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Joint spacings in granitic rocks of eastern Kuala Lumpur area, Peninsular Malaysia

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Abstract: The set spacing and general spacing of joints in granitic rocks in the eastern Kuala Lumpur area were studied. The set spacing which is the perpendicular distance between two joints of the same set, was measured in the field. It was found that the set spacing parameters for the major joint sets do not vary significantly. The set joint spacings are mainly less than 50 cm. More than half of the modal spacings are about 15 cm and the mean spacing mainly ranges from 35 to 45 cm. Photographic prints were used to obtain the general spacing, which is the distance between points where two adjacent joints intersect a scanline. 90% of the general joint spacings are less than 1 m and 50% are less than 30 cm, and generally, the mean values lies between 20 to 43 cm, and the modal values between 10 to 30 cm. The frequency distribution of the general joint spacings can be fitted to the negative exponential model. The Rock Quality Designation (RQD) calculated from the general joint spacings is generally more than 90% and it is also shown that the RQD can be estimated from the joint frequency.

INTRODUCTION

Joints are one of the most common structural features of a rock mass, occurring in virtually all rock types and tectonic environments. Information of the deformation of a region can be obtained from the joints if the origins of the joints and their relationship with other structures is well understood (Segall and Pollard, 1983; Hancock, 1985). Such paleostress studies have been carried out amongst others by Parker (1942), Hodgson (1961), Scheidegger (1977) and Engelder and Geiser (1980). Joint spacings in the sedimentary rocks have been related to the thickness of the bedding and sediment lithification (Huang and Angelier, 1989). Joint orientations in intrusive rocks have been compared to the orientation of the flow structures, dikes as well as the geometry of the pluton (Balk, 1937; Marre, 1986).

Joints and other discontinuities play an important role in controlling the mechanical properties of a rock mass. The strength and deformability of a rock mass, rock slope stability, as well as the ability of a rock mass to transmit and hold fluids depends more on the discontinuity systems within the rock mass than on the rock mass itself (Hoek and Bray, 1974; Jaeger and Cook, 1979). Thus, joints or discontinuity survey is an essential part of site investigation for almost all geological engineering projects. The International Society of Rock Mechanics (ISRM, 1978) have suggested 11 parameters for the quantitative description of discontinuities. Orientation and spacing are two of the most commonly reported parameters. Joint spacing and length are also often analysed statistically by computing a best fit curve or line to the data sets according to the theoretical distribution functions which enables these joint parameters to be described numerically (Priest and Hudson, 1976; Segall and Pollard, 1983; Miller and Borgman, 1985; Huang and Angelier, 1989). Based on the theoretical distribution, a relationship between the spacings and Rock Quality Designation has also been made (Priest and Hudson, 1976).

In this study, joint spacing and other parameters (orientation, length, aperture, and others) in granitic rocks are measured to provide a detailed joint description. The joint spacings are measured in the field and also from photographic prints of exposures with well defined joints. The spacing of joints in individual joint sets (referred to as **set joint spacing**), and the spacing between joints in general (irrespective of joint sets and referred to as **general joint spacing**) are discussed separately here. The distribution of the general joint spacing and its relationship to the Rock Quality Designation are described.

GEOLOGY

The area of study is located to the east of Kuala Lumpur (Fig. 1). This area is underlain by granitic rocks of the Main Range batholith which intruded into folded and regionally metamorphosed clastic and calcareous rocks. The oldest rock unit is the Lower Paleozoic Dinding Schist. It is conformably overlain by the Hawthornden Schist which is in turn overlain by the Upper Silurian Kuala Lumpur Limestone (Gobbett, 1964, 1973). The Kenny Hill formation lies conformably over the Kuala Lumpur Limestone (Yeap, 1970; Khoo and Tan, 1983).

The granitic rocks comprises three main bodies: the Kuala Lumpur Granite, the Genting Sempah Microgranite and the Bukit Tinggi Granite. The Kuala Lumpur Granite is the main granitic body and it is separated from the Genting Sempah Microgranite by a metasedimentary screen at its eastern margin. It is predominantly megacrystic consisting of K-feldspar megacrysts set in a medium to coarse grained allotriomorphic to hypidiomorphic groundmass. The Genting Sempah Microgranite is made up of subvolcanic (micrograndiorite) and volcanic rocks (Liew, 1983; Cobbing and Mallick, 1987). The Bukit Tinggi Granite comprises very

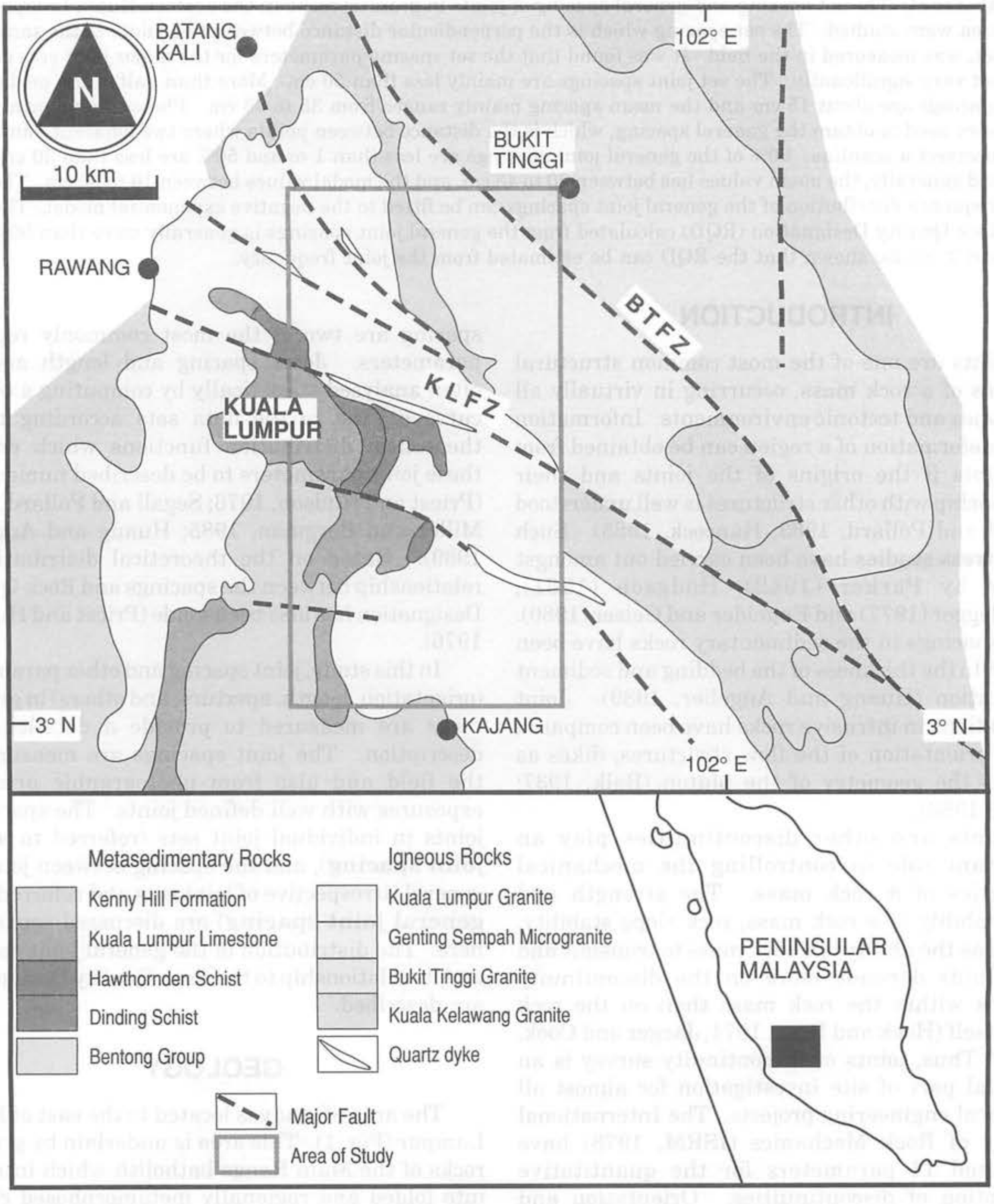

Figure 1. Simplified geological map of the Kuala Lumpur and adjacent areas showing the area of study. Modified after Gobbett (1964) and Cobbing and Mallick (1987).

coarse grained megacrystic biotite granite. Geochronological studies by Bignell and Snelling (1977), Liew (1983) and Darbyshire (1988) suggest a Late Triassic age of emplacement for the above granitic rocks.

The study area is cut by two major fault zones — the Bukit Tinggi Fault Zone (BTFZ) and the Kuala Lumpur Fault Zone (KLFZ). Mesoscopic faults and shear zones are commonly observed. They are steeply dipping and strike mainly at NW-SE, N-S and NE-SW. Faulting have given rise to a diverse assemblage of deformed rocks including fault breccias, cataclasites and mylonites (Ng, 1994). Joints are ubiquitous in the granitic rocks. Systematic relationships between the joints and the geometry of the pluton, the flow structures and dykes are not observed. However, the orientation of the major joint sets and the mesoscopic faults are similar. The spacings of joints are observed to decrease towards the faults. Thus, the joints and faults are likely to be cogenetic.

CHARACTERISTICS OF THE JOINTS

The orientations of joints from 26 granite exposures, 23 from the Kuala Lumpur Granite and 3 from the Genting Sempah Microgranite, were measured. The joints mainly occur as sets of discontinuities, each set having similar orientations. Projection of poles to joint planes for the various exposures are shown in Figure 2. Up to 8 joint sets are present, though most exposures display between 3 to 5 joint sets. In addition to these sets, randomly orientated joints and sheet structures are also present. Two or 3 joint sets are generally common and form a prominent maxima in the projection of poles to joint planes. Four joint sets are common to almost all the exposures and these can be considered to be the major or systematic joint sets which occur regionally. The four major joint sets are steeply dipping and strike approximately NW-SE (maxima of composite projection of poles to joint planes at 322°/vertical), N-S (pole maxima at 014°/76°E), E-W (pole maxima at 88°/78°S) and NE-SW (pole maxima at 52°/74°SE).

The major joints are more prominent and persistent than the other more localized joints (minor or non-systematic joint sets). Most (> 90%) of the major joints have lengths between 0.1 to 3 m, while the minor joints are mainly between 0.1 to 2 m. These measurements, however, may not represent the typical joint lengths as about half (54% in Perkuat Quarry) of the measured joints have at least one end which continues beyond the exposure.

In the study area, the roughness of the joint surfaces ranges from smooth planar (minimum roughness) to rough undulating (maximum roughness). The most frequently observed degree of roughness in all the exposures appears to be similar, which is smooth and slightly undulating. Mineral coatings are common on the joint surfaces. The joint surfaces coated with minerals such as chlorite and calcite are smoother than those devoid of mineral coating. The most common mineral coating is chlorite, followed by quartz and carbonate. Other minerals such as fluorite, epidote and pyrolusite are also observed, though they are less common. Joint and fault surfaces are also often stained by iron oxide.

SET JOINT SPACING

The set joint spacing is the perpendicular distance between two adjacent joints of the same set. Whenever possible, the spacing is measured along a scanline perpendicular to the joint planes. When the scanline is not normal to the joint plane, the apparent spacing is measured, and the spacing calculated with the following equation:

$$S = S'\cos\theta$$

where S is the spacing, S' is the apparent spacing, and θ is the smallest angle between the scanline and the pole to the joint plane (Hudson and Priest, 1983). This angle θ can be obtained using stereographic projection (Fig. 3).

It is desirable to measure the joint spacing along a single scanline on a planar exposure, but most of the studied exposures have uneven surfaces. Most spacing determinations were thus carried out along several short, near linear scanlines, each 3 to 5 m long, giving a total scanline length of more than 50 times the mean joint spacing. The apparent spacing was measured with a measuring tape and was later converted to true spacing.

The set spacings of the major joint sets were determined from three quarries (Perkuat, Dayapi and Kajang) and two road-cuts along the Karak Highway (km 23 and 27.2). The spacing results were treated statistically where the minimum spacing (S_{min}), maximum spacing (S_{max}), modal spacing (S_{mod} = spacings having the highest frequency of occurrence), mean spacing (S = sum of spacings divided by the number of measurements) and standard deviation (σ) were calculated. These parameters are shown together with the joint spacing distribution bar charts in Figure 4 and are also summarized in Table 1. From the results, it is obvious that the differences between the spacing parameters of various joint sets are not significant. The majority of the joint spacings are less than 50 cm. The modal spacing ranges from 5 to 45 cm, but more than half of the joint sets have a modal spacing of about 15 cm. The mean spacing ranges from 35

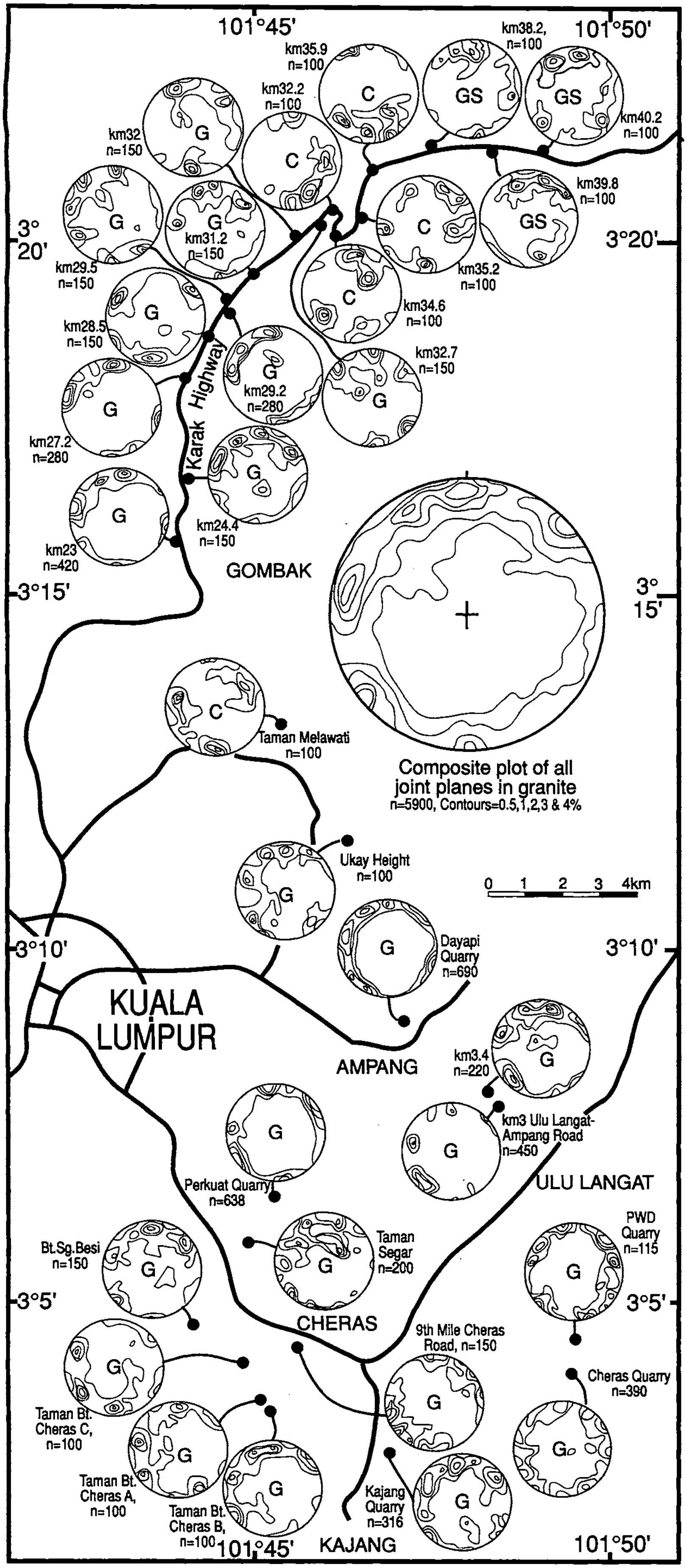

Figure 2. Orientation of joints in the eastern Kuala Lumpur area. Lower hemisphere equal area projections of poles to joint planes, contoured at 1, 3, 5 and 7 percent per 1 percent area. G = Kuala Lumpur Granite, GS = Genting Sempah Microgranite, C = country rock, n = number of readings.

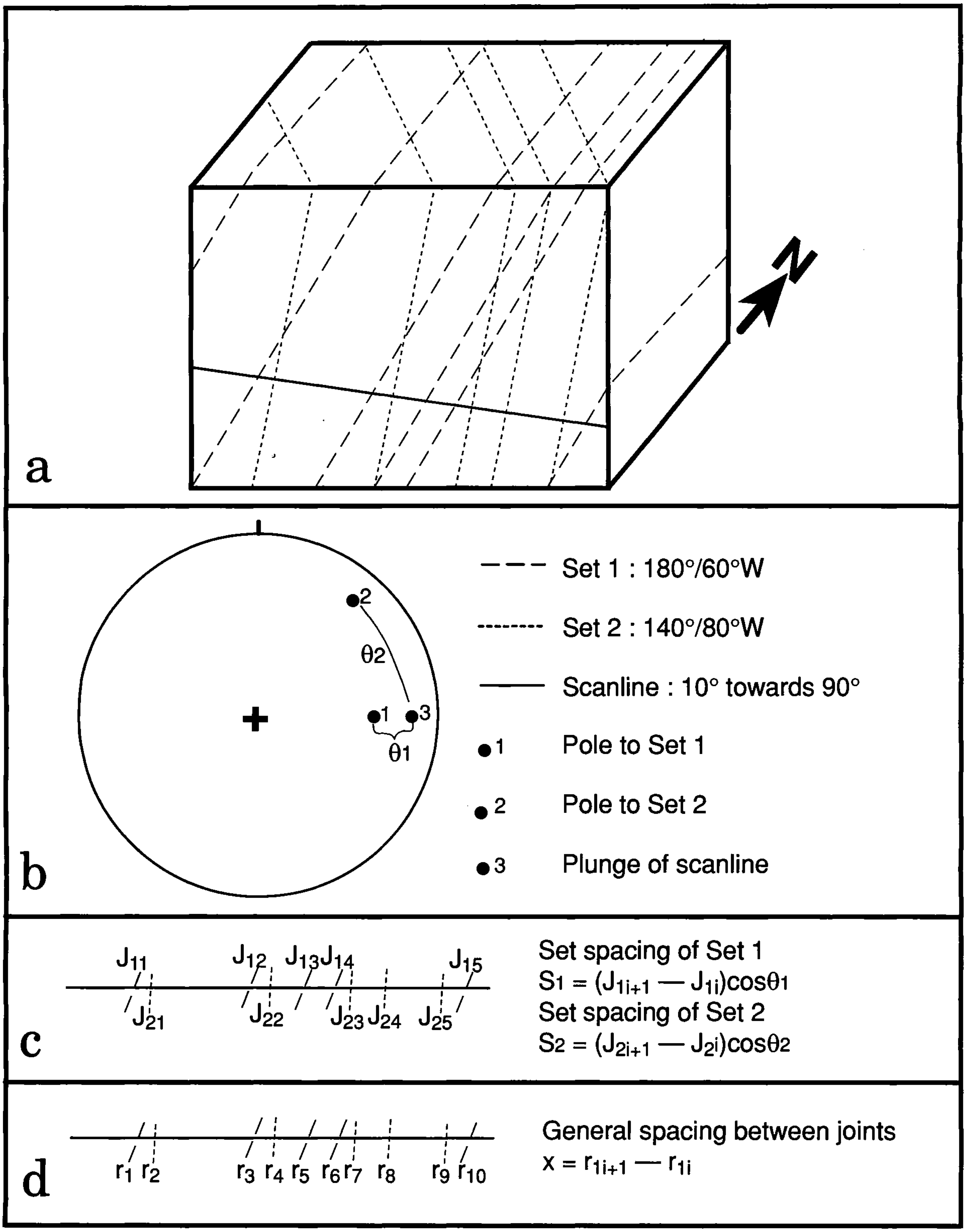

Figure 3. Schematic diagrams showing the procedures used to calculate the spacing in individual joint set (set spacing) and spacing between joints in general (general spacing). a) Block diagram showing two joint sets intersect by a scanline. b) Equal angle projection of pole to joint planes and plunge of scanline. The angle θ is the smallest angle between scanline and pole to joint plane. Set spacing was calculated using equation in c, while general spacing was obtained directly (d).

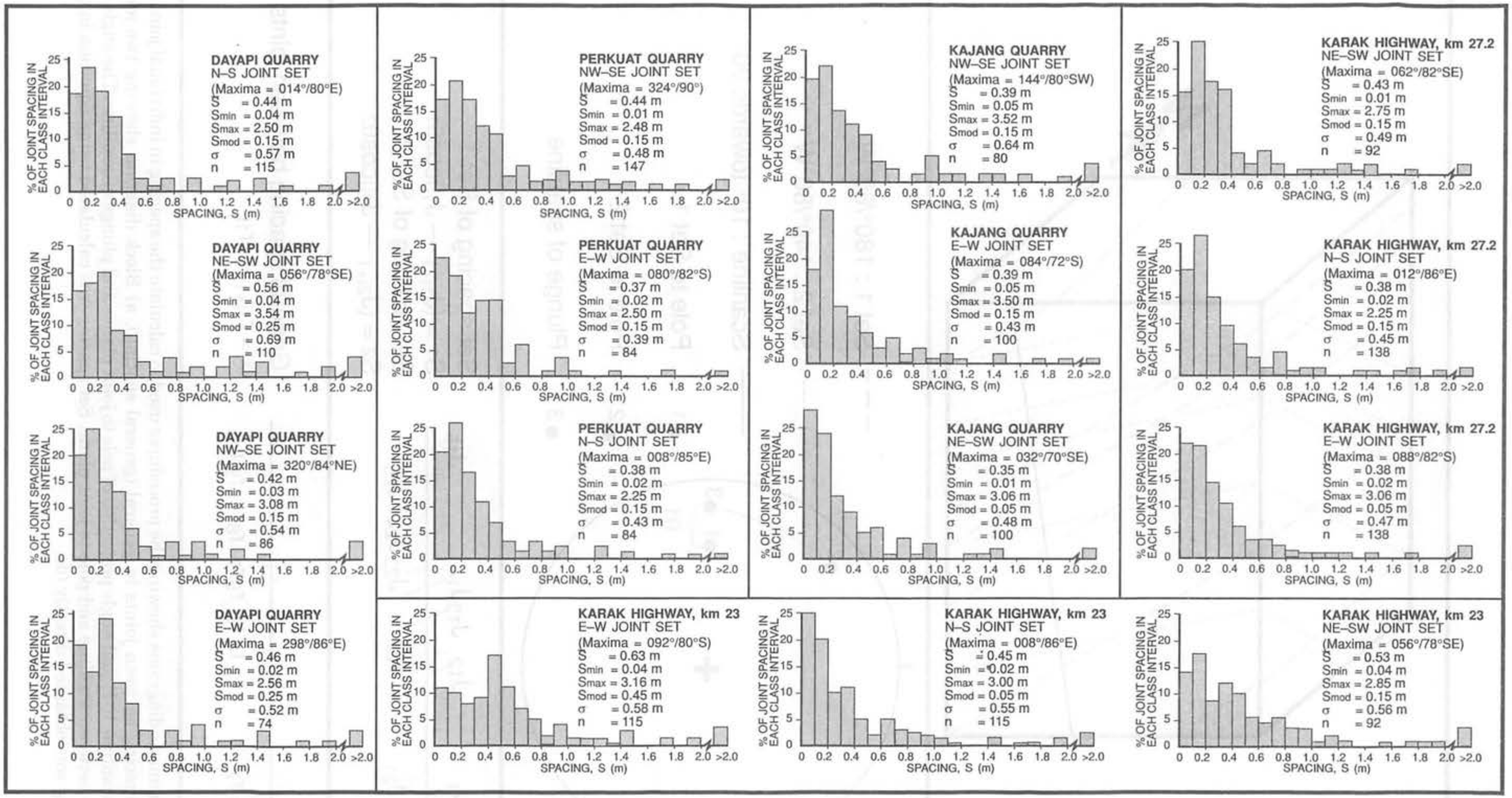

Figure 4. Bar charts showing the distribution of the set joint spacings measured from Perkuat Quarry, Kajang Quarry, Dayapi Quarry, km 23 and km 27.2 of the Karak highway. $\overline{S}$ = mean spacing, S_{min} = minimum spacing, S_{max} = maximum spacing, S_{mod} = modal spacing, σ = standard deviation, n = number of readings.

Table 1. Summary of the spacing of the individual joint sets. $\bar{S}$ = mean spacing, Smin = minimum spacing, S_{max} = maximum spacing, S_{mod} = modal spacing, s = standard deviation, n = number of readings.

Joint Set		(maxima)	Spacing (m) $\bar{S}$	S_{min}	S_{max}	S_{mod}	σ(m)	n
	Perkuat Quarry							
A	NW-SE	(324°/90°)	0.44	0.01	2.48	0.15	0.48	147
B	E-W	(080°/82°S)	0.37	0.02	2.50	0.15	0.39	84
C	N-S	(008°/85°E)	0.38	0.02	2.25	0.15	0.43	84
	Dayapi Quarry							
A	N-S	(014°/80°E)	0.44	0.04	2.50	0.15	0.57	115
B	NE-SW	(056°/78°SE)	0.56	0.04	3.54	0.25	0.69	110
C	NW-SE	(320°/84°NE)	0.42	0.03	3.08	0.15	0.54	86
D	E-W	(298°/86°N)	0.46	0.02	2.56	0.25	0.52	74
	Kajang Quarry							
A	NW-SE	(144°/80°SW)	0.39	0.05	3.52	0.15	0.64	80
B	E-W	(084°/72°S)	0.39	0.05	3.50	0.15	0.43	100
C	NE-SW	(032°/70°SE)	0.35	0.01	3.06	0.05	0.48	100
	Karak highway, km 23							
A	N-S	(008°/86°E)	0.45	0.02	3.00	0.05	0.55	115
B	E-W	(092°/80°S)	0.63	0.04	3.16	0.45	0.58	115
C	NE-SW	(056°/78°SE)	0.53	0.04	2.85	0.15	0.56	92
	Karak Highway, km 27.2							
A	N-S	(012°/86°E)	0.38	0.02	2.25	0.15	0.45	138
B	E-W	(088°/82°S)	0.38	0.02	3.06	0.05	0.47	138
C	NE-SW	(062°/82°SE)	0.43	0.01	2.75	0.15	0.49	92

Figure 5. Well defined joints in Dayapi Quarry (Domain III) with 1 m scale (arrow).

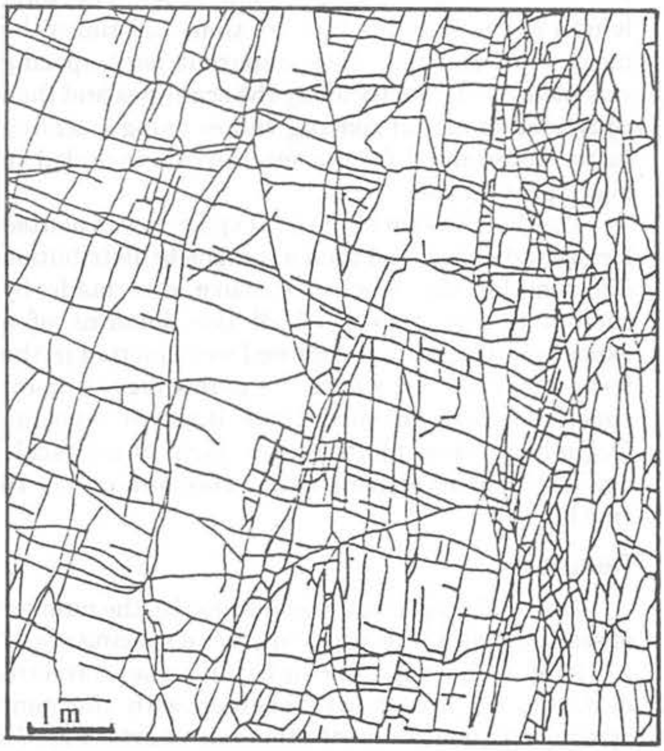

Figure 6. Tracing of joints of the photographic prints in Figure 5.

to 63 cm (75% between 35 and 45 cm). The minimum spacing is between 1 and 5 cm while the maximum spacing between 2.25 to 3.54 m.

GENERAL JOINT SPACING

The general joint spacing (x) refers to the distances between points where two adjacent joints intersect a scanline (Fig. 3). The orientations of the joints are disregarded for this measurement. These spacing values are dependent on the set joint spacing (S), the number of joint sets, and the orientation of the scanline.

The spacing between joints was determined from photographs of selected representative rock faces (Fig. 5). The measurements were not carried out in the field because only the lower portion of these sub-vertical rock faces are accessible whereas in the photographs, scanlines can be drawn in any desired position and direction. The rock faces chosen are reasonably planar and the joints well defined. Large inhomogeneous exposures were divided into several domains in each of which joint features are more or less homogeneous. All the joints observed on 20 cm by 25 cm photographic prints of every domain of the rock faces were traced onto the tracing paper for subsequent determination of the joint spacing (Fig. 6). Several scanlines (usually about 6) were drawn at different directions on the tracings of the joints. Usually, two scanlines were positioned approximately perpendicular to each major joint set, and one to the minor joint sets. The total length of the scanline is more than 150 times the mean joint spacing. The apparent joint spacing was measured directly along the scanlines and then converted to actual spacing values using a scaling factor determined from a metre-scale included in every photograph.

The distribution of the joint spacing was plotted for every domain, and then a composite distribution diagram for the whole exposure was made by combining the results of all the domains of a exposure. The results obtained were plotted in the form of bar charts, where the percentages of joint spacing values in each class interval (spacing frequency) were plotted in a logarithmic scale against the joint spacing with a class interval of 10 cm (Fig. 7).

Results

The total length of the scanlines (L), the number of scanline-joint intercepts (n), mean spacing ($\bar{x} = L/n$), joint frequency ($\lambda = n/L$) and the standard deviation (σ) are shown together with the joint spacing frequency distribution bar charts (Fig. 7). The differences in general joint spacing distributions between various domains and exposures are not significant (Table 2). A majority of the general joint spacings, x, are less than 1 m (more than 90% are less than 1 m; more than 50% less than 30 cm), with a higher concentration at the lower spacings. All the mean spacings, $\bar{x}$, are between 20 cm to 43 cm, except for two localities adjacent to fault zones (Dayapi Quarry and 3rd km Ulu Langat-Ampang road), where the mean spacings are 15 cm and 12 cm respectively. Modal spacings, x_{mod}, generally lie between 10 to 30 cm.

Frequency Distribution of General Joint Spacing

Priest and Hudson (1976) made an interesting study on the distribution of joint (discontinuity) spacings along straight lines through rock masses. They suggested that for randomly positioned discontinuities, the frequency distribution of joint spacings is of negative exponential form with the probability density f(x) defined by:

$$f(x) = \lambda e^{-\lambda x}$$

where f(x) is the frequency of occurrence of spacing value x, λ is the average number of discontinuities per metre or discontinuity frequency. In this mono-parametric distribution, the mean spacing and the standard deviation are both equal to the reciprocal of the discontinuity frequency ($1/\lambda$). The standard statistical theory of this type of distribution is explained in Appendix A of Priest and Hudson (1976).

In this study, a negative exponential function in the form of:

$$f(x) = ae^{-bx}$$

is fitted statistically to the data. This negative exponential function is transformed to the form of:

$$\ln f(x) = \ln(a) - bx$$

which is a straight line. A best fit line is calculated using the least squares method, and it is superimposed onto the bar charts (Fig. 7). The parameters a and b, and the coefficient of correlation (r) for the best fit lines are shown together with the bar charts and are also summarised in Table 2.

The results show that the frequency of joint spacing values can be fitted on to the negative exponential distribution, implying that the joints are randomly positioned in the granitic rock masses investigated. One of the characteristics of a negative exponential distribution is that the mean spacing ($\bar{x}$) is equal to the standard deviation (σ). The calculated standard deviation of the joint spacings mainly falls within –25% to +10% about the mean spacing. The calculated parameter -b (slope of best fit line) is very close to the measured joint frequencies, λ, ($-b = \lambda \pm 15\%$). The coefficient of correlation (r) of the best fit lines ranges from –0.87 to –0.99, implying a strong negative correlation between the frequency of joint spacing and joint

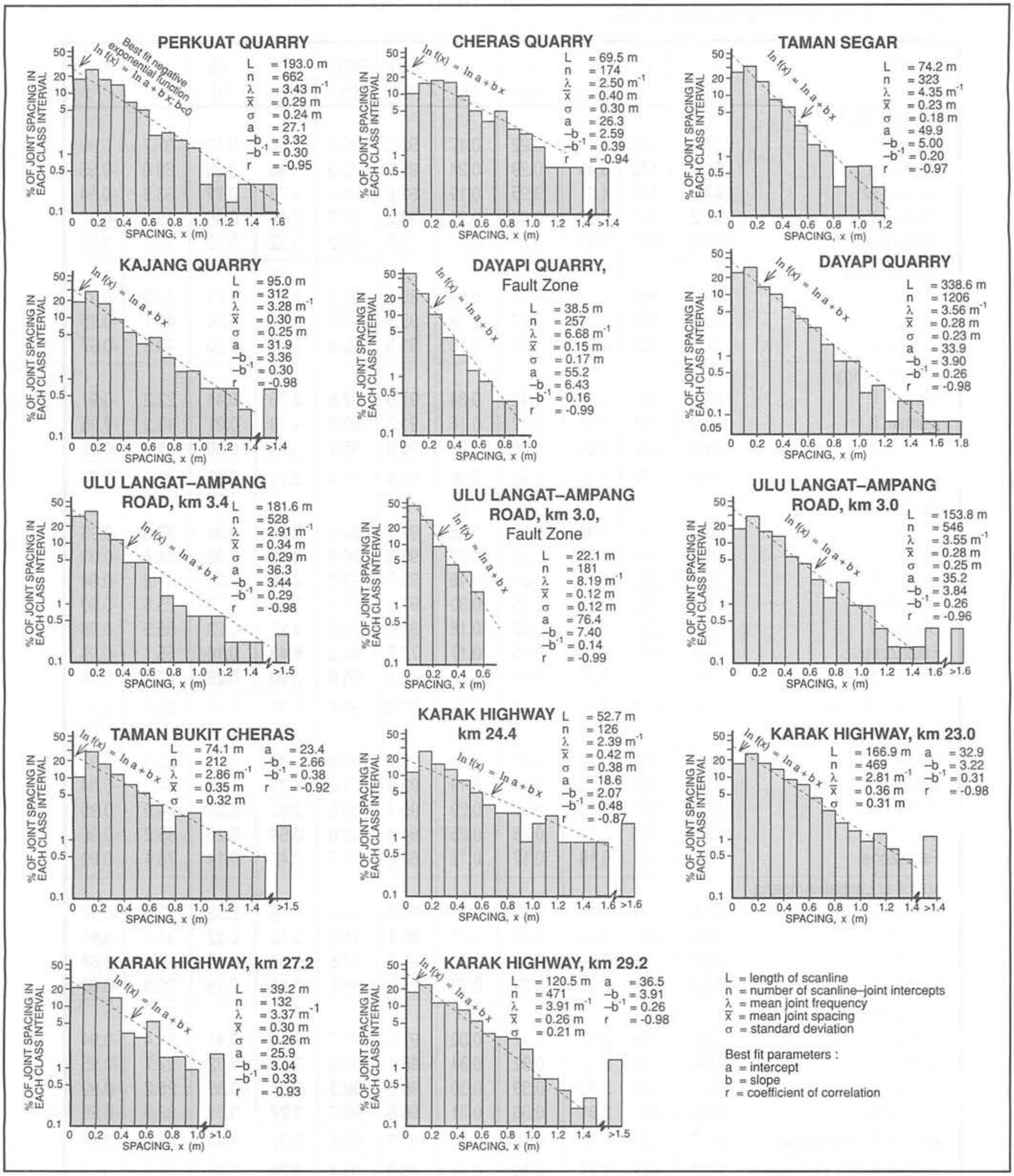

Figure 7. Bar charts showing the distribution of the general joint spacings with the best fit negative exponential distribution.

Table 2. Summary of the parameters of the general joint spacing. L = length of scanline, n = number of scanline-joint intercepts, λ = joint frequency, $\bar{x}$ = mean spacing, σ = standard deviation, *RQD* = Rock Quality Designation; *RQD** = theoretical Rock Quality Designation; b = slope of best fit line, a = intercept of best fit line, and r = coefficient of correlation of the best fit line.

Location	L (m)	n	λ (m^{-1})	$\bar{x}$ (m)	σ (m)	RQD (%)	RQD* (%)	-b (m^{-1})	-1/b (m)	a (%)	r
Perkuat Quarry											
Domain I	37.0	170	4.59	0.22	0.17	92.5	92.3	3.52	0.28	37.7	-0.90
Domain II	51.2	176	3.44	0.29	0.24	95.2	95.3	3.48	0.29	33.0	-0.95
Domain IV	43.6	175	4.01	0.25	0.19	92.6	90.2	3.73	0.27	33.8	-0.94
Domain V	61.2	141	2.30	0.43	0.35	98.2	97.7	2.16	0.46	19.8	-0.87
Composite	193.0	662	3.43	0.29	0.24	95.5	95.2	3.32	0.30	21.1	-0.95
Taman Segar											
Domain I	35.0	158	4.51	0.22	0.18	89.3	92.3	4.71	0.21	44.5	-0.97
Domain II	39.2	168	4.29	0.23	0.18	93.5	92.3	4.10	0.24	40.1	-0.95
Composite	74.2	323	4.35	0.23	0.18	91.5	92.9	5.00	0.20	49.9	-0.97
Kajang Quarry											
Domain I	57.1	136	2.38	0.42	0.34	97.8	97.6	2.25	0.44	22.2	-0.91
Domain II	37.9	176	4.64	0.22	0.16	91.3	92.3	4.78	0.21	43.2	-0.95
Composite	95.0	312	3.28	0.30	0.25	96.0	95.7	3.36	0.30	31.9	-0.98
Cheras Quarry	69.5	174	2.50	0.40	0.30	96.6	97.4	2.59	0.39	26.3	-0.94
Dyapi Quarry											
Domain I	65.8	197	2.99	0.33	0.28	92.1	94.9	2.98	0.34	27.6	-0.96
Domain II	58.3	165	2.83	0.35	0.27	95.2	96.6	2.82	0.35	24.4	-0.93
Domain III	52.2	222	4.25	0.24	0.18	92.5	92.9	4.68	0.21	41.8	-0.94
Domain IV	70.2	186	2.65	0.38	0.30	97.1	97.1	2.80	0.36	25.6	-0.93
Domain V	53.6	230	4.29	0.23	0.18	91.0	92.9	4.27	0.23	55.9	-0.98
Fault Zone	38.5	257	6.68	0.15	0.17	72.7	85.6	6.43	0.16	55.1	-0.99
Composite	338.6	1206	3.56	0.28	0.23	93.4	95.0	3.90	0.26	33.9	-0.98
Taman Bt. Cheras	74.1	212	2.86	0.35	0.32	97.6	96.6	2.66	0.38	23.4	-0.92
km3, U.Langat–Ampang											
Domain I	51.9	169	3.26	0.31	0.28	95.8	95.8	2.86	0.35	22.9	-0.92
Domain II	44.9	166	3.70	0.27	0.19	93.6	94.6	4.36	0.23	44.5	-0.94
Domain III	57.0	211	3.70	0.27	0.29	95.1	94.6	2.92	0.34	24.9	-0.95
Composite	153.8	546	3.55	0.28	0.25	94.9	95.0	3.84	0.26	35.2	-0.96
Fault Zone	22.1	181	8.19	0.12	0.12	68.8	79.7	7.40	0.14	76.4	-0.99
km3.4 U.Langat–Ampang											
Domain I	57.5	179	3.11	0.32	0.27	94.5	96.0	3.16	0.32	32.5	-0.97
Domain II	65.2	208	3.19	0.31	0.27	95.4	95.8	3.10	0.32	31.7	-0.98
Domain III	58.9	141	2.39	0.42	0.32	97.8	97.6	2.02	0.50	19.1	-0.88
Composite	181.6	528	2.91	0.34	0.29	95.9	96.5	3.44	0.29	36.3	-0.98
km23, Karak Highway											
Domain I	68.2	165	2.42	0.41	0.30	97.2	97.5	2.45	0.41	24.4	-0.94
Domain II	48.0	152	3.17	0.32	0.34	96.4	95.9	3.16	0.32	27.7	-0.95
Domain III	50.7	152	3.00	0.33	0.30	96.0	96.3	2.84	0.35	25.2	-0.92
Composite	166.9	469	2.81	0.36	0.31	96.6	96.7	3.22	0.31	32.9	-0.98
km24.4, Karak Highway	52.7	126	2.39	0.42	0.38	97.9	97.6	2.07	0.48	18.6	-0.87
km27.2, Karak Highway	39.2	132	3.37	0.30	0.26	95.0	95.4	3.04	0.33	25.9	-0.93
km29.2, Karak Highway											
Domain I	65.6	224	3.41	0.29	0.26	94.2	95.3	3.20	0.31	27.4	-0.97
Domain II	54.9	247	4.50	0.22	0.16	90.0	92.3	4.84	0.21	45.6	-0.98
Composite	120.5	471	3.91	0.26	0.21	92.3	94.2	3.91	0.26	35.5	-0.98

Table 3. Rock Quality designation (*RQD*) and theoretical Rock Quality Designation (*RQD**) computed from the joint frequency (λ) of selected exposures of the Kuala Lumpur Granite. ΔRQD is the difference between the *RQD* and *RQD**.

LOCATION	λ (m^{-1})	RQD (%)	RQD* (%)	ΔRQD (%)
Perkuat Quarry				
Domain I	4.59	92.5	92.3	0.2
Domain II	3.44	95.2	95.3	-0.1
Domain IV	4.01	92.6	90.2	2.4
Domain V	2.30	98.2	97.7	0.5
Composite	3.43	95.5	95.2	0.3
Taman Segar				
Domain I	4.51	89.3	92.3	-3.0
Domain II	4.29	93.5	92.3	1.2
Composite	4.35	91.5	92.9	-1.4
Kajang Quarry				
Domain I	2.38	97.8	97.6	0.2
Domain II	4.64	91.3	92.3	-1.0
Composite	3.28	96.0	95.7	0.3
Cheras Quarry	2.50	96.6	97.4	-0.8
Dayapi Quarry				
Domain I	2.99	92.1	94.9	-2.8
Domain II	2.83	95.2	96.6	-1.4
Domain III	4.25	92.5	92.9	-0.4
Domain IV	2.65	97.1	97.1	0.0
Domain V	4.29	91.0	92.9	-1.8
Fault Zone	6.68	72.7	85.6	-12.9
Composite	3.56	93.4	95.0	-1.6
Taman. Bt. Cheras	2.86	97.6	96.6	1.0
km3, U.Langat–Ampang				
Domain I	3.26	95.8	95.8	0.0
Domain II	3.70	93.6	94.6	-1.0
Domain III	3.70	95.1	94.6	0.5
Composite	3.55	94.9	95.0	-0.1
Fault Zone	8.19	68.8	79.7	-10.9
km3.4 U.Langat–Ampang				
Domain I	3.11	94.5	96.0	-1.5
Domain II	3.19	95.4	95.8	-0.4
Domain III	2.39	97.8	97.6	0.2
Composite	2.91	95.9	96.5	-0.6
km23, Karak Highway				
Domain I	2.42	97.2	97.5	-0.3
Domain II	3.17	96.4	95.9	0.5
Domain III	3.00	96.0	96.3	-0.3
Composite	2.81	96.6	96.7	-0.1
km24.4, Karak Hy.	2.39	97.9	97.6	0.3
km27.2, Karak Hy.	3.37	95.0	95.4	-0.4
km29.2, Karak Hy.				
Domain I	3.41	94.2	95.3	-1.1
Domain II	4.50	90.0	92.3	-2.3
Composite	3.91	92.3	94.2	-1.9

spacing values (number of joints decreases as joint spacing increases).

In most of the bar charts, the first spacing interval (0–10 cm) has frequency values (percentage of joint spacing) lower than the expected best fit values. This is probably caused by the omission of some of the smaller joint spacings, as the resolution of the photographic prints is insufficient to separate very closely spaced joints.

Relationship Between General Joint Spacing and Rock Quality Designation (*RQD*)

Deere (1963) proposed the Rock Quality Designation (*RQD*) as an index for the quality of rock cores recovered during site investigations. The *RQD* is defined as the proportion of borehole cores that consist of intact lengths that are 10 cm or longer. The *RQD* can be used to describe the joint spacing along a scanline by assuming the scanline as analogous to a borehole, and the joint spacing as analogous with the length of intact rock cores (Priest and Hudson, 1976). In the present study, *RQD* is calculated by summing up all the joint spacings that are greater than 10 cm, and expressed as a percentage of the scanline length:

$$RQD = 100 \sum_{i=1}^{N} x_i/L$$

where x_i is the spacing value of the i-th spacing that is greater than 10 cm, N is number of spacing values greater than 10 cm, and L is total scanline length.

Priest and Hudson (1976) proposed a theoretical Rock Quality Designation (*RQD**) for discontinuity spacings that follow the negative exponential distribution. *RQD** is defined as :

$$RQD^* = 100\, e^{-\lambda t} (\lambda t + 1)$$

where t is the threshold value. For a threshold value of t = 0.1 m (following conventional *RQD*), the *RQD** becomes (Priest and Hudson, 1976) :

$$RQD^* = 100e^{-0.1\lambda} (0.1\lambda + 1)$$

The *RQD* and their corresponding *RQD** values for t = 0.1 m for the locations investigated are listed in Table 3. The RQD values range from 68.8% to 98.2%, while *RQD** values range from 79.9% to

97.7%. All but two of the 38 *RQD* values determined are greater than 90%, which can be rated as excellent bedrock quality. The two locations which have low *RQD* values are situated near to the fault zones. The *RQD** values calculated using the joint frequency are accurate to within ±3% of the *RQD*, except for the two locations near to the fault zones, which deviate up to –13%.

SUMMARY

The Kuala Lumpur Granite bedrock mass is cut by up to 8 joint sets, though 4 major joint sets are recognized. The major joints have a regional distribution and are more prominent and persistent than the minor joints and sheet structures. They are steeply dipping and strike approximately NW-SE, N-S, E-W and NE-SW.

Although the set joint spacings (S) of the various major joint sets may range from 1 cm to more than 3 m, the majority of them have spacing values of less than 50 cm. In general, their mean ($\bar{S}$) and modal (S_{mod}) spacings also do not vary significantly, the former being about 35 to 45 cm and the later about 15 cm.

Analysis of joints carried out on photographic prints of granite exposures show that more than half of the general joint spacings (x) have values of 30 cm or less, and mean spacings ($\bar{x}$) mainly between 20 and 40 cm. It has been shown that the frequency distribution of joint spacings can be described by the negative exponential distribution implying that the joints are randomly positioned. The theoretical Rock Quality Designation (*RQD**) computed using the joint frequency (λ) is found to be within ±3% to the actual *RQD* calculated from the spacing values.

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