Structural studies for the prediction of karst in the Kuala Lumpur limestone

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Abstract: This paper reports the results of research currently being undertaken into the geological structure of Kuala Lumpur Limestone and its relationship to karst beneath the city of Kuala Lumpur. Reference to the existing geological map permits the basic geology of the area to be related to river patterns. From this relationship an indication can be obtained of the direction of fractures expected in the limestone and hence the direction in which karst is likely to be readily developed. These data are presented; two directions appear to be special interest: N040 to 070 and N300 to 330. The evidence for this is given and the methods used for these studies are described.

Résumé: Cet article résume les résultats de recherches en cours sur la structure géologique du Calcaire de Kuala Lumpur et sa relation avec le karst qui s'étend sous la ville de Kuala Lumpur. En se référant à la carte géologique en vigueur, il est possible d'établir une relation entre les principales caractéristiques géologiques de la région et le réseau hydrographique. Cette relation permet d'obtenir des indications quant à la direction privilégiée des fractures dans le calcaire et ainsi de prédire la direction dans laquelle le développement karstique est le plus probable. Ces données sont presentées, deux directions semblant être particulièrement dignes d'intérêt : N040 à 070 et N300 à 330. Les preuves de ceci sont données, et les méthodes utilisées dans cette étude sont décrites.

Keywords: Limestone, cavities, karst, fractures, rivers and streams, Kuala Lumpur

INTRODUCTION

Much of Kuala Lumpur, including its commercial centre, is founded on limestone of Silurian age, in which karst has been extensively developed. This karst could be classified as Extreme Karst, class kV (Waltham and Fookes 2003) and can be considered to occur in Kuala Lumpur at two scales: the smaller scale is that of a buried karstic landscape with highs and lows to bedrock depth below an almost horizontal ground level; the larger scale is that of the limestone below bedrock where discontinuities have been opened by dissolution and caves created, many of which have collapsed and are partially filled. These features, at both scales, create many problems for the design and construction of civil engineering structures. At present there are no guidelines for predicting the likely occurrence of the larger scale features and this paper reports research which addresses that problem; can the larger scale karst in Kuala Lumpur be predicted?

The approach used in this work has been to compare the structural geology of the limestone with the river patterns developed upon it, to discover whether any relationships can be found between its geology and its groundwater. Close relationships between fracture patterns and drainage lines have been long suspected by many researchers because weathering and erosion process are expected to be more aggressive within fractures than in the more massive rock they cut (Bannister & Arbor 1980, Ericson, Migon & Olvmo 2004, Waltham, Bell & Culshaw 2005). In limestone, fractures offer lines or zones that are susceptible to dissolution to form major cavities and underground rivers (Sowers 1976, Waltham & Fookes, 2003).

Four steps were followed in this approach; first, the structure of the limestone was defined, using the 1: 63,600 geological map of the region, to obtain the likely direction of joints; then the drainage network of the region was studied using the same scale map (in fact the same map) to obtain the directions and frequencies of linear river segments; these river directions were then compared with the structural directions. From this comparison it became evident that rivers and structures shared certain directions but not others; the question therefore was, are the structural directions in which there are no rivers (ie no water at the surface) the same directions in which karst has most severely developed and if so, is this a means of predicting likely preferential directions of karst? The fourth step was to confirm the correctness of this idea and approach, by field observations in Kuala Lumpur.

STUDY AREA

The study area is situated in the centre of the capital city of Malaysia, Kuala Lumpur. This city started around 150 years ago with the discovery of cassiterite (SnO_2) in the alluvium overlying bedrock (Yeap 1985, 1987). Since then, Kuala Lumpur has never stopped developing and is now part of the Federal Territory of Malaysia. Generally, Kuala

Lumpur is situated in the broad valley of the River Klang, which consists of a flat alluvial plain, bounded by hills predominantly of granitic rock to the west and east.

GENERAL GEOLOGY

The solid geology of the area consists of sedimentary rocks ranging in age from Middle-Upper Silurian to Mesozoic or Younger. At the bottom of this sequence is the oldest strata, the Hawthornden Formation and the Kuala Lumpur Limestone Formation, above it: these are both from the Middle-Upper Silurian (Gobbett 1964). This Lower Palaeozoic formation experienced its first phase of folding during the Devonian, followed by an extensive period of weathering and erosion. During the Permo-Carboniferous, the Kenny Hill Formation was deposited upon the eroded surface of the Kuala Lumpur Limestone Formation, to form an angular unconformity. A second phase of folding followed, perhaps during the Jurassic, resulting in further deformation to the Lower Palaeozoic rocks. It can be seen that in the Lower Palaeozoic sequence, the bedding dips are commonly steep and overturned, contrasting with the more gentle dips of the Kenny Hill Formation which over lies them. The geological sequence was then intruded by granites, estimated to be either younger or broadly contemporaneous with the second phase of folding. The last period of deformation is NE-SW and NW-SE trending faulting, which has affected all the formations and the granitic outcrop (Stauffer 1968). The faulting has displaced the Kuala Lumpur Limestone Formation.

KARST IN KUALA LUMPUR

The highly irregular topography of limestone rock head in the Kuala Lumpur region was first discovered in opencast tin mines, around 150 years ago; deep borehole records from construction sites in the city confirm its wide spread occurrence (Tan 1986a, 1986b, 1987). The rock head karst is stated to have developed during the Quaternary, although it is possible that considerable dissolution also 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 & Hong 1985). Paton (1964) believed that the presence of mature karstic features in this area is the result of climate; Kuala Lumpur receives approximately 2400mm of rain per year at a temperature of around 26.5^{0}C: this imparts much CO_2 to the ground water of these humid areas.

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 & Fang 1985, Tan & Komoo 1990). A large number of geotechnical problems have occurred during the construction of the previous engineering projects in the limestone formation, for example, during the construction of the Petronas Twin Tower (Tan 1996, Pollalis 2002), the Berjaya Times Square Complex (Gue & Tan 2001), the Pan Pacific Hotel (Mitchell 1985) and the SriMARA Complex (Tan, Ting & Toh 1985).

APPROACH TO PREDICTIONS

The predictions started with analyses of the structural geology of the area based on the 1: 63,360 New Series geological map for the area of Selangor (Sheet 94; 1976). Using the same map the streams of the area, which exhibit a trellis-like pattern betraying some degree of structural control, were analysed. In both cases the directions were gathered for structures and for linear sections of streams.

FRACTURES ANALYSIS

The Kuala Lumpur Limestone Formation contains many folds and the axes of those recorded are shown on the geological map. Fracture orientations were predicted from the orientation of fold axes and bedding planes in these folds, based on assumption that each of the readings can be used to deduce a likely direction of shear and tensile joints in a fold (Price, 1966). The accumulation of fractures line directions was then displayed, measured from Grid North (within 0^0 3' East of Magnetic North), by using a rose diagram to produce percentages in any given direction. The fracture lines were then grouped in 18 classes of equal size, N001^0- 010^0, N011^0- 020^0, N021^0- 030^0, etc, Figure 1.

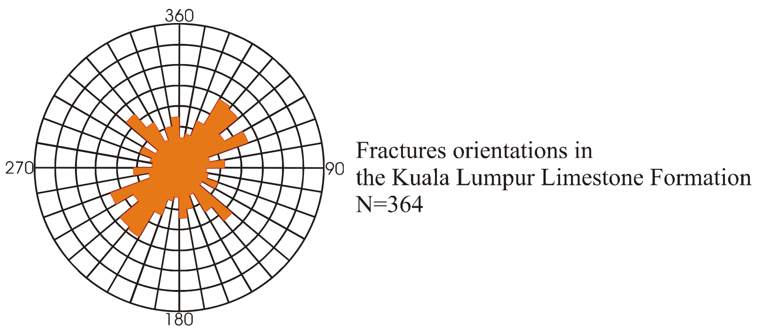

Figure 1. Fracture orientation in the Kuala Lumpur Limestone Formation, as deduced from the geological map. Radial division = 2.5%; outer circle= 30%.

DRAINAGE ANALYSIS

The orientation of all drainage lines in all the outcrops was measured from magnetic North and then grouped in 18 classes of equal size, N001^0- 010^0, N011^0- 020^0, N021^0- 030^0, etc and plotted to make a complete diagram for each outcrop type, Figure 2.

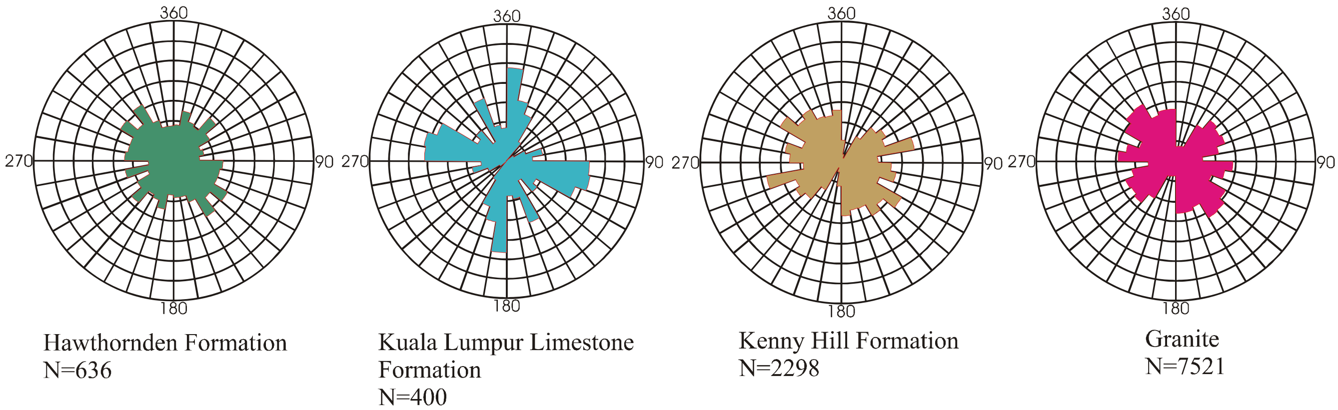

Figure 2. Rose diagrams of drainage direction for streams on all the geological formations in the Kuala Lumpur area. (N= number of readings). Radial division = 2.5%; outer circle= 30%.

DRAINAGE-FRACTURES PATTERN RELATIONSHIP

Analysis of the drainage patterns on every formation outcropping over the area shown on the Selangor geological map reflect a strong link between their direction and the underling geological history; the directions are shown in Figure 2, where the oldest rocks are on the left (Hawthornden Formation) and the youngest on the right (granites). The oldest rocks will have undergone the most phases of deformation and the youngest the least phases. Stream directions in the Hawthornden Formation are more uniformly distributed than those in the Kenny Hill Formation (where, for example, almost none are present between N360^0 and N040^0); the granites have a drainage pattern largely independent of the history of their country rock. Thus the stream patterns appear to reflect geological structure. Those same structures might be expected in the Kuala Lumpur Limestone, which occurs between the Hawthornden and Kenny Hill Formations, and to some extent they do, but there are significant differences; these are shown in Figure 3. Prominent directions exist in the limestone between N360^0 and N010^0, and between N090^0 and N120^0, and there are almost no streams in the directions N030^0 to N090^0.

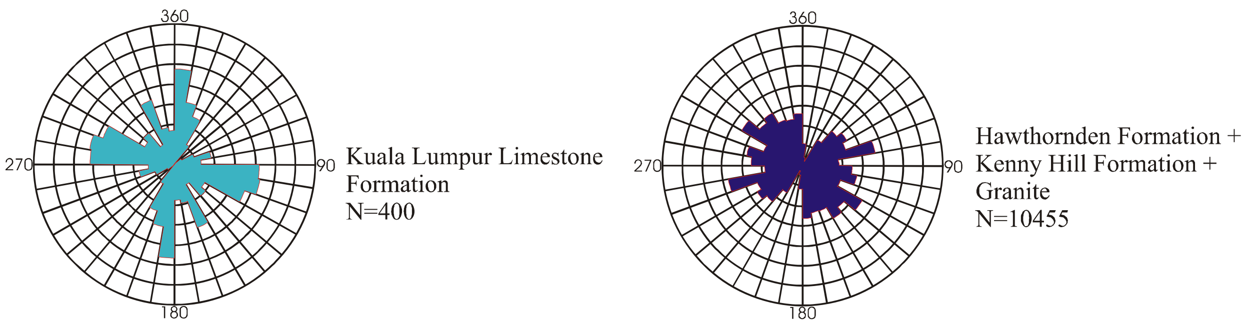

Figure 3. Difference between prominent directions of the drainage lines in the Kuala Lumpur Limestone Formation and the other formations in the study area. (N= number of readings). Radial division = 2.5%; outer circle= 30%.

The structural information for fractures in the Kuala Lumpur Limestone is shown in Fig 1; this shows a prominent direction between N030^0 and N070^0 and another around N130^0 and N140^0. Comparing Figs 1 and 3 suggests that the lack of surface water in the direction N030^0 to N090^0 may be related to the structural direction N030^0 and N070^0, Figure 4. This difference is seen again when the stream orientations for all the outcrops are compared, Figure 5.

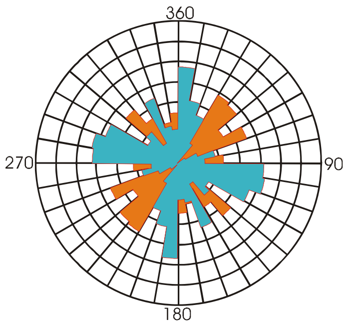

Figure 4. Stream directions and fracture lines in the Kuala Lumpur Limestone Formation. Radial division = 2.5%; outer circle= 30%.

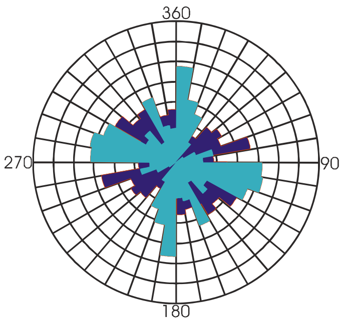

Figure 5. Stream directions in the Kuala Lumpur Limestone Formation and the other formations on the Selangor geological map. Radial division = 2.5%; outer circle= 30%

FIELD DATA AND BOREHOLE ANALYSIS

Fracture data for the larger scale karst, developed as open discontinuities and cavities, either open, partially filled or completely filled, was collected from two localities presently exposed during construction of the SMART tunnel, the North Shaft in Kampung Pandan Roundabout and the South Shaft in Sungai Besi (Figure 6). Existing borehole data from the site investigation report for construction of the SMART project (www.smarttunnel.com.my) permits a detailed study of such karst to be conducted, since the Kuala Lumpur Limestone Formation is the predominant geological formation at tunnel level throughout the route. Inspection of the borehole logs for locations along the tunnel alignment allowed the construction of 3D-models of the ground to be made showing the underground profile of the formation and the location of opened discontinuities and cavities; it is hoped that these models will enable a more general model of karst in Kuala Lumpur to be created but they are still under construction and at present are much better in some places than in others.

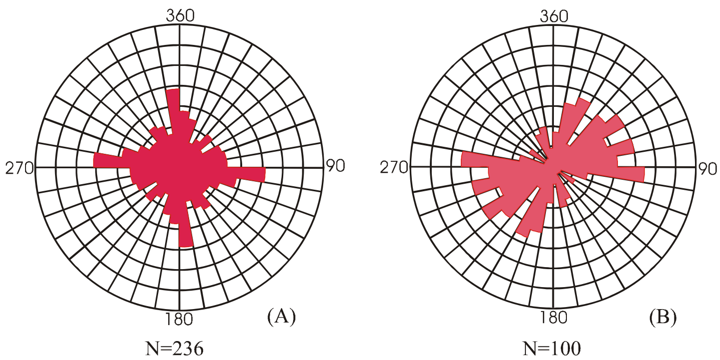

Figure 6. (A) Joint from the North Shaft, (B) Joint from the South Shaft. (N=number of readings). Radial division = 2.5%; outer circle= 30%.

To analyse the borehole logs quantitatively a further classification on the quality of the limestone rock has been made in order to define the presence, or absence, of such larger scale karst; this was based on the Solid Core Recovery (SCR) value. The limestone was classified as follows: 100% - 70% value of SCR was taken as good quality of rock because solid rock was being recovered with that range of SCR, That is, values less than 100% could not be assumed to represent natural voids; 69% - 50% of SCR was taken as 'weathered' limestone, where weathering had opened discontinuities and hence represented areas of ground having great potential to contain well developed large scale karst; SCR 49% - 0% was taken as fully developed void-like karst. Following this system, the SCR values were reclassified between aligned boreholes for every borehole location where closely spaced clusters of boreholes existed (boreholes spaced at distances of between 10 and 20 m) and in different directions, to produce a percentage of dissolution in given directions. The final values of SCR were then plotted as rose diagrams. Major directions in these diagrams reflect high values of SCR and are assumed to present a reasonably good quality of limestone in which little dissolution might be expected, whereas minor directions are expected to be more likely to contain dissolution that has been better developed. To the civil and tunnel engineers all such dissolution is viewed as 'karst.'

The karst as described is expected to develop in all directions beneath the Kuala Lumpur area. However, the question is, in which direction is larger scale karst believed to be well developed? The comparisons between predicted and established karst at that scale, as obtained to date (the research is still underway), are summarised in Figure 7; two field comparisons exist, one is shown to the east of the tunnel and the other to the west of the tunnel. To the east of the tunnel are shown five rose diagrams; the second down shows karst as studied from a close group of boreholes (BH10 – BH22) at the northern end of the tunnel; the remainder show karst as revealed by lines of boreholes arranged along the tunnel alignment – for the present they may be ignored because their data are biased to the directions of the line of boreholes. The group data shows the directions of karst measured in the field, and the predictions made based on the absence of streams (N030^0 to N070^0 and N120^0 to N150^0); reasonably good agreement exists.

On the west side of the tunnel the findings from a second group of boreholes are shown in three central rose diagrams; these were located towards the southern end of the tunnel (DBH-MT22 – BHA7, South Drive and Southern Package). Here the predicted directions of karst do not agree as well with the observed directions, which reflect the directions of streams; ie the presence of streams, Figure 3. As can be seen in Figure 7, the karst from BH22 to A7 tends to follow surface streams (Figure 3), the karst from South Drive follow both the surface streams and the joint directions where there are no streams, whereas the karst in the Southern Package is between the direction of streams and joints coincident with the absence of streams.

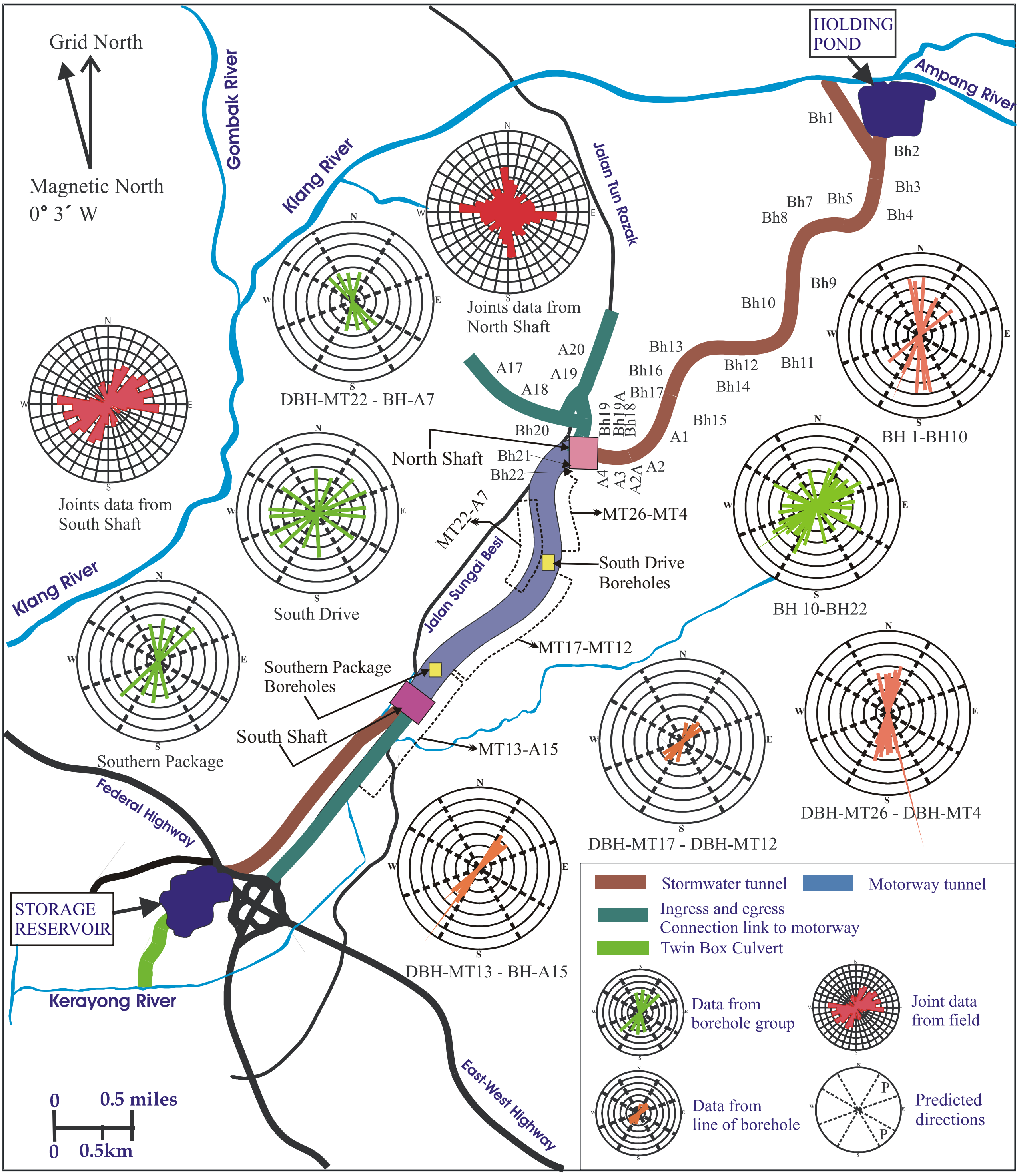

Figure 7. Directions of karst along the SMART tunnel alignment through central Kuala Lumpur. There are two sets of data: karst and joint data collected in the field from the North and the South Shafts, and karst direction deduced from existing borehole data from the SI report. Radial division = 2.5%; outer circle= 30%.

Joint data collected from the North Shaft is dominated in the direction between the N350^0 to N010^0 and N090^0 to N100^0, whereas joint data collected from the South Shaft is trending the N010^0 to N030^0 and N050^0 to N100^0, Figure 6. The prominent directions of karst direction deduced from the boreholes in the north section of the tunnel differ from those in the south section of the tunnel.

CONCLUSIONS

Although the karst at Kuala Lumpur can be described as Extreme Karst class kV, most of its features are now buried beneath alluvium. These features can be encountered at two scales; the smaller controlling the depth of bedrock below ground level and the larger influencing the dissolution of discontinuites below rockhead. This paper deals with the latter. Predictions of the larger scale karst directions, based on the pattern of streams and their relationship to fractures, appears to be partially successful. The research to date has demonstrated that such relationships can be useful but that great care has to be taken to avoid the mixing of incompatible data. In this case the information to date suggests that karst in the Kuala Lumpur Limestone around the north of the tunnel follows the line of absent surface drainage whereas in the area towards the south of the tunnel the karst seems to following part the pattern of visible surface drainage. How one tells which prediction method to use in a given area is still a matter for inquiry, and the research continues.

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REFERENCES

BANNISTER, E. & ARBOR, A. 1980. Joint and drainage orientation of S. W. Pennsylvania. *Zeitschrift fur Geomorphologie. Neuefolge.* **24**, 273 – 286.

CHAN, S.F. & HONG, L.P. 1985. Pile foundations in limestone areas on Malaysia. In: *Proceedings of the 8th Southeast Asian Geotechnical Conference, Kuala Lumpur, 11-15 March, 1985*, **1**, P4/17-P4/28.

ERICSON, K., MIGON, P. & OLVMO, M. 2004. Fractures and drainage in the granite mountainous area, a study from Sierra Nevada, USA. *Journal Geomorphology.* **64**, 97-116.

GOBBETT, D.J. 1964. The Lower Paleozoic Rocks of Kuala Lumpur, Malaysia. *Federation Museum's Journal,* **9**, 67-79

GUE, S.S. & TAN, Y.C. 2001. *The foundation system for Berjaya Times Square*. Seminar on Mega projects: A Study on Civil Engineering Projects, University Technology Malaysia, Johor Bharu, Malaysia.

IBRAHIM, O.B. & FANG, H.T. 1985. Piled foundation in limestone formation. In: *Proceedings of the 8th Southeast Asian Geotechnical Conference, Kuala Lumpur, 11-15 March, 1985*, **1**. Kuala Lumpur: Organising Committee, 1985, P4/45 - P4/52.

MITCHELL, J.M. 1985. Foundations for the Pan Pacific Hotel on pinnacled and cavernous limestone. In: *Proceedings of the 8th Southeast Asian Geotechnical Conference, Kuala Lumpur, 11-15 March, 1985*, **1**. Kuala Lumpur: Organising Committee, 1985, P4/29 - P4/44.

PATON, J.R. 1964. The origin of the limestone hills of Malaya. *Journal Tropical Geography*, **18**, 134 – 147.

POLLALIS, S. 2002. The Petronas Twin Towers, Kuala Lumpur, Malaysia. International Cooperation and Information Transfer in the Realization of the World's Tallest Buildings. Harvard School Design. Publishing Division, Harvard Design School, 1 - 33.

PRICE, N.J. 1966. *Fault and joint development in brittle and semi-brittle rock*, 164. Pergamon Press Ltd.

SOWERS, G.F. 1976. Failures in limestones in humid subtropics. *Proceedings of the American Society of Civil Engineers*, **101** (GT8), 771 – 787.

TAN, G.Y., TING, W.H. & TOH, C.T. 1985. Foundation for Srimara Complex, Kuala Lumpur. In: *Proceedings of the 8th Southeast Asian Geotechnical Conference, Kuala Lumpur, 11-15 March, 1985*, **1**. Kuala Lumpur: Organising Committee, 1985, P4/68 -P4/72.

TAN, B.K. 1986a. Geological and Geotechnical Problems of Urban Centres in Malaysia. In: *Proceedings of LANDPLAN II Symposium, Kuala Lumpur, April 1984*, Association of Geoscientists for International Development, Kuala Lumpur, 10-14.

TAN, B.K. 1986b. Use of Standard Penetration Test of ground interpretation – some examples from Peninsular Malaysia. In: *Proceedings of the 5th Congress of the International Association of Engineering Geology, Buenos Aires*, 839 – 846.

TAN, B.K. 1987. Geology and urban development of Kuala Lumpur, Malaysia. In: *Proceedings of LANDPLAN III Symposium, Hong Kong, December 1986,* Association of Geoscientists for International Development, Hong Kong, 127-140.

TAN, B.K. & KOMOO, I. 1990. Urban geology: case study of Kuala Lumpur, Malaysia*.* *Engineering Geology*, **28**, 71-194

TAN, B.K. 1996. Project KLCC: Geology, soils and foundations. *Warta Geology*, **22** (2), 73-74.

STAUFFER, P.H. 1968. The Kuala Lumpur fault zone: a proposed major strike-slip fault across Malaya. *Newsletter Geological Society Malaysia*, **15**, 2-4.

WALTHAM, A.C. & FOOKES, P.G. 2003. Engineering classification of karst ground conditions. *Quarterly Journal of Engineering Geology and Hydrogeology,* **38**, 101-118.

WALTHAM, A.C., BELL, F.G. & CULSHAW, M.G. 2005. *Sinkholes and subsidence: karst and cavernous rocks in engineering and construction*. Praxis Publishing, 381.

www.smarttunnel.com.my (accessed July 2005)

YEAP, E.B. 1985. Irregular topography of the subsurface carbonate bedrock in the Kuala Lumpur area. In: *Proceedings of the 8th Southeast Asian Geotechnical Conference, Kuala Lumpur, 11-15 March, 1985*, **1**. Kuala Lumpur: Organising Committee, 1985, P4/1-P4/12.

YEAP, E.B. 1987. Engineering geological site investigation of former mining areas for urban development in Peninsular Malaysia. *Geological Society of Hong Kong Bulletin*, **3**, 319–334.