian (Basir et al., 2005). The tuffaceous material had diluted the siliceous sediments and prevented the formation of radiolarians chert during Middle Permian.

**Tectonics implications**

Paleozoic-Lower Mesozoic sedimentary sequences in Langkawi and Perlis consist of shallow marine environment namely the Machinchang, Setul, Singa, Kubang Pasu and Chuping Formations. The whole sequences were deposited in continental shelf environment. In Kedah, the sedimentary sequences of the Mahang, Kubang Pasu and Semanggol Formations were deposited in deeper water ranging from deep-sea fan (continental rise) to basin environment (Basir, 1999). These formations represent the passive continental margin of the Sibumasu terrane.

Since the Sibumasu terrane was a passive margin, the source of the tuffaceous material was originated from the volcanism in the East Malaya/Indochina terrane. This volcanism was related to an early phase of closing the Palaeo-Tethys where the oceanic plate of the Palaeo-Tethys subducted under the East Malaya/Indochina terrane during Middle Permian. Azman (2009) reported the oldest acid volcanic rock from Pulau Sibu, Johor which indicate an age of 297 Ma, Early Permian. This was probably the source of tuffaceous material in the Permian sediments. The collision took place at Bentong-Raub Suture Zone where the accretionary complex developed (Tjia & Almashoor, 1996).

The occurrence of Middle Permian oceanic sediments (radiolarians bearing siliceous sediments) indicate the Palaeo-Tethys was divided into two depositional basins namely the Semanggol basin in the Western Belt and Semantan/ Gua Musang/Aring basin in Central Belt (Sashida et al., 1995). These basins were separated by Bentong-Raub Suture Zone (Figure 5). The Palaeo-Tethys became narrow and shallow during Triassic where patchy of limestone beds were deposited (Fontaine et al., 1995) and the volcanic activities became more intense in the Central Belt. At the end of Triassic there was an uplifting episode caused by
the emplacement of granite and finally the Palaeo-Tethys diminished.

CONCLUSION

Middle Permian radiolarians from Pos Blau were recovered from the siliceous mudstone interbeds with tuffaceous mudstone. Two radiolarian assemblages were identified namely, *Pseudoalbaillella fusiformis* and *Follicucullus monacanthus* Zones, which represent late Roadian and Wordian age respectively. Similar radiolarian assemblages were also reported in siliceous mudstone associated with tuffaceous sediments from the Semanggol Formation in the Western Belt and in Jengka area Central Belt. Widespread occurrence of tuffaceous material in Western and Central Belts was related to volcanism as a result of collision between Palaeo-Tethys oceanic crust and the East Malaya terrane. The Palaeo-Tethys subducted under the East Malaya terrane, the convergence processes continued and the Palaeo-Tethys became narrower and shallower in Triassic. Finally, Palaeo-Tethys disappeared in Late Triassic by an uplifting episode caused by granite intrusion.

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Beberapa fitur dan tapak bernilai warisan geologi di Pulau Sibu, Mersing, Johor

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Geological heritage values of several features and sites of Pulau Sibu, Mersing, Johor

Abstract: There are four sites in Pulau Sibu that have geological heritage value and potential to be geosite namely Pantai Tanjung Musoh, Pantai Tanjung Semanggar, Pantai Berkembar (Twin Beach) and Tanjung Keramat. Pantai Tanjung Musoh and Pantai Tanjung Semanggar have various pyroclastic rocks and lava outcrop and can be part of type location for Sedili Formation. Pantai Berkembar (Twin Beach) and Tanjung Keramat have morphology from erosion and deposition processes such as tombolo, sea arch and sea stack. All these sites are tourist attraction for activities such as scuba diving, snorkeling or picnic. Geological conservation and geotourism concepts need to be applied to ensure both conservation and development could work hand in hand.

Keywords: geological heritage, geological conservation, geotourism, Pulau Sibu

PENGENALAN


Sumber geologi yang terdiri daripada batuan, mineral, fosil dan rupabumi merupakan aset kekayaan negara. Pembentukannya yang mengambil masa jutaan tahun akan musnah dalam masa yang singkat sekiranya tiada langkah-langkah pemuliharaan diambil. Pembangunan pada beberapa dekad yang lalu lebih memfokus ke arah pembangunan prasarana dan eksplorasi sumber secara meluas hingga melampaui tampungan alam sekitarnya. Kepentingan pemuliharaan di dalam sesuatu perancangan pembangunan perlu diberi perhatian serius di dalam usaha untuk mengekalkan aset penting yang berusia jutaan tahun ini.


TOPOGRAFI DAN GEOMORFOLOGI

Keseluruhan Pulau Sibu merupakan tanah rendah yang landai dan tiada bukit yang tinggi (Rajah 2). Puncak yang tertinggi hanyalah 155 m iaitu Bukit Sibu berhampiran Kampung Duku. Batuan sekiranya yang terdiri daripada batuan piroklas yang tidak padat menyebabkan terdedah kepada proses hakisan. Morfologi hakan pantai seperti tunggul laut, gerbang laut, gua dan dataran hakisan pantai banyak terdedah di bahagian timur pulau ini yang mana terdedah kepada angin monsun timur laut. Pantai di bahagian timur kebanyakan membentuk ciri pantai berbatu yang mempunyai tebing yang tinggi dan hampir menegak seperti di Tanjung Semanggar, Pantai Berkembar, Tanjung Batu Birod dan Tanjung Keramat. Morfologi tebing tinggi juga terdedah di bahagian utara pulau iaitu di sekitar Tanjung Buntot Meriam.

GEOLOGI PULAU SIBU


piroklastik di Pulau Sibu adalah jelas dan boleh di cerap dengan mudah. Singkapan ini boleh dijadikan lokaliti tip (type location) mewakili singkapan lava Formasi Sedili.

**TAPAK BERNILAI WARISAN GEOLOGI DI PULAU SIBU**

Terdapat empat tapak di kawasan sekitar Pulau Sibu yang dikenalpasti berpotensi dijadikan geotapak iaitu Pantai Tanjung Musoh, Pantai Tanjung Semanggar, Pantai Berkembar (Twin Beach) dan Tanjung Keramat (Rajah 4). Pemilihan tapak-tapak ini adalah berdasarkan nilai-nilai saintifik, pendidikan dan rekreasi yang ada pada setiap tapak.

**Tapak Pantai Tanjung Musoh**

Di Pantai Tanjung Musoh terdapat singkapan sedimen piroklas berlapis yang paling jelas di pulau ini. Tidak seperti di kebanyakan singkapan lain yang terletak di bawah aras air pasang, singkapan di tapak ini masih boleh dicerap dengan baik pada waktu air pasang. Singkapan boleh dicerap di sepanjang pantai hingga 150m ke utara (Rajah 5). Sekiranya air surut singkapan boleh dicerap sehingga Tanjung Yaina dan bersambung hingga Tanjung Buntot Meriam. Lapisan adalah berjurus sekitar 0° hingga 20° dengan kemiringan sekitar 40° hingga 45°. Cerapan log AB, CD, dan EF menunjukkan lapisan di Tanjung Musoh adalah paling muda manakala ke utara (Tanjung Yaina) semakin tua (Rajah 6).

Di sepanjang AB iaitu di kawasan berhampiran Tanjung Yaina, lapisannya tebal tetapi kurang jelas. Keseluruhannya singkapan adalah merupakan endapan aliran aliran piroklastik (pyroclastic flow deposits). Bahagian paling bawah lapisan terdiri daripada breksia gunung berapi diikuti dengan tuf lapili di bahagian tengah dan tuf (Rajah 7a) di bahagian atas.


Singkapan EF merangkumi kawasan Tanjung Musoh. Pada umumnya batuannya hampir sama dengan batuan...
berhampiran D tetapi kebanyakkan lapisan adalah nipis sekitar 0.5 m hingga 1 cm. Buih-buih kaca seperti di CD juga terdapat pada beberapa lapisan di sini tetapi sangat kurang. Lapisan yang membunyai butiran bersaiz lumpur atau berkaca adalah dominan (Rajah 8a). Fotomikro nikel silang menunjukkan vesikel-vesikel (buih) yang halus pada bahagian atas lapisan riolit. (c) Fossil *Stigmaria* yang dijumpai di Tanjung Musoh.

**Rajah 6:** Log tapak Tanjung Musoh: Log (a) merupakan jujukan paling tua (berhampiran Tanjung Yaina) manakala (c) jujukan paling muda (Tanjung Musoh).

**Rajah 7:** (a) Batuan tuf yang terdapat di Tanjung Yaina iaitu sekitar B. (b) Batuan tuf yang berlapis di sekitar kawasan CD. (c) Bom volkano bersaiz pebel yang jatuh memasuki lapisan tuf (anak panah). (d) Lapisan riolit yang mempunyai vesikel kaca di atasnya.

**Rajah 8:** (a) Singkapan berhadapan chalet De’ Coconut, jurus/kemiringan: 0°/45° yang terdiri daripada lapisan riolit bersaiz lumpur atau berkaca. (b) Fotomikro nikel silang menunjukkan vesikel-vesikel (buih) yang halus pada bahagian atas lapisan riolit. (c) Fossil *Stigmaria* yang dijumpai di Tanjung Musoh.


Singkapan IJ pula didapati hampir sama dengan singkapan AB di Geotapak Tanjung Musoh. Namun, demikian agak sukar menentukan lapisan yang atas atau bawah kerana lapisannya tidak jelas dan berkecamuk. Endapan piroklas...
Beberapa fitur dan tapak bernilai warisan geologi di Pulau Sibu, Mersing, Johor

Tapak Pantai Berkembar (Twin Beach)

Tapak ini berada di bahagian genting di tengah-tengah Pulau Sibu yang ramping hingga Pantai Pasir Belakang di bahagian timur dan Pantai Teluk Perepat di bahagian barat hampir bercantum (Rajah 14). Landskap ini sebenarnya merupakan morfologi tombolo iaitu gumuk pasir yang terhasil daripada pengendapan pasir persisir pantai yang menghubungkan antara dua pulau. Ini bermakna Pulau Sibu ini pada asalnya terbahagi kepada dua iaitu utara dan selatan. Proses pengendapan pasir yang berterusan menghasilkan morfologi tombolo di antara kedua-dua pulau. Penurunan aras laut menyebabkan tombolo ini menjadi lebih tinggi dan
lebar seperti sekarang. Penemuan morfologi pentas abrasi di Kampung Kambau (berhampiran Pantai Berkembar) yang berada di atas aras air pasang penuh menyokong teori penurunan aras laut ini (Rajah 15). Ciri pantai berkembar ini juga secara tidak langsung menyediakan tempat rekreasi yang unik dan jarang sekali terdapat di tempat lain.

**Tapak Tanjung Keramat**

Keseluruhan tapak ini terdiri daripada batuan piroklas jenis tuf, tuf lapili dan lapili bertuf. Perlapisan batuan jelas tetapi sukar ditentukan jurus kemiringannya kerana agak rencam. Batuan ini membentuk tebing-tebing yang curam dan hampir tiada pantai berpasir.


**PERNYATAAN PENUTUP**

Hasil kajian ini mencadangkan keempat-empat tapak di Pulau Sibu ini dipulihara sebagai geotapak bertaraf kebangsaan dengan Pulau Sibu sendiri diangkat sebagai salah satu geotop di Malaysia. Tapak Tanjung Musoh dan tapak Tanjung Semanggar mempunyai nilai saintifik yang tinggi dan jarang di temui di Malaysia. Singkapan lava dan batuan piroklasnya jelas dan segar berbanding di tempat lain di Semenanjung Malaysia. Sebagai contoh, singkapan di Sungai Jasin dan di pantai Mersing (juga dikenali sebagai volkanik Jasin) tidak mengandungi urutan atau siri yang
Beberapa fitur dan tapak bernilai warisan geologi di Pulau Sibu, Mersing, Johor


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Sedimentology of the Passage beds between the Kubang Pasu Formation and Chuping Formation, Berseri, Perlis

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Abstract: The Passage beds between the Kubang Pasu Formation and Chuping Formation crops out in Berseri, Perlis. A detailed sedimentological study was carried out at Quarry B from which four facies have been identified. These facies are sandstone interbedded with thin mudstone beds facies, thickly-bedded mudstone, thickly-bedded sandstone with thin mud and bioturbated sandstone. In general the sequence is fine-grained with increasing calcareous content towards the upper part of the Passage beds showing evidence that these facies were deposited in a shallow marine environment. Meanwhile, the relationships among these facies show that there are two trends which can be differentiated by its lithological pattern. There are coarsening upwards trends which indicate depositional that took place on regressing shoreline environment and also fining upwards trend showing that deposition happened otherwise. The recurrence of these sequences overlapping each other indicates a third order regressive and transgressive phase which may take place in the shallow marine environment.

Keywords: sedimentology, Passage beds, regression, continental shelf

PENGENALAN


**KAEDAH PENYELIDIKAN**

Bagi tujuan penakrifan sesuatu fasies, analisis dan cerapan secara terperinci di lapangan telah dilakukan dengan mengambil kira setiap aspek-aspek yang boleh mencirikan sekitaran pengendapan yang berbeza. Perincian ini bergantung kepada ketebalan jujukan yang diukur. Semakin banyak data dan cirian yang dicerap, semakin banyak maklumat yang kita peroleh daripada analisis cerapan tersebut. Selain daripada cerapan di lapangan, data dari makmal seperti kajian petrografi juga digunakan dalam perincian tersebut.

Di lapangan, pengelasan unit batuan yang berbeza dilihat daripada aspek-aspek seperti jenis dan saiz butiran, warna, bentuk dan struktur sedimen, dan fosil. Jenis dan saiz butiran adalah digunakan untuk membezakan jenis litologi yang berbeza seperti breksi, konglomerat, batu pasir, batu lumpur, syal, batu kapur dan lain-lain. Litologi yang berbeza mewakili proses pengendapan yang berbeza. Warna batuan juga kadang kala memainkan peranan dalam penentuan sekitaran. Sebagai contoh, batuan sedimen yang berwarna merah selalunya mencirikan endapan dalam keadaan teroksida manakala yang berwarna kelabu selalunya mencirikan sifat kanduanan batuan yang berkarbon.

Struktur sedimen pula adalah merupakan parameter yang sangat penting berbanding parameter-parameter penentuan sekitaran yang lain kerana ia terbentuk semasa pengendapan berlaku di dalam sekitaran tersebut sendiri. Struktur sedimen juga digunakan untuk memberi maklumat seperti kedalaman air, tenaga dan halaju serta arah arus semasa pengendapan berlaku.

Fosil juga penting dalam penentuan sekitaran kerana cara mereka hidup dan berinteraksi antara satu sama lain dikuasai oleh jenis sekitaran dan habitat di mana mereka tinggal. Dua jenis fosil yang terdapat merupakan maklumat sub-sekitaran pengendapan ialah mikrofosil dan fosil surih. (Felix, 2000)

Bagi tujuan kajian ini, terdapat sebanyak 6 lokaliti telah digunakan dan dibuat cerapan iaitu dua singkapan di kuari A, tiga singkapan di kuari B dan satu singkapan di Bukit Merah (Rajah 1).

**Lapisan Perantaraan**


Pemerhatian di lapangan mendapati bahawa bahagian bawah lapisan perantaraan yang telah tersingkap di kuari B ini dicirikan oleh jujukan batu pasir berbutir halus dengan pelibat batu lumpur di bahagian permukaan dan berlaminasi silang. Unit ini diikuti oleh selang lapis nipis batu lumpur dan batu pasir berbutir halus dan berlaminasi bergelombang yang kemudiannya ditindih oleh batu syal tebal berwarna hitam dengan fosil surih di bahagian permukaannya (Rajah 3B dan 3F).

Unit ini diikuti oleh selang lapis nipis batu pasir dan batu lumpur sebelum ditindih oleh jujukan batu pasir berbutir sederhana tebal yang diselang dengan selang lapis dominan batu pasir berbutir halus dan batu lumpur nipis (Rajah 3A). Batu syal hitam tebal ditemui mengambil keadaan lapisan ini dan diikuti oleh jujukan tebal selang lapis batu pasir dan syal dengan kewujudan klasta lumpur di dalam lapisan batu pasir ini. Ini menandakan keadaan arus aliran air yang berubah-ubah semasa pengendapan berlaku.

Jujukan ini kemudian diikuti oleh batu pasir berbutir sederhana dengan struktur palung dalam bahagian bawah dan “mud-partings” di bahagian atasnya. Struktur palung ini...
ditemui secara turut menurut di dalam lapisan batu pasir yang seterusnya menunjukkan pengendapan di sekitaran alur (Rajah 3C). Kesalan riak simetri juga ditemui di dalam julukan ini dan diikuti oleh perulangan batu pasir dan salut yang sama tebal (Rajah 3D).

Di bahagian atas selang lapis ini dijumpai pula lapisan batu pasir berkalka sebanyak 13 cm tebal yang menandakan bahawa julukan batuan perantaraan ini semakin bersifat berkalka iaitu menghampiri sempadan antara buatan klastik Formasi Kubang pasu dan batuan karbonat Formasi Chuping. Tren mengkasar ke atas ini juga menunjukkan sekitaran yang semakin mencetek.

Batu pasir berkalka ini kemudian ditindih oleh batu pasir berbutir halus dan sederhana dan diikuti oleh batu lumpur hitam berfosil. Kajian petrografi menunjukkan batu lumpur ini mempunyai spesis fosil yang pelbagai iaitu terdiri daripada foraminifera, gastropod, krinoid, bivalvia, alga dan bryozoa (Rajah 4). Fosil-fosil ini mempunyai simen yang berbentuk berbilah dan isopak (sama panjang) yang menandakan proses diagenesis yang berlaku di sekitaran phreatic marin (Flugel, 2004).


**SEKUTUAN FASIES**

Secara keseluruhan kawasan kajian ini terdiri daripada perulangan batu pasir berbutir sederhana, batu pasir berbutur halus, batu lumpur dan salut. Bagi tujuan pembahagian fasies, parameter seperti litologi, ketebalan lapisan, fosil dan struktur sedimen yang menggambarkan sekitaran pengendapan yang berbeza akan digunakan. Dengan menggunakan parameter-parameter ini, singkapan ini bolehlah dibahagikan kepada empat fasies iaitu selang lapis batu pasir dan batu lumpur nipis, batu lumpur tebal, batu pasir berpelapisan tebal dengan sedikit lumpur dan batu pasir yang terbioturbasi.

**Fasies selang lapis batu pasir dan lumpur nipis**

Fasies ini terdiri daripada batu pasir yang berselang lapis dengan batu lumpur nipis. Lapisan batu pasir di dalam jujukan ini adalah dominan berbutur halus dan mempunyai ketebalan 1 ke 10 cm manakala batu lumpur datar.
pula adalah 0.5 ke 5 cm tebal. Antara struktur sedimen yang
dijumpai dalam fasies ini adalah laminasi silang, laminasi
bergelombang, palung dan klasta lumpur tercabut. Fasies
ini juga mempunyai simen jenis berbilah dan isopak yang menunjukkan sekitaran diagenehis
phreatic air tawar. (F) Fosil krinoid dalam batu pasir kaya quzar.

Fasies batu pasir yang terbioturbasi
Fasies ini adalah merupakan jujukan batu pasir yang
telah mengalami perubahan dari segi struktur disebabkan
oleh proses biologi, juga dikenali sebagai gangguan biologi.
Ini ditunjukkan dengan adanya fosil surih dan litologi yang
bercampur aduk, iaitu batu pasir dan batu lumpur (Hart et al., 2011). Keadaan litologi yang terdiri daripada batu pasir
dan batu lumpur ini menunjukkan bahawa batuan ini telah
terdendap di kawasan yang tenaga arusnya berubah-ubah.
Kewujudan bukti aktiviti biologi pula menandakan kawasan
yang mempunyai tenaga arus sederhana (Alonso et al., 2011).
Oleh yang demikian ditafsirkan bahwa butiran pasir ini
telah dienapkan oleh arus yang tinggi dan kemudian berlaku
perubahan pasir yang dikacau oleh bioturbasi setelah air
kembali tenang.

Setelah fasies-fasies yang berbeza telah dikenalpasti,
hubungan antara fasies-fasies ini dilihat dari segi pola jujukan
iaitu samada mengkarak atau menghalus ke atas. Ini akan
memberi gambaran yang lebih jelas mengenai sekitaran
pengendapan yang terlibat kerana kedua-dua jenis jujukan
ini menunjukkan jenis sekitaran yang berbeza.

Fasies batu pasir yang terbioturbasi
Fasies ini adalah merupakan jujukan batu pasir yang
berubah-ubah dan terendap secara gabungan mendapan dan
seretan (Felix, 2000).

Analisis fases bagi singkapan ini menunjukkan terdapat
dua jenis jujukan batuan iaitu jujukan mengkasar ke atas
(JKA) dan jujukan menghalus ke atas (JHA). Jujukan
mengkasar ke atas adalah dimulai dengan fases I dan dikuti
oleh fases III. Jujukan ini kebanyakannya mempunyai
kesan simetri ataupun gelombang laut cetek dan
difsisirkan sebagai maraan garis pantai. Jujukan menghalus
ke atas pula dimulai oleh fases III dan dikuti oleh fases I
dan II. Terdapat banyak struktur palung di dalam jujukan
ini. Fasies ini difsisirkan sebagai endapan alur.

Perulangan jujukan batuan yang mengkarak dan
menghalus ke atas ini menunjukkan adanya perubahan aras
laut yang berlaku berulang kali yang mempengaruhi tenaga
aliran arus dan punca sedimen semasa proses pengendapan
berlaku.

TAFSIRAN SEKITARAN PENGENDAPAN
Penafsiran sekitaran pengendapan dilakukan dengan
melihat hubungan antara satu sekituan fases dengan
fases di sekitarmnya. Sekutuan ini melambangkan sekitaran
pengendapan yang berlaku pada masa yang berbeza. Merujuk
pada Rajah 2, bahagian bawah lapisan perantaraan ini adalah
terendap dalam sekitaran alur iaitu melihat pada struktur
lapisan silang, palung dan riak yang ada. Alur ini mungkin
terbentuk di kawasan maraan garis pantai di mana sumber
sedimen yang lebih kasar hadir dan terendap membentuk
jujukan yang mengkarak ke atas.

Rajah 4: Fotomikrograf menunjukkan limpahan fosil di dalam
sampel daripada Kuari B (A) Fosil Foraminifera di dalam batu
lumpur hitam. (B) Alga. (C) dan (D) limpahan fosil bryozoa dan
alga dalam matrik lumpur kalsit. (E) Fosil yang mempunyai simen
jenis berbilah dan isopak yang menunjukkan sekitaran diagenehis
phreatic air tawar. (F) Fosil krinoid dalam batu pasir kaya quzar.

Jujuan seterusnya menunjukkan pola menghalus ke
atas menandakan berlakunya proses transgresi ataupun
kenaikan aras air laut. Struktur-struktur palung yang banyak
ditemui di sepanjang fases ini menggambarkan adanya
pengaruh alur di dalam kawasan pengendapan jujukan ini
iaitu kawasan air cetek.

KESIMPULAN
Secara keseluruhannya perubahan jujukan-jujukan fasies di dalam lapisan perantaraan Kubang Pasu ini menunjukkan bahawa berkemungkinan proses pengendapan lapisan ini berlaku secara berulang kali, disebabkan oleh fasa regresi dan transgressi di kawasan laut cetek (Sukhantar, 2004; Felix, 2000). Pengendapan sedimen karbonat Formasi Chuping berkemungkinan berlaku apabila air laut telah menjadi stabil melalui proses biokimia. Keadaan air yang tenang membenarkan pembentukan karbonat dan hidupan laut yang menyumbang kepada pembentukan rangka karbonat. Pemendapan secara organik ini juga dipengaruhi oleh beberapa faktor penting yang lain seperti suhu, kemusinan dan kedalaman air serta pengaruh sedimen klastik (Felix, 2000).

REFERENCES / RUJUKAN
Sumber permineralan emas dan bijih timah di Jalur Barat Semenanjung Malaysia: Bukti dari kajian geokimia dan mineral berat

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Sources of gold and tin mineralization in the Western Belt of Peninsular Malaysia: Evidence from geochemical and heavy mineral studies

Abstract: Peninsular Malaysia has traditionally been divided into three mineral belts, viz the Western Belt for gold, the Central Belt for tin and gold. Although the Western Belt is accepted as the tin belt, examination of geological maps and reports revealed that gold do occur in various places in this tin belt. In Johor and Negeri Sembilan gold has been mined and in Tapah-Bidor, Perak and Batu Cave, Selangor gold has been recovered as a byproduct in placer tin mining. Tin deposits are widespread in the Western belt, some in the Eastern Belt and absent in the Central Belt. A study of heavy mineral concentrates in the stream sediments in Tapah area in Perak was carried out to determine their distribution patterns. The heavy mineral concentrates were panned from the streams and studied under a binocular microscope. Bedrock geology is underlain by granite and metasediments.

In Tapah area, fine gold flakes and cassiterite grains are common and variably observed in almost all heavy mineral concentrates collected. When their respective geochemical values were plotted on a map, gold and tin have dissimilar distribution patterns. Concentrates with gold flakes are confined to the metasedimentary areas, whereas cassiterite bearing concentrates are found both in the metasedimentary areas as well in the granite areas. This is because cassiterite veins originated from the granite bodies can cut across both the granite and the metasediment country rock. Cassiterite originates from late magmatic fluids and being carried by hydrothermal solution from the magma and deposited in veins regardless of the bedrock type. Gold on the other hand originates from the sedimentary rocks. It is being squeezed out from the metasedimentary rocks, dissolved by circulating hydrothermal fluids and deposited in the veins. Since it originates not from granite fluid, it is found away from the granite.

Keywords: gold and tin mineralization, Western Belt, heavy minerals, geochemistry
PENDAHULUAN


KAEDAH KAJIAN

Kajian geokimia dan mineral berat telah dijalankan pada sedimen saliran sungai di kawasan Tapah, Negeri Perak, meliputi kawasan seluas 250km². Sebanyak 462 sampel kelodak sungai, 397 konsentrat minerat berat dan 28 sampel batuan dikutip dari kawasan kajian dan dianalisis. Persampelan geokimia telah dijalankan berdasarkan panduan oleh (Hamzah et al., 2003).

Persampelan sedimen sungai dibuat pada lokaliti sungai aktif yang bertenaga tinggi dan rendah dan mewakili setiap lembangan sungai yang terdapat di kawasan kajian. Sampel kelodak dipunyai secara bersamaan di aliran air yang aktif dan bertena pada setiap lokasi persampelan. Anggaran berat sampel yang dikutip adalah 60 g dan dianalisis kandungan Pb, Cu, Zn, Au dan Sn. Kekeralan persampelan kelodak ialah 0.5 km² hingga 0.7 km² bagi setiap sampel. Sampel konsentrat mineral berat dipunyai di lokasi yang sama dengan lokasi kelodak. Sampel konsentrat diperolehi dengan cara mendulang menggunakan dulang piawai yang berisipadu 5 liter. Sampel konsentrat yang dikutip dibahagikan kepada dua bahagian iaitu sebanyak lima kali pendulangan piawai untuk analisis Au. Ia mengandungi konsentrat mineral berat seberat 30 g - 40 g setelah dikeringkan. Sampel ini tidak didulang sehingga bersih bagi mengelakkan kehilangan butiran halus emas (Au) dan perlu mengandungi nisbah pasir dengan konsentrat dengan kadar 1:3. Sampel konsentrat keda dikuhasukan untuk analisis unsur Sn. Sampel ini terdiri daripada 3 dalung piawai konsentrat mineral berat yang berat keringnya kira-kira 5 g - 10 g dan didulang sehingga bersih tanpa kandungan pasir. Kekeralan persampelan konsentrat ialah satu sampel setiap 0.5 km hingga 1.0 km persegi atau satu sampel konsentrat bagi tiga sampel kelodak.

Sampel-sampel sedimen sungai akan dikerikan dan dianalisis berasaskan bagi mendapatkan komposisi kimia bagi Au (fire-assay-AAS) dan Sn (kolorometri). Sebilangan sampel konsentrat tertentu dianalisis secara kualitatif (QME) bagi mengasaskan dan mendapatkan peratusan kandungan mineral emas dan kasiterit pada setiap lokasi tersebut. Sampel konsentrat dipisahkan daripada mineral lebih ringan menggunakan cecear bromoform dan dipisah menggunakan mikroskop binokular. Sampel batuan yang dipunyai adalah sampel yang mewakili unit litologi dalam sesuatu kawasan. Keutamaan persampelan batuan ini adalah di kawasan pemineralan dan zon ubahan. Secara am persampelan batuan dilakukan setiap 1.5 km persegi.

ANALISIS DATA


KEPUTUSAN

Parameter statistik

Hasil pengolahan data-data geokimia, pengkelsen...
Jadual 1: Ringkasan kaedah analisis geokimia dan QME.

<table>
<thead>
<tr>
<th>Media</th>
<th>Unsur</th>
<th>Kaedah Analisis</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Kelodak Sungai</td>
<td>Au</td>
<td>Fire Assay - AAS</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>Kolorometri</td>
</tr>
<tr>
<td>ii) Konsentrat Sungai</td>
<td>Au (Sampel 5 dulang piawai)</td>
<td>Fire Assay - AAS</td>
</tr>
<tr>
<td></td>
<td>Sn (Sampel 3 dulang piawai)</td>
<td>Kolorometri</td>
</tr>
<tr>
<td>iii) Batuan</td>
<td>Au</td>
<td>Fire Assay - AAS</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>Kolorometri</td>
</tr>
<tr>
<td>iv) Qualitative Mineral Examination (QME)</td>
<td>Mineral berat dan lebih ringan</td>
<td>Cecair bromoform, Pemisah Isodinamik Frantz</td>
</tr>
<tr>
<td></td>
<td>Penentuan mineral</td>
<td>Mikroskop binokular</td>
</tr>
</tbody>
</table>

Jadual 2: Pengelasan parameter statistik.

<table>
<thead>
<tr>
<th>Persentil</th>
<th>Keterangan</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 persentil</td>
<td>Nilai penengah</td>
</tr>
<tr>
<td>&lt; 85 persentil</td>
<td>nilai latar belakang</td>
</tr>
<tr>
<td>≥ 85 persentil</td>
<td>nilai latar belakang tinggi</td>
</tr>
<tr>
<td>≥ 97 persentil</td>
<td>nilai anomali</td>
</tr>
<tr>
<td>≥ 99 persentil</td>
<td>nilai anomali tinggi</td>
</tr>
</tbody>
</table>

Nota: Paras statistik yang dipaparkan adalah untuk semua unsur yang dianalisis melainkan nilai anomali unsur Au pada 95 persentil.


Kepingan emas

Sebanyak enam puluh tiga (63) lokasi telah ditemui kepingan emas. Bilangan kepingan emas yang ditemui dalam lima dulang piawai berjulat antara 1 – 62 kepingan. Antara kawasan ditemui kepingan emas adalah Sungai Cherok (Sg. Gading dan anak-anak sungai tidak bernama) dengan julat antara 2 – 62 kepingan, Sungai Chenderiang (Sg. Jong dan Sg. Cheras) antara 1 – 50 kepingan, Sungai Batang Padang (Sg. Mas, Sg. Pana dan anak sungai tidak bernama) antara 1 – 33 kepingan, Sungai Gempa (Sg. Kelindo, Sg. Kemoi) antara 1 – 30 kepingan, Sungai Jangka antara 2 – 16 kepingan. Secara umumnya kepingan emas yang ditemui di dalam kawasan kajian adalah bersaiz antara 0.1 mm hingga 3 mm panjang dan bersifat bersudut hingga subbundar. Rajah 5 menunjukkan taburan kepingan emas di dalam kawasan kajian.

Taburan Unsur Au

Rajah 6 menunjukkan taburan Au dalam kelodak dan konsentrat di kawasan kajian serta menunjukkan terdapat sepuluh lokaliti anomali dan lima lokaliti beranomali tinggi di dalam kelodak manakala terdapat lapan lokaliti anomali dan empat lokaliti beranomali tinggi di dalam konsentrat. Sejumlah satu hingga enam puluh dua kepingan emas ditemui di 63 lokaliti di mana sampel konsentrat dikutip. Anomali Au dalam kawasan kajian secara amnya bertumpu di Sungai Jong, anak Sungai Cheras dan anak Sungai Cerok (ke timur Sungai Cheras) di bahagian utara Bandar Tapah serta Sungai...
Jangka, Sungai Kemoi, Sungai Kelindo dan Sungai Mas di bahagian tenggara Bandar Tapah. Nilai anomali Au dalam kelodak berjulat dari 0.17 - 0.46 ppm. Nilai anomali Au dalam konsentrat pula berjulat antara 206 -448 ppm.


Taburan kepingan emas dalam konsentrat mineral berat dan emas dalam kelodak mempunyai pola tersendiri iaitu secara keseluruhan taburannya tertumpu di kawasan batuan metasedimen, manakala dalam kawasan batuan granit nilaiannya rendah. Terdapat satu sampel konsentrat yang mengandungi sedikit emas dalam kawasan granit di bahagian selatan kawasan kajian, tetapi inipun apabila diteliti, adalah hasil pembawaan oleh sungai dari kawasan metasedimen.

Taburan Unsur Sn

Taburan Sn dalam kelodak dan konsentrat mineral berat sungai kawasan Tapah ditunjukkan dalam Rajah 7. Terdapat sepuluh lokaltiti anomali dan lima lokaltiti anomali tinggi dalam kelodak berjulat 170 ppm hingga 381 ppm manakala dalam konsentrat terdapat tujuh lokasi anomali dan lima lokasi anomali tinggi berjulat 269,273 ppm hingga 350,000 ppm.

Anomali Sn dalam kelodak di kesan di Sungai Gempe dan anak-anak Sungai Batang Padang manakala dalam konsentrat, anomali unsur ini di kesan di Sungai Kenoh, Sungai Kelindo dan anak Sungai Batang Padang (barat Sungai Pana). Nilai tertinggi Sn dalam kelodak dengan nilai 8,120 ppm telah di kesan di sekitar lembangan Sungai Gempe dan anak Sungai Batang Padang manakala nilai tertinggi Sn dalam konsentrat pada di kesan di Sungai Kelindo dengan nilai 450,00 ppm. Selain dari itu Sn juga di kesan dalam konsentrat di Sungai Kenoh dan anak sungai di timur Sungai Pana.

Pola taburan Sn dalam kelodak dan konsentrat didapati berbeza daripada taburan emas. Taburannya terdapat dalam kedua-dua kawasan batuan metasedimen dan juga kawasan batuan granit.

PERBINCANGAN

Sumber emas dalam longgokan emas hidrotermal telah menjadi suatu persoalan sejak sekian lama. Ada yang mengatakan emas berasal daripada air hidrotermal granit fasa lewat (Emmons, 1933). Kebelakangan ini ramai mulai berpendapat emas bukan berpunca daripada magma granit tetapi daripada pengikisan batuan oleh air hidrotermal terhadap batuan sekeliling (Boyle, 1987; Groves et al., 1998). Dalam pandangan ini, jasad granit berperanan sebagai pembekal haba yang menyebabkan air hidrotermal berkitar keliling jasad granit.
Sumber permineralan emas dan bijih timah di jalur Semenanjung Malaya: bukti dari kajian geokimia dan mineral berat.

Rajah 7: Anomali Sn di dalam kelodak dan konsentrat. Taburan anomali merangkumi kedua-dua kawasan batuan, granit dan metasedimen.


**KESIMPULAN**

Taburan emas dan timah di kawasan Tapah menunjukkan pola berbeza antara satu sama lain. Taburan emas dalam sedimen sungai tertumpu di kawasan batuan dasar metasedimen sahaja manakala taburan timah dalam sedimen sungai pula tertumpu di kawasan metasedimen dan juga kawasan granit. Taburan timah dalam kawasan granit dan metasedimen menunjukkan sumber permineralan timah ialah daripada larutan hidroterma magma. Taburan emas pula berlakunya daripada kawasan granit iaitu tertumpu di kawasan metasedimen menunjukkan sumber emas ialah daripada larutan hidroterma bukan magma iaitu daripada air dalam batuan keliling.


Sebagai usaha untuk menambahkan pangkalan data mineral berlogam, maklumat-maklumat geokimia dan kawasan-kawasan beranomali boleh dijadikan panduan untuk meneruskan kajian susulan terhadap unsur-unsur berlogam pada masa hadapan selain data-data yang diperolehi boleh digunakan bagi perancangan gunatanah serta pemantauan alam sekitar di negeri ini.

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Microfacies and diagenesis in the Setul Limestone in Langkawi and Perlis

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Abstract: The Setul limestone outcrops in Langkawi and Perlis show a variety of facies consisting of thickly bedded mudstone, wackestone, packstone, grainstone and dolomitic limestone. Seven microfacies have been recognized comprising of dolomicritic mudstone, bioclastic wackestone, peloidal wackestone, intraclastic wackestone, peloidal packstone, peloidal grainstone and dolomitic limestone. The presence of bioclasts such as brachiopods, trilobites, ostracods, bivalves, crinoids and the microfacies spectrum reflect that the sediments were deposited in broad environments ranging from tidal flats to lagoon and shallow subtidal of a carbonate ramp. The diagenetic processes that have taken place include cementation, dolomitization, stylolitization, neomorphism, dissolution, compaction and micritization. Petrographic studies show that diagenesis took place in wide digenetic environments including freshwater phreatic zone, marine phreatic zone, mixing zone and deep burial zone.

Keywords: carbonate sedimentology, carbonate diagenesis, Setul Formation, depositional environment

INTRODUCTION

The Setul Formation is widely distributed in the Northwestern part of the Peninsular Malaysia and southern Thailand (Figure 1). The limestone forms a broad range of hills extending up to 30 km from Kuala Perlis to Thailand. The Setul Formation was first described by Jones (1981) as a prominent limestone of considerable thickness forming the rugged karst topography the Setul Boundary Range in west Perlis and also occurs extensively in the eastern part of Langkawi Island. The same limestone is known as the Thung Song Limestone in Thailand. In the Kilim area of Langkawi, this limestone which forms picturesque tower karsts standing out from the dense green mangrove forests is a great tourist attraction. The landscape was carved by prolonged geomorphological processes especially dissolution that took place in a humid tropical climate when it was exposed to the atmosphere.

This paper will focus on describing the microfacies in this rock and also the diagenetic aspects which have not been described in detail before.

METHODOLOGY

Samples of the Setul Limestone were collected from Kilim area in Langkawi and close-spaced sampling was done at the Kang Giap Quarry in Perlis. About 200 samples from the quarry in Perlis and sea-cliffs in the Kilim area in Langkawi were thin-sectioned and studied under the polarizer microscope for detailed petrographic investigation to classify the limestone and diagenetic studies. Thin sections were stained prior to study under the petrographic microscope according to the procedure described by Friedman and Johnson (1992) in order to discriminate ferroan calcite, non-ferroan calcite and dolomite. The rock microfacies were classified according to Dunham (1962).

GEOLOGICAL SETTING

The study area covers a limestone quarry in Northern Perlis and limestone exposures in the western part of the Langkawi Island. Basically the geology of the northwestern part of the Malaysia Peninsula is dominated by a complete sequence of Paleozoic sedimentary rocks. The deposition started with an Upper Cambrian clastic Machinchang Formation deposited under fluviodeltaic conditions which was then followed by the deposition of the subsequent younger sedimentary sequence that was almost uninterrupted until the Upper Permian and Triassic time.

The Setul Limestone was deposited conformably on top of the clastic rock of the Machinchang Formation. This gradual change was suggested to be due to the reduction of clastic input as the source area was peneplained (Lee, 2005).

Gobett in his chapter in Gobett & Hutchison (1973) has interpreted the Setul Limestone to be Ordovician in age based on its fossil content. Jones (1981) however, has assigned the age of this rock formation to Ordovician – Lower Devonian. This is further confirmed by Lee (2001; 2005) who found Scyphocrinites loboliths in the upper part of the formation which he interpreted to represent the late Silurian – early Devonian time.

Jones (1981) has divided the Setul Formation into four units namely Lower Limestone Member, Lower Detrital Member, Upper Limestone Member and Upper Detrital Member. The base of the formation is not exposed but the passage beds are exposed at Kuala Kubang Badak in Langkawi while the top is exposed on Pulau Langgun where the Singa formation rests unconformably. The total thickness was estimated to be around 2000 meters.

The rock of the Setul Formation comprises crystalline, hard brittle, dark colored, thick bedded, variably impure, crystalline limestone with subordinate detrital facies
composed of quartzite, flagstone, carbonaceous shale, slate and black cherty mudstone (Jones, 1981). In the field (Figure 2) the Setul Formation appears dark grey in colour with massive and thick layers. Wavy stromatolites are common features in this rock formation and columnar stromatolites are also found at two localities in the Kang Giap Quarry in Perlis. Generally, the rock is devoid of sedimentary structures but in certain areas, weak evidence of rare current bedding occurs as shown by weak cross bedding.

**CARBONATE MICROFACIES**

The limestone is normally made up of allochems, matrix and cement. All these three components are found in most of the samples collected from the study areas. Allochems in the Setul Limestone comprise skeletal materials, peloids, ooid and some intraclasts. Skeletal and peloidal grains are widely distributed in the rock but ooids and intraclasts are rather limited.

The main skeletal components found in this limestone are bivalves, tentaculites, pelecypods and some trilobite skeletal fragments. Micrite is also a major component in this rock consisting of microcrystalline carbonate material of less than 5µm in size. It normal forms the background material in most of the samples. Cement is another important component that binds the rock together. Different cement types occur in this rock and will be discussed in greater detail later.

Studies of thin sections of the rock samples from Langkawi and Perlis show that the carbonate rocks of the Setul Formation can be divided into several microfacies based on Dunham’s (1962) classification. The major microfacies are mudstone, wackestone, packstone, and grainstone (Figure 3). The microfacies have been either partly or fully dolomitized. The fully dolomitized rock has become a new microfacies called dolomite.

**Mudstone**

*Description:* The mudstone microfacies consists almost entirely of carbonate mud and the allochems do not exceed 5% (Figure 3A). The facies appears thickly bedded and dark grey at outcrops. The allochem comprises mainly of crinoids, shell fragments (of gastropods and brachiopods) and peloidal materials. This microfacies has been partly or fully dolomitized and turned into dolomicritic mudstone characterized by the presence of lime mud with dolomite crystals disseminated in the matrix. The well formed crystals are fine in size and show euhedral hipidiotopic texture.

*Interpretation:* At present, most of lime muds accumulate in a wide range of environments ranging from intertidal to lagoonal and basinal areas (Gischler et al, 2013; Adjjas et al, 1990, Wright, 1990; Scoffin, 1987). In the Setul Limestone however, the microfacies is interpreted to have been deposited in a shallow but quite water setting as shown by the association of this microfacies with other shallow water facies. This condition might occur in protected areas of an open shelf.
Wackestone

Description: The wackestone facies in the Setul Limestone is made up of allochems embedded in a matrix of lime mud (Figure 3B) and the rock appears fine to medium grained at outcrops. The allochems are represented by fragments of crinoids, bryozoans, trilobites, brachiopods, thin shelled bivalves and some peloidal materials. The grains made up about 10% of the rock volume. There are two types of wackestone microfacies found, namely bioclastic wackestone and peloidal wackestone depending on the major allochem present. Bioclastic wackestone in the Setul formation is characterized by the presence of fragments of various skeletal materials including trilobites, bivalves, crinoids and some brachiopod shells. Some peloidal materials are also present some of which could have been produced from the micritized skeletal fragments.

Peloidal wackestone on the other hand contains about 10% of peloidal material embedded in micrite. There are also some minor amounts of skeletal material present in this microfacies. The peloids range from 0.05 to 3 mm in size and most of them are either rounded or elongated in shape. Some of these peloids could have originated from the micritization of skeletal grains while some others could represent fecal pellets.

Interpretation: This microfacies was deposited in a low energy environment but the allochem might have been derived from high energy areas as shown by the battered and fragmented nature of the grains. The grains could have been transported into deeper quiter water during storms or accumulated at the foot of gentle slopes.

Figure 3: Microfacies in the Setul Limestone. A. Mudstone; B. Wackestone; C. Peloidal Packstone; D. Bioclastic Packstone; E. Peloidal Grainstone; F. Dolomite.

Packstone

Description: Packstone is a grain-supported microfacies consisting of a mixture of allochems and lime mud matrix (Figure 3C & D). Peloids and bioclastic tests are the main components that make up this microfacies producing two types of packstone i.e. peloidal packstone and bioclastic packstone. The bioclasts are represented by crinoids, bivalve shells and styliolinid tests. The presence of bioclasts is less than 25% while the percentage of peloids ranges from 10 to 45% in the samples. Some of the peloids had been compressed and aligned parallel to the bedding plane due to compaction while some other peloids have undergone dolomitization. The euhedral dolomite grains however were not compressed indicating that dolomitization took place after the sediment has been buried deeper in the subsurface.

The packstone microfacies is the most dominant facies representing about 43 percent of the total rock in the Kilim area.

Interpretation: The texture of this microfacies reflects deposition that took place under slightly higher energy conditions compared to the wackestone and mudstone microfacies. This is shown by the nature of the allochems that appear battered, broken and abraded reflecting the high energy condition closer to that of a skeletal shoal on a carbonate platform (Wilson, 1975).

Grainstone

Description: Grainstone is grain supported microfacies, with minimum amount of micrite present (less than 5%) and the rock is cemented by calcite cements. The amount of allochem is about 35% to 55% of the total rock volume, comprising peloids, bioclasts and some intraclasts (Figure 3E). In some samples, the pelloidal materials are so dominant that the rock can be classified as peloidal grainstone. The peloids were arranged parallel to the bedding plane during compaction. Calcite cements make up about 30% to 50% and dolomite is also present ranging from 1% to 10%. Figure 3E is a photomicrograph of the microfacies.

Interpretation: Its coarse grain texture and the lack of micritic material indicate that this microfacies was deposited in a high energy environment while peloids are derived from shallow water areas such as in the back barrier. The widespread cementation in the microfacies however indicates that the peloids and other allochems were deposited in rather open and agitated areas forming peloidal-skeletal shoals.

Dolomite

Description: This facies consists entirely of coarse grained replacive dolomite. It is quite impossible to recognize the original facies and grain type in this facies due to extensive dolomitization that had taken place and obliterated the original texture and fabrics of the rocks. Judging from the evenness of the dolomite grains however, we can deduce that the original microfacies could be lime mudstone with no significant amounts of allochem presents.

Interpretation: The evenness of the crystal sizes, together with some large and well formed crystals produced
by extensive dolomitization indicate that dolomitization occurred late during diagenesis. Dolomitization in this microfacies had almost completely replaced both the grains and matrix. This process normally occurs deep in the subsurface where all crystals have enough time to grow and form euhedral texture.

Microfacies distribution
This facies is not evenly distributed laterally and vertically in the Kilim area. Since no sedimentary logging was carried out in Kilim area, the distribution can only be mapped laterally as shown in Figure 4. The mudstone and wackestone make up the bulk of the facies found in Kilim and they represent about 43 percent of the total sample collected in Langkawi. Meanwhile, the sequence at the Kang Giap Quarry is dominated by packstone and grainstone. Packstone is the second largest facies representing about 33 percent of the total samples collected whilst grainstone is the least with an amount of about 5 percent. About 18 percent of the total samples collected are represented by dolomite. The dolomite microfacies is seen to be associated with or to occur close to the mudstone microfacies. This phenomenon might indicate that a close genetic relationship for these two microfacies.

Detailed logging and mapping was at the Kang Giap Quarry have resulted in the lateral and vertical facies distributions presented in Figures 5 & 6. The microfacies changes from mudstone and wackestone into packstone and grainstone and continue further up with bioclastic wackestone and dolomitic limestone from bottom to top. The original texture of the microfacies cannot be ascertained due to pervasive dolomitization in the samples examined. Wavy stromatolites can be seen dominating this facies in the outcrop.

DIAGENESIS
Diagenesis involves processes that caused the physical, chemical and mineralogical changes in limestone. These processes had occurred since the sediment was deposited and normally it would lead to a more stable condition.

Factors that control the digenetic processes include the original composition of the sediment, pore water chemistry and its movements in the subsurface and also the time involved (Scoffin, 1987). Diagenesis can occur in various environment such as vadose, freshwater phreatic, sea water

<table>
<thead>
<tr>
<th>Microfacies</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mudstone-wackestone</td>
<td>43 %</td>
</tr>
<tr>
<td>Packstone</td>
<td>33 %</td>
</tr>
<tr>
<td>Grainstone</td>
<td>5 %</td>
</tr>
<tr>
<td>Dolomite</td>
<td>18 %</td>
</tr>
</tbody>
</table>

Table 1: Microfacies percentage in the Setul Limestone from the Kilim area, Langkawi.

Figure 4: Microfacies distribution in Kilim Langkawi.  
Figure 5: Limestone sequence logged at the Kang Giap Quarry.
Microfacies and diagenesis in the Setul Limestone in Langkawi and Perlis

Microfacies and diagenesis in the Setul Limestone in Langkawi and Perlis

phreatic and in the deep burial environment in the subsurface. Each of the environments will produce different diagenetic textures and fabrics.

Diagenesis in the Setul Limestone occurred very early even during deposition as shown by the presence of early marine cements. The various effects of diagenesis can be observed in the samples collected from Kilim and Kang Giap Quarry such as micritization, cementation, compaction, dissolution, neomorphism, dolomitization and silicification (Figure 7).

**Cementation**

Cementation was not a dominant diagenetic process in the Setul Limestone. Only minor amounts of calcite cementation are observed in the samples collected. Two generations of cement are observed in the Setul Limestone. The first generation is represented by fibrous isopachous calcite rim. This cement was superseded by the second generation cement consisting of blocky calcite cement.

The fibrous cement can be recognized from the presence of radiaxial fibrous calcite which had evolved from the originally microfibrous calcite cement. The cement was precipitated early during diagenesis when the sediment was still in a marine phreatic condition at or near the surface (Kendall, 1985). Another type of early generation cement occurs in the form of syntaxial overgrowth that affects mostly crinoid grains where the grain is now enveloped by a large calcite crystal. This type of cementation normally occurs in freshwater phreatic condition or deep in the subsurface when there is fresh water recharge to the environment. The final stage of cementation took place in deep burial in reducing conditions. This has brought about the precipitation of ferroan calcite as shown in Figure 7D.

**Dolomitization**

Dolomitization is another dominant process that took place in the limestone. About half of the rock volume in the Setul Formation has been dolomitized. It involves direct precipitation of dolomite minerals and also replacement of calcite by dolomite. Early dolomitization occurs in discontinuity in the rock mass such as stylolites. Most dolomite in stylolites show fine and well formed crystals. Meanwhile the replacive dolomite tends to occur everywhere in the rock replacing matrix, grains and calcite cements.

Almost all samples contain some amount of dolomites. The dolomite crystals show subhedral to euhedral rhombohedron crystals with idiotopic texture. There is also some hipidiotopic dolomite texture found in the samples.

Large dolomite crystals that were produced during late stage deep burial diagenesis can also be found in the samples. They are represented by baroque dolomites or saddle dolomites. This type of dolomite is characterized by big crystals with curved boundaries and showing undulose extinction. Petrographic evidence clearly shows that there

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**Figure 6:** Microfacies distribution at Kang Giap Kuari in Perlis.

**Figure 7:** Diagenesis in the Setul Limestone. A. Compaction often produces fracture fabric in the rock. B. Loosely packed fabric produced by dissolution in the limestone. C. Cementation has plugged up all interparticle porosities. D. Late stage calcite cementation precipitated ferroan calcite in the remaining pore spaces. E. Replacive dolomitization produced dolomite crystals seen floating in calcite cements. F. Late stage compaction postdates cementation as seen in this image.

is a mutual exclusion between saddle dolomite and other dolomite types

**Compaction**

It is a widely accepted fact that, increasing overburden stresses on carbonate sediment will lead to compaction. In the Setul Limestone, mechanical compaction which involves rearrangement of particles and closer grain packing began as soon as there is any overlying sediment. The effects of compaction are more noticeable in more muddy sediments where labile grains such as peloids have been compressed.

Chemical compaction and pressure solution are also very common in the muddy sediment of the Setul Limestone. The effect of chemical compaction is shown by the presence of dissolution seams and stylolites. Dissolution seams which lack the distinctive sutures of stylolites mostly go around and between grains. It is assumed that dissolution seams were formed at a very early stage during shallow burial as they have low amplitude and no accumulated clay seams. This phenomenon is common and has been widely described by earlier workers (e.g. Bathurst, 1971; Rickens, 1985; Koch & Schorr, 1986).

Unlike dissolution seams, stylolites are normally seen in tightly cemented grainy limestone (packstone). Some of them are seen cross-cutting the cements, indicating that their formation postdate calcite cementations (Figure 13).

**Micritization**

Micritization is a process that took place soon after the sediment was deposited. Observations in samples from the Setul Formation show that most shelly materials and algae have undergone micritization. Some peloids may have resulted from prolonged micritization processes. Micritization normally take place in quiet environment such as lagoon or back reef areas.

**Dissolution and neomorphism**

Dissolution is not a common feature found in this rock. Where it is present dissolution is normally shown by the poorly packed fabric with a lot of pore space. Dissolution involves matrix and bioclasts especially bivalve and other shell fragments. The pore spaces produced during dissolution were later plugged up by calcite cement during deeper burial diagenesis. Dissolution is normally related to the invasion of fresh water into the rock formation especially when the rock was exposed to the atmosphere during low sea-level. This kind of dissolution normally produces micro karsts as shown by a section on Pulau Langgun in Langkawi (Figure 8).

In contrasts to dissolution which involves destruction of depositional fabrics, neomorphism often led to preservation of the original structure of skeletal material. A considerable portion of skeletal materials were altered into low Mg-Fe-calcite. This type of neomorphism normally produced a non-ferroan microspar mosaic. Neomorphism also occurs in matrix and produced microspars.

**Silicification**

Silicification was also observed in the samples from the Setul Limestone. Like dolomitization, silicification can take place during early or late diagenesis (Tucker, 1991). In the Setul Limestone silicification takes the form of pervasive replacement. The silica occurs as microquartz and calcedonic quartz replacing grains cement and matrix. The nature of replacement indicates that silicification processes took place very late in the diagenetic sequence of the Setul Limestone (Figure 9).

**Diagenetic sequence**

The Setul Limestone has a long and complicated diagenetic history. A wide spectrum of diagenetic processes and products has been recognized including cementation, near surface dissolution, dolomite precipitation and burial calcite precipitation. Some of the processes were controlled by relative sea-level changes.

The Setul Limestone diagenetic spectrum can be subdivided into three stages: 1) early marine, 2) near surface and 3) deep burial. The diagenetic sequence is depicted in Table 2.

Early marine diagenesis is recorded by the presence of fibrous cements. The fibrous cements grew in interskeletal and intraskeletal pores. The cements were later stabilized, recrystalized and evolved into bladed cements. The presence of these cements seems to be very important in consolidating the sediments.
Microfacies and diagenesis in the Setul Limestone in Langkawi and Perlis

Meteor diagenetic processes occurred during the relative sea-level lowstands and were only detected from one locality on Pulau Langgun in Langkawi just below the transgressive sequence. The second diagenetic stage took place in the deeper burial environments and involved late stage cement precipitation including blocky calcite and saddle dolomite. Some of these diagenetic features were later obliterated by the silicification processes that took place at the latest stage.

DEPOSITIONAL ENVIRONMENT

Various environments of deposition in the Setul Limestone have been identified. These include tidal flat, lagoon or protected environment, skeletal shoal and deeper outer ramp. Muddy microfacies with wavy stromatolites laminae or laterally linked hemispheroids can be interpreted to represent tidal flat deposits or on protected shorelines (Hoffman, 1976). Most of the other fine grained facies including mudstone and wackestone were deposited either in protected environments or deepwater outer ramp areas. Coarse-grained microfacies such as packstone and grainstone could represent higher energy setting in shallower water areas such as skeletal banks. The abundance of peloidal materials in the limestone again reflects the quietness of the depositional environment in general during the deposition of the Setul Limestone.

According to Wright (1990) stromatolites morphology can be used as an indicator of energy condition. The presence of columnar stromatolites in the Kang Giap Quarry in Perlis (Figure 2E) reflects deeper water condition with high energy setting. In Shark Bay, this type of stromatolites occurs on headlands fully exposed to waves.

The overall facies indicates the changes in environment of deposition that might have been controlled by the sea-level changes. The relationship between the facies and the sea-level changes is shown in Figure 10.

CONCLUSION

Generally, the rock of the Setul Formation is muddy in nature as shown by the presence of abundant muddy microfacies. The rock also contains both shallow and deep marine elements. The presence of tentatculites, graptolites and loboliths indicates that there were times when the limestone was deposited in deeper marine condition as shown in Figure 10. In contrast, there are also evidences that point to very shallow water conditions as shown by the presence of shallow marine benthic fossils such as brachiopods and trilobites. At a locality on the Langgun island there is even an indication of sub-aerial dissolution preserved in the sequence. In conclusion, it can be said that the Setul Limestone was deposited in a ramp setting with depositional environments ranging from intertidal to deep open marine. The limestone is also rich in peloidal and algal materials. In places peloids become the main component in this limestone and it could be related in origin to coccoidal microbes. Normally peloids collect in lagoons and shallow intertidal zones where they are protected from rough ocean currents. Sun and Wright (1989) who studied the limestone in the Weald Basin have interpreted that peloids were produced microbially either by direct precipitation or by induction in areas which had relatively low framework growth rate, low sedimentation rate and moderate energy level.

The limestone has undergone complete diagenetic processes right from the time of deposition at the surface up to the time when it was buried deep in the subsurface. Petrographic evidences show that during deposition and near surface burial the sediment was affected by very little early marine cementation as shown by the rare occurrence...
of early marine cementation in the rock sequence. This evidence together with the fossil occurrence support the earlier interpretation that most of the sediment was deposited in deeper water setting except for the algal rich part of the limestone facies. Soon after deposition, the sediment was subjected to compaction that resulted in development dissolution seams and distortion of labile grains such as peloids. During the depositional processes there were times when the area was subject to the sub aerial exposure due the lowering of sea-level. This has resulted in the formation of the karstic surface. Further burial processes have produced late stage calcite cementation represented by large crystal calcite mosaic crystals followed by dolomitization. Dolomitization took place in two phases. The first phase of dolomitization occurred mainly through styloïlites and spread outwards replacing whatever material that contain high amount of magnesium (high magnesium calcite) whilst the second phase occurred very late and produced large crystals of saddle dolomite. All in all, the Setul Limestone was deposited in a broad depositional setting ranging from shallow to deep marine condition and experienced all stage of diagenetic sequence in it history. The Lower Setul Limestone was basically deposited in shallow marine conditions. At one stage there are areas where the sediments were exposed to the atmosphere. This phenomenon marked the end the deposition of the Lower Setul Limestone. It was then transgressed by the sea water leaving behind an evidence of shallow water inundation as shown by the presence of the trilobite layer in the lower part of the Lower Clastic Member. The environmental deposition of the Lower Detrital Member was then drastically change to deep marine as shown by the occurrence of thinly bedded cherty mudstone in the top of this sequence. Then suddenly the area once again witnessed the change of sediment type to generally muddy carbonates in the area during the deposition of the Upper Setul Limestone. This limestone member was deposited in deeper marine conditions as shown by the presence of Scyphocrinites lobolith and tentaculites in this part of the Setul Limestone. It was then followed by the deposition of another clastic interval of the Upper Detrital Member which also occurred in deep marine conditions. Evidence of deep marine again was shown by the presence of tentaculites in this member.

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Evidence of Holocene and historical changes of sea level in the Langkawi Islands

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Abstract: About eighty radiometrically dated biogenic and morphological indicators of sea level of the Langkawi Islands prove that since the maximum Mid-Holocene inundation, the paleo-sea surface descended stepwise thrice to reach its current position several hundred years ago. In presumably historical time some parts of the island group were raised between 0.5 and one meter. One of such events was related to the Aceh/Simeulue mega-earthquake of December 2004 which caused live bands of rock-clinging oysters and barnacles to shift 30 to 40 centimeters upward at Teluk Burau. GPS study also yields evidence of 9 to 11 millimeters co-seismic uplift of the northwestern sector of Peninsular Malaysia. The anomalously high sea stands in the early part of the Holocene and latest Pleistocene in northwestern Peninsular Malaysia remain the most outstanding issue in this investigation. Comparison with recently published sea-level curves of the Sunda Shelf strongly suggests that the geoid of the Strait of Malacca was 50 to 40 meters higher in the period of the LGM (Last Glacial Maximum: 21 ka to 19 ka) to the early half of the Holocene at 10 ka to 5 ka. In the early period of the Holocene, sea level was still up to 24 meters higher than over the Sunda Shelf.

Keywords: geoid high, stepwise descent since Mid-Holocene, effect of Aceh mega-earthquake.

INTRODUCTION

Peninsular Malaysia is located on the Sunda subplate, which has the geological characteristics of a Cenozoic semi-cratonic platform devoid of explosive andesitic volcanism, of strong vertical movement, of tectonically folded Tertiary sediments, and of devastating seismicity. The geological outcrops are also predominantly of pre-Tertiary age, implying absence of major subsidence in the Cenozoic. Magnitude of long-term vertical displacement of the crust is in the hundredths to thousandths millimeters per year range and is thus distinctly different from centimeter-rates of crustal uplift and subsidence associated with reef terraces in the tectonically mobile island arcs framing the Sunda subplate. Figure 1 indexes the localities treated in this article.

Recent observations, however, have yielded evidence of moderate but localised co-seismic ground disturbance, morphological anomalies and GPS-determined ground movements in historical time that imply minor differential crustal deformation in the Langkawi Islands. The dated evidence is discussed according to three periods, that is, with reference to latest Pleistocene - Early Holocene sea stands, with respect to the systematically descending sea levels during the Mid-Holocene to the present interval, and those that occurred in historical time. The radiometrically dated evidence for paleo-sea levels of the Peninsular Malaysia region are tabulated in Tjia & Sharifah Mastura (2013). The paleo-sea level data include geographic coordinates, type of dated material, position with respect to current sea level (most commonly the in situ determined high-tide), the radiocarbon ages and the associated laboratory or original publication. The age of shoreline indicators consisting of marine material has also been corrected for the ‘marine reservoir effect’. At this stage of knowledge, the correction applied was by subtracting 400 years from all previously published age data. No MRE correction is needed for radiometric ages of plant material (mainly mangrove and peat).

Figure 1: Index of localities mentioned in the article. Width of the main island measures 70 kilometers.
LATEST PLEISTOCENE TO EARLY HOLOCENE SEA LEVELS

A score of fossil mangrove and peat material from the bottom of the Strait of Malacca define the Late Pleistocene to Early Holocene sea stands (Geyh et al., 1979; Streif, 1979). Figure 2 compiles this information showing a steadily rising sea from a depth of around 68 meters about 34 000 years ago to reach current sea level position by the Mid-Holocene. The average rate of inundation amounts to 2.4 millimeters annually. The available data points suggest that, during the Last Glacial Minimum (LGM) at 21 to 19 k years ago, sea level in the Strait was at least 75-80 meters higher than the -130 m lowstand generally accepted for that period. Shorelines of the Early Holocene are represented by a scatter of data points time-wise and also in elevation sense. An extreme elevation of 23 m above high tide was reported for fossil rock-clinging oysters occurring in a notch in the Setul Limestone of Pulau Tanjung Dendang (Zaiton Harun et al., 2000). The notch profile is of the fish-hook type and should have been related to stable crustal condition of the sample location. Figure 3 illustrates the two contrasting basic notch profiles that develop on a tectonically stable coast (fish-hook) and tectonically rising coast (lazy-V). The deepest cut of a notch corresponds with mean sea level; the opening height is dependent on tidal range and arriving wave strength. The lower, gently sloping segment of the fish-hook notch merges very gradually into the almost-level wave-base position. In contrast the lower sloping arm of the lazy-V notch joins the wave-base level with a distinct break-in-slope (Figure 3).

During this period between 34k and 5k years, sea stands in the Strait of Malacca (including the Langkawi Islands) were thus significantly higher compared to those interpreted for western Southeast Asia as a whole (e.g. Sathiamurthy & Vorhis, 2006). Hanebuth et al. (2000) showed sea-level over the Sunda Shelf during the period 14.6 - 14.3 ka to have risen from -96 m to -80 m. During the same period the Strait of Malacca was covered by about 40-meter deep sea, again indicating a 40 to 50 m difference from that of the South China Sea (Figure 4). One plausible cause could

Figure 2: The Late Pleistocene to Early Holocene sea levels indicated by radiocarbon ages of paleo-shoreline indicators in Strait Malacca and Langkawi Islands. The questionable data points concern plant material (including ‘wood’) without specific reference to sea level.

Figure 3: Notches in limestone cliffs. (a) and (b) are of the lazy-V type characteristic for rising coasts in tectonically mobile regions: respectively Selu Island (Tanimbar group, Outer Banda Arc, eastern Indonesia) and Semporna (eastern Sabah). Its MRE corrected radiocarbon age is 18 630 ± 450 y BP. At that time of the LGM, global seas were at their minimum position at least 100 m below current datum. The Semporna reef sample represents tectonic uplift of ≥102 m or an average of 5.5 mm each year. Figures 3 (c) and (d) illustrate fish-hook type notches in the limestone cliff of Kodiang (Kedah) and Pulau Tanjung Dendang, Langkawi, respectively. The fish-hook notch profile of (d) implies the current high position of the Mid-Holocene rock-clinging oysters was reached by secular drop of sea level.

Figure 4: Radiometrically dated paleo-sea level indicators representing Peninsular Malaysia. Five pre-6000 y BP data points from Langkawi presumably relate to a high geoid position. Most of data points fall within the two wavy solid lines as well as within the stepwise descending grey zone. Elevation and occurrence of stacked notches in Langkawi and elsewhere in the Peninsula are in agreement with the stepwise descent of the sea during the Later Holocene (discussion in the text). Each of the paleosea stillstands lasted 1000 to 1200 years.
be that the geoid had a different configuration. At present, the Strait of Malacca roughly coincides with a neutral geoid zone that demarcates a positively high geoid culminating some 60 meters in the New Guinea region from a negative geoid region that reaches a deep 100 meters depression in the Srilangka region. During a reduction of the angular velocity of the Earth’s rotation, geoidal relief will probably “flatten” and its neutral zone shifts westward. This westward shift brings Peninsular Malaysia into the positive geoidal region concomitant with high sea stands.

Radiometrically dated paleo-sea level indicators of Peninsular Malaysia is shown on Figure 4. Seven of the data points represent sea stands in the pre-6000 y BP interval. Five of these data points originate from the Langkawi Islands and possess distinctly anomalous positions with respect to the projected sea level rise in the Malacca Strait (single black line on Figure 2). Sea levels during the Early Holocene (10 k to 6 k years) in Langkawi were 20 to 24 m higher than projected. The most extremely high position is that of 6600 years BP rock-clinging oysters at Pulau Tanjung Dendang situated 24 m above current mean sea level (Zaiton Harun et al., 2000). The fossil oysters are hosted in a typical fish-hook notch profile (Figure 2d) which should correspond with a tectonically stable substrate. These five anomalously high paleo-sea level indicators of Langkawi most probably represent a geoid high.

The other two post-6000 y BP data points are from the west coast and from the east coast of the Peninsula, respectively.

**MID - HOLOCENE TO RECENT SEA STANDS**

Approximately 80 data points of paleo-sea level indicators on the coasts of Peninsular Malaysia define secular changes during the later part of the Holocene (Figure 4). More than a third of the data points originate from the Langkawi Islands and nearby shores of Perlis and northern Kedah. The paleo-sea level indicators include fossil rock-clinging oysters, mollusc beach ridges, coral, some calcareous algal crusts, calcareous beachrock, and coastal plant remains, notably mangrove parts. The radiometric ages of the paleo-sea level indicators of marine origin were adjusted for marine reservoir effect, which at this stage was determined to be 400 years younger. The MRE adjustment possibly needs refinement when new reliable standards become available.

The scatter of data points is generally contained within either the progressively descending zone demarcated by the wavy black solid lines, or reside within the step-like grey zone. A third and simpler explanation favoured by other paleo-sea level researchers is for a Mid-Holocene high sea level in Peninsular Malaysia between 5000 and 4000 y BP followed by a general decrease to the present datum level. This opinion is, however, not borne out by field observations or clustering of radiocarbon ages of paleo-sea level indicators as will be shown below. The scatter of data points in terms of elevation may be attributed to various uncertainties in determining the corresponding position of the paleo-sea.

Among these are range of paleotides, the original position of the fossil oyster within the paleotidal range, and paleo-wave height influenced by coastal configuration at different elevation of the former seas. The material collected for the laboratory analysis was measured at the site with respect of the reigning high tide level, which is the most practical benchmark recognisable as slope breaks of the beach surface, up-beach limit of loose shells and other flotsam. The high-tide mark may vary in excess of a meter depending on the season. In view of these variables, it has been impractical to apply corrections to the vertical positions of the paleo-sea indicators. Nevertheless, the distinct clustering of data points in Figure 4 has been considered sufficiently representative of the paleo-sea level changes of the younger part of the Holocene.

Initially my close collaborators on paleo-sea levels and I (Tjia et al., 1977) preferred the wave-like descent of sea level since the Mid-Holocene for Peninsular Malaysia. Resulting from many follow-up studies, including coastal observations on other islands of the tectonically stable Sunda Shelf, e.g., the Indonesian tin islands of Bangka, Belitung and Kandur, it became clear that stacked Later-Holocene sea level indicators are common occurrences. The compelling evidence consists of sea-level notches and clusters of fossil rock-clinging oysters arranged at three or more levels at various locations in the region. A still stand -however temporary- of sea level is required to develop the notches. Still stands of the descending post-Mid Holocene sea are best explained by the stepwise descent in Figure 4. Figure 5 illustrates the situation at Pulau Ular, a small islet just off the southwest coast of Langkawi main island. Pulau Ular consists of the Permo-Carboniferous Singa Formation that crops out as three low hills protruding several meters from a base of a well-developed abrasion platform approximately 1 to 1.5 m above current high tide. Three notches at 5.5 m, 2.7 m and corresponding with the 1.5 meter above high tide abrasion platform are stacked on the face of the northern hill side. The lowest notch is of a typical fish-hook type. The elevations of the three notches correspond with paleo-sea levels at around 2300 y BP (1.5 m above high tide), 4400 - 3800 y BP (2.7 m aht), and the Mid-Holocene inundation peak between 5000 and 4400 y BP (5.5 m high notch).

An other example suggesting stepwise change of paleo-sea level during post-Mid Holocene are several abrasion terraces cut across granite at Teluk Burau which is located on the west central coast of Langkawi main island (Figure 6, upper). Four levels of abrasion benches, each several meters wide correspond with former low-tides at 0.5 m aht (above high tide, or a corresponding sea level at 1.5 m), 1.75 - 2 m aht (representing 2.75 to 3 paleo-sea level), 3.5 m aht (its associated paleo-sea level was 4.5 m) and 5.5 m aht (of paleo-sea level at 6.5 m). Each of the virtually level bench surfaces indicates approximately the corresponding wave base or paleo-low-tide.

The lower Figure 6 is a synoptic sketch of fossil oyster positions within Gua Kelawar, a short through cave in the
Kilim GeoForest Park, northwest Langkawi. The higher oyster cluster is located 1.2 m to 2.2 m above current high tide; the lower oyster cluster is 0.35 to 0.4 m above high tide. Samples GK-1 and Gk-2 were collected for pending radiocarbon age analysis. The Gua Kelawar fossil oysters suggest that no sun or day light was required for their existence. Note also the so called ‘wind-vane’ stalactites at one of the exits of Gua Kelawar.

General tectonic stability of the main Langkawi Island is also demonstrated by the well-developed fish-hook notch on the cliff of a small peninsula of Setul Limestone located on the southeast of the big island (Figure 7). The crystalline Setul Limestone is laced with crinkly siliceous laminations mistakenly indicated as ‘stylolites’ in the ‘Geology of the Malay Peninsula’ (Jones, 1973, p. 35). The smooth, uniformly abraded surface of the lower leg of the notch distinctly contradicts the notion that notches in coastal limestone cliffs are products of bio-erosion (Hodgkin, 1970). Instead mechanical down wear or abrasion has been the cause. Figure 7 further shows the top limit of live rock-clinging oysters equates with the high tide level.

**CRUSTAL DEFORMATION IN HISTORICAL TIME**

In historical time, crustal deformation of parts of the Langkawi Islands are implied by the following evidence.

Analysis of GPS records of ground movements attributed to the 26 December 2004 mega-earthquake of Simeulue in the Indian Ocean west of Aceh in northern Sumatera, shows vertical displacements in Peninsular Malaysia. Ami Hassan Md Din *et al.* (2012) computed 9 to 11 mm uplift in GPS stations in Perlis and northern Kedah, while recording subsidence of similar values for southwest Johor. The co-seismic ground displacements were lowest in Negeri Sembilan-Selangor region.

Just two years and a few months after the December 2004 disaster, the coastal exposure at Teluk Burau, west-central part of Langkawi, was captured in Figure 8. Live barnacles occupy positions up to 30 centimeters above the top of rock-clinging oyster clusters, a position commonly seen on Malaysian shores. The top limit of growing oysters also marks the maximum reach of high tide. The exposure at Teluk Burau consists of two barnacle-oyster bands. The upper band of 54 centimeters is populated by live specimens. The small size of the live oysters indicate young age. This upper barnacle-oyster association is followed downward by a 35 cm lower barnacle-oyster band that ultimately disappears below loose beach sand (Figure 8), whose surface is approximately a meter above current low tide. The lower barnacle-oyster band has no living individuals and the dead oyster shells have a greenish sheen. The exposure at Teluk Burau appears to indicate: (a) very recent -in historical sense- ground subsidence of at least 35 cm that caused beach sand to smother the lower barnacle-oyster association; (b) followed by uninterrupted development of a younger barnacle-oyster band higher up on the same granite surface; and finally (c) scouring by tidal currents that re-exposed part of the lower dead barnacle-oyster band. The youthful small size of the live oysters could well equate with growth following the tsunami inundation of the western coast of Langkawi which accompanied the Simeulue mega-quake of December 2004.
Stacked, relatively shallow notches in the Setul Limestone of the Kilim Geoforest Park are exposed along the Kilim river and its branches. Figure 9 illustrates three stacked notches. The photograph was taken at the approximate time of mean sea level that corresponds with the lowest exposed notch position. The top limit of live rock-clinging oyster cluster is ~1.5 m above this lowest notch. Approximately 0.5 m above the live oyster limit is a relatively shallow notch with irregular lateral extent. This notch is oblique to stratification of the limestone which is moderately steep. Although irregular, the notch closely parallels the sea surface. A well-developed notch is ~ 1.2 m above the top limit of live oysters. This notch has a lazy-V profile (marked X) that should represent formation associated with falling sea level caused by land uplift.

In the limestone cliffs along Pantai Beringin, a stretch of only a few hundred meters long between Pantai Syed Omar and Tanjung Cawat, southeast Langkawi, both lazy-V together with fish-hook notch profiles occur side by side close above present sea level. The occurrence is interpreted as result of recent differential ‘tectonic’ behaviour, that is presumably attributable to compartmentalisation of the coastal stretch. The Kisap Thrust zone runs nearby (see Jones 1978, pages 158-170; and also Figure 1). Apparently ground disturbance -in historical time as the closeness to current sea level suggests- only affected the coast with lazy-V notch profile.

CONCLUSIONS

During the period of ~36 ka to ~5 ka (latest Pleistocene to Mid-Holocene) sea level in the Langkawi-Malacca Strait zone was between 40 m to 24 m higher compared to sea level on the Sunda Shelf of the South China Sea. This condition can be attributed to a geoid configuration that differed from the current situation. Currently the roughly North-South trending zero geoid zone occupies Strait Malacca. A prominent geoid high (+80 m) is located in the West Papua region 42 degrees longitude to the East of the Strait, while a current geoid depression (-100 m) lies off Srilangka some 20 degrees to the West. If the Earth’s rotation decreases, one could expect the geoid relief to flatten and to shift westward. The opposite will probably happen if the angular velocity accelerates.
From the Mid-Holocene maximum inundation of the region at 4400 yr BP onward, regional sea level progressively dropped stepwise three times. Periods of sea level stillstands, each of about 1100 to 1200 years duration, allow abrasion to develop level benches on hard rock (granite at Teluk Burau) and notches on limestone cliffs. Figure 4 shows the elevation of the stepwise descent.

Effects of mega-earthquakes, estimated to occur in periods of 400 to 1000 years apart, appear to have extended into the Langkawi areas. Local crustal deformation of the Simeulue event of December 2004 probably caused the 35-cm ground subsidence at Teluk Burau burying and killing a band of barnacle-oyster while permitting a new barnacle-oyster band to evolve at a higher elevation (Figure 8).

The majority of notches in Langkawi are of the fish-hook type indicating development during ground stability. At Pantai Beringin and nearby Tanjung Cawat notches of the fish-hook as well as of the lazy-V types are located side by side and occur close to current mean sea level. Their position with respect to the current sea surface implies recent ages. Compartmentalisation by the Kisap Thrust zone may account for differential ground instability along this short coastal reach.

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Input geologi untuk Sistem Sokongan Membuat Keputusan dalam pengurusan risiko bencana: Kajian kes Universiti Kebangsaan Malaysia

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Kata kunci: Sistem Sokongan Membuat Keputusan, tanah runtuh, peta terain geologi, zon prioriti

Geological input for Decision Support System to manage the risk of disasters: A case study of Universiti Kebangsaan Malaysia

Abstract: This paper describes the use of geological information and terrain assessment in a Decision Support System (DSS) to address landslide problems in the campus of Universiti Kebangsaan Malaysia (UKM) in Bangi, Malaysia. Zones of priority were derived from systematic analysis of field data and overlays of the geological terrain map, landslide location, and various elements at-risk, using Geographic Information System (GIS). Among the criteria used to identify the zones of priority are seriousness of landslide impacts, manageability of mitigating measures, urgency in the need to resolve the problem and the potential for further deterioration. Results indicate that this geological-based DSS facilitates the Development and Maintenance Department (Jabatan Pembangunan dan Penyelenggaraan, JPP) of UKM in planning and decision-making with respect to such zones.

Keywords: Decision Support System, landslide, geological terrain mapping, priority zones

PENGENALAN

Kekerapan berlakunya kejadian bencana seringkali berkait rapat dengan kepesatan dan kemajuan serta pertambahan kepadatan populasi sesebuah negara (Coppola, 2007). Bencana biasanya peristiwa katastropik yang berpunca daripada bahaya yang bersifat semulajadi serta bahaya cetusan manusia yang umumnya bersifat teknologi dan sengaja ataupun antropogenik (Lim, 2004; Coppola, 2007). Kemasukan akibat daripada bencana sukar untuk diukur malah ia seringkali berbeza-beza mengikut lokasi geografi dan tahap kerentanannya (Ghosh, 2012). Bagi kebanyakan negara Asia, bahaya yang bersifat semulajadi seperti tanah runtuh, banjir, gempa bumi, letusan gunung berapi, ribut dan tsunami menjadi kebimbangan paling utama (Kishore, 2003; Billa et al., 2006; UNISDR, 2006; Djalante & Thomalla, 2012). Jenis-jenis bahaya semulajadi yang dihadapi oleh sesuatu negara juga bergantung kepada keadaan iklim, geografi, geologi dan amalan penggunaan tanah negara tersebut. Bahaya semulajadi seperti ini seterusnya berganjak menjadi malapetaka ataupun bencana apabila berlakunya kemusnahan harta benda, infrastruktur, kehilangan nyawa, gangguan ekonomi, kemusnahan alam sekitar serta mengganggu fungsi kehidupan (McEntire, 2001; Coppola, 2007; Palliyaguru et al., 2010).

Di samping itu, banyak kajian literatur telah menjelaskan bahawa bencana lebih cenderung berlaku di kawasan bandar malah kesannya adalah lebih signifikan (Bendimerad, 2003; Bull-Kamaga et al., 2003; Wisner et al., 2003; Khailani & Perera, 2013). Dalam Satterthwaite et al. (2007), kawasan bandar ditafsirkan sebagai rumah kepada sebahagian besar populasi di dunia, aktiviti-aktiviti ekonomi dan infrastruktur fizikal yang sudah sedia adanya dilihatkan bengkel bahaya dan kemudiannya dijangka akan bertambah serta bertukar menjadi bencana. Proses pembangunan kawasan bandar dikenali sebagai perbandaran. Sungguhpun aktiviti-aktiviti perbandaran sebenarnya membawa kemajuan kepada...
Ibrahim Komoo aktor-aktor utama dalam setiap peringkat iaitu persekutuan, negeri dan daerah (Ibrahim Komoo et al., 2011). Jelas sekali di negara ini, segala koordinasi yang lebih berkesan merupakan salah satu tugas yang agak strategi pengurangan risiko dan kerentanan bencana dengan penting lagi, mengetahui bagaimana untuk melaksanakan yang relevan agar kesan-kesannya dapat dibendung. Lebih mengurangkan risiko bencana merupakan satu pendekatan kekerapan berlakunya bencana sejak akhir-akhir ini, usaha mengurangkan risiko bencana merupakan satu pendekatan yang relevan agar kesan-kesannya dapat dibendung. Lebih penting lagi, mengetahui bagaimana untuk melaksanakan strategi pengurangan risiko dan kerentanan bencana dengan lebih berkesan merupakan salah satu tugas yang agak rumit. Jelas sekali di negara ini, segala koordinasi yang berkaitan dengan hal-hal bencana lazimnya diuruskan oleh aktor-aktor utama dalam setiap peringkat iaitu persekutuan, negeri dan daerah (Ibrahim Komoo et al., 2011). Selain itu, pihak-pihak berkepentingan (stakeholders) utama (terutama sekali para pembuat keputusan atau decision-makers) yang biasanya datang dari agensi-agensi kerajaan memainkan peranan penting dalam menangani isu ini. Pihak-pihak ini memerlukan satu medium yang berupaya menyokong serta menyediakan mereka input-input yang boleh dipercayai, berguna dan berkesan dalam proses membuat keputusan (decision-making process) untuk mengurangkan risiko bencana. Oleh yang demikian, usaha mewujudkan satu rangka kerja konsep yang dikenali sebagai Sistem Sokongan Membuat Keputusan (Decision Support System, DSS) merupakan satu pendekatan bijak yang sejarah dengan keperluannya berdasarkan realiti masa kini. DSS merupakan satu sistem sokongan yang mempunyai keupayaan untuk membantu para pembuat keputusan ke arah membuat keputusan dengan lebih baik (Pick, 2008) dalam mengurangkan risiko bencana dan seterusnya mempengaruhi susun-atur strategi pengurangan risiko yang lebih sistematik dan berkesan.

Kertas ini mengemukakan satu kajian kes bagaimana aplikasi maklumat berorientasi geologi dimanfaat sebagai alat sokongan untuk perancang pengurangan risiko bencana untuk satu bandar-mini, iaitu sebuah kampus universiti. Kajian ini akan menerangkan penggunaan data geologi dan analisis terain dalam sistem sokongan membuat keputusan atau DSS bagi konteks pengurusan pembangunan kawasan berkeruh dan masalah tanah runtuh di dalam kawasan lingkungan kampus Banu, Universiti Kebangsaan Malaysia (UKM). Justeru, bahagian berikut kertas ini secara umum akan membincangkan tentang peta terrain dan juga DSS. Diikuti dengan penjelasan tentang kaedah serta latarbelakang kawasan kajian, hasil dan perbincangan serta akhir sekali kesimpulan.

**Peta Terain Geologi**

Untuk pengurusan dan pengurangan risiko bencana terutamanya dalam bencana tanah runtuh, pihak pengurusan atau khasnya perancang bandar memerlukan input maklumat penting seperti geologi, topografi, bentuk muka bumi, keadaan cerun dan zon berpotensi bahaya dan kesesuaian pembangunan. Maklumat ini juga perlu dipajakan dalam bentuk yang mudah difahami (Lim et al., 2000) seperti peta dan kod atau pengelasan yang ringkas tetapi bermaklumat untuk perancang atau pembuat keputusan membuat pertimbangan dan keputusan secara tepat. Peta pengelasan terrain dan peta-peta tematik yang lain seperti bentuk muka bumi, hakisan, kekangan fizikal, kesesuaian pembangunan dan sebagainya dapat berfungsi sebagai alat ataupun perkakas untuk mencapai tujuan berkenaan. Peta terrain geologi (geological terrain map) menggunakan pendekatan penilaian terrain merupakan salah satu maklumat penting yang dapat membantu dalam proses membuat keputusan untuk pengurangan risiko bencana. Secara umum, peta ini merupakan sejenis peta yang mengkategorikan, menerangkan dan menggambarkan ciri-ciri dan atribut bahan-bahan surficial, rupabumi (landforms), dan proses geologi dalam landskap semulajadi (Forest Practice Code, 1999). Aplikasi sistem penilaian terrain ini telah digunapakai...
oleh beberapa negara untuk tujuan tertentu seperti Skema Amerika (American Scheme) digunakan untuk pengurusan dan hakisan tanah (Waynell, 1978), Sistem British (British System) untuk geologi dan rupabumi (Lawrance, 1972), kaedah Kanada (Canadian method) berkaitan dengan litupan tumbuhan (Vold, 1981), dan Hong Kong pula menghasilkan peta terrain digunakan untuk perancangan pembangunan yang betul dan selamat serta banyak lagi. Di Malaysia, peta terrain dihasilkan oleh Jabatan Mineral dan Geosains Malaysia merupakan versi yang telah diubahsuai daripada model Hong Kong (Zakaria Mohamad & Chow, 2003).


**Peta Rupabumi** - Peta ini meringkaskan keadaan bentuk muka bumi am iaitu terain dan morfologi cerun dan keadaan sudut cerun, untuk tujuan maklumat rupabumi am dan boleh digunakan oleh ahli teknikal dan bukan teknikal.

**Peta Hakisan** – Peta ini menunjukkan keadaan permukaan fitur hakisan dan ketidakstabilan pada cerun yang wujud. Peta ini boleh digunakan oleh ahli teknikal dan bukan teknikal untuk melihat tahap hakisan dan sebarang ketidakstabilan pernah wujud untuk kegunaan perancangan dan kejururatan.

**Peta Kekangan Fizikal** – Peta ini merupakan intepretasi kekangan atau kesesuaian fizikal sumber bumi untuk jenis pembangunan berdasarkan keadaan terain untuk perancangan dan pembangunan kejururatan. Peta ini juga sesuai digunakan oleh ahli teknikal dan bukan teknikal.

**Peta Geologi Kejururatan** – Peta ini menggunakan atribut pengelasan terain dengan gabungan data geologi lain seperti peta geologi, peta bencana geologi dan lain-lain. Peta ini menggambarkan taburan bahan-bahan geologi berdasarkan pencirian sifat kejururatan mereka. Peta ini sesuai digunakan untuk ahli teknikal yang memerlukan maklumat geoteknikal untuk perancangan strategik dan kejururatan.

**Peta Kesesuaian Pembinaan** – Peta ini menggunakan atribut pengelasan terain untuk menggambarkan pembatasan atau rintangan geoteknikal dan kesesuaian kegunaan pembinaan dalam bentuk empat klasifikasi: Kelas 1 dan Kelas 2, ialah masing-masing limitasi geoteknikal rendah kepada sederhana; Kelas 3 ialah pembatasan geoteknikal tinggi; dan Kelas 4 ialah pembatasan geoteknikal yang ekstrim. Pembatasan geoteknikal rendah menggambarkan kesesuaian untuk pembangunan tanah dan kemungkinan masalah geoteknikal yang rendah, manakala limitasi geoteknikal yang tinggi hingga ekstrim menggambarkan kesesuaian untuk pembangunan tanah, kemungkinan untuk menghadapi masalah geoteknikal amat tinggi dan kos pembangunan juga akan bertambah. Sebarang kerja pembangunan pada Kelas 3 dan Kelas 4 adalah amnya kurang sesuai dan tidak sesuai, dan juga diwajibkan penyiasatan tapak yang intensif.

Dalam konteks kajian ini, kompilasi input geologi penting dalam peta terain akan diintegrasikan dalam DSS supaya dapat membantu pembuat keputusan, perancang bandar dan pihak-pihak berkepentingan menggunakan output yang berfungsi sebagai alat sokongan untuk mencegah dan mengurangkan risiko bencana serta kerentanannya dengan lebih teratur dan sistematik.

**Sistem Sokongan Membuat Keputusan**

Sistem Sokongan Membuat Keputusan (Decision Support System, DSS) ditakrifkan secara meluas sebagai sistem interaktif yang berasaskan komputer, menggunakan komunikasi teknologi, data, pengetahuan dan model, bagi menyediakan maklumat untuk membantu para pembuat keputusan menyelesaikan masalah separa berstruktur dan tidak berstruktur (Sprague & Watson, 1989; Gheorge & Vamanu, 2004; Power & Sharda, 2009; Alter, 2002). Dalam usaha untuk mencapai mencapai prestasi DSS yang tinggi dan berkhas, terdapat beberapa syarat yang harus diiktui kira semasa membangunkan sistem ini (Sprague & Watson, 1989). Ini termasuklah:

DSS seharusnya menyediakan sokongan kepada para pembuat keputusan di samping memberi penekanan terhadap keputusan-keputusan separa struktur dan tidak berstruktur.

DSS harus memberikan sokongan dalam membuat keputusan kepada semua peringkat pengurus, dan membantu dalam integrasi antara mana-mana peringkat pada masa yang bersesuaian.

DSS harus menyokong keputusan yang saling bergantung dan tidak bergantung

DSS harus menyokong semua fasas proses membuat keputusan tetapi tidak bergantung kepada mana-mana satu.

DSS haruslah mudah dan mudah difahami.

Secara amnya, DSS adalah sistem sampingan yang digunakan untuk menyokong keputusan pengurusan dengan bantuan pelbagai teknologi geospacial moden seperti teknologi penderiaan jauh (Remote Sensing), Sistem Maklumat Geografi (GIS), kartografi, pengukuran dan pemetaan dan fotogrametri (Billa et al., 2004; Chang, 2012). Namun, dalam kajian ini, teknologi GIS akan diberikan keutamaan. GIS akan berfungsi sebagai landasan kepada proses DSS (Billa et al., 2006). Selain daripada itu, DSS bukanlah bertujuan untuk menggantikan kemahiran.


Matlamat utama DSS dibangunkan dalam kajian ini adalah untuk menyokong dan menyediakan keputusan yang lebih baik dalam usaha pengurangan risiko bencana kepada para pembuat keputusan. Keputusan yang lebih baik dalam erti kata, sebaik sahaja ia dilaksanakan, ia memberi kesan yang signifikan seperti risiko bencana dapat dikurangkan, kerentanan diminimumkan, pengurangan kos mengendalikan bencana, peningkatan tahap kesedaran dan pemahaman semua pihak berkepentingan, peranan institusi dan agensi-agensi yang mengendalikan bencana lebih cekap dan sebagainya. Sebaliknya, jika DSS tidak membawa kepada keputusan yang lebih baik, ia mungkin dapat mempertingkatkan kualiti dalam proses membuat keputusan (Pick, 2008). Terdapat pelbagai cara yang jelas dilihat dengan apabila kualiti proses membuat keputusan diperbaiki. Antaranya; i) output yang terhasil mungkin sama, namun, proses yang dipandu DSS mungkin lebih cepat dan menjimatkan kos, ii) proses yang diperbaiki mungkin lebih memberikan gambaran pemahaman terperinci terhadap apakah punca risiko dan kerentanan bencana meningkat dan sebagainya. Sehubungan dengan itu, dalam kajian ini, DSS dapat dilihat sebagai satu rangka kerja konsep yang berlaku sebagai penyelidikan masalah dalam mengurangkan risiko bencana dengan cara membantu, menyokong dan memandu para pembuat keputusan dan pihak berkepentingan dalam membuat keputusan. Lantaran, strategi tindakan yang dirancang seperti langkah-langkah mitigasi berstruktur yang diambil selepas ini akan lebih efektif.

**LATARBELAKANG KAWASAN KAJIAN**


**Geologi dan geomorfologi**

UKM Bangi terletak di pertemuan antara Sungai Langat dan Sungai Semenyih. Ia bertempat pada lingkungan koordinat 101.75-101.79°T dan 2.90-2.94°U, kita-kira 2 km dari pekan Bandar Baru Bangi dan 35 km dari Kuala Lumpur (Rajah 2). Geomorfologi kampus terdiri daripada perbukitan beralun rendah, ketinggian kawasan berjulat 18 m hingga 110 m, saliran utama di sektor barat hingga utara mengalir ke Sungai Langat manakala saliran utama di sektor selatan mengalir ke Sungai Semenyih. Geologi kawasan Bangi termasuk UKM terdiri daripada batuan sedimen atau metasedimen klastik yang digolongkan dalam Formasi Kenny Hill. Istilah metasedimen juga digunakan untuk menjelaskan batuan sedimen yang mengalami metamorfisme rendah. Formasi Kenny Hill terbentuk terdiri daripada batuan utama iaitu filit, syis, kuarzit, metagrewaik dan telerang dan kekataan kuara adalah lazim. Batuan utama yang lazim tersingkap di kawasan UKM ialah batuan filit dan batu pasir hingga kuarzit. Batuan di permukaan dan cerun telah terdedah kebanyakannya telah mengalami perluluhawa

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**Rajah 1:** Lokasi kejadian tanah runtuh, a) Berhadapan Fakulti Sains Sosial dan Kemanusiaan, b) Berdekatan dengan rumah haiwan, c) Berhadapan Puri Pujangga, d) Di antara bangunan Fakulti Teknologi Maklumat.
tinggi kepada lempung berpasir, lodak berpasir atau pasir berlodak. Lapisan tanah aluvium sungai biasanya dijumpai di sepanjang koridor saliran terutamanya kawasan rendah yang elevasi kurang daripada 20 m.


Penilaian cerun UKM

Pemetaan terawal mengenai kegagalan cerun di sekitar kawasan kajian oleh Ibrahim Komoo (1984; 1987) iaitu cerapan dilakukan sejak kampus ini mula beroperasi pada tahun 1977 sehingga 1984 menunjukkan terdapat 19 lokasi cerun di UKM telah mengalami kegagalan, di mana terdapat 3 kegagalan bersaiz agak besar (isipadu jasad gagal melebihi 1000 meter padu, kebanyakannya antara 1000-1600), 1 kegagalan bersaiz sederhana besar (isipadu jasad gagal antara 500-1000 meter padu), dan 15 kegagalan kecil (isipadu jasad yang gagal antara 0-500, kebanyakannya tidak melebihi 100 meter padu). Hampir kesemua cerun yang gagal ini bersudut antara 30°-45° dan telah terluluhawa tinggi sehingga gred V dan VI, malahan sesetengah potongan cerun juga mendedahkan batuan gred III dan IV.


KAEDAH KAJIAN

Kaedah dalam kajian ini dilaksanakan melalui penilaian cerun untuk pengurusan risiko bencana dalam UKM.

Analisis terain geologi


Kerja Lapangan

Kerja lapangan awalan melibatkan pengesahan umum jenis geologi, geomorfologi dan atribut dalam peta terain geologi (JMG 2012) yang diperolehi dan ditentusahkan.

Rajah 2: Peta lokasi Universiti Kebangsaan Malaysia, kampus Bangi.
Penentuan zon prioriti bencana


Penilaian bencana

Penilaian bencana tanah runtuh merupakan penilaian tahap bahaya (hazard) tanah runtuh, bergantung kepada faktor fizikal/alam sekitar yang mengawal keselamatan cerun seperti jenis geologi, terain, cerun, ganggunan kepada cerun dan kewujudan sejarah kejadian tanah runtuh juga dilakukan. Ini juga mengambil kira binaan yang telah mengalami kerosakan impak tanah runtuh dan potensi terdedah kepada ancaman bahaya jika aktiviti tanah runtuh merebak secara progresif atau retrogressif.

Element at Risk


Peta zon prioriti dihasilkan melalui analisis peta tinjali pusat-peta berikut:

- Peta terain geologi JMG – Kelas kesesuaian pembinaan.
- Peta lokasi tanah runtuh untuk semua tanah runtuh sejak tahun 2009. Tanah runtuh yang bukan cetusan geologi tidak diambil bina sebagai data Unsur Mengalami Risiko.
- Peta unit pembinaan yang mempunyai potensi serius untuk berubah menjadi lebih buruk.
- Peta unit pembinaan yang mempunyai potensi menjadi lebih buruk.

Peta unit pembinaan yang didelineasi daripada peta shaded-relief. Peta shaded-relief yang dijana dengan bantuan peta kontrol, sempadan bawah setiap bukit dikenali (Rajah 3). Proses ini membahagiakan kawasan kepada unit pemetaan lebih kecil yang digelar unit terain atau wilayah terain (van Zuidam, 1985; Way, 1978) di mana geomorfologi permukaan bumi dibahagi kepada unit-unit geomorfologi permukaan bumi lebih kecil mengikut jasad timbul, dalam kes ini sempadan unit bukit kecil di dalam UKM.

Peta tapak bangunan dan Jalan Utama, peta ini digunakan sebagai data Unsur Mengalami Risiko (Elements at Risk) yang bermakna bangunan-bangunan dan jalan raya ini mungkin rosak akibat bencana. Atribut tambahan kepada data tapak bangunan dan diberi
### Jadual 1: Lokasi tanah runtuh di Universiti Kebangsaan Malaysia 2009-2012.

<table>
<thead>
<tr>
<th>Tahun</th>
<th>Lokasi</th>
<th>Tinggi Cerun (m)</th>
<th>Sudut Cerun (°)</th>
<th>Saiz runtuhan (tinggi, m)</th>
<th>Sejarah / tanda-tanda pernah berlaku</th>
<th>Catatan</th>
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<td>2009</td>
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<td>*45</td>
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<td>n.a</td>
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<td></td>
<td>Runtuhan cerun berhampiran tempat letak kenderaan di PUSANIKA</td>
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<td>7.5</td>
<td>n.a</td>
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<tr>
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<td></td>
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<td>24.5</td>
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<td>20.0</td>
<td>tiada</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Runtuhan cerun di Kolej Ungku Omar</td>
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<td>10.0</td>
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<td>40</td>
<td>10.0</td>
<td>ya</td>
<td></td>
</tr>
</tbody>
</table>

*- anggaran daripada peta, ** - ditafsirkan cetusan bukan faktor geologi/geomorfologi tabii, n.a – tiada maklumat
penarafan atau ranking lebih tinggi bergantung kepada bilangan orang yang menduduki bangunan, status atau nilai utiliti/aset/peralatan yang mahal dan kewujudan bahan berbahaya (kimia/radioaktif).

Penilaian dan cerapan lapangan mengenai keadaan cerun, fitur hakisan dan sejarah tanah runtuh lama.

**HASIL DAN PERBINCANGAN**


Korelasi kedua-dua maklumat (taburan lokasi tanah runtuh dan terain) memberikan maklumat yang amat baik, kebanyakan terain tersebut (>10m) yang gagal terdiri dari Klas III dan IV (seerti yang ditunjukkan di Rajah 5). Ini juga menunjukkan peta terain geologi JMG amat praktikal, ia bukan sahaja sesuai digunakan untuk menilai kesesuaian

<table>
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<td>Runtuhan cerun antara Bangunan Wawasan dan Dewan Gemilang</td>
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<td>Runtuhan cerun berhadapan dengan Fak. Sains Sosial &amp; Kemanusiaan</td>
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<td>III</td>
<td>Runtuhan cerun di belakang laluan Fak. Pendidikan</td>
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<td>Runtuhan cerun berhampiran tangki air lingkungan 2, Fakulti Pendidikan</td>
</tr>
</tbody>
</table>

**Rajah 3:** Sebahagian daripada unit perbukitan (bertanda merah) yang didelineasi di bahagian timur-laut Universiti Kebangsaan Malaysia menggunakan peta shaded-relief dan kontur.

**Rajah 4:** Sebahagian daripada unit perbukitan (bertanda merah) yang didelineasi di bahagian timur-laut Universiti Kebangsaan Malaysia menggunakan peta shaded-relief dan kontur.

**Jadual 2:** Klas terain bagi setiap lokasi runtuhan cerun di Universiti Kebangsaan Malaysia.
Input geologi untuk sistem sokongan keputusan dalam pengurusan risiko bencana

Pengkaji lepas juga menjelaskan bahawa terdapat banyak kegagalan cerun dan tanah runtuh telah berlaku di UKM, antaranya disebabkan oleh luluhawa pantas pada muka cerun terdedah, hujan dan resapan ke dalam tanah, satah gelincir pada sempadan gred luluhawa terdedah, dan saliran permukaan cerun (Ibrahim Komoo, 1987); dan kelemahan dalam aspek kejuruteraan dan bahan cerun mudah terhakis, pengumpulan air yang berlebihan di bawah tanah, kekurangan langkah-langkah mitigasi ke atas cerun, dan tidak semua cerun dibetulkan dan ada yang terbengkalai tanpa apa-apa tindakan (Jaafar et al., 2011).

Prognosis awal kajian ini terhadap siri kejadian yang tiba-tiba mendapati beberapa faktor pencetus dan pendorong yang menyumbangkan kepada fenomena ini, iaitu:

1. Jumlah hujan yang luar biasa untuk jangka masa sebulan merupakan antara pencetus utama. Berdasarkan data stesen cuaca terdekat di Empangan Semenyih (JMM 2013) merokodkan jumlah hujan bulanan pada Oktober 2012 (336.6mm), November 2012 (826.0mm), dan Disember 2012 (271.6mm); jumlah hujan yang turun dalam 14 hari sebelum kejadian pertama (11 Nov 2012) telah mencapai 422.8mm manakala jumlah hujan pada bulan November itu sendiri merupakan 2-3 kali ganda hujan bulanan.

2. Saliran cerun menjadi salah satu punca pencetus. Saliran atas cerun yang tidak berfungsi seperti tersumbat dan terputus atau tidak efisien untuk mengalirkan air dan mengurangkan air menyerap ke dalam cerun.


Selain itu, kebanyakan cerun yang gagal merupakan kes perulangan di mana pada cerun tersebut atau bersebelahan mempunyai petanda sejarah kerakan cerun pada masa lepas. Tanda-tanda ini dapat diperhatikan semasa kajian lapangan yang menunjukkan kesan ceburam cerun tersebut telah pernah bergerak atau gagal. Rekod penyelenggaraan juga menyokong ada beberapa cerun yang diperbaiki pada kali kedua.

Perubahan bentuk rupawisma disebabkan oleh pembangunan pesat di UKM serta aktiviti-aktiviti antropogenik yang berlaku di atas cerun-cerun tersebut. Peta jasad timbul atau shaded-relief telah dijana untuk membahagikan kawasan UKM kepada unit pemetaan lebih kecil yang digelar unit terain atau wilayah terain (van Zuidam, 1985; Way, 1978). Rajah 6 menunjukkan tindan-lapis peta shaded-relief, bersama kelas terain III dan IV dan lokasi tanah runtuh serta hasil akhir yang diperolehi iaitu Peta Zon Prioriti. Hasil analisis mengenalpasti 4 zon prioriti utama yang perlu perhatian segera, di mana 3 zon yang dikenalpasti mempunyai kepadatan bangunan dan kependudukan bilangan manusia yang tinggi, 1 zon lagi (Bangunan Elektron Mikroskopi) menempatkan peralatan mahal, jalan raya ke kawasan tersebut merupakan jalan tunggal yang tidak ada jalan alternatif dan wujudnya sejarah perulangan kejadian tanah runtuh pada lokasi yang sama dan berdekanan.

Rajah 7 telah mempamerkan rangka kerja konsep DSS dicadangkan untuk UKM yang mana, hasil akhir DSS ini merupakan satu peta risiko bencana. Melalui sistem ini, dapat dilihat pelbagai atribut penting mengenai bencana, seperti faktor yang mempengaruhi (causative factors/environmental factors) dan meningkatkan keretakan bencana telah disatukan menggunakan keupayaan GIS. Seperti yang diterangkan dalam Pick (2008), DSS yang bersifat menyeluruh bukan sahaja menyediakan maklumat, tetapi membantu, memanipulasi, meringkaskan, dan menganalisis data dan maklumat tersebut dalam usaha memberi bantuan. Hasil yang diperolehi dipercayai dapat membantu dalam membuat keputusan serta mengesyorkan cadangan-cadangan yang relevan untuk digunakan dalam mengurangkan risiko bencana di UKM.

Justeru, dengan bantuan DSS, peta kejadian tanah runtuh dari tahun 2009 hingga 2012 telah dibangunkan. Kesemua rekod kejadian tanah runtuh di UKM dapat dikumpulkan dengan bantuan maklumat dari pihak JPP UKM dan hanya kejadian yang berlaku dari tahun 2009 sehingga 2012 sahaja dapat diakses buat masa ini. Melalui kajian ini, kawasan hotspots di kawasan kajian dikenalpasti berdasarkan kawasan yang mempunyai kepadatan populasi terutama sekali pelajar yang tinggi (vulnerable community) yang mana meletakkan komuniti ini di tahap keretalan yang tinggi serta lokasi kejadian yang berlaku berhampiran dengan kolej kediaman, bangunan akademik serta infrastruktur penting UKM. Peta Zon Prioriti telah dihasilkan berdasarkan...
tindan-lapis beberapa lapisan peta dan penilaia kriteria. Justeru, berdasarkan output yang diperoleh, kajian ini telah memberikan input yang berguna kepada pihak JPP UKM supaya fokus yang lebih dapat diberi kepada kawasan yang berada dalam zon dan perhatian yang secukupnya diberikan terhadap komuniti yang tinggal di zon tersebut.


KESIMPULAN


PENGHARGAAN


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A heritage of Palaeo-Tethys

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Abstract: Bentong-Raub Suture Zone is considered as a collision zone between the Sibumasu and East Malaya (Indochina) terranes. Sibumasu was a part of the Cimmerian plate, which was attached to Gondwana during the Carboniferous. East Malaya was attached to the Indochina plate. From the Devonian to the Permian the Sibumasu and East Malaya blocks were separated by an ocean called Palaeo-Tethys. The closure of Palaeo-Tethys was completed during the Triassic. The major part of the history of the Palaeo-Tethys was destroyed and only a small portion is still preserved in blocks of oceanic sedimentary rocks such as cherts. The chert blocks are exposed in several localities along the Bentong-Raub road (3°35’N, 101°54’E), Gua Musang-Cameron Highland road (4°45’N, 101°45’E) and at a road-cut in Langkap (2°38’N, 102°21’E). The chert blocks consist of thinly bedded chert interbedded with mudstone. Some chert layers contain radiolarians. The oldest chert block found at Bentong-Raub road-cut yielded an assemblage of radiolarians belonging to the Trilongche minax Zone of early Frasnian, (Early Devonian) age. A chert block from Langkap, Negeri Sembilan yielded radiolarians belonging to the Albaillella deflandrei Assemblage Zone, Tournaisian, (Early Carboniferous) age. Permian radiolarians were retrieved from several chert blocks in the vicinity of Pos Blau, Ulu Kelantan. The youngest radiolarian assemblage in the area is from the Follicucullus monacanthus Assemblage Zone indicating Wordian, (Middle Permian) age. The occurrence of radiolarian chert suggests high plankton productivity during the Late Devonian, Early Carboniferous and Permian. These chert blocks are the natural heritage of the Palaeo-Tethys which needed to be conserved as National Heritage sites.

Keywords: chert block; Bentong-Raub Suture Zone; radiolarians, Palaeo-Tethys, heritage

INTRODUCTION

The Bentong–Raub Suture Zone (Metcalfe, 2000) extends from Tomo, southern Thailand southwards through Bentong and Raub to Melaka (Tjia, 1989) (Figure 1). It is an extension of the Nan-Uttaradit suture of Thailand. The Bentong-Raub line was proposed by Hutchison (1973) as the major tectonic boundary between the Western and Central belts of Peninsular Malaysia. Hutchison (1975) named it the Bentong-Raub ophiolite line. Tjia (1989) extended to the suture further south to Bengkalis, Sumatra and named it the Bentong-Bengkalis suture. The suture zone extends northwards to Lancangjian, Changning–Menglian, Yunnan Province Southwest China and Chiangmai, north Thailand (Metcalfe, 2000). The Lancangjian, Changning–Menglian, Chiangmai and Bentong-Raub suture zones represent the main Palaeo-Tethys ocean.

The Bentong-Raub suture Zone in Peninsular Malaysia is located between the Sibumasu Terrane and the East Malaya (Indochina) Terrane. The Sibumasu terrane was attached to the Cimmerian plate and the East Malaya terrane attached to the Indochina and the South China plate. The Sibumasu and East Malaya blocks were separated by an ocean called Palaeo-Tethys. The opening of the Palaeo-Tethys was initiated when the sliver of North and South China, Indochina and Tarim plate rifted from Gondwanaland during Devonian. The Palaeo-Tethys was diminished when the Sibumasu terrane...
collided with East Malaya (Indochina) terrane during the Triassic. The remnant of Palaeo-Tethys was only preserved in the chert blocks in the Bentong-Raub Suture Zone.

**GEOLOGY OF BENTONG-RAUB SUTURE ZONE.**

The Bentong-Raub Suture Zone is well-exposed at road-cuts along the Gua Musang-Cameron Highland road, Karak Highway and Bentong-Raub road. The suture is an approximately 13 km wide zone of deformed rocks consists of schist, phyllite, meta-sedimentary rocks, sandstone, cherts, olistostrome and mélangé (Tjia & Almashoor, 1996). Metcalfe (2000) estimated the suture to be approximately 20 km wide. Small serpentinite bodies are also found in the suture zone at Pos Mering, Sungai Chero, Durian Tipus and Bukit Rokan (Metcalfe, 2000). But there is little evidence to support the presence of true ophiolites along the Bentong–Raub Suture Zone.

The Bentong-Raub Suture Zone is marked by a belt of mélangé and olistostrome which comprise blocks or clasts of cherts, sandstone, limestone, conglomerate, interbedded sandstone and mudstone and tuffaceous mudstone embedded in a sheared matrix of mudstone. The sizes of clasts vary from a few cm to hundreds of meters. The most important clasts' blocks are cherts which are considered to represent the oceanic sedimentary rocks.

**WHAT IS RADIOLARIAN CHERT**

Radiolarian chert (radiolarite) is a microcrystalline or cryptocrystalline biogenic sedimentary rock composed of siliceous skeletons of radiolarians (Figure 2). The chert comprises chalcedony or opaline silica, usually as thinly bedded ribbon chert. Radiolarians occur almost exclusively in the open ocean as part of the plankton community. Their skeletons occur abundantly in oceanic sediments. Development of radiolarian chert is related to the planktic productivity of the ocean at a distance from the continental margin. The plankton productivity is controlled by the amount of nutrients. High productivity is related to the upwelling of nutrient-rich bottom water which brings the material to the surface. The deposition of chert is usually episodic. The radiolarian cherts are well-developed in an oceanic realm where the supply of clastic material is lacking. The chert can be used as an indicator of oceanic sediment. The occurrence of radiolarian chert blocks in the Bentong-Raub Suture Zone represents the remnant of the Palaeo-Tethys sediments.

**THE OCCURRENCE OF CHERT BLOCKS**

The chert blocks in the Bentong-Raub Suture Zone are mainly associated with clastic sediments such as mudstone and sandstone, which were metamorphosed in places to form schist or/and phyllite. This rock association is considered as a continental margin chert association (Jones & Murchey, 1986). Although blocks of serpentinite were reported in Sungai Rokan, Negeri Sembilan, Sungai Chero, Pahang, and Sungai Cherd, Kelantan (Metcalfe, 2000) there was no apparent ophiolitic-chert association observed in the zone. Spiller & Metcalfe (1995) reported that Cerium anomaly values indicate the chert was deposited in an ocean basin. The absence of carbonate rock in the chert sequence suggests that the chert was deposited in a deep marine environment below the calcite compensation depth.

Chert blocks have been recorded in many localities in the suture zone at Langkap, Negeri Sembilan; Genting Sempah, Selangor; Karak and Bentong, Pahang; and Pos Blau, Kelantan (Spiller, 2002; Basir & Che Aziz, 1997a,1997b, Basir et al., 2004). Three of these chert blocks yielded significant radiolarian faunas and are hereby proposed to be considered for conservation as heritage of the Malaysian Palaeo-Tethys (Figure 1).

<table>
<thead>
<tr>
<th>Chert from Bentong, Pahang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chert from Langkap, Negeri Sembilan</td>
</tr>
<tr>
<td>Chert from Pos Blau, Kelantan</td>
</tr>
</tbody>
</table>

The chert blocks yielded three different radiolarian assemblages belong to three different ages.

**Chert Block from Bentong, Pahang**

The chert block is exposed at a road-cut of Bentong-Raub road (3°35’N, 101°54’E). The outcrop consists of mélangé containing blocks of ribbon chert, siliceous mudstone and massive dark gray sandstone. The width of the chert block is approximately 30 m. The chert layers are strongly faulted (Figure 3).

Basir et al. (2004) identified ten taxa of radiolarians and wrongly assigned it to Fennoscandian age. The occurrence of *Trilochne minax* (Hinde), *Trilochne david* (Hinde),

![Figure 1: Bentong-Raub Suture Zone and the radiolarian chert blocks localities.](image-url)
Chert blocks in Bentong-Raub Suture Zone: A heritage of Palaeo-Tethys

Trilonche vestusa Hinde, Trilonche tretactinia (Foreman), and Stigmosphaerostylus herculean (Foreman) (Plate 1, figs. 1-5) represent the Trilonche minax assemblage zone of Aitchison et al., (1999) indicating early Frasnian (early Late Devonian) age. This is the oldest radiolarian chert in Bentong-Raub Suture Zone. Spiller (2002) reported Holoeciscus Assemblage Zone, middle and upper Famennian (late Devonian) from radiolarian chert blocks in Karak, Pahang.

Chert Block from Langkap, Negeri Sembilan

The Langkap chert is exposed at a road-cut near Langkap, Negeri Sembilan (2°38’N, 102°21’E). The chert block is located within the Bentong-Raub Suture Zone. It is faulted and folded. The chert layers strikes 060° and dips 50° (Figure 4). The chert block is approximately 105 m long. The lower part comprises chert layers interbedded with thinly bedded mudstone. The top part consists of black laminated mudstones which contain well-preserved radiolarians.

The chert sequence in Langkap yielded 34 radiolarians (Basir & Che Aziz, 1997a). The occurrence of Albaillella deflandrei Gourmelon, Albaillella paradoxa Deflandre, Albaillella undulata Deflandre, Albaillella indensis ambigua Braun, Ceratoikiscum avinexpectans Deflandre, Ceratoikiscum berggreni Gourmelon, and Ceratoikiscum umbriculum Won (Plate 1, figs. 6-12) indicates a Tournaisian (Early Carboniferous) age. Spiller & Metcalfe (1995), and Spiller, (2002) reported the occurrence of Late Devonian and Early Carboniferous radiolarians from the same locality.

Chert Blocks from Pos Blau, Kelantan

Several chert blocks are exposed at the Gua Musang-Cameron Highland road. The sizes of the chert blocks range from 30 m to several hundred metres. The largest block is located at Pos Blau (4°45’N, 101°45’E). The block has red coloured ribbon-chert (Figure 5).

Twenty two species of radiolarians were identified from the chert block (Basir & Che Aziz, 1997b). The zone is characterized by the occurrence of the zonal marker Pseudoalbaillella lomentaria Ishiga and Imoto, Pseudoalbaillella ornata Ishiga and Imoto, Pseudoalbaillella sakmarensis Kozur, Pseudoalbaillella scalprata scalprata Ishiga and Pseudoalbaillella scalprata postscalprata Ishiga (Plate 2, figs. 1-5). The assemblage is indicative of a late Asselian-early Sakmarian (Early Permian) age.
Recently, more radiolarian species have been recovered from a chert block near Sungai Berok (4°44′49″N 101°45′05″E). The chert yielded at least two assemblages of radiolarians. The first assemblage contains *Pseudoalbaillella* longtanensis Sheng & Wang, *Pseudoalbaillella nanjingensis* Sheng & Wang, *Pseudoalbaillella globosa* Ishiga & Imoto, *Pseudoalbaillella* cf. longicornis Ishiga & Imoto, *Albaillella* asymmetrica Ishiga and Imoto, and *Pseudoalbaillella* fusiformis Holdsworth & Jones (Plate 2, figs. 6-11). This assemblage belongs to the *Pseudoalbaillella* globosa Assemblage Zone (Ishiga, 1990). Another assemblage contains *Follicucullus scholasticus* Ormiston & Babcock, *Follicucullus monacanthus* Ishiga & Imoto, and *Hagleria mammilla* (Sheng and Wang) (Plate 2, figs. 12-15) that represent the *Follicucullus monacanthus* Assemblage Zone of Wordian (Middle Permian) age (Ishiga, 1990). This *Follicucullus monacanthus* zone is the youngest zone obtained from the chert blocks in the Bentong-Raub Suture Zone to date.

**HISTORICAL SIGNIFICANCE OF CHERTS**

The radiolarian cherts in the Bentong-Raub Suture Zone indicate that radiolarian productivities were very high at times during the Late Devonian, Early Carboniferous, and late Early Permian to Middle Permian (Figure 6). The Early Carboniferous and Middle Permian radiolarian cherts were deposited during the global hypersiliceous period (Racki & Cordey, 2000).
Radiolarian chert blocks in the Bentong-Raub Suture Zone are the remnants of oceanic sediments deposited in Palaeo-Tethys Ocean. The Palaeo-Tethys was developed during the Early or Middle Devonian. During the early Frasnian (Late Devonian), the Palaeo-Tethys was an ocean where the oldest radiolarian chert was deposited. The Palaeo-Tethys became wider during the Carboniferous. The Palaeo-Tethys oceanic crust collided and subducted eastwards under the East Malaya terrane during Late Permian (Mitchell, 1977). The Palaeo-Tethys became a shallow sea during Early Triassic and was dominated by scattered fossiliferous limestone (Fontaine et al., 1995). The closure of Palaeo-Tethys was completed during Triassic and to form the Bentong-Raub Suture Zone (Figure 7). More than 120 million years history of sedimentation of the Palaeo-Tethys has been destroyed by the collision and only small fractions of the palaeo-ocean are preserved in the chert blocks within the mélange of the Bentong-Raub Suture.

CHERTS AS NATURAL HERITAGE
The operational guideline for implementation of the World Heritage Convention (UNESCO, 1995) has set up a list of criteria for natural heritage sites. The sites nominated should be outstanding examples representing major stages
of earth’s history, including the record of life, significant on-going geological processes in the development of land forms, or significant geomorphic or physiographic features.

The chert blocks of the Bentong-Raub Suture Zone represent a very important history of the Palaeo-Tethys and should be conserved as a National heritage. It is recommended that these three sites of the chert blocks from Langkap, Negeri Sembilan; Bentong, Pahang; and Pos Blau, Kelantan to be proposed at least as National Heritage sites and perhaps even as a regional heritage sites.

CONCLUSION

Radiolarian cherts are oceanic sedimentary rocks usually deposited in deep-ocean basins. The cherts are thinly bedded and known as ribbon cherts. The absence of calcareous fossils in the cherts indicates that the cherts were deposited below the Calcite Compensation Depth. Radiolarian chert blocks in the Bentong-Raub Suture Zone are remnant of the Palaeo-Tethys ocean. They are very important for age determination and paleobiogeographic studies. The occurrence of Frasnian radiolarian chert suggests that the Palaeo-Tethys already existed during the early Late Devonian and continued through to the Carboniferous and Permian. The youngest chert in the Bentong-Raub Suture Zone is Wordian (Middle Permian). The deposition of chert was diminished in the Late Permian and the Palaeo-Tethys became a narrow shallow sea during Triassic. The 120 million years history of Palaeo-Tethys was partially recorded in the radiolarian cherts blocks. The oceanic sedimentary rocks were deformed and destroyed during the collision of Sibumasu terrane and East Malaya Terrane. Only chert blocks are left as remnants of the Palaeo-Tethys. The chert blocks could be conserved as National Heritage sites.

ACKNOWLEDGEMENTS

I would like to express our gratitude to Cik Atilia Bashardin for her help in sample preparation. I would like to thank Prof. Dr. Lee Chai Peng for critical comments on the manuscript. I would like to thank Universiti Kebangsaan Malaysia for the research grant UKM-GUP-PLW-08-11-141.

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Chert blocks in Bentong-Raub Suture Zone: a heritage of Palaeo-Tethys


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Discovery of Late Devonian (Frasnian) conodonts from the “Sanai limestone”, Guar Jentik, Perlis, Malaysia

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Abstract: Late Devonian (Frasnian) conodonts (Ancyrodella, Ancyrognathus, Palmatolepis, Polygnathus, Icriodus, Ozarkodina and Belodella) of linguiformis Zone, which includes the Upper Kellwasser Event recorded in Europe, North America, China and elsewhere, are for the first time recorded from Perlis, Malaysia. The conodonts are fairly rich in the uppermost part of the “Sanai limestone” which was previously reported as of the upper part of Upper Devonian (Famennian) age. Stratigraphically it is located near the top of the Jentik Formation, unconformably overlain by the Lower Carboniferous Kubang Pasu Formation. The limestone is pelagic in nature and consists of planar bedded, grey micritic limestone, with thin shale partings and styliolites. In addition to the conodonts, the limestone contains abundant fossils of tentaculitids, straight-coned nautiloids, trilobites and bivalves. The “Sanai limestone” has a limited distribution in Malaysia and the assemblage of Malaysian Frasnian conodonts are closely compared with some conodont fauna (linguiformis Zone) of northwestern Thailand.

Keywords: Malaysia, Late Devonian, Frasnian, conodonts

INTRODUCTION

Late Devonian (Frasnian) conodonts have not been previously reported from Perlis, Malaysia, in fact even the presence of Late Devonian conodonts (asymmetricus Zone) were described from the Public Works Department Quarry, Gunong Kantang, District of Kinta, Perak, Malaysia (Lane et al., 1979). Meor & Lee (2002) had mapped the area in this study and first proposed the Jentik Formation with a brief description of the “Sanai limestone” and consequently, the limestone has been described in detail (Meor & Lee, 2003). Field trips were carried out in 2011 to 2012 at Hill B locality, in the Kampung Guar Jentik by two of us (AKA & MHH) and some postgraduate and undergraduate students from the Geology Department, University of Malaya (Mahfuzah, Atirah, Zahid and Kadeah). The comprehensive reports on the stratigraphy of the Hill B sections at Guar Jentik, produced by Meor (2004), Meor & Lee (2003, 2005) and Noor Atirah (2010) are essentially being used as the frame of the present report.

“THE SANAI LIMESTONE”

The “Sanai limestone” (Meor & Lee, 2003) was named after Guar Sanai ridge, in Kampung Guar Jentik, Beseri District, Perlis, just south of the Timah Tasoh Dam, approximately 10 km north of Kangar (Figure 1). The section exposed in the northwestern part of the ridge is about 50m thick and the beds dip about 60° towards northeast. It consists of fine-grained limestone. Fresh samples are light grey in colour, weathering to reddish white. Large, black coloured mottles in the rock may be impurities of either carbonaceous or intraclastic material. Large bivalve shells and cephalopod fossils are commonly found in it. Petrographically, the limestone is a sparse biomicrite, or wacke, with skeletal grains representing crinoid, trilobite, tentaculitid and ostracod fossils (Meor & Lee, 2003).

The limestone contains abundant pelagic fossils including tentaculitids, conodonts, straight-coned nautiloids together with some ostracods and trilobites. The depositional environment is interpreted as relatively deep water marine. The limestone shows many sedimentary features of deeper water, pelagic limestone facies, including the fine-grained, thin-bedded nature of the limestone with shale partings and the predominance of pelagic fossils (Scholle et al., 1983). The conodonts give further support to this interpretation. Following the conodont biofacies classification of Sandberg & Dreesen (1984), the palmatolepid-polygnathid association (most abundant conodonts in the section) is restricted to their biofacies II, which indicates a slope to basin environment.

The unit is strictly confined to Hill B and stratigraphically restricted laterally. The lithologic boundaries of the “Sanai limestone” is marked by two unconformities with the Lower Devonian Timah Tasoh Formation below and the Lower Carboniferous Kubang Pasu Formation) above in this area (Figure 2).

MATERIAL AND METHODS

A number of spot samples were first collected from the prominent limestone outcrops occurring within the “Sanai Limestone” in 2011. Preliminary work on the conodonts from the “Sanai limestone” in Guar Jentik showed that they are richest in the top section (Table 1) with 50 conodonts per kilogram of the samples, especially in palmatolepids and polygnathids. More selective re-collecting of previously collected limestone outcrops was made during the second trip in 2012. The detrital limestones from the sequence were sampled between 3 to 10 meter intervals or at closer
when necessary. Twenty two samples with an average weight of 10 kg from three biostratigraphic sections at Hill B (B1-3) were collected (Table 1). Conodonts were richest in the light grey, fine-grained limestone containing 2043 specimens from 80 kg of samples. Laboratory work and conodont taxonomy were undertaken at Geology Department, University of Malaya. The limestone samples were leached in 60% industrial acetic acid for a period of two days. The dissolved material was then sieved. Mesh of 16 microns was set up over 180 microns mesh. The residues were thoroughly washed. The mixed solution was then slowly poured through the sieves. Any residue in upper part sieve is returned to a plastic container for further acid treatment. The residue was dried overnight on a hot plate at a very low setting or under a heat lamp or in low-temperature oven. The conodonts were picked from the dried residues under a binocular microscope and stored in wall slides.

The photographs of the conodonts were taken using a digital camera (Nikon D300) attached to a Nikon Opthiphot microscope illuminated using a Nikon fiber optic light source. The camera was connected to a computer and the exposure was set manually using the software Nikon Camera Control Pro. The microscope stage was adjusted until the top-most part of the conodont is in focus and a photograph was taken. The stage was then raised so that a slightly lower part of the conodont is in focus and another photograph was taken. This was repeated until the lowest-most part of the conodont was photographed. Generally, for a single conodont, between 10 to 20 photographs, each focused at different parts of the conodont were taken. These photographs were merged using the focus stacking software Combine ZM, which produce a sharp image of the whole conodont.

SANAI CONODONT FAUNAS

The conodonts examined in this study and figured specimens are housed in the Department of Geology, University of Malaya (prefix UM). The zonal classification of Frasnian conodont zones used in this paper follows (Klapper & Becker, 1999, Text-fig. 1).

One conodont zone, linguiformis Zone has been recognized in the three measured stratigraphic sections sampled for conodonts (B1, B2, and B3) (Figs 1&3). The section B1 is in the southern part of the outcrop at Hill B where there is a clear lithologic contact between the “Sanai limestone” and the underlying Lower Devonian Timah Tasoh Formation. The section B2 is through the larger “Sanai limestone” lens where the base of the limestone is faulted, and B3 at northern part of Hill B (Figure 3). Conodonts recovered from the measured sections indicate that the “Sanai limestone” represents only one conodont zone, linguiformis Zone of Upper Frasnian age. The yields are low in the lower beds (B1-42, B2-1, 2) become more common in beds B2-2, 5 and are highest in bed B3 at the top of the section. The systematic study of the Sanai conodonts is in progress.

The stratigraphically lowest sample (B1-42) at 2 m above the base of section B1, produced a useful single conodont, Palmatolepis linguiformis Müller (1956), the zonal form for the uppermost zone (linguiformis Zone) of Frasnian, and (B2-1) at 3 m above the base of section B2, contains five specimens of Ozarkodina sp. and one Belodella sp. with no other conodonts occurring in this level. The conodonts are barren in other two beds of the “Sanai limestone” (B1-45, 48) in section B1. The sample from bed B2-2, at 4 m above the base of the section produced three specimens of Palmatolepis linguiformis co-occur with large number of Palmatolepis hassi, Müller & Müller,

**Figure 1**: Location map of Hill B, Guar Jentik, Perlis, Malaysia and outcrop of the Sanai Limestone.

<table>
<thead>
<tr>
<th>CARBONIFEROUS</th>
<th>VISEAN</th>
<th>KUBANG PASU FORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOUROSIAN</td>
<td>No record</td>
</tr>
<tr>
<td>DEVONIAN</td>
<td>FAMENNIAN</td>
<td>No record</td>
</tr>
<tr>
<td></td>
<td>FRASNIAN</td>
<td>Givetian</td>
</tr>
<tr>
<td></td>
<td>EIFELIAN</td>
<td>No record</td>
</tr>
<tr>
<td></td>
<td>EMSIAN</td>
<td>TIMAH TASOH FORMATION</td>
</tr>
<tr>
<td></td>
<td>PRAGIAN</td>
<td>LOCHKOVIAN</td>
</tr>
<tr>
<td></td>
<td>PRIDOLIAN</td>
<td>MEMPELAM LIMESTONE</td>
</tr>
</tbody>
</table>

**Figure 2**: Stratigraphic units of the Guar Jentik area, Perlis, northwest Peninsular Malaysia.

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Discovery of Late Devonian (Frasnian) conodonts from the “Sanai Limestone”, Guar Jentik, Perlis, Malaysia

Table 1: Distribution of the conodonts in the section (B2) at lower to middle part, and B3, the topmost part of the Sanai Limestone, Hill B, Guar Jentik, Perlis, northwest Peninsular Malaysia.

<table>
<thead>
<tr>
<th>Conodont zone</th>
<th>linguiformis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meters above base of section</td>
<td>3</td>
</tr>
<tr>
<td>Sample weight (kg)</td>
<td>1</td>
</tr>
<tr>
<td>Ancyrodella gigas</td>
<td>0</td>
</tr>
<tr>
<td>Ancyrodella nodosa</td>
<td>0</td>
</tr>
<tr>
<td>Ancyrognathus asymmetricus</td>
<td>0</td>
</tr>
<tr>
<td>Palmatolepis hassi</td>
<td>0</td>
</tr>
<tr>
<td>Palmatolepis jamiaeae</td>
<td>0</td>
</tr>
<tr>
<td>Palmatolepis rhenana</td>
<td>0</td>
</tr>
<tr>
<td>Palmatolepis linguiformis</td>
<td>1</td>
</tr>
<tr>
<td>Polygnathus decorosus</td>
<td>0</td>
</tr>
<tr>
<td>Polygnathus webbi</td>
<td>0</td>
</tr>
<tr>
<td>Icriodus alternatus</td>
<td>0</td>
</tr>
<tr>
<td>Ozarkodina sp.</td>
<td>5</td>
</tr>
<tr>
<td>Belodella sp.</td>
<td>1</td>
</tr>
</tbody>
</table>

1957, Polygnathus decorosus Stauffer, 1938, Polygnathus webbi Stauffer, 1938, Icriodus alternatus Branson & Mehl, 1934 and Ozarkodina sp. (Table 1), suggests this particular horizon to be already within the linguiformis Zone and possibly not many metres below the Frasnian-Famennian boundary. The next sample, 6m above the base (B2-5), yielded more conodont faunas including Ancyrodella gigas Youquist, 1947, Ancyrodella nodosa Ulrich & Bassler, 1926, Ancyrognathus asymmetricus Ulrich & Bassler, 1926, Palmatolepis linguiformis Müller, 1956, Palmatolepis hassi, Polygnathus decorosus, Polygnathus webbi, Icriodus alternatus, Ozarkodina sp., and Belodella sp.

The conodont fauna from the higher bed of section B3 at 48 m above the base of the section, is heavily dominated by palmatolepids, polygnathids, and icriodids, and it includes the recently described Palmatolepis linguiformis, Palmatolepis hassi, Palmatolepis jamiaeae, Ziegler & Sandberg, 1990, Polygnathus decorosus, Ancyrognathus gigas, Ancyrognathus nodosa, Icriodus alternatus and Palmatolepis rhennana Bischoff, 1956. The two palmatolepid species, Pa. hassi and Pa. rhenana are likely to be among the few survivors from the lower level (rhenana Zone).

All the above conodonts are illustrated in (Figures 6 & 7). It therefore appears that the “Sanai limestone” is of latest linguiformis Zone age.

**DISTRIBUTION OF FRASNIAN CONODONTs IN SOUTHEAST ASIA**

Apart from the “Sanai Limestone” at Hill, B, Guar Jentik, Perlis, the Frasnian conodonts are only known from only one locality in Perak, Peninsular Malaysia. Lane et al. (1979) first reported and described Devonian and Carboniferous conodonts from a slightly metamorphosed sequence of carbonates at the Public Works Department Quarry at Gunong Kantang in Perak. The fauna includes standard Euro-North American conodont zones from the late Lower Devonian gronbergi Zone to the early Upper Devonian asymmetricus Zone and Carboniferous faunal assemblages of late Visean or early Numurian age. They also described a new conodont genus (Klapperina, Lane et al., 1979) of Frasnian age. The Late Devonian (Frasnian-Famennian) conodonts (late rhenana to middle triangularis Zones) are known from the Thong Pha Phum area, western Thailand (Savage et al., 2006). The Frasnian-Famennian conodonts, mostly of cosmopolitan species are abundant with 80 conodont faunas from 10 zones (late rhenana, linguiformis, triangularis, crepida, rhomboidea, marginifera, trachytera, postera, expansa, and praesulcata Zones) from the Mae Sariang section of Northwestern Thailand (Savage, 2013).
Figure 4: Outcrops of the "Sanai limestone" at Hill B. Photographs taken facing east.
A. Base of the "Sanai limestone", section B1, bed B1-42; B. Section B2, bed B2-1; C. bed B2-2; D. bed B2-5; E. B2-9 (black shale) and outcrops of the topmost part.


MP – Mempelam Limestone (Silurian), TT – Timah Tasoh Formation, black shale (Lower Devonian), SN – "Sanai Limestone" with black shale intercalations (Upper Devonian), KP – Kubang Pasu Formation, sandstone – shale interbeds (Lower Carboniferous).
CONCLUSION
Available conodont data indicate that at Hill B, Kg. Guar Jentik, Perlis, the “Sanai limestone” is of latest Frasnian (latest *linguiformis* Zone age). The conodonts confirm that the recognized species are mostly cosmopolitan. The Hill B-Sanai section includes the global Upper Kellwasser event that marks at the top of Frasnian (Figure 5) recorded in other part of the world. There is no conodont evidence which may represent the presence of Famennian age in this section. This suggests that there may be two regional unconformities present. The first is between this limestone and Timah Tasoh Formation of Lower Devonian age below, and the second is with the Kubang Pasu Formation of Lower Carboniferous age above. The Perak conodonts of early Upper Devonian (*asymmetricus* Zone) are much earlier than that of the Perlis late Upper Devonian (*linguiformis* Zone) which are in part contemporary to those of north-western Thailand.

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Discovery of Late Devonian (Frasnian) conodonts from the “Sanai Limestone”, Guar Jentik, Perlis, Malaysia


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Geological landscape and public perception: A case for Dataran Lang viewpoint, Langkawi

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Abstract: In order to understand the aesthetic value of geological landscape, a study was conducted at Dataran Lang viewing point, Kuah, Langkawi based on horizontal viewpoint landscape mapping and public perception survey method. From the mapping exercise several types of landforms and landscapes have been identified and associated to their various geological formations. In addition to these natural landforms, several man-made landscapes were also identified. Data obtained were transformed into a simple schematic sketch to relate the landscapes with the rock types. Using this sketch as a guide, a public perception survey was carried out to find out the visitors’ understanding and perception on landscape of scenic beauty and their relationship with geology. The survey has shown that most visitors agreed that landscapes seen from Dataran Lang have scenic appeal or aesthetic value. The sketch was useful to help them relating the different landscapes with different geological or scientific information. The schematic geological sketch interpretation is an important tool for enhancing public understanding on geological landscape, geoheritage, and geotourism as well as a tool in future development planning related to the aesthetic geological landscapes.

Keywords: geological landscape, public perception, geoheritage, geotourism

INTRODUCTION

Geological landscape is a term used to describe the natural physical landscape or natural environment that is viewed from a geological perspective. From this perspective a natural landscape is perceived as an assemblage of landforms that contains enormous intrinsic value associated with its formation. In understanding the origin and the formation of natural landscape it is crucial to understand the properties of the earth material which form the landscape, the natural processes responsible in crafting various landforms, and the evolutionary stages which make it unique at present time and scenario. Therefore, the beauty of the landscape is the mixture of intrinsic value of the above assemblages and the extrinsic value manifested informs of mountain, gorge and hill.

Geological landscape has been closely connected to man since the existence of human kind. The terms such as hill, river, gully, barrow and mountain in name of places are a manifestation of landscape in most geographic destination or addresses clearly indicated human appreciation to geological landscape. Among world famous geological landscapes are, Arthur’s Seat of Edinburg, Scotland which is an extinct volcano system, Table Mountain of Cape Town, South Africa, a mesa made of sandstone bed, and Sugarloaf Mountain of Rio De Janeiro, Brazil, a granite bornhardt landform. As long as man and landscape live side by side, they will always tried to explain this connection in various manners through various perspectives.

In Malaysia, geological landscape has been fundamental to most of the ecotourism industries, even before the word ecotourism was created (Ibrahim Komoo, 1997a; Mohd Shafeea Leman, 1997). Tourists from local and abroad for examples have flocked to Langkawi, Tioman, Taman Negara, Gunung Kinabalu and Gunung Mulu merely to enjoy the natural beauty behind these geological landscapes. As a matter of fact it was due to these phenomena that the Malaysian Geological Heritage Group was established to look at matters pertaining to research on geoheritage conservation in this country (Ibrahim Komoo, 1997b).

Public without adequate geological background often looks at geological landscape solely on its beauty, hence only value it based on the geometrical shape and vegetation cover. Various studies in the past decades have recognised that substantial components of the world’s landscapes were shaped not on the Earth’s surface, but at the base of the regolith (Twidale, 2002; Garcia-Quintana et al., 2004). Surface geomorphic processes are strongly influenced by the physical properties of the rocks, in terms of restively toward weathering and erosion, the chemical properties as well as the structural properties of the rocks. Therefore, understanding on basic geology is as important as understanding on geomorphic processes in the study of geological landscape. This paper wills elaborate on the relationship between geological landscape and the geology that formed the landscape. A horizontal view from Dataran Lang Langkawi from where geological landscapes of various origins are seen will be ideal to demonstrate this relationship.

Landscape as perceive by human is an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factor (Council of Europe, 2007). Human perception is therefore very important in determining the significance, the potential for sustainable utilisation and the need for conservation of geological landscape. The establishment of first national park in America i.e. Yellowstone National Park in 1872, a conservation statue for large area was due to the aesthetic beauty of its
landscape (Yard, 1920). Based on this understanding this current study aims to introduce the geological component embedded within a landscape and how it has influenced the beauty or aesthetic of an area.

In conservation geology the increasing awareness in geology among the public will benefit the long term protection and management of geological heritage resources (UNESCO, 2006). Thus, there is a need to provide and implant as much as possible of geological information on geological heritage of a sites on this case a geological landscape. This has been done through publications of geological material, exhibitions on geology, series of talk, seminars and dialogues with various stakeholders as well as on site information on panels (Dias & Brilha, 2004; McKeever, 2009). However, more often than not information given was either very highly scientific or very dilute, hence losing some essential the facts and meanings. In general it can be said that the geology are yet to reach the public at large.

In tackling these issues a study has been conducted on evaluating efficiencies of geological communication to the public using simplified geological landscape.

**GEOLOGICAL LANDSCAPE FOR THE PUBLIC**

Numerous studies have been carried out in interpreting and assessing the values of landscape to the public, such as Zube et al. (1974, 1982) through public perception assessment on landscape of scenic beauty. This work identified differences on the results based on the types of evaluator known as expert technique, quantitative survey, focus group and individual experiential. The application of this landscape assessment approach was carried out in various subjects and perspectives. Among the sound approach was from psychology perspective by Bernaldez & Parra (1979), Kane (1981), Daniel (1990), Purcell & Lamb (1998) and Canas et al. (2009), management approach as promoted by Brown et al. (1990) and Ulrich et al. (1991) and cultural perspective by Zube et al. (1974), Tips & Savasdisara (1986), Hull & Grant (1989) and Terkenli (2001). The common principle of assessment in these studies indicates differences between the onsite and indoor approach by using photographs, slides and at the landscape while filling in the questionnaires (Shafer & Brush, 1977; Kaplan & Kaplan, 1989; Canas et al., 2009).

Most of these studies were dealing with landscape as a land cover or cultural landscape parallel with the definition of European convention on landscape. For such, the landscape means an area, as perceived by the people, whose character is a result of the action and interaction of natural environment and/or human factors. The assessment of landscape beauty by integrating geology and landscape or geological landscape has been introduced by Tanot Unjah & Ibrahim Komoo (2004; 2005; 2007). They have made their assessment based on the physical component of geological landscape. The physical component includes types of rock that form the landscape, geological structures that control the landscape (e.g. bedding properties, joints and faults) and geological processes that continue to shape it (e.g. erosion, dissolution and mass wasting). Basically, the appreciation and understanding of these physical components of the landscape is the key to sharing geological knowledge to the public. Application of landscape beauty assessment using geological landscape components had been applied at Lata Chenai, Kelantan and while horizontal landscape mapping had been experimented at Kilim and Selat Kuah, both in Langkawi, Kedah.

Previous experiment on horizontal landscape mapping at Kilim only developed basic technique and procedures on viewpoint landform mapping and characterization of carbonate rock landform. The need for more comprehensive study on the characterization of other types of rock is critical. Beside the ability of the landform data to be used as part of the knowledge tourism, is crucial in creating appreciation toward the landscape. In order to incubate appreciation we have to understanding how scientific knowledge contributes to the beauty of the landscape.

**DATARAN LANG**

A study was conducted at Dataran Lang, Kuah in Langkawi Geopark (Figure 1), the first national geopark in Southeast Asia and the 52nd member of Global Geopark Network supported by UNESCO. Being part of the geopark, it is crucial to have protected geological, cultural and biological sites. For this purposes numerous tourism sites have been promoted either by adding simple geological information for existing cultural sites or establishing new geologically based sites such as Pantai Pasir Hitam (Black Sand Beach), Pantai Pasir Tengkorak, Gua Kelawar (Bat Cave,), Tasik Dayang Bunting and Pulau Anak Tikus (Mohd Shafee Leman et al., 2006; 2007).

Dataran Lang is one the well-known site for viewing Langkawi’s beautiful landscape. It is where the grand eagle statue that signified Langkawi’s identity was erected. It is a small esplanade at one corner of the Straits of Kuah, connected by bridges to the Lagenda Park and the Kuah Jetty Port. The area was developed by the local authority with recreational facilities such as benches, gardens, craft arcades, tiled pathways and open spaces (Local Management Plan District of Langkawi, 2003).

**APPROACH AND METHODOLOGY**

**Horizontal Viewpoint Landscape Mapping**

The viewpoint mapping is the mapping of landforms from a selected viewing point. The best viewpoint is a site where one can observe a landscape at horizontal level with furthest distance of clarity (Tanot Unjah & Ibrahim Komoo, 2005). Landforms observed from the selected viewpoint point are sketched and described based on their rock types with related geological structures and processes.

The mapping can be divided into four levels known as identification of view point, scope of observation, field landscape sketch and landscape analysis. A viewpoint is identified from the topographic map, having the best view of the surrounding areas with minimum crossing angle of observation. This is followed by identification and selection...
on scope of observation. The scope of observation is read based on 360° degrees in the horizontal view. It can be captured during field observation and later confirmed using a topographic map. Next is the field landscape sketching and this can be divided into two levels of sketching, i.e. general landscape on the area and the specific sketch of the landform. Basically, the general sketch directly captures the whole area with a degree of observation while the specific sketch of the landform component must consider the distance between the view point and the landform. Groups of landforms are later sketched based on 0.5 km intervals up to the last visible object. Each landform component is identified as one of several shapes simplified into an alphabetical code to minimize the space in the sketch. Analysis of data was then carried out to understand the dominant landform, and to interpret the major geological processes and history of the area.

Landscape analysis was carried out using the landform classification by Tanot Unjah & Ibrahim Komoo (2005; 2007). The classification is an identification of landform according to rock type. Three types of rock in the area are carbonate sedimentary rocks, clastic sedimentary rocks and igneous rocks (Table 1). Examples of the landform representing different types of rock are shown in Figures 1, 2 and 3.

**Carbonate sedimentary rock landforms**

Tanot Unjah & Ibrahim Komoo (2005) classified carbonate rock into 10 major landforms. The landforms are mogote with rounded top (L1), mogote with flat top (L2), cone tower hill (L3), cone hill (L4), coconut shell-like hill (L5), pinnacle (L6), karst stack (L7), structure-control hill (L8), dome (L9) and structure-control pinnacle (L10). Some images on the observed carbonate sedimentary rock landforms are shown in Figure 1.

**Clastic sedimentary rock landforms**

Clastic sedimentary rock was classified into six main landforms (S1 to S6). Each of these landforms shows the influence of bedding and erosion. The landforms are: rounded to almost flat top with medium slope hill (S1), one sided cone hill (S2), irregular top and gentle slope hill (S3), low cone with gentle slope hill (S4), flat top or ridge-like with gentle slope hill (S5), and sea stack or isolated hill due to erosion (S6). Some images of the observed clastic sedimentary rock landforms are shown in Figure 2.

**Igneous rock landform**

There are three types of igneous rock landforms in Langkawi (G1 to G3, Figure 3). They are symmetrical hill with gentle slope (G1), flat and almost rounded top hill with medium slope (G2) and ridge-like hill (G3).

**Public Perception Survey**

Surveys were carried out using a set of questionnaire on respondent’s personal particulars, basic ideas of scenic landscape, perception on scenic landscape in Langkawi, scientific input on geology and perceived plan for future development of the area surrounding the landscape.

Questionnaire was prepared specially for groups that directly interact with the landscape. In this study, tourists were the main aim as it was purposely used to identify the beauty of this area. The questionnaire was based on the focus group method, usually used for social research techniques to understand and describe the feelings and perceptions of groups of people who interact with the landscape (Zube et al., 1982). A simplified questionnaire was prepared to test the participant understanding on the scenic value of a landscape in relation to its scientific geological input. A total of 35 respondents mainly tourists that visited Dataran Lang were interviewed at different times over several weeks of
2008. The data from the questionnaire was later analyses using a Statistical software (SPSS).

RESULT AND DISCUSSION

Topographic sketches of landforms for each 180° have been made from Dataran Lang with Bt Panchor being referred as starting viewing angle (i.e. 0°). Dataran Lang is a perfect viewing point where various landforms can be observed for a complete 360° circle up to 6 km without much object of interference (Figure 4). From these sketches, three groups of landforms reflecting clastic sedimentary, carbonate sedimentary and igneous rocks can be observed and classified in detail. The clastic sedimentary rocks are represented by the Machinchang and Singa formations, while the carbonate sedimentary rocks are represented by the Setul and Chuping formations. The igneous rock is made up of Gunung Raya Granite. Quaternary sediments are less obvious as much have been cover by vegetation or part of the man-made landscape.

The observation from Dataran Lang viewpoint identified four types of landform each for clastic and carbonate sedimentary rocks and three types of igneous landform (Figure 5 and Table 2). The carbonate landforms are represented by two mogotes (L1), three cone towers (trapezoid) (L2); five conical hills (L3), and one structurally controlled hill (L5). Meanwhile clastic sedimentary landforms consist of five one sided cone with bedding influence (S2), two hills with irregular top and gentle slope (S3), three low conical hills with gentle slope (S4) and one flat top hill with gentle slope (S5). On the other hand igneous landforms are identified as one symmetrical hill with gentle slope (G1), three rounded hills with gentle slope (G2) and three ridges (G3).

Although the landscape is dominated by sedimentary rocks, rare igneous landscapes are still outstanding in size.
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The landforms observe from this viewpoint are mainly due to weathering and mass wasting. Heavy annual rainfalls contributed to the well-formed carbonate rock and symmetrical peak of the igneous rock landforms. Mass wasting which include rock falls and landslides create steep slopes and rugged peaks.

Perceptions obtained from questionnaire survey revealed that 82.9% of the respondents are domestic tourist and 17.1% of the visitors are foreign tourists mostly from Australia, Brunei, Singapore, Indonesia and Taiwan. The high number of the local tourist in comparison to the international strongly indicates their appreciation on local tourist destination. Perhaps this is due to the extensive promotion by the Tourism Ministry and the local authority on the natural beauty of the island as well as its reputation as duty free island.

Most tourists are English literate. In terms of age, 40% of the respondents come from 25 to 34, 22.9% from 35 to 40, 20% from 15-24, 14.3% from 45 to 54 and 2.9% from 55 to 64 years age groups (Figure 6). The highest age group are also known to be generation X and Y which they are known to have the powerhouse in generating next economic and they are known as educated buyer (William & Page, 2011).

In term of educational background most of the respondents are degree holder (42.9%), the rests are senior high school students and school leavers (40%) and diploma holder (11.4%). Others are students from junior secondary schools (2.9%) and Master or PhD holder (2.9%). For the detail of the distribution please refer to Figure 7.

Most of the respondents (88.6%) came to Dataran Lang as part of their holiday trip to Langkawi, while 8.6% of them are on official trip and only 9% are local people. In terms of occupation, 40% of the respondents are working with private company, 20% are student and retiree, 17.1 % are government employee, 8.6% each are involved in academic and business and 5.7% as professional (Figure 8). The survey also shows that only 31.4% of the respondents come to Dataran Lang for the first time while others have been to this place several times.

On their basic idea of scenic landscape, all of them agree that the landscapes viewed from Dataran Lang have great scenic beauty. However, their criteria or element of scenic beauty vary from mixture of natural and man-made landscape (54.3%), totally natural landscape (40%) and solely man-made landscape (5.7%).

For comparative beauty 34.0% of the respondents considered this area as the most scenic spot in Langkawi, while 25.0% of them choose Machinchang Cable Car, 17.0% choose Pantai Chenang and 3.0% each refer to Gallery Perdana, Padang Matsirat, Pasir Tengkorak, Porto Malai, Tanjung Rhu, Telaga Harbour and Telaga Tujuh as the most scenic spot in Langkawi (Figure 9).

On perceived scientific inputs toward the sketched on display, 88.6% of the respondents indicated that they have never came across such a sketch. However, 82.9% of them say that they can relate the actual landscape with the sketch, while the other 17.1% cannot. For those who respond, their understanding of the sketch and landscape were varied from natural topography at 31.4%, man-made topography with 17.1%, panoramic perspective in the sketch with 17.1%, diversity of geological and geomorphological 45.7% and sketch that portray the landscape with 34.3%.

After being briefed on the science of the sketch, more than 57% respondents agree that the information give additional value to the landscape while 34% consider it does not add any value, while 9% thought the information somehow degrade the value of the landscape beauty.
CONCLUDING REMARKS

The finding of this study concludes that geological landscape approach have the ability to link observed landforms recognised through their physical appearance with knowledge on geological structure, as well as physical properties and erosion attribute to different types of rocks. Observation through horizontal viewpoint has the advantage of having a common view with general tourists. It provides a platform to enhance the observed landscape by providing various scientific values. This approach has the ability to expose the various hidden value of natural resources for ecotourism or specifically geotourism in landscape perspective.

The survey on public perception on landscape of scenic beauty shows that the common public recognised the importance of geological sketches in promoting the scenic value of the area. The survey offered more option for tourists in terms of their preference on viewing and understanding of scenic landscapes on the island. As mentioned by Fyhri et al. (2009) research on the qualitative survey of public perception is vital in areas where tourism is a key economic factor. It is also very important in understanding the awareness level among the local residents and in assessing development and other environmental challenges that have visual consequences. As a global geopark, Langkawi has the responsibility to enhance current tourist attractions by introducing knowledge based tourism, particularly knowledge on geology.

The study also agree with Jensen & Koch (1998) that this kind of research seeks for better comprehension of various recreationists’ landscape preference by looking forward for nature management staff and several other landscape–related decision-makers on their perspectives of scenic beauty. Therefore, their expertise and knowledge contribute to better recommendations on recreation and tourism with respect to nature and various environmental problems (Vining, 1992). As for Langkawi, since public knowledge enhancement, geotourism and environmental sustainability are among key objectives of the transformation of Langkawi into a geopark (Mohd Shafeea leman et al., 2007), data and other types of information gathered through this landscape study approach will certainly be very useful in future development planning of the geopark.

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