Morphometric and geological features of potential karst depressions in Kanthan limestone formation, Malaysia

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Abstract. In Malaysia, limestones extensively outcrops in the northern half of Peninsular Malaysia, such as in Langkawi Islands, northern Perlis, Kinta Valley in Perak, southern Kelantan and Kuala Lumpur Valley in Selangor. Although these limestone formations vary considerably in geological age and tectonic setting they are very similar in chemical composition; being dense, recrystallized, and massive varieties of limestone with little impurity; these are more likely to develop large caverns within them. Currently, most of these limestones are continuously quarrying for the production of dimension stone, aggregate resources, and raw materials for cement industries, part of urban development infrastructure and could be foreseen as future potential reservoirs of high-quality groundwater. Nonetheless, the fragility of karst environments makes it highly vulnerable to a variety of different geological hazards. The aim of this study is to determine the geohazard susceptibility of karst depressions in Kinta Valley, Ipoh using morphometric measurement and joints properties calculations. The joint properties calculate include spacing, roughness, aperture, persistence, infilling and weathering. This study describes the field data measurements of few quarries in Kinta Valley, Ipoh to examine the morphometric and geological features of limestone karst in the area. The effect of geologic evolution, structural properties and hydrogeologic variables on the geomorphologic and spatial distribution of karst depressions are discussed in this study.

1. Introduction

Many researchers have attempted to link geology and karstic prone potential based classification system. As karst is so diverse and varied in morphology from one place to another, most of the current classifications are made to inadvertently cater only for certain study areas, e.g. in temperate and tropical climate zones. Much extensive study and hence its classification system is required that related to sinkhole formation, as the development is frequently hampered by hazardous localized rapid or gradual subsidence event [1].

A functional combination of climate and geological events, to describe the process of sedimentation and structural history have broadly influenced the current karst classification system used, such as [1-3], and it must therefore be acknowledged in mind that the level of karst complexity increases in heavily tectonized rock. Thus, it is essential to consider the importance of the geological structures as preferential lines for karstification, such as faults, folds, joints and bedding planes [4]. In Ipoh area, the long tectonic history has resulted in a complex fracturing system and, having considering the relationship between folds and their fracture patterns, two important sets of fracturing have been deduced: two shear joint sets trending southwest–northeast and southeast–northwest, and a further
extensional joint set directed east–west. These joint orientations have been predicted to form in the ground by previous researchers [5–7]. In this paper, it is believed that the geology of limestone formation has largely influenced the pattern of ground response towards karstification. By having to consider the geology of the Kinta Limestone Formation, a better understanding on how the ground might behave in response to the dissolution process might be achieved

2. Geological setting

The study site is located in the central part of Peninsular Malaysia, based on two limestone quarries situated in the Keramat Pulai industrial area, Simpang Pulai, Perak. Figure 1 (a) shows part of the industrial area of Simpang Pulai, where the quarry is located as seen from Google’s satellite image.

![Figure 1. (a) Part of Keramat Pulai industrial area; (b) Geology of Keramat Pulai area, Perak.](image)

Geologically, the quarry sites are predominantly underlain by the Kanthan Limestone Formation. The Kanthan Limestone of age Silurian-Devonian is part of the Kinta Valley Palaeozoic bedrock formations, figure 1 (b). The formation was described by [8] as slightly metamorphosed and heavily faulted carbonates. The Kanthan Limestone consists of thin-bedded, fine-grained, black carbonaceous limestone lacking of microfossils, with some argillaceous beds, with estimation thickness of > 330 m. Locally, at the quarry site, the Kanthan Limestone is predominantly made up of massive and thin bedded varieties, grayish white and with black carbonaceous patches/spots, fined grained limestone, frequently and in places intercalated or associated with carbonaceous (fissile) phyllite/schist. Dolomite of massive, about 4 m thick, cream to pinkish white colored, fined grained have been observed cutting across the central part of the quarry area in N-S direction. Structurally, this limestone is often looked massive and interbedded in places as observed in many studied quarry faces. The limestone beds thickness can varies from a few cm to a very massive outcrop. There are gently folded locally and occasionally interbedded with thin carbonaceous meta-argillaceous layers. Geologically, Keramat Pulai and Simpang Pulai, Kinta Valley are underlain by marble, schist and granite from west to the east. Schist of Paleozoic (Devonian-Permian) age is the oldest rock which occupies only a narrow zone between the younger Kinta Valley Limestone comprises of recrystallized marble and Slim granite to the east.

3. Method

In order to investigate the development of sub-surface karst forms, the morphometric profiles were assessed based on the geological mapping carried out at two quarried mentioned. Standard geological mapping exercise was carried out by measuring the strike and dips of joints and planes on the expose outcrops.

Window mapping technique was used to map the quarry faces. Discontinuity sampling surveys were performed at Quarry A. A total of 11 windows were mapped (table 1), where the slopes are divided into section of 30 m interval. In this method, a 30 m long of measuring tape is pull along the toe of the slopes
where dip direction/strike and dip angle of the expose slope face, trend and plunge of the window, location of the mapped slope, the rock type and general condition of rock mass were first recorded. For discontinuities, in sets or randomly formed, that intersect each window, the intersection distance, dip direction/strike, dip angle, semi trace lengths on each side of the window, termination type (terminate on rock, terminate on another joint and joint intersect other joints) for each joint, aperture/opening, roughness, in-filled materials (clay filling, Ca or SiO2 in-filling and no filling) and groundwater condition (dry, with no evidence of water flow; dry, but evidence of water flow; damp, but no free water; occasional drop of water; continuous flow of water) were also recorded. The standard geological compass was used to measure the orientation (dip direction/strike and dip) of the discontinuities (joints, fault, veins, bedding plane and shear plane, if any) that intersects the tape within the measured window. Photographs of each section are taken and potential unstable rock blocks are determined and marked on the photographs.

Table 1. Limestone bedrock and discontinuities mapped from 11 windows of Quarry A

| No | Windows | Length (m) | Height (RL m) | Remarks |
|----|---------|------------|---------------|---------|
| 1  | LK-A    | 50         | 150           | Grey to dark grey, tightly jointed, massive to bedded limestone. |
| 2  | LK-B    | 35         | 140           | Grey to dark grey, interbedded to massive limestone with the presence of gouge, weathered materials (cave-karst), jointed and gently folded. |
| 3  | LK-C    | 50         | 135           | As above-weathered and ferruginous rock bodies near the top and no gouge/cave-karst. |
| 4  | LK-D    | 40         | 130           | Grey to dark grey, highly jointed and slightly interbedded limestone wall. |
| 5  | LK-E    | 50         | 160           | Grey to dark grey, highly jointed and moderately weathered near top section. |
| 6  | LK-F    | 40         | 145           | Grey to dark grey, interbedded limestone occasionally with fissile dark shale and massive pink course grained dolomite. Faulted and gently folded in places, and jointed. |
| 7  | LK-G    | 25         | 150           | Grey to dark grey, massive to bedded and highly jointed limestone (minimum 3 set), folded in places (anticline) |
| 8  | LK-H    | 35         | 150           | Grey to dark grey, massive to bedded and highly jointed limestone (minimum 3 set), folded in places (anticline) |
| 9  | LK-I    | 25         | 145           | Grey to dark grey, highly jointed and moderately weathered near top section. |
| 10 | LK-J    | 40         | 230           | Grey to dark grey, slightly weathered, ferruginous, jointed and limestone interbeds and dolomite. |
| 11 | LK-K    | 30         | 140           | Grey to dark grey, tightly jointed, massive to bedded limestone, and locally gently folded. |

4. Fracturing in Kanthan Limestone Formation

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, $\sigma_1$ and intermediate stress, $\sigma_2$ and perpendicular to the minimum stress, $\sigma_3$. In folded rock, extensional joints, normally cut perpendicular to the bedding, can also form as shear joints, with oblique orientations to the principle stresses [9-11] (figure 2).

The existence of joints in a rock means they have the potential to cross all the geological boundaries. Three possible causes of joints are proposed: first, there is hydrostatic pressure to help form possibly the earliest type of joints in the ground, hydraulic joints, developed at depths greater than 5 km in the vertical compaction of overlying sediment during the burial. Upon deposition, the increase of vertical stress leads to a reduction of pore size in the underlying sediment, which can also lead to abnormally high pore pressure within the sediment. The pressure is released by the formation of joints. Second, development of horizontal compression can occur at depths less than 3 km, and which normally causes extensional and shear joints to form. Third is the release of stored strain in a bed during unloading sediment through
weathering process to form unloading and release joints; these could explain the occurrence of joints in non-deformed or slightly tectonized horizontal beds. Great stress is accumulated in a bed as the thickness of sediment above compresses it, but when the load is released, once the upper layers of sediment have been eroded, some expansion of the rock can occur so developing extensional joints.

Based on the fold–fracture relationship illustrated in figure 3, four joint directions can be predicted to have formed in the folded limestone formation: an extensional joint set, oriented north–south; two shear joint sets trending southwest–northeast and southeast–northwest and a further extensional joint set, directed east–west.

**Figure 2.** Schematicly illustrates the four orientations of joints developed in the folded bed of the Kanthan Limestone Formation and drawn in stereographic diagram [10].

**Figure 3.** In a folded bed of rock, extensional joint commonly to be found cut the fold axes in 90, in contrast to the longitudinal joint formed in parallel to the fold axes [11].

5. Results and discussion

5.1. Weathered limestone forms

Exposè limestone bedrocks in almost survey areas (LK-A to LK-K) show different and unique structural and weathering grade profiles as in table 1. The working rock face/quarry face indicated these limestone bedrocks can be categorized either by massive and competent bedrock or bedded layers in order of few to over 50 cm thick, occasionally deformed, folded and faulted in places. Window G shows that the rock bedding there striking in the order of 200°/40° and 210°/5° dipping to S-W.

The limestone bedrock is often medium to heavily jointed, often tight, fresh, smooth to rough surfaces and occasionally as milky white filled (calcite veins), iron stained, filled by clay. In-filled calcite veins occur either as continuous, short, or irregular lenses. Locally deformed and displaced, especially in competent dark grey limestone variety. Presence of close spacing discontinuities (bedding, joint, fractures, and local fault) are widespread (figure 4). At least about 3 to 4 major joint sets, close spacing were recognized on many quarry faces in the order of few cm to 20 cm wide, cross-cutting the bedding. These joint set apertures are often tight to very narrow about 2 mm. Tension cracks due to blasting activity are widespread, irregular and high roughness. Often dry in nature, accept in high water
seepage section or during raining condition. Draining channel of running water can be observed which are often characterized by highly ferruginous clay stained at Window A and E.

A few rock faces especially near the top benches, at Window B, C and E were overlain by thin brownish to ferruginous red, loose to soft top soil, completely disintegrated rock and loose fragmented rocks (figure 5). This is mainly due to the physical weathering and alteration by water. This weathered top bedrock, loose soil, highly fractured and fragmented materials often exhibit more porous segment with high interstitial spaces. The typical cave features where calcite which is stalactite and stalagmite and ferruginous brown clay mineral can also be observed at Window B. These features are more likely to collapse and subside especially when disturbed by the blasting activities and induced by excessive water due to long raining [12].

Figure 4. Thinly bedded and heavily jointed of brownish to greyish colored limestone outcrops mapped at Quarry A.

Figure 5. Disintegrated rock and loose fragmented rocks with ferruginous red soils are seen at top section of mapped quarries.
The recorded Kanthan limestone generally striking in N-S direction trend, however due to the localised deformation events, this bedrock especially highly interbedded argillaceous black shale and carbonates frequently observed gently folded and seen to form local anticline especially in Window G. Pinches and boundinage structures are obvious in Window F. Localised faulting and the other minor deformation also noticed in many windows. Slickenside or shear features can be found at Window A, F, G and J, where light greenish clay mineral infilling (chlorite mineral bearing cement) characterized the plane face was noticed.

5.2. Potential orientation of surface karst depression

Measured orientations of all discontinuities from 11 windows were analyzed using a rose diagram, to link the possible correlation between joints, fault zones and potential karst area. A correlation is made based on the known assumption of the close link between geological structures and karst that could be seen in the field/exposed quarry faces by studying slickensided and weathered limestone surfaces. Frequently found at site, mainly Window A, F, G and J, is wet yellow colored slickensided or smooth surfaces believed to have formed as a result of shear displacement and later modified by the continuous flow of running water. These planes have higher changes to be weathered by dissolution than the intact adjacent rock mass, and contribute to the formation of the trellis sub-surface karst system [13 & 14].

![Figure 6](image_url)

**Figure 6.** Rose diagrams of mapped discontinuities; (a) combined discontinuities from Quarry A and B; (b) discontinuities from Quarry A and (c) discontinuities from Quarry B

![Figure 7](image_url)

**Figure 7.** Regional scale of structures to show at similar orientations of joints mapped at quarries faces and fault zones seen in map [15].
In figure 6, it can be seen that joints are preferentially to follow the prominent fault zones, at N030° – N040° and N130° – 140°. Karst surfaces are predicted to develop within the dominant joint orientations; there are six different windows that have been measured to have this particular pattern of relationship, but the dominant are Window E, G, I and J1, which all clearly show that the karst orients parallel to the dominant joints orientations (figure 6a). Such as, in Window E, joints and karst surfaces are aligned along the N310° direction; another example is in Window I, where the N135° and N150° are the preferential directions of joints for karst to develop. Comparing figure 6 and 7, suggests that the dominant orientation of fault that cut crossed Kinta Limestone Formation and granitic body in the direction N130° to N140° may be related to the karst direction N030° and N070°. These orientations are seen again when joint orientations from Quarry A are compared, figure 6c. Similar patterns of dominant joints orientations between two quarries in the study area could be linked with the existence of solution features below ground level in the limestone formation, presumably to form a complex underdrainage system. Therefore, based on the analysis carried out, karst in the Kinta Limestone Formation is preliminary predicted to form extensively in the orientation of N030° to N040° and N130° to N140°, and follows the fault zones in the Kinta Limestone Formation and granitic body.

6. Conclusions
Strong correlations between discontinuities or joint patterns and drainage trellis have been long suspected by many researchers in the past [17]. An assumption was made at this stage, that any fracture lines or zones within the host rock, the carbonates offer lines or zones of decreased resistance to dissolution, and are more easily exploited and modified by weathering and erosion processes than the adjacent more massive rock. The end product of the continuous weathering and erosion process is a stream or river channel, developed along a fracture orientation. Our study demonstrates the primary role of joints and faults during the early stage of karst formation and could contribute to a better understanding of how the sub-surface drainage are formed.

Acknowledgement
The Ministry of Higher Education (MOHE), Malaysia under the Fundamental Research Grant Scheme (FRGS), No. 6071361, financially supports this research project. Authors would like to express the gratitude towards all of the people involved in this research especially for the assistance and permission to access the quarry.

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