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Sinkholes in the Bukit Chuping area, Kangar, Perlis

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Abstract: On the evening of 14th October 2000, four sinkholes with sizes varying from 8.5 m to 15.0 m in diameter and with depths varying from 5.0 m to 10.0 m suddenly formed in an area between Bukit Chuping and Bukit Cowder near Mata Ayer, Perlis. Investigations comprising aerial photography study, surface geological mapping, subsurface geological mapping (involving geophysical surveys and Mackintosh Probe study), hydrogeological study and ground vibration monitoring were conducted from 17th October to 2nd December 2000. Results showed that all sinkholes, incipient sinkholes and circular features related to sinkhole formation were within a zone about 350 m wide trending NE-SW in the study area. This zone, which is underlain by limestone, might be a continuation of a fault zone present at the southern end of Bukit Chuping. Monitoring of groundwater levels indicated that there was a general flow towards the central part of the study area, culminating in a depression near to the largest sinkhole in the study area. Monitoring of vibration due to blasting operations in the CIMACO Quarry revealed that the vibration levels recorded in the study area were low. There was also some other low, but more regular vibrations resulting from the movement of heavy vehicles in the study area. The light to moderate rainfall a few days before the occurrence of the sinkholes could have added extra weight to the thin soil roofs, which were present over some voids in the ground, and the collapse of these roofs resulted in the formation of the sinkholes. It is recommended that the sinkholes and the incipient sinkholes be refilled and buildings should not be sited over the sinkhole zone. Areas with circular features such as circular patches of green grass or areas with ponding of water should be constantly monitored for telltale signs, which might indicate the potential formation of sinkholes. Future development should be directed towards the southern part of the study area near to Bukit Cowder, which is underlain by sandstone.

Abstrak: Pada malam 14 Oktober 2000, empat lubang mendap yang mempunyai diameter berjulat dari 8.5 m hingga 15.0 m dan kedalaman berjulat dari 5.0 m hingga 10.0 m tiba-tiba terbentuk di kawasan antara Bukit Chuping dan Bukit Cowder berdekatan Mata Ayer, Perlis. Penyiasatan yang terdiri daripada kajian foto udara, pemetaan geologi permukaan, pemetaan geologi sub-permukaan (melibatkan survei geofizikal dan kajian alat Mackintosh), kajian hidrogeologi dan pemantauan getaran tanah telah dijalankan dari 17 Oktober hingga 2 Disember 2000. Keputusan kajian menunjukkan semua lubang mendap, lubang mendap permulaan dan ciri-ciri membulat yang berkaitan dengan pembentukan lubang mendap adalah terletak di dalam satu zon yang mempunyai kelebaran lebih kurang 350 m dan bercorak tenggara-barat daya dalam kawasan kajian. Zon ini yang didasari oleh batu kapur adalah berkemungkinan sambungan zon sesar yang wujud di bahagian hujung selatan Bukit Chuping. Pemantauan aras air tanah menunjukkan berlakunya aliran ke bahagian tengah kawasan kajian dan ianya semakin meningkat di kawasan rendah berhampiran lubang mendap yang terbesar di kawasan kajian. Pemantauan getaran terhadap aktiviti letupan yang dijalankan oleh Kuari CIMACO, merekodkan tahap getaran di kawasan kajian adalah rendah. Terdapat juga getaran dengan tahap rendah tetapi kerap berlaku disebabkan oleh pergerakan kenderaan berat di kawasan kajian. Kehadiran hujan yang kurang lebat ke sederhana lebat beberapa hari sebelum kewujudan lubang mendap ini mungkin menyebabkan pertambahan berat ke atas bumbung tanah yang nipis. Bumbung tanah yang nipis ini wujud di atas beberapa ruang kosong yang terdapat di dalam bumi dan keruntuhan bumbung ini menyebabkan pembentukan lubang mendap. Adalah disarankan supaya lubang mendap dan lubang mendap permulaan ini diisikan semula dan tiada bangunan yang boleh terletak di zon lubang mendap. Kawasan dengan ciri-ciri membulat seperti rumput hijau dengan tompok-tompok membulat atau kawasan takungan air haruslah dilakukan pemantauan yang berterusan untuk mengesan tanda-tanda mekanikal yang mungkin boleh menunjukkan potensi pembentukan lubang mendap. Pembangunan pada masa depan haruslah ditumpukan ke atas bahagian selatan kawasan kajian berhampiran Bukit Cowder yang didasari oleh batu pasir.

INTRODUCTION

On 14th October, 2000 at about 7.00 pm, four sinkholes suddenly formed in an area about 500 m wide and 600 m long located immediately to the south of Bukit Chuping near Mata Ayer, Perlis. These sinkholes measured between 8.5 m to 15.0 m in diameter, with depths reaching 5.0 m to 10.0 m.

In addition, there were another fourteen incipient sinkholes where circular cracks had formed and the ground had depressions of a few centimetres. These sinkholes were spectacular in that not only were they large, but were also the first major reported occurrence in Perlis.

LOCATION

Bukit Chuping is an isolated hill located about 10 km to the northeast of Kangar. The area is accessible via a network of metalled roads from Kangar. The sinkholes occurred mostly in open ground over an area 500 m wide by 600 m long immediately to the south of Bukit Chuping (Fig. 1).

METHOD OF INVESTIGATION

Aerial photographs of the area were studied and geological structures in two hills, Bukit Chuping and Bukit Cowder were demarcated. Surface geological mapping was conducted and the locations and characteristics of all sinkholes were studied.

An integrated geophysical survey involving the microgravity and resistivity techniques was carried out to study the subsurface lithology (JPKM, 1996a, b; Mohd. Anuar, 2000; Mohd. Nasir, 1997; Mohd. Rais Ramli, 1997). Probing with a Mackintosh Probe was also conducted. A hydrogeological investigation was conducted to study the groundwater regime.

Vibration levels resulting from blasting operations in the nearby CIMACO Quarry and from movement of heavy vehicles in the study area were investigated.

RESULTS OF INVESTIGATION

Geology

Bukit Chuping is an isolated limestone mogote belonging to the Chuping Formation (Jones, 1957). The hill was originally about 2 km long, but quarrying activities had removed the northern portion of the hill, with only a third of the hill remaining (Fig. 2). About 1 km to the south of Bukit Chuping is another isolated hill, Bukit Cowder, a sandstone hill belonging to the Kubang Pasu Formation.

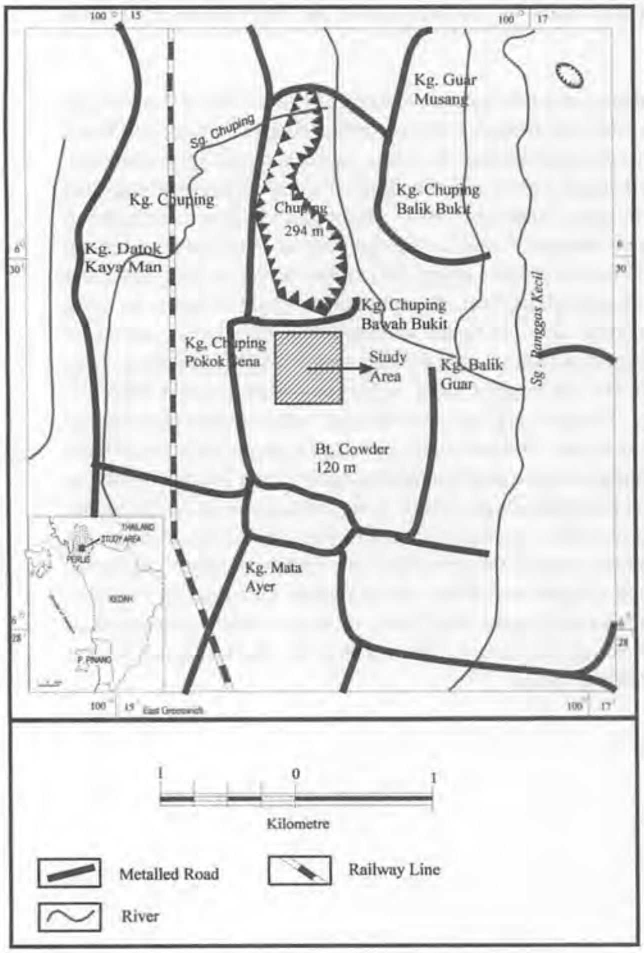

Figure 1. Location map of the study area.

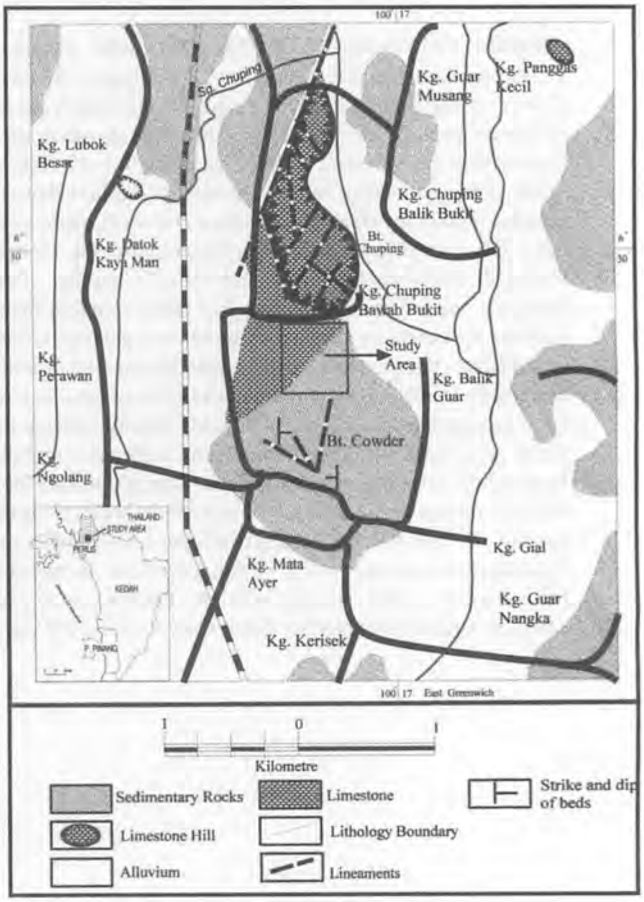

Figure 2. Geology of the study area.

The study area, which is located between Bukit Chuping and Bukit Cowder, is likely to be underlain by residual soil derived from the weathering of the limestone and sandstone. Surrounding these two hills is a flat alluvial plain.

Aerial photograph studies showed that there are 3 major sets of fractures striking NE-SW, NNE-SSW and NW-SE in Bukit Chuping. Detailed structural mapping showed that there are 2 major brecciated fault zones in Bukit Chuping. One of these zones is 310 m wide, striking 030° and dipping 40°SE. Another zone, which is smaller, strikes in the 010° direction and dips 70-80°E. In Bukit Cowder, there are 2 major sets of fractures striking NE-SW and NNE-SSW.

Topography

The study area is flat to gently sloping, with an elevation of about 25 m at the southeast corner. The topography slopes gently towards the northwestern corner where the gradient is about 14 m.

Features of sinkholes

On the 14th October 2000, four sinkholes S1, S2, S3 and S4 with diameters varying from 8.3 m to 15.0 m and with depths varying between 5.0 m to 10.0 m were formed (Table 1a). The sides of sinkholes S3 and S4 collapsed gradually and on the 11th November, the two sinkholes measured 24 m in diameter whilst sinkhole S1 increased in size from 15 m to 48 m (Fig. 3).

On the 19th October 2000, another sinkhole S5 measuring 12 m in diameter and with a depth of 6.3 m occurred. On the 31st October, a smaller sinkhole S6 measuring about 3 m in diameter and with a depth of 2.8 m occurred. Other than these 6 sinkholes, there were 14 other incipient sinkholes (P1 to P14) where circular cracks were formed and the ground had sunk a few centimetres. Such incipient sinkholes were unstable and would develop into sinkholes with time (Table 1b).

Aerial observation of the study area showed that there were circular features (Table 1c) whereby the grass was greener, or some parts had depressions, as there were ponding of water (C1 to C15). These features are indicative of potential sinkhole sites.

Subsurface geology

A total of 72 holes were probed with a Mackintosh Probe at 25 m by 50 m grid spacings and results showed that there was a layer of very soft soil within the uppermost 2 to 6 m of the soil profile. This layer could have resulted from the movement of soil particles towards cavities or caverns within the limestone bedrock.

Microgravity survey

A microgravity survey was carried out with a La Coste & Romberg D 161 gravity meter and readings were taken at 10 m spacings. A total of 1,200 stations were established in the study area. Bouguer and residual anomaly maps (Figs. 4 and 5) showed the presence of a fault zone which trends in the NW-SE direction in the study area. A zone depicting the presence of troughs within the karstic limestone bedrock was also demarcated. The results also

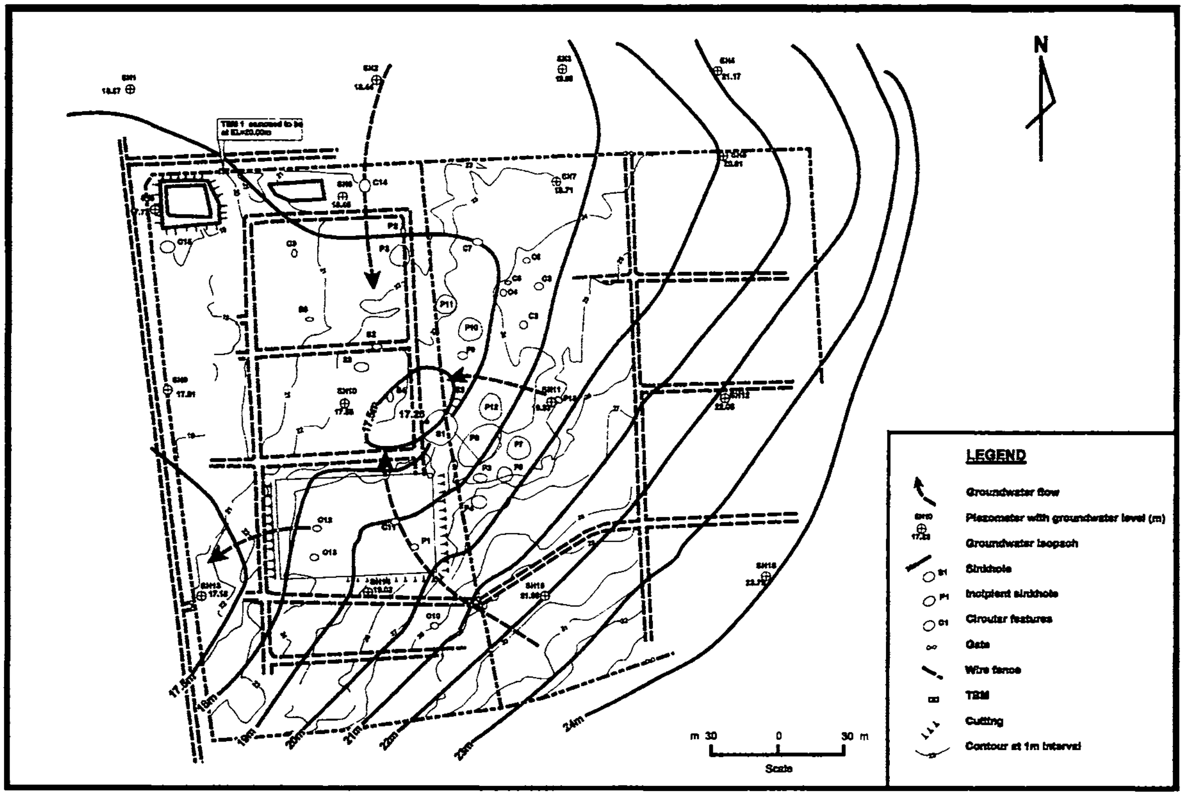

Figure 3. Location of sinkholes, incipient sinkholes, circular features and groundwater regime in the study area.

Table 1a. Sinkholes in the study area.

Number of feature	Type of feature	Date of occurrence	Diameter (m)	Depth (m)	Depth of water table (m)*
S1	Sinkhole	14/10/00	15.0; 48 .0 on 11/11	10.00	Dry; 13.7 on 11/11
S2	Sinkhole	14/10/00	11.0; 24.0 on 11/11	6.00	5.0
S3	Sinkhole	14/10/00	13.5; 24.0 on 11/11	6.00	5.0
S4	Sinkhole	14/10/00	8.5	5.00	Dry
S5	Sinkhole	19/10/00	12.0; 14 on 11/11	6.30	6.3
S6	Sinkhole	31/10/00	3.0	2.80	2.8
* below ground surface					

Table 1b. Incipient sinkholes in the study area.

Number of feature	Type of feature	Date of occurrence	Diameter (m)	Depth (m)	Depth of water table (m)*
P1	Incipient sinkhole	14/10/00	8.0	0.3	Dry
P2	Incipient sinkhole	14/10/00	3.5	0.6	Dry
P3	Incipient sinkhole; collapsed on 26/10	14/10/00	17.0	0.06	Dry
P4	Incipient sinkhole	19/10/00	14.0	0.5	Dry
P5	Incipient sinkhole	19/10/00	11.0	0.1	Dry
P6	Incipient sinkhole	19/10/00	14.0	0.2	Dry
P7	Incipient sinkhole	14/10/00	24.0	0.15	Dry
P8	Incipient sinkhole	14/10/00	40.0	0.5	Dry
P9	Incipient sinkhole; collapsed on 19/10	14/10/00	10.0	0.2	Dry
P10	Incipient sinkhole	14/10/00	24.0	0.1	Dry
P11	Incipient sinkhole	14/10/00	20.0	0.6	Dry
P12	Incipient sinkhole	14/10/00	28.0	0.12	Dry
P13	Incipient sinkhole	14/10/00	10.0	1.5	Dry
P14	Incipient sinkhole; collapsed on 19/10	14/10/00	33.0	0.2	Dry
* below ground surface					

Table 1c. Circular features in the study area.

Number of feature	Type of feature	Date of occurrence	Diameter (m)	Depth (m)	Depth of water table (m)*
C1	Circular depression	-	5.0	0.1	Dry
C2	Circular grass patch	-	7.0	-	Dry
C3	Circular grass patch	-	12.0	-	Dry
C4	Circular grass patch	-	8.0	-	Dry
C5	Circular grass patch	-	3.0	-	Dry
C6	Circular grass patch	-	7.0	-	Dry
C7	Circular grass patch	-	6.0	-	Dry
C8	Circular grass patch	-	6.0	-	Dry
C9	Circular depression	-	12.0	0.05	Dry
C10	Circular grass patch	-	6.0	-	Dry
C11	Pounding of water	-	6.0	-	Moist
C12	Pounding of water	-	4.0	-	Moist
C13	Pounding of water	-	5.0	-	Moist
C14	Circular depression with cracks	-	13.0	1.5	Puddle of water
C15	Circular depression with cracks	-	15.0	1.0	Dry
* below ground surface					

showed that there is a zone of inter-connected cavities/caverns within the limestone bedrock.

2D-Resistivity imaging survey

A resistivity survey using a STING RI resistimeter was conducted using the Wenner Configuration with electrodes at 5 m spacings. Results showed that the depth of the limestone bedrock is more than 20 m. Profiling showed the presence of an uppermost layer of dry sand, a second layer comprising of alternating dry sand and clay and a third layer of clay (Fig. 6). The results also showed that sinkholes and ground settlement had occurred in areas where the layer of dry sand is relatively thinner.

Hydrogeological survey

Investigation of the groundwater levels in the study area from standpipe piezometers showed that the groundwater regime generally flowed towards the centre of the study, culminating in a depression near to sinkhole S1 that is also the largest sinkhole (Fig. 3). The fact that the groundwater flowed towards a depression indicated that there might be a large funnel leading to a series of interconnected cavities/caverns within the limestone bedrock.

Abstraction of groundwater.

There were a number of tube wells in the Chuping District where groundwater was abstracted for industrial purposes. The wells were located at Gula Felda Chuping (6 km away from the study area), Loji Air Chuping (13 km away from the study area), Loji Arau (9 km away from the study area) and Cement Industries Of Malaysia, CIMA, (2 km away from to study area). The wells abstracted 0.5 mgd, 4.6 mgd, 1.4 mgd and 0.2 mgd respectively (Table 2).

Although the total volume of groundwater abstracted is large, the wells are located at distances far away from the study area and hence their influence is expected to be minimal.

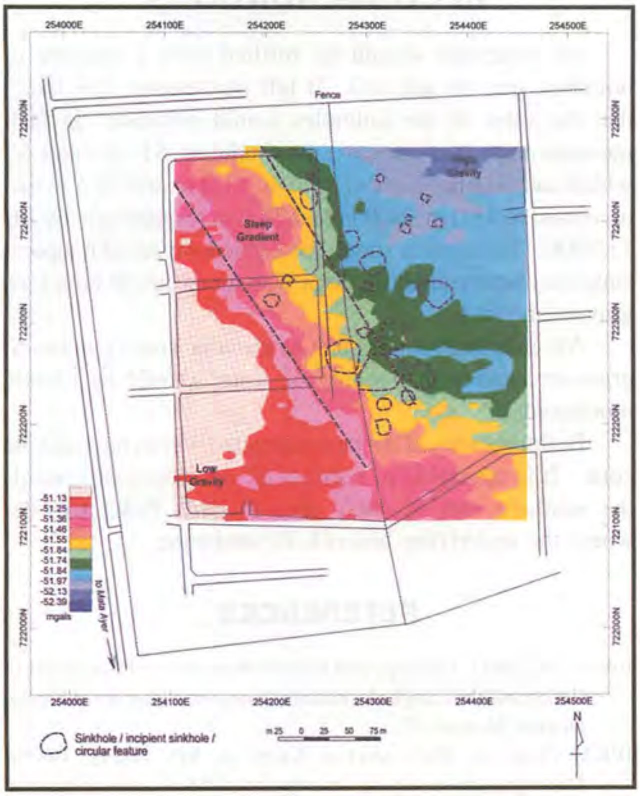

Figure 4. Bouguer anomaly map in the study area.

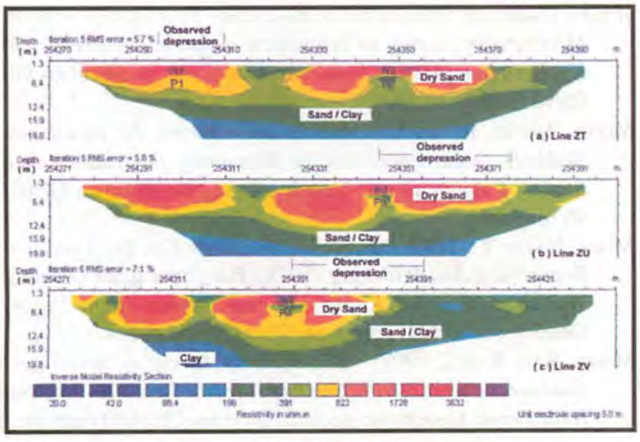

Figure 6. Examples of 2D resistivity imaging profiles conducted in the study area.

Vibration from blasting in the CIMACO Quarry

The CIMACO Quarry is located about 1 km to the north of the study area and blasting was carried out at 5.00 pm daily. Monitoring of vibrations from the blasting showed that on 21st October 2000, 6th November 2000 and 7th November 2000, a vibration level between 0.14 mm/sec to 0.45 mm/sec was recorded at a distance of 1,100 m (Table 3). At a distance of 1,300 m, the vibration levels were lower, measuring between 0.06 mm/sec to 0.18 mm/sec. The vibration levels recorded on 22nd October 2000 however, were much lower, with intensities between 0.05 to 0.06 mm/sec and 0.05 mm/sec at distances of 1,100 m and 1,300 m respectively. The operator probably had undertaken stringent precautions on that day as advanced notice of the monitoring programme was issued to them.

Monitoring of vibrations induced by the movement of vehicles in the study area showed that two heavy trucks moving at a speed of about 30 km/hr had caused a vibration level of between 0.18 mm/sec to 0.25 mm/sec and between 0.16 mm/sec to 0.22 mm/sec at distances of 5 m and 10 m respectively (Table 4).

Rainfall

The Chuping Rainfall Station which is located about 1 km to the south of the study area recorded low to moderate daily rainfall of 3 mm to 10 mm between 3/10/2000 to 14/10/2000 and in fact, there was no rainfall on 3 days (15/10/2000, 7/10/2000 and 14/10/2000). Two days prior to the

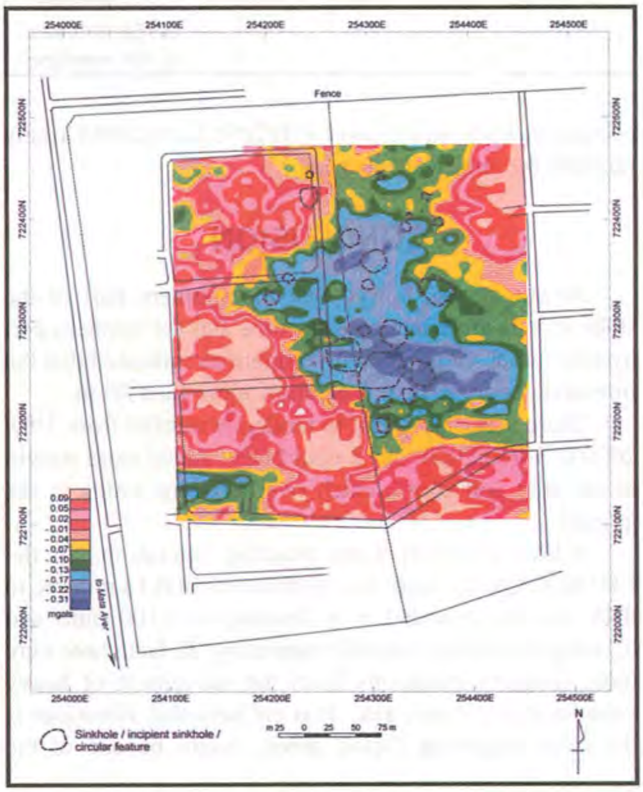

Figure 5. Residual anomaly map in the study area.

Table 2. Tube wells in the Chuping District.

Location	Abstraction (mgd)	Distance from study area (km)
Kilang Gula Felda Chuping	0.5	6
Loji Air Chuping	4.6	13
Loji Arau	1.4	9
Kilang CIMA	0.2	2

Table 3. Vibration levels from blasting operations in CIMACO Quarry.

Date	Distance from quarry	Charge per delay	Peak Particle Velocity
21/10/2000	1,100 m	5.0 kg	0.318 mm/sec 0.445 mm/sec
22/10/2000	1,100 m	6.0 kg	0.047 mm/sec 0.063 mm/sec
6/11/2000	1,100 m	Not determined	0.143 mm/sec 0.397 mm/sec
7/11/2000	1,100 m	Not determined	0.349 mm/sec
21/10/2000	1, 300 m	5.0 kg	0.063 mm/sec
22/10/2000	1,300 m	6.0 kg	0.047 mm/sec 0.047 mm/sec 0.047 mm/sec
6/11/2000	1,300 m	Not determined	0.175 mm/sec 0.159 mm/sec

Table 4. Vibration levels from movement of two heavy vehicles (at 30 km/hr).

Date	Distance from vehicles	Peak Particle Velocity
7/11/2000	5 m	0.191 mm/sec 0.254 mm/sec 0.175 mm/sec
7/11/2000	10 m	0.222 mm/sec 0.159 mm/sec 0.191 mm/sec

occurrence of the sinkholes (13/10/2000,14/10/2000) a daily rainfall of 8 mm was recorded.

CONCLUSION

Investigations showed that the southern part of the study area is underlain by sandstone and the northern part by limestone. Geological investigations indicated that the limestone bedrock is at a depth of more than 20 m.

There was only slight to moderate rainfall from 3/10/2000 to 14/10/2000, but it could have added extra weight to the thin soil roofs which overlay some voids in the ground.

Vibration levels from blasting operations in the CIMACO Quarry were low (with levels of 0.14 mm/sec to 0.45 mm/sec recorded at a distance of 1,100 mm) and blasting was carried out only once daily. In fact, there were more frequent vibrations from the movement of heavy vehicles in the study area. It is unlikely that vibrations is the main triggering factor, albeit, might be one of the contributory factors.

The groundwater regime in the study area flowed towards a depression at the centre near to sinkhole S1. It is possible that there might be a large funnel leading to a series of interconnected cavities/caverns within the limestone bedrock.

All sinkholes and incipient sinkholes are located within a zone about 350 m wide, trending NE-SW. It is likely that this zone is an extension of the brecciated fault zone at the southern end of Bukit Chuping where there are numerous caves and cavities. The sinkholes occurred due to the collapse of the thin soil roofs, which overlay some voids in the ground.

RECOMMENDATIONS

All sinkholes should be refilled with a mixture of boulders, gravels and soil. If left unattended, it is likely that the sides of the sinkholes would collapse. In fact, measurements had shown that sinkholes S1, S2 and S3 which had original sizes of 15.0 m, 11.0 m and 13.5 m had increased to 48.0 m, 24.0 m and 24.0 m respectively by 11/11/2000. Excavation should be carried out an all incipient sinkholes before refilling them with a mixture of boulders, gravels and soil.

All circular features such as circular green patches of grass or areas with ponding of water should be closely monitored.

Buildings should not be constructed within the sinkhole zone. It is advisable to redirect all development towards the southern end of study area towards Bukit Cowder where the underlying bedrock as sandstone.

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