PREFERRED DIRECTION OF KARST IN THE KUALA LUMPUR LIMESTONE FORMATION: A SMART TUNNEL CASE STUDY

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Abstract

In this paper, a karstified limestone formation beneath the city of Kuala Lumpur is studied in reference to its relationship between the geological structure and river patterns. A preliminary prediction of karst that was likely to be readily developed was made based on the existing geological map, where the basic geology of the area was expected to be related to river patterns; which suspected can be obtained from the direction of fractures expected in the limestone. Two directions appear to be special interest: N030° to 070° and N120° to 150°; the investigation was then carried out in the field, using the two sites exposed for construction of the SMART tunnel under Kuala Lumpur to verify the prediction made in the desk study analysis. The method used for this study and the evidence are described.

Keywords: Fractures, Karst, Kuala lumpur, Limestone, Rivers and streams

Introduction

Most of Kuala Lumpur, including its commercial centre, is founded on alluvium overlying limestone of Silurian age, in which Extreme karst, classified as KV according to Waltham & Fookes (2003), has been extensively developed. This buried karst landscape of Kuala Lumpur can be further grouped into two classes in accordance with its dimensions and characteristics. The first class is a Karst Scale 1 (K1) that is well developed, creating a highly irregular level of rock below the alluvium, varying in elevation by tens of metres over tens of metres and containing numerous voids, many of which have collapsed and are partially filled. The second is a Karst Scale 2 (K2) that is much smaller and concentrated on fractures having been investigated concerning an openness (measured in centimetres) and freshness that is still being actively developed (Zabidi and deFreitas, 2010). This smaller scale karst creates many problems for the design and construction of civil engineering structures in Kuala Lumpur because the void of it is so permeable that it provides major sources of inflow and locations for considerable grout loss, and zones of great weakness under load. The highly irregular topography of limestone rock head in the Kuala Lumpur region was first discovered in opencast tin mines, nearly 150 years ago. Deep borehole records from construction sites in the city confirm its wide spread occurrence (Tan, 1986a & 1986b). This karst feature is generally believed to have been developed during the Quaternary, although it is possible that considerable dissolution also has occurred prior to the deposition of the Permo-Carboniferous Kenny Hill Formation; this paleo-landscape has been buried by alluvium to form the current landscape of Kuala Lumpur (Chan and Hong, 1985).

The construction of high rise buildings on a flat alluvial plain that conceals the highly irregular topography of limestone bedrock has always been a challenge for engineers in Kuala Lumpur (Ibrahim and Fang, 1985; Tan and Komoo, 1990) and considerable geotechnical problems have occurred during the construction of many engineering projects, large and small, in the limestone formation. Well recorded case histories for the construction of the Petronas Twin Tower (Tan, 1996; Pollalis, 2002), the Berjaya Times Square Complex (Gue and Tan, 2001), the Pan Pacific Hotel (Mitchell, 1985) and the SriMARA Complex (Tan *et. al.*, 1985) illustrate the types of conditions encountered. The difficulty in locating them is eliminated by ground investigations that depend heavily on vertical boreholes to study the complexity of the ground; but, these give no guarantee of finding either karst at this scale or trends in such karst development. Therefore, the other methods of prediction are needed. In this paper studies of the relationship between drainage patterns, fracture patterns and K2 karst forms are reported, and their use for predicting karst during desk studies are assessed.

Geology of Kuala Lumpur

Kuala Lumpur lies on a flat alluvial plain within the broad valley of the Klang River, bounded by high hills predominantly of granitic rock to west and east. The Klang River drains a catchment area of approximately 1,288km^2, traverses a distance of nearly 120km while crossing two states, Selangor and Wilayah, before discharging into the Straits of Melaka. The geology of the study area consists of sediments ranging in age from Middle Ordovician to possibly Permian, and a granitic body intruded during the Late Triassic (Figure 1). At the base of the sequence is the Hawthornden Formation (Middle Ordovician to Middle Silurian), overlain by the Kuala Lumpur Limestone Formation (Middle Silurian to Lower-Middle Devonian) (Gobbett, 1964). The Hawthornden Formation is a mixture of quartz – mica amphibolites and carbonaceous schists, phyllites and quartzites. The overlying Kuala Lumpur Limestone Formation is composed of fine to coarse grained, white to grey, predominantly recrystallised limestones, with local developments of dolomitic limestone and dolomites, all with few impurities. These Lower Palaeozoic formations experienced their first phase of folding during the Devonian to form east-west fold axes. An extensive period of uplift, weathering and erosion followed during which karst was developed in the Kuala Lumpur Limestone Formation. These Lower Palaeozoic formations are overlain unconformably by the shales, mudstones and sandstones of the Kenny Hill Formation, which accumulated towards the end of the Carboniferous and the start of the Permian. These sediments were folded by a second tectonic during the Late Triassic. This activity strongly deformed the Lower Paleozoic rocks to produce the metamorphic grades and folded strata to follow a north-south trend. The Lower Palaeozoic sequence has bedding dips that are commonly steep and overturned; contrasting with the more gentles dips of the Kenny Hill Formation overlying them. The country rock was then intruded by granite, estimated to be either broadly contemporaneous or younger than the second phase of folding, occurring towards the Late Triassic. The last period of deformation is NE-SW and NW-SE trending faulting, which has affected all the formations, including the granite. The fault zones of the Ampang Fault, trending at N285°, and the Gombak Fault, at N200°, have markedly displaced the Kuala Lumpur Limestone Formation and can be expected to have affected its hydraulic conductivity.

Method of Prediction

An assumption has been made that fractures offer lines of decreased hydraulic resistance to groundwater flow and therefore they are more easily exploited by weathering and erosion processes than their adjacent rock (Verstappen, 1960; Paton, 1964; Gobbett, 1965; Sower, 1975 and Ericson *et al.*, 2004). With this assumption, the existing geological and geomorphological data can be interpreted and potential links between the drainage pattern and possible directions for karst can be identified. Thus, by studying the pattern of river and structural orientation from the geological map, an initial prediction for the orientation of karst can be made. Four steps were followed to explore this approach: (i) the structure of the limestone was defined, using the 1: 63,600 geological map of the region, to obtain the likely direction of joints; (ii) the drainage network of the region was studied using the same scale map (in fact in this study it was the same map) to obtain the directions and frequencies of linear river segments; (iii) the river directions from the drainage analysis were then compared with the structural directions obtained from the fracture analysis, which showed that rivers and structures shared certain directions but not other, suggesting the needs to know whether the structural directions in which there are no rivers (i.e. no water at the surface) are the same as those in which karst has most severely developed, and if so, whether this is a means of predicting likely preferential directions of karst; and (iv) the correctness of this approach was confirmed by field observations in Kuala Lumpur. In this exercise, geological mapping was carried out at the two previously excavated boxes, which was constructed as part of the Stormwater Management and Road Tunnel (SMART) project.

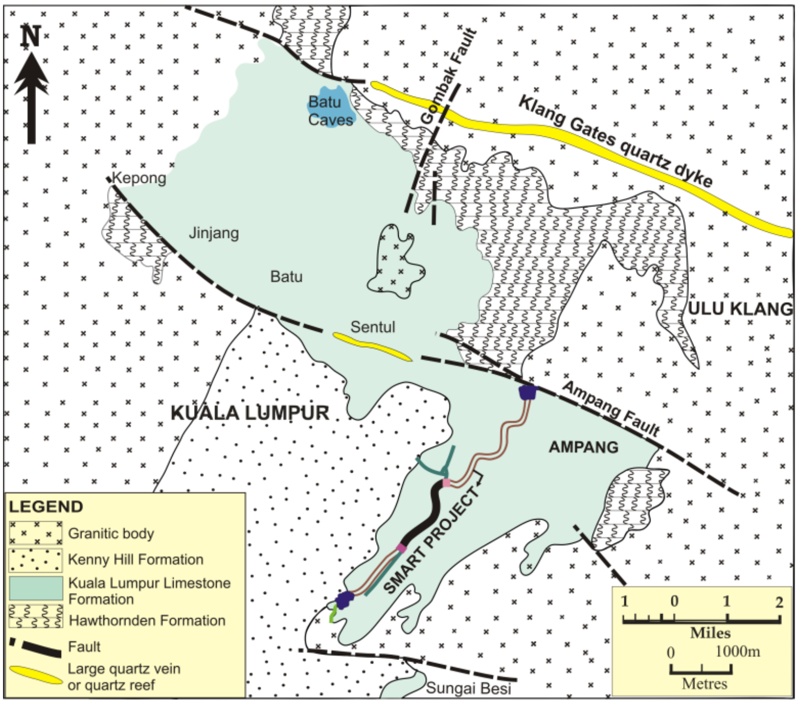

Figure 1. A simplified version of the geological map of Selangor, Sheet 94 (Yin, 1967).

Fractures Analysis

A joint is a fissure in rock across which there is no appreciable displacement; it develops in almost all types of rock and in diverse tectonic settings. Systematic joint sets provide crucial information on the directions of principal stress involved in the formation of the ground. In slightly deformed, horizontal or near-horizontally bedded rock, failure in tension can occur, to form an extensional joint oriented parallel to the maximum stress, σ_1 and intermediate stress, σ_2 and perpendicular to the minimum stress, σ_3 (Hatcher, 1995). In folded rock, extensional joints, normally cut perpendicular to the bedding, can also form as shear joints, with oblique orientations to the principle stresses (Price, 1966).

The predictions of preferential directions of karst started with an analysis of the structural geology of the area based on the 1: 63,360 New Series geological map for the Selangor area, Sheet 94 (Yin, 1967). The Kuala Lumpur Limestone Formation contains many folds and the axes of a few recorded folds on the geological map as shown in Figure 2. From this the likely directions of fractures (joints and faults) were identified. Fracture orientations were predicted from the orientation of fold axes and bedding planes, based on the assumption that orientations of strike and dip can be used to deduce another three joints orientations according to the fold – fracture relationship for obtaining extensional joint, longitudinal joint and two shear joints (Price, 1966). That is possible by using the stereonet; E1 is bedding reading from the geological map, whereas the other three readings are collected from the stereonet (Figure 2). The accumulation of fracture line directions was then displayed, measured from Grid North (which is within 0° 3' East of Magnetic North in this area), by using a rose diagram to produce percentages in any given direction grouped in batches of 10° from North, with all the readings are grouped in 18 equal sizes, N001° – N010°, etc. The 3D characterization of these fractures could equally be shown using a stereonet (Figure 3), however since most of these fractures are vertical or near vertical, simple rose diagrams are used for clarity.

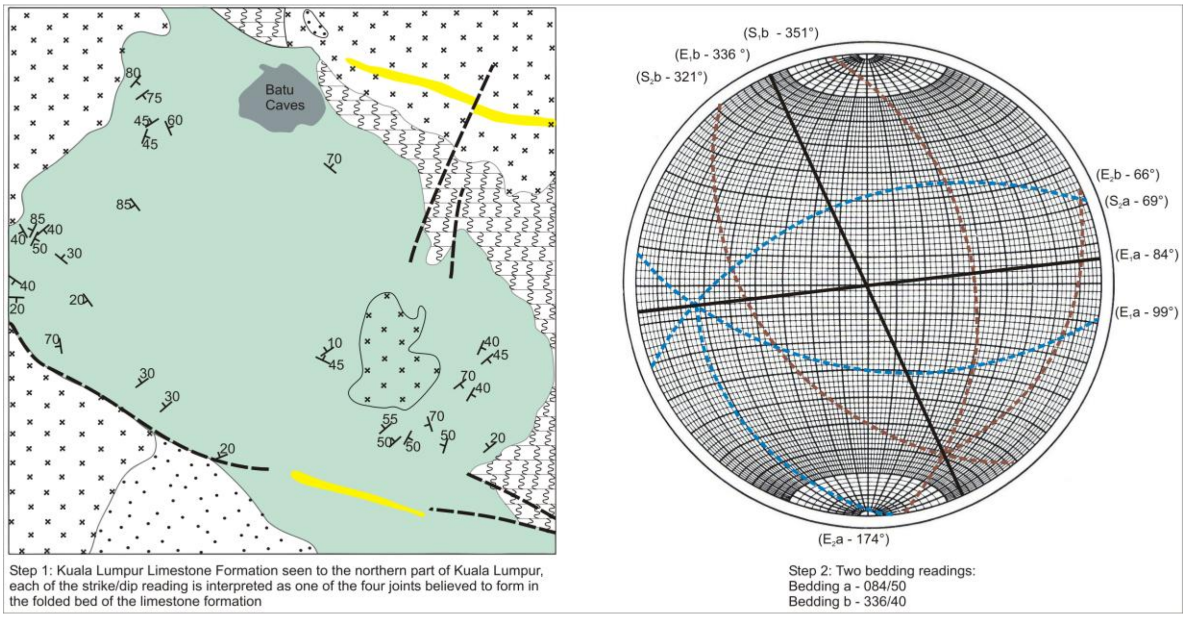

Figure 2. Fracture analysis carried out in the Kuala Lumpur Limestone Formation

Drainage Analysis

Using the same map, the stream directions in the area, which exhibit a trellis-like pattern indicating some degree of structural control, were analysed. This orientation has frequently been mentioned by the previous researchers as the prominent structure orientation, (e.g. Stauffer (1968), Shu (1969), Tjia (1972), and Ong (1978)). Strong correlations between fracture patterns and drainage lines have been long suspected by many researchers in the past (Herold, *et al*., 2000 & Mayer, *et al.*, 2003). An assumption was made at this stage in the work that some fracture lines or zones within the host rock offer lines or zones of decreased resistance to dissolution, and is more easily exploited by weathering and erosion processes than more massive adjacent rock. The end product of the weathering and erosion process is a stream or river channel, developed along a fracture orientation.

Stream analysis was carried out by tracing the drainage network shown on the 1:63, 360 geological map for all geological formations in the study area and dividing the stream channels into six different groups based on their direction from magnetic North to produce a stream line map (Figure 4). The lines were grouped into 6 classes of equal orientation size, (N001° – N030°), (N031° – N060°), (N061° - N090°), etc. Figure 4 shows part of the study area, located further Northwest of Kuala Lumpur area. Apparently, it is rather obvious that the first upper part of the traced map is dominated with the NW direction of lines, marked in red pen. A comparison was then completed between the orientations of the drainage channels in the Kuala Lumpur Limestone Formation and the orientations of the drainage channels in the other geological formations including the granites, the Kenny Hill Formation and the Hawthornden Formation; i.e. formations that were older and younger than the Kuala Lumpur Formation. The accumulated number of measured drainage channels for each geological formation was then grouped into 18 classes of equal size, (N001°–010°), (N011°–N020°), (N021°–N030°), etc., i.e., using the same intervals as used for fractures, and plotted to make a complete diagram for the evidence from each outcrop type (Figure 5).

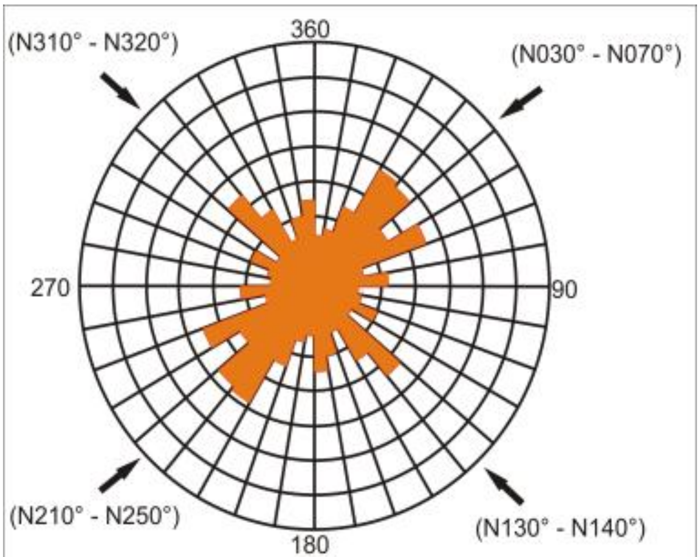

Figure 3. Joint orientations in the Kuala Lumpur Limestone Formation, as deduced from the geological map. The two prominent orientations are trending from N030 – N070 and N130 – N140. (N = number of readings) Radial division = 2.5%; outer circle = 30%

Analysis of the drainage patterns developed on the outcrops of each formation revealed a strong link between their direction and the direction of underling geological structures; (Figure 5); in this study, the oldest rocks, and thus the ones that have undergone the most phases of deformation, are on the top left (Hawthornden Formation) and the youngest (granites) are on the bottom right. The stream directions in the Hawthornden Formation, which is older than the Kuala Lumpur Limestone Formation, are more uniformly distributed than those in the Kenny Hill Formation, which is younger than the Kuala Lumpur Limestone Formation and where, for example, almost none are present between (N360°-N040°); the granites have a drainage pattern largely independent of the fold history of their country rock. Thus the stream patterns appear to reflect geological structure and history. The same structures might be expected in the Kuala Lumpur Limestone, because it occurs between the Hawthornden and Kenny Hill Formations, and to some extent the structures do follow the pattern but there are significant differences; these are shown in Figure 6. The Figure shows the comparison of drainage patterns traced in the Kuala Lumpur Limestone Formation and the other formations combined together in one rose diagram.

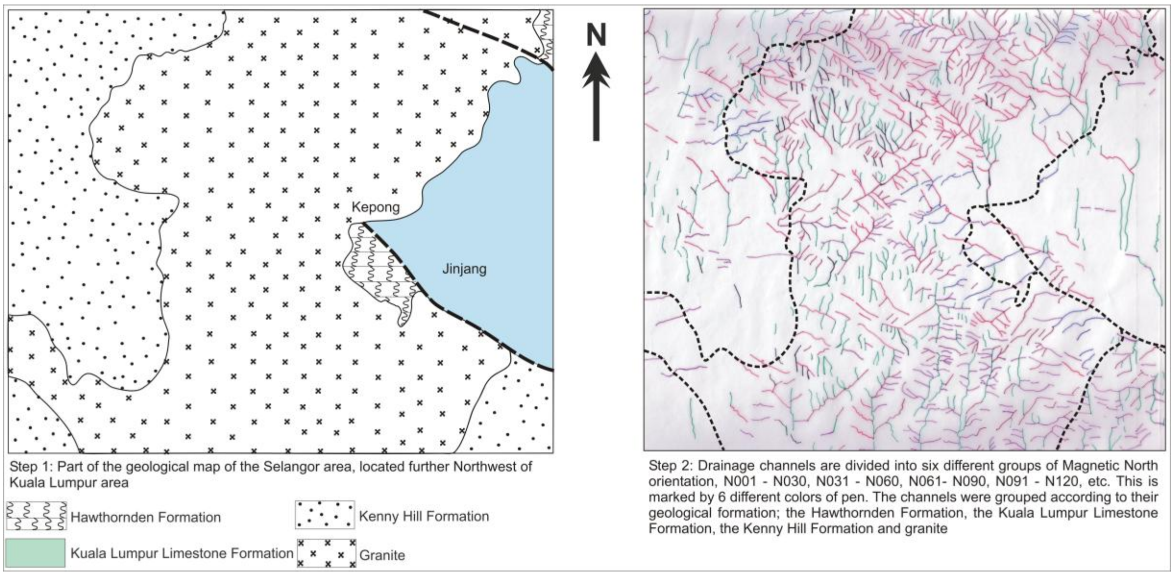

Figure 4. Drainage analysis carried out based on the geological map for the Selangor area, showing part of the study area, located further Northwest of Kuala Lumpur area.

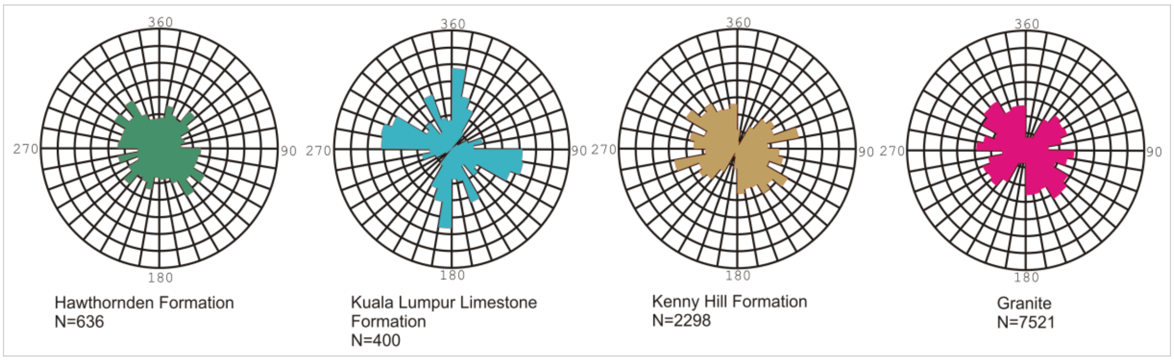

Figure 5. Rose diagrams of drainage direction for streams on all the geological formations in the Kuala Lumpur area.

The stream patterns in the Kuala Lumpur Limestone Formation have a prominent trend of N360°-N010°, N090°-N120° and N150°-N160°. The stream channels from the other formations produce a fairly uniform distribution of orientations as shown in Figure 6b with a few slightly higher percentages, as in the trends of N070°-N080° and N120°-N130°. There are no streams on the trend of N360°-N030°, but they are strongly developed between N030° and N180°. The contrast between the drainage orientations obtained for the Kuala Lumpur Limestone Formation and the other formations could be linked to an extensive underground drainage system in the limestone formation; a condition that would explain the lack of surface drainage across its mapped outcrop, as seen in the 1: 63,360 geological map. The relationship of the orientations between fracture and drainage demonstrates that there is a close and interesting link between them. That might be diagnostic of karst.

Karst Pattern Prediction

Prominent directions of drainage channels exist in the limestone between N000°−N010°, N090°-N120°, and N150°−N160°. In contrast there are almost no streams in the directions N030°-N090°. The structural information for fractures in the Kuala Lumpur Limestone

(Figure 3) shows a prominent direction between N030°-N070° and another around N130°-N140°. By comparing with Figures 3 and 6, Figure 7 suggests that the lack of surface water on the outcrop of the Kuala Lumpur Limestone Formation in the direction N030°-N090° may be related to the structural direction N030°-N070° (Figure 7a). This difference is seen again when comparing it with the stream orientations for all the outcrops (Figure 7b). These differences in the dominant orientations between the Kuala Lumpur Limestone Formation and the other formations could be linked to the existence of solution features below ground level. Therefore, based on the analysis, karst in the Kuala Lumpur Limestone Formation can be predicted to form most favourably, i.e. to have the greatest risk of karst occurring, in the orientation N030°-N070° and N120°-N150°, following the fractures patterns in the Kuala Lumpur Limestone Formation. Nonetheless, the prediction made from this geological map study requires further validation and thus geological mapping at the two previously exposed boxes constructed for the SMART project has been carried out.

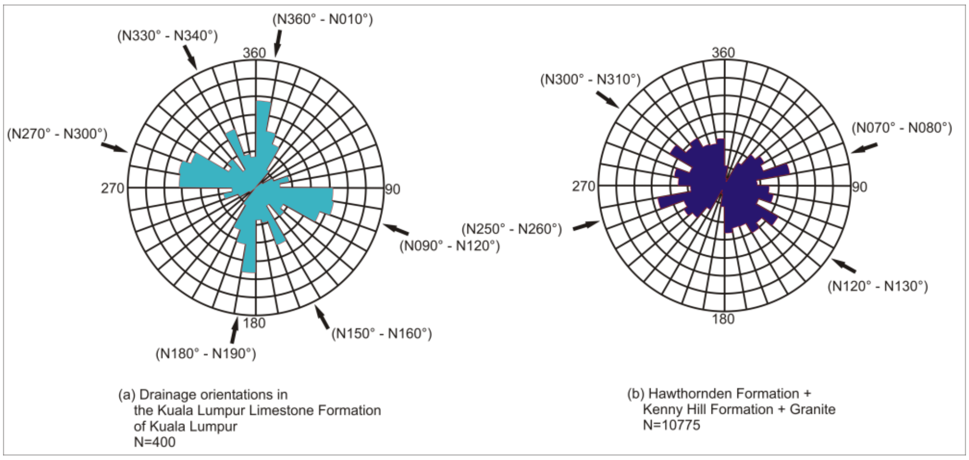

Figure 6. Different between prominent directions of the drainage lines in the Kuala Lumpur Limestone Formation and the other formations in the study area.

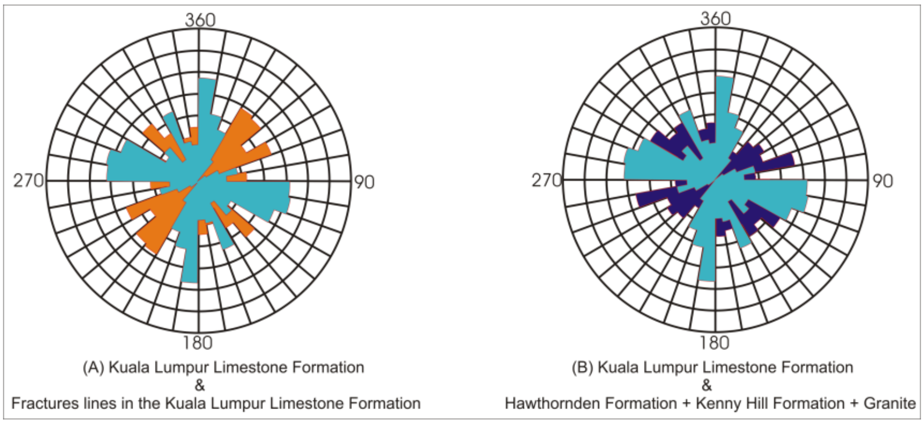

Figure 7. Fracture orientation in the Kuala Lumpur Limestone Formation, as deduced from the geological map of Selangor.

Mapping of Karst at the SMART Project Sites

The geological data available to check these predictions came from detailed geological mapping of the excavation sites located at the Kampung Pandan Roundabout (North Junction Box) and at the Sungai Besi (South Junction Box) excavated for the Stormwater Management and Road Tunnel (SMART) tunnel (SMART, 2005). At the North Junction

Box, exposure of karst features occurs on the excavated sides of a rectangular box, approximately 500m in length, 20m in width and 30m in depth. The rock profile in the Kampung Pandan Roundabout can generally be classified as strongly deformed and heavily fractured (Bieniawski, 1989) and contains numerous karst features; e.g. between Ch300 and Ch380, two large zones of depression, of the type previously described as Karst Scale 1(K1) were exposed on both sides of the box (Figure 8); their trend followed the direction (N040°), and this is close to that of the Gombak Fault (N020°) direction. So it is possible that features of K1 scale karst are related to major deformation episodes in the Kuala Lumpur area. The excavation also revealed a clear evidence of left-lateral strike-slip faulting directed along N330°, the trend of the Ampang Fault and the Klang Gates Quartz Reef (Figure 1). The highly broken limestone seen in Figure 8 represents the (K2) scale karst; joints are a dominant character of the rock mass and contain a wide range of cavity sizes.

The second site is the South Junction Box, which is 70 m long, 20 m wide and approximately 30 m high, and located between the KL-Seremban Expressway and Jalan Sungai Besi, at approximately at Ch7500 of the SMART tunnel. The limestone here is generally of far better quality than that seen in the Kampung Pandan Roundabout box; being massive, dense and frequently recrystallised, reflecting its proximity to the granite (Figure 1). Joints are dominantly orientated N160° and N230°, and are not as frequent as seen in the North Junction Box. The limestone has within it a bed of originally argillaceous sediment, now phyllite, orientated at N020°, in which the weathering has taken place, shown by the occurrence of a 30 cm thick brown yellow discolouration, but apart from that the limestone is fresh and solid rock.

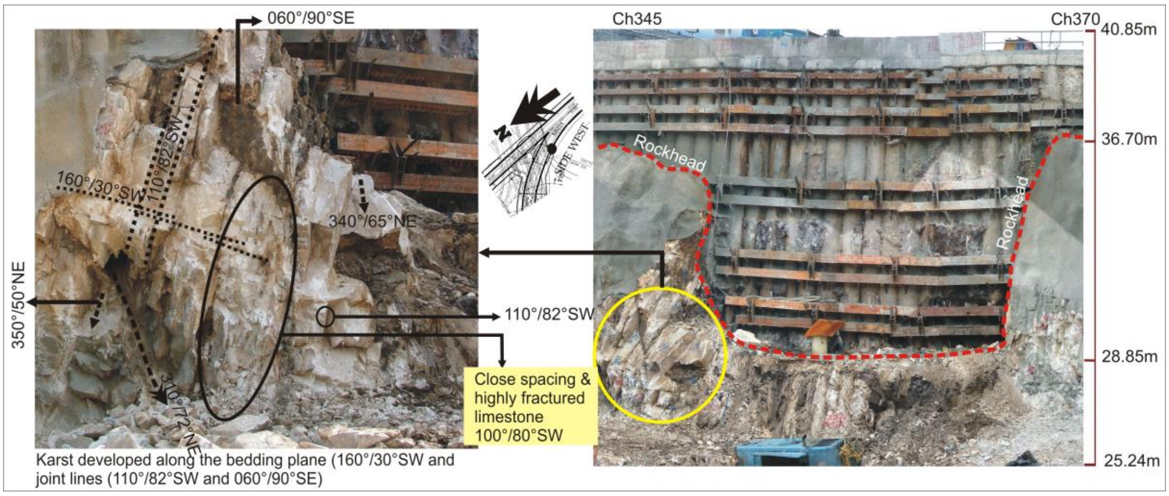

Figure 8. Two large zones of depression in the Kampung Pandan Roundabout, classified as Karst Scale 1(K1) were exposed on both sides of the box.

Conclusions

In this study, the results obtained from geological maps and fracture analyses were compared and further validated based on observations carried out at the two selected sites in Kuala Lumpur. Based on the assumption that there could be a close relationship between drainage, fracture pattern and karst formation, the geological map analysis was carried out, and then the results were verified by the geological mapping collected from the two boxes, known as the Kampung Pandan Roundabout and the Sungai Besi sites. Interestingly, the results obtained from the two analyses have yielded the same ranges of domination, as in the geological map analysis, the karst is predicted to form in the N030°–N070° and N120°–N150° directions. In the geological structures mapping taken from the two selected sites in Kuala Lumpur, a highly weathered and strongly deformed rock mass, thus containing numerous karst features has also seen to develop in the N030° and N330° directions; which is in a good agreement with the first predicted orientations. This in-direct method of karst prediction orientations is proposed to be an alternative method to study the subsurface orientations of karst adding to the currently used method of dye tracing testing and other geophysical surveys. The joint/stream correspondence was found in the fracture pattern developed in the limestone formation with the system of rivers meandering in the non-carbonate rock formations. Joint orientation is important to the development of all these stream orientations and presumably leads to the finding of subsurface karst in carbonate formation. Nonetheless, the validation of karst prediction has just been made based on a small part of the whole Kuala Lumpur area and hence much representative data mapping and analysis are required to predict the formation of karst as a whole. Some variations on the quality of rock mass properties can be seen between the Kampung Pandan Roundabout and the Sungai Besi sites, considering the dominant structural events that occurred at the vicinity of the areas. The Kampung Pandan Roundabout site is more affected by the Ampang fault system and in the Sungai Besi site the limestone is recrystallised by the close contact of a granitic body.

Acknowledgements

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