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Design Charts for Rock-cut Slopes Along Motorways in Southern Saudi Arabia

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ABSTRACT. This paper describes a new set of design charts which have been compiled to assist in the preliminary analysis of excavated slopes in Saudi Arabia. Data for the charts were collected from Al-Dilaa and Al-Juwah descents. Both stable and unstable slopes were assessed utilizing rock mass classification systems, basic mapping, and index tests, so that the basic geotechnical features of the stable and unstable rock masses could be defined. Furthermore, date were supplemented by a study of the stability of slopes together with the remedial and support measures.

The parameter known as volumetric joint count (Jv) is found to be sensitive to the performance of slopes in hard Saudi Arabian rocks. Correlation with either overall slope height or overall slope angle provides useful design charts for roads cuts. The charts could be zoned, with each zone being ascribed a likely combination of support measures.

Furthermore, it is also suggested that the constructed charts could provide quick assessment to the design, construction, maintenance and safety requirements of rock slopes excavated in the mountainous terrain of Saudi Arabia along the Red Sea.

Introduction

Many engineers and engineering geologists have found that design charts can be of a considerable help during the early stages of planning an engineering structure. The charts are particularly appropriate when the geology of the region is poorly known. The present programme of road construction in Saudi Arabia could benefit generally from the existence of such charts.

This paper describes the methods used to assess the stability and performance of cut slopes in the mountain descents of Al-Dilaa and Al-Juwah in the southwestern region of Saudi Arabia. A total length of 29 km of cut slope has been studied, that included 68 major slopes in which 21 major landslides have occurred. This paper also explains the logic that was employed to utilize these data in the construction of design charts that may be used at an initial stage of planning and design of cut slopes in rock is also explained.

Six design charts are presented, each one is based on the real performance of existing slopes. A sensible use of the charts may achieve a slope design, that provides a higher safety factor with a minimum cost.

Geologic Setting and Geomorphology

At Abha city, the mountainous southwestern part of Saudi Arabia, reaches altitudes of 3,000 metres or more, forming part of the Red Sea escarpment. It is located about 75 kilometres inland, east of the Red Sea coast. The escarpment divides the Arabian Shield into two regions: (1) a high plateau that slopes gently eastwards from the escarpment, and (2) a highly dissected mountainous terrain that merges with and slopes precipitously westward towards the Red Sea coastal plain, through a number of deep descents, canyons and rugged mountains.

The studied portion of the Al-Dilaa descent, Section 2b, is bounded by Longitudes 42°20′21″ and 42°31′18″, and Latitudes 18°9′20″ and 18°11′43″, and formed of granite, granodiorite, tonalite, diorite, and gabbro of Precambrian age. Al-Juwah descent is bounded by Longitudes 42°29′21″ and 42°31′18″ and Latitudes 18°9′20″ and 18°11′43″, and it is formed of monzogranite, granodiorite, tonalite, and diorite, of Precambrian age, and former laterite and basalt of Tertiary age. Greenwood *et al.* (1980) reviews the formation of the Precambrian rocks in the Arabian Shield.

Both Al-Dilaa and Al-Juwah descents are located along the hillside of the escarpment connecting the lowlands with the highlands by motorways at Asir province, Fig. 1. Both motorways projects are constructed in one of the most difficult areas of the Kingdom as far as terrain is concerned. The areas are formed of hard rocks, generally fresh to slightly weathered, with a wide range of intensity of jointing. The rock characteristics are different from one place to another in response to changes in rock types, lithology, and origin.

Predictions

Predictions which are made to forecast the behaviour of a rock mass are usually based upon prior knowledge and experience. In engineering practice, prediction is always difficult to make because: (1) a rock mass is a complex engineering material which is discontinuous, inhomogeneous, anisotropic, and not perfectly elastic, (2) the diversity of the rock's properties is considerable, and (3) financial investment from the commissioning authorities is usually limited. The predictions could be easier to state if the number of effective variables is reduced.

In this study, prediction is guided by analyzing and interpreting field and laboratory data pertinent to the routes of the motorways at the Al-Dilaa and Al-Juwah de-

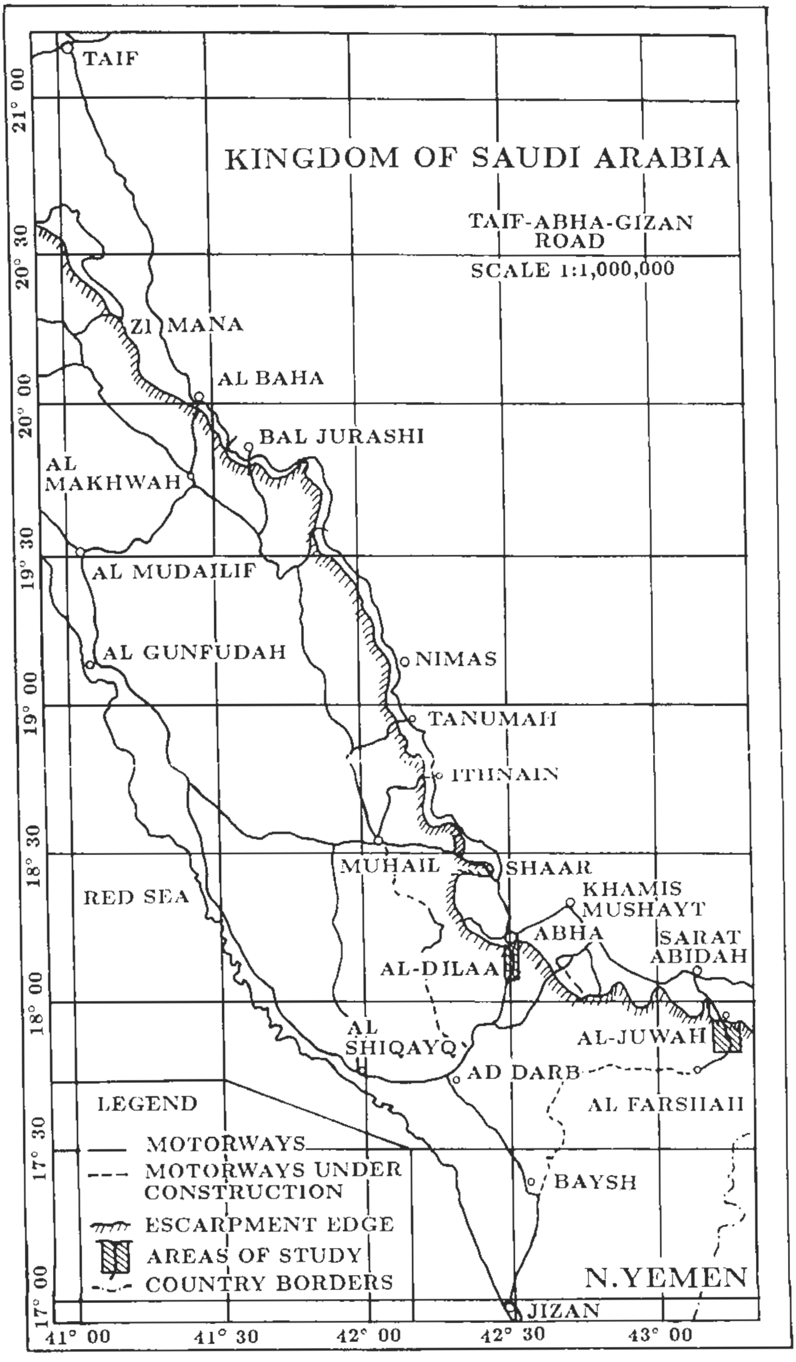

FIG. 1. Location of the Al-Dilaa and Al-Juwah descents.

scents. The data were used to create design charts that can be related to the information recorded on engineering geological maps. Such combination of these maps with the design charts may help in predicting the behaviour of similar rock types under the same conditions in different areas.

Collection of the Relevant Geotechnical Data

Data for the design charts were collected from the rock slope-cuts along the 11 and 18 kilometres-long motorways at Al-Dilaa and Al-Juwah descents, respectively. These exposures include 68 major slopes which are representative of the surrounding rock masses, in which 14 and 7 major landslides took place at Al-Dilaa and Al-Juwah descents, respectively. With the aid of the rock mass classifications (RMR and Q indices), basic engineering geologic mapping, and index tests of strength, both stable and unstable rock slopes were assessed, and the geotechnical characteristics of various rock masses were also identified. A measure of the stability of slopes along with the remedial and support measures were included; details are given by Sadagah (1989).

Design Charts

In order to make a conservative design we may assume consistently the worst conditions. However, an expensive design may not provide the desired level of performance or safety. Decisions based on a trade-off between cost and safety are often necessary. The most desirable design is the one that provides maximum safety at a minimum cost.

Watters (1972) used field data and air photo measurements to develop graphs showing the relationship between the slope height and the angle of stable and unstable natural slopes for metamorphic rocks only: no other variables were included. Hoek and Bray (1981) postulated that a general relationship exists between the factor of safety against failure by sliding and the slope angle for wet and dry slopes; no other variables were included.

A natural slope can only maintain a slope face angle consistent with the attitude of its discontinuities. If the angle is increased, failure would be generated until a new slope face angle consistent with the orientation of discontinuities is obtained. In fact, instability could be enhanced if the shear strength of the joints is low, or the slope face angle is increased. The relationship between the orientation of discontinuities, the slope angle and the angle of friction of the rock surfaces is discussed by Goodman (1976) and Hoek and Bray (1981).

Selection and Interrelationship of the Variables

In the present work, the following factors have been used to develop design charts: (1) overall slope angle, (2) slope height, (3) volumetric joint count (Jv), (4) range of rock quality designation, and (5) remedical measures. These charts are illustrated later in Fig. 2, 3, 8, 9, 14, and 15, with relevant details presented in Fig. 4-7, 10-13, and 16-19.

Factors 1 and 2 are choosen since they have a considerable effect on the final engineering design of the rock slopes. However, the Jv value is the most important factor, since it provides an assessment of the stability of the whole rock mass. As Jv increases, the degree of interlocking between blocks decreases. In support of choosing Jv as an essential variable, Terzaghi (1962) indicated that, if the continuous joints form a three-dimensional network (which was recognized later as (Jv) the joints should transform the rock mass into a detachable blocks comparable to dry masonry. Decreasing the spacing between the joint planes is frequently increasing the instability of the whole rock mass. Palmstrom (1982 and 1985) described, in detail, the classification, calculation and importance of Jv to rock masses. His approach agrees with that of Hunt (1986) who stated that the slope stability depends on the rock quality (including the degree of weathering and orientation of discontinuities, and degree of fracturing in three dimensions). Since the state of weathering along the motorways in the studied area was almost fresh, weathering as a factor was excluded from the charts. Factor 4, the range of rock quality designation was choosen because it indicates the necessary support requirements relative to Jv. Rock quality percentage (RQP) is related to RQD and has been used by Sadagah (1989) as a parameter for rock mass behaviour. RQP was first introduced and described by Şen (1990). The remedial measures, factor 5, refer to those which have been used in practice in the studied areas. The intact strength of the rock material is not an issue in the rock slope factor of safety for strong rocks cut by joints; this has been demonstrated by Hoek and Bray (1981). Along the Al-Juwah descent, no failure has been observed in the rocks of the former laterite (of an average intact strength of 67 MPa). All failures along both Al-Juwah and Al-Dilaa descents occurred on joint surface in both acidic and basic rocks which have an average intact strength between a 100 and 248 MPa. Hence, the uniaxial compressive strength was excluded from the charts.

Relationship between the Overall Angle of Slope and Jv

In contrary to the expected relationship, the overall slope angle along the descents increases as Jv increases due to the presence of support measures. To establish the relationship between the geometry of the slope and the degree of fracturing with the support requirements, data were collected for every rock mass along the road cut (Sadagah 1989). The general geometry and dimensions of each of the studied slopes are depicted graphically, details are given by Sadagah (1989). For every slope cut, the tangent of the overall slope angle was plotted against Jv value on a log-log graph. Furthermore, all the observed protection measures taken for every slope are mentioned on the graphs (Fig. 2 and 3). Consequently, each graph is subdivided vertically into zones of slope angles. Zones are then subdivided horizontally, based on the type of support taken or required for the different ranges of Jv. Due to the lack of data on support measures, zone 4 in Fig. 2 was subdivided arbitrarily on the basis of the general trend of the subdivisions in the neighbouring zones (3 and 5). In order to differentiate between the behaviour of different rock types, the acidic and basic rocks in each descent were plotted separately, Fig. 4-7.

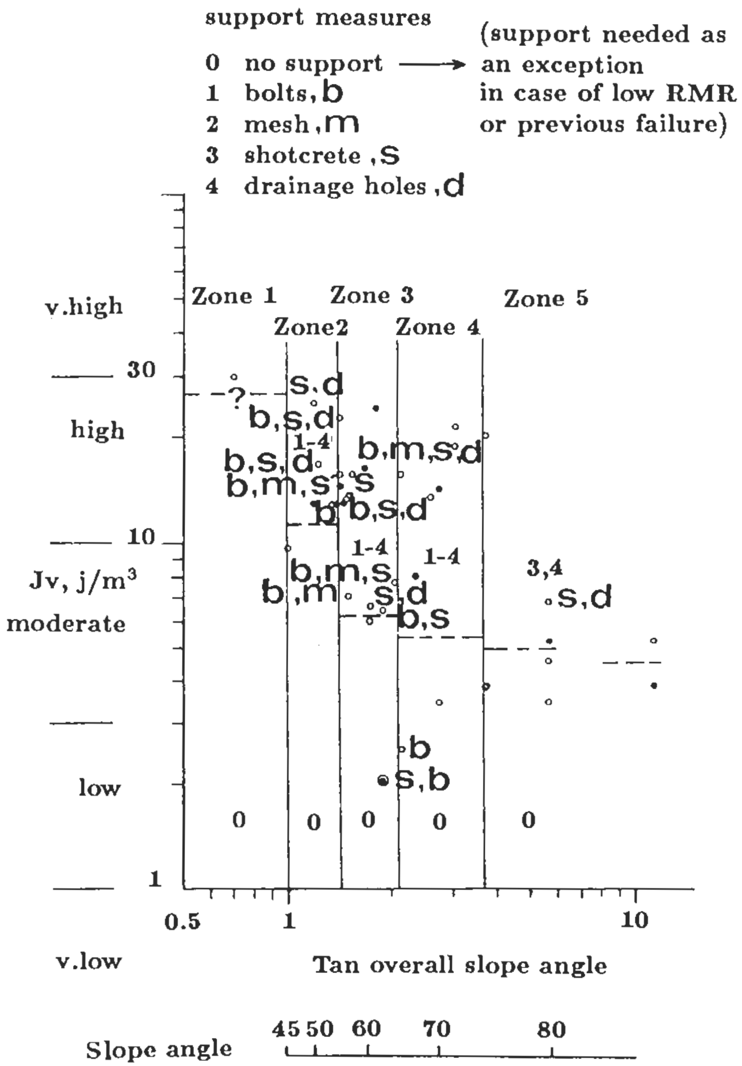

FIG. 2. Log Jv versus tan overall slope angle for all unweathered rock types of Al-Dilaa descent.

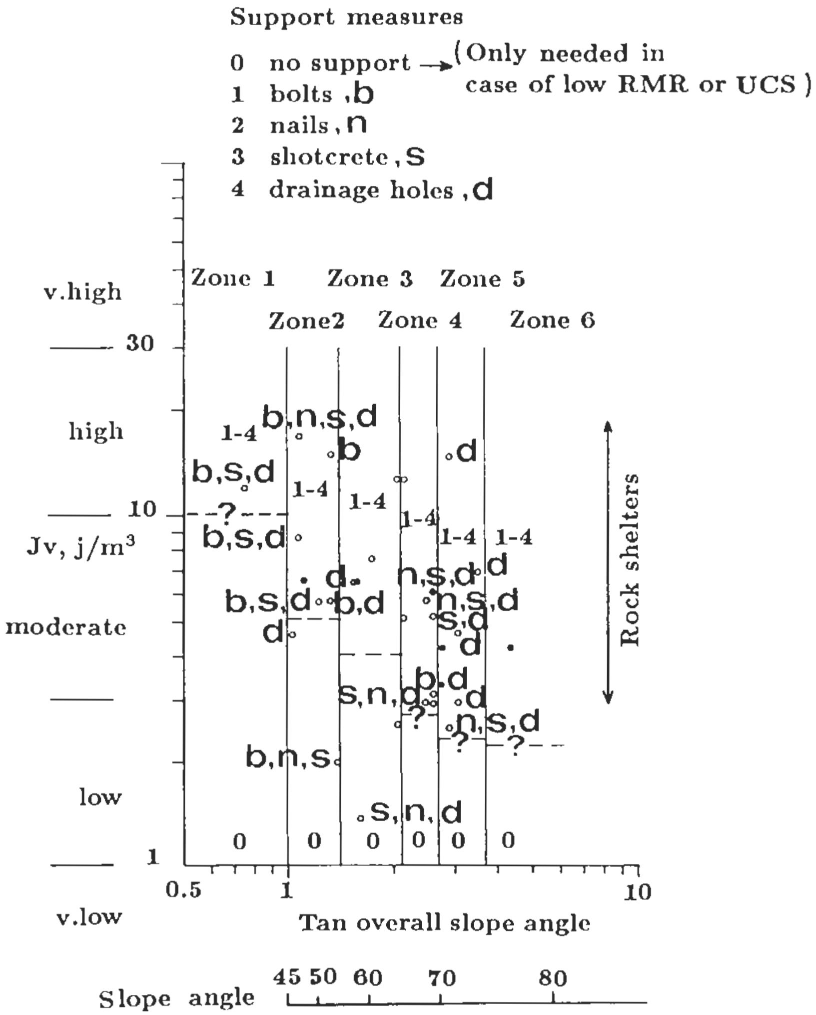

FIG. 3. Log Jv values versus log tan overall slope angle for all unweathered rock types at Al-Juwah descent.

Acidic Rocks: Al-Dilaa

At Al-Dilaa descent, the acidic rocks, (Fig. 4) have an overall slope angle ranges between 60 and 85, and Jv between 2 and 8.2. No particular trend is observed because the rock masses are competent and less fractured. Some failures were experienced, especially at relatively high Jv (8.2) and high slope angle (80 to 85) because of lack of support. Another failure happened at a Jv of 2 and a slope angle of 62, due to the effect of a flash rain storm over the rock mass area.

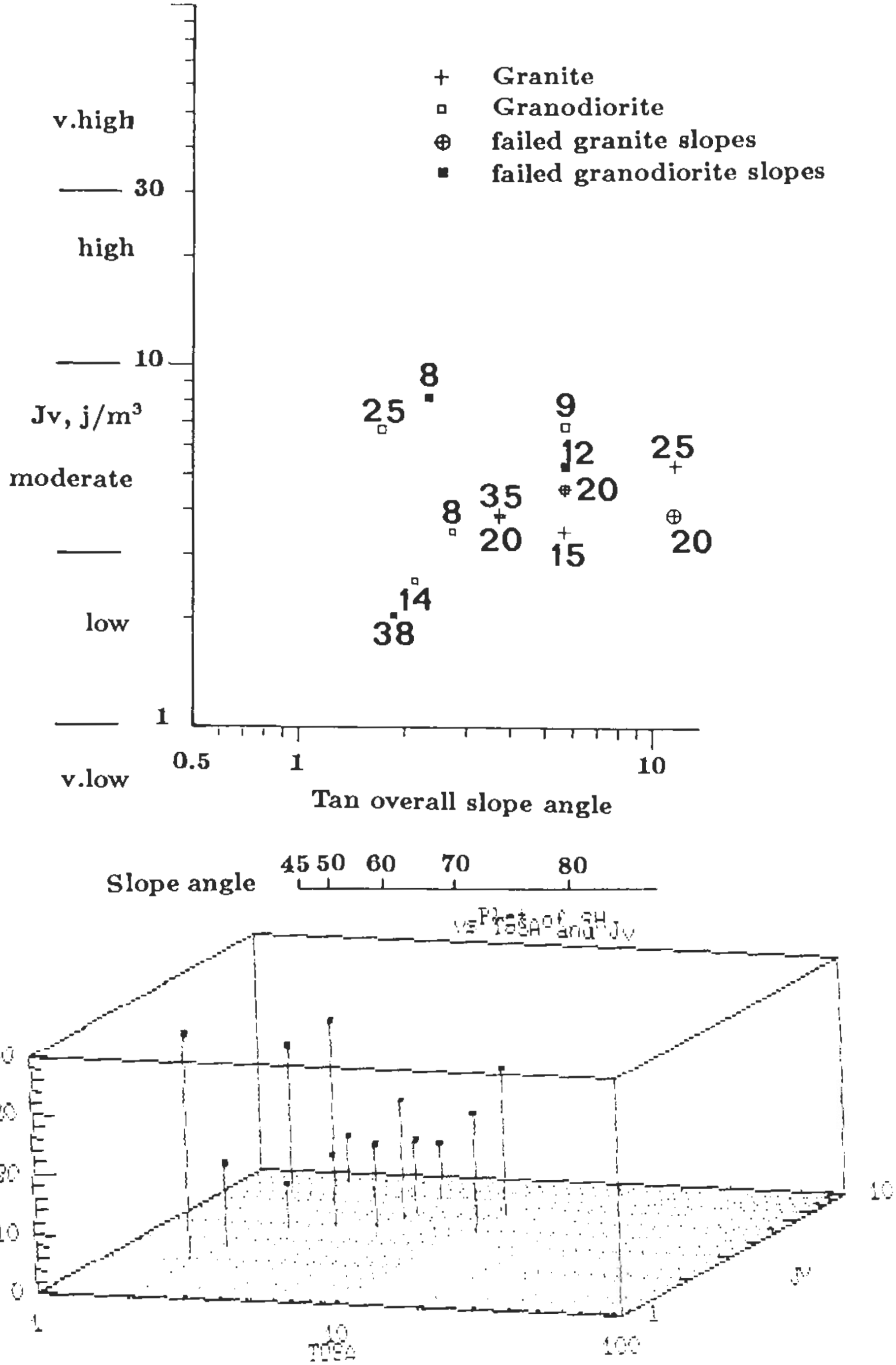

FIG. 4a & b. Log Jv versus log tan overall slope angle for the acidic rocks at Al-Dilaa descent, heights in meters are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

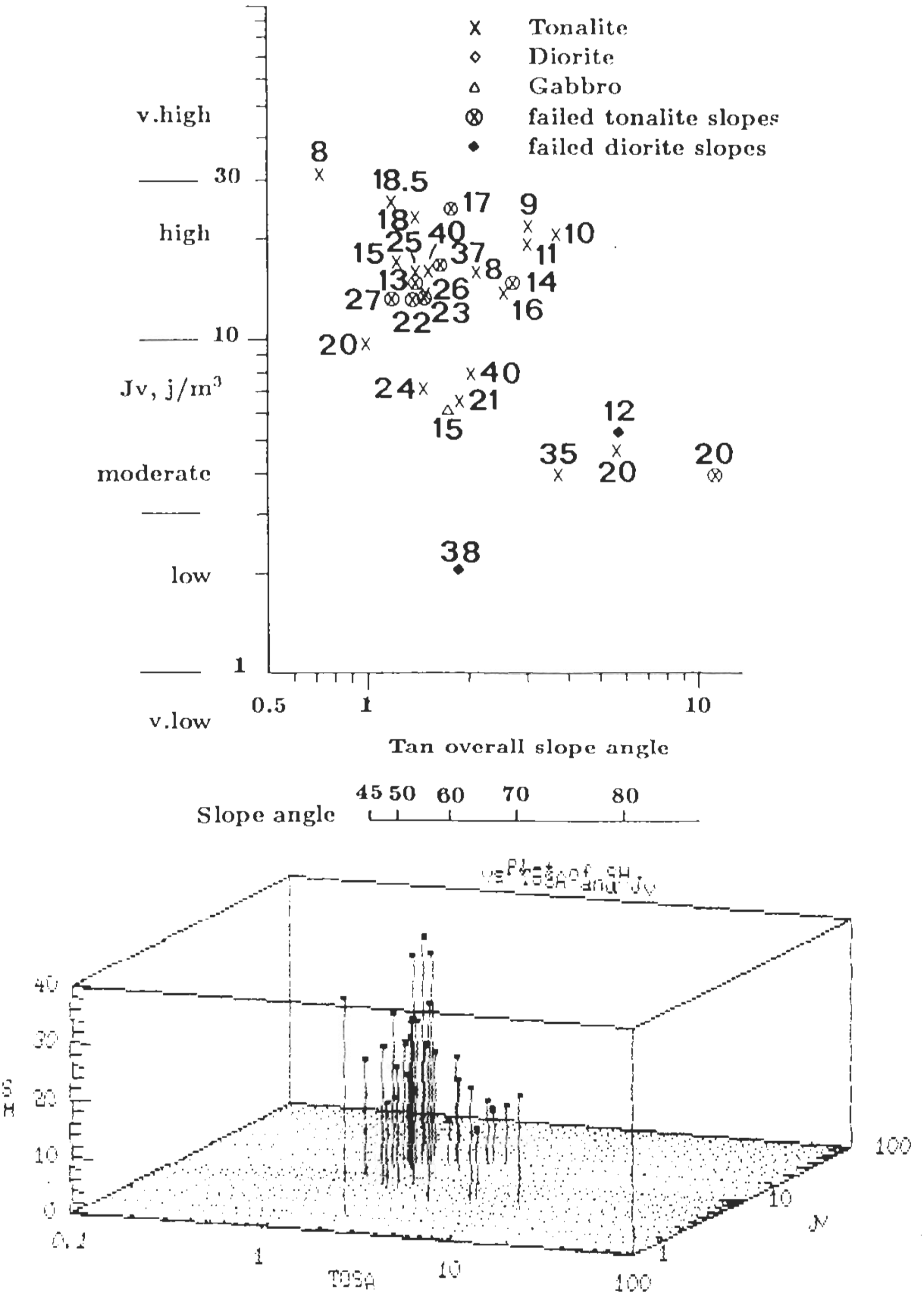

FIG 5a & b. Log Jv versus log tan overall slope for the basic rocks at Al-Dilaa descent, heights in meters are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

Basic Rocks: Al-Dilaa

The basic rocks, particularly tonalite (Fig. 5) show a negative trend between the overall slope angle and Jv. Tonalite shows a number of failed slopes at a high Jv (between 13 and 24.5) and at an overall slope angle between 50 and 70. All slope failures were developed in response to the high Jv and the heavy jointing, which was induced by pervasive schistosity in the tonalite. As the schistosity caused the planes of weakness to be continued for more than five metres, the shear strength can easily approach the basic value of friction, due to negligible interlocking between joint blocks. Most failures took place in diorites and tonalites at a high overall slope angles ranges between 62 and 85. Since no support was used with those high slope angles, failure was the expected result.

Figure 2 shows in general terms that, for rocks of overall slope angle ranging between 45 and 75 and Jv of 5.6 and greater (Fig. 2), the support system requires three or four measures, while for slope angle above 75 and Jv above 5.2, the system would require at least two measures. Slopes with angles different from those mentioned above do not require any support below the above mentioned Jv values (Fig. 2). Any extra protection measures are useful depending upon the local slope cut conditions.

Acidic Rocks: Al-Juwah

At Al-Juwah descent, the acidic rocks (Fig. 6) have an overall slope angle ranging between 47 and 77 and a Jv between 1.3 and 17. Similar to Al-Dilaa descent, no trend is observed between Jv and the slope angle for either failed or unfailed slopes at any range of height, mainly because the rocks are massive and less fractured. However, some failures were experienced due to the unfavourable geometrical distribution of joints within the rock mass, which led to plane and wedge failures. In spite of that, no support measures were taken against those failures. All the failures took place at Jv above 3 and a slope angle above 57.

Basic Rocks: Al-Juwah

The basic rocks (Fig. 7) show an unexpected relationship, with high Jv values ranging from 4.6 to 15 corresponding to slope angles ranging between 37 and 71. Most of the slopes are supported by two to four measures (Fig. 3). Failures were not experienced because the rock masses were supported. Figure 3 shows that for all rocks with an overall slope angle less than 75 and a Jv value ranging between 2.3 and 10, the support system requires either two or three measures. Zone 6 was subdivided horizontally arbitrarily on basis of the general trend of the horizontal subdivisions in the previous zones. In the area below the horizontal subdivision, any slope of different angle does not require any support between the above mentioned values of Jv, however, there are two exception cases in laterite and granite slopes where the support was required; this is due to the locally low UCS and very poor RMR values.

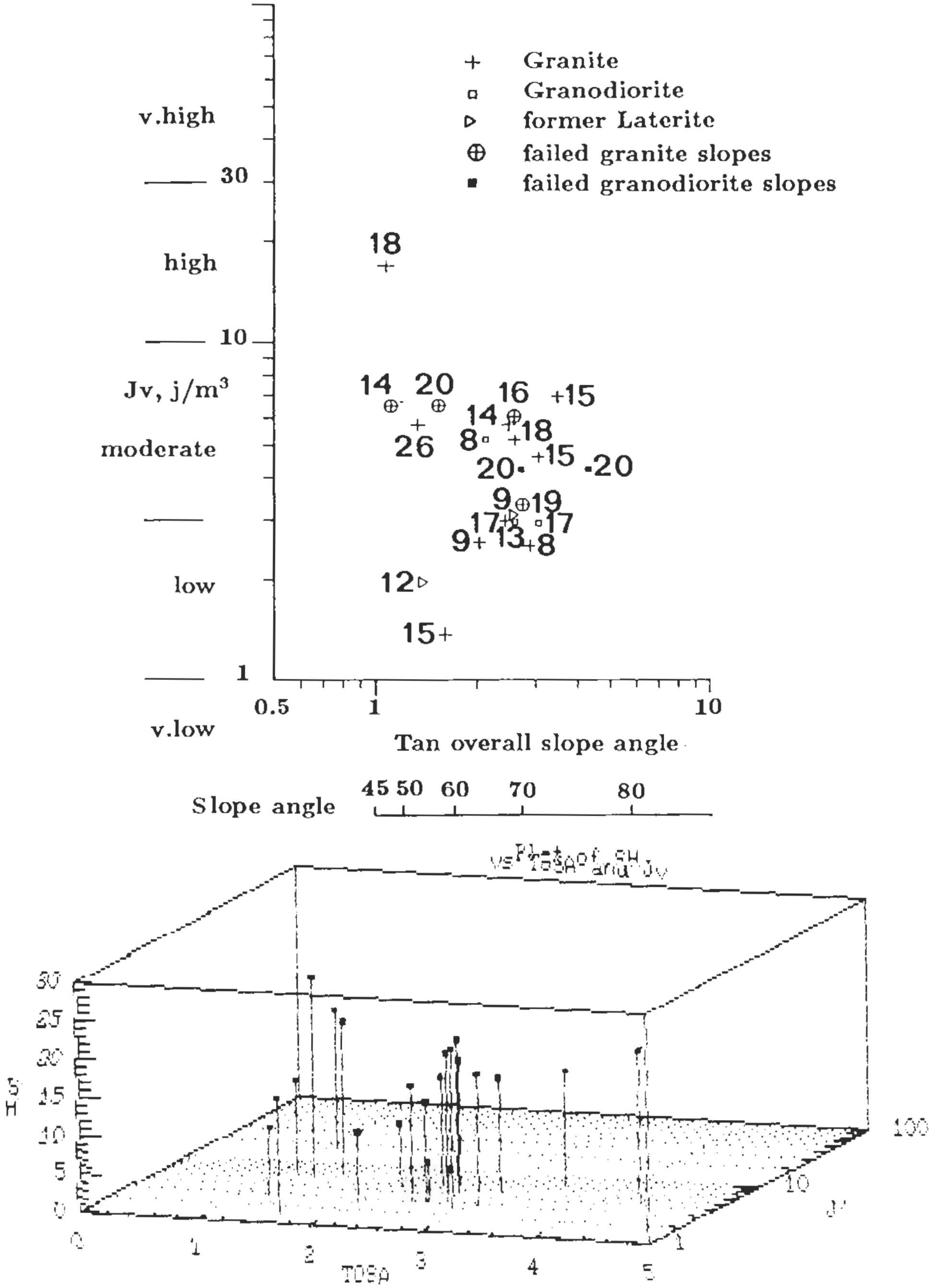

FIG. 6a & b. Log Jv versus log tan overall slope angle for the acidic rocks at Al-Juwah descent, heights in meters are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

Figures 2 and 3 show identical support requirements for rock slope cuts with different values of Jv for the boundaries of the different levels of support. They are roughly subdivided about a certain value of Jv. However, the exact Jv value is controlled by the local conditions and mechanical properties of the rock mass.

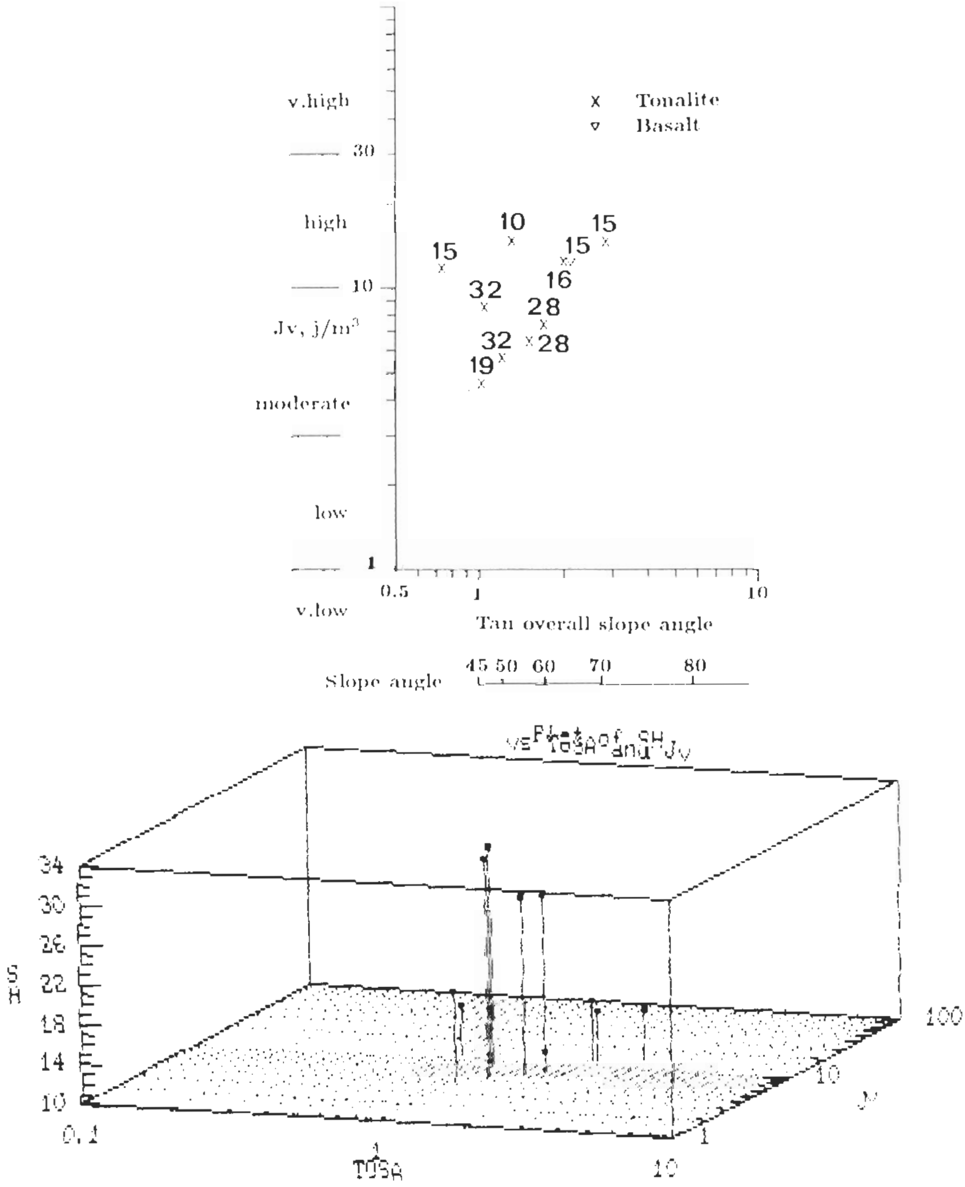

FIG. 7a&b. Log Jv versus log tan overall slope angle for the basic rocks at Al-Juwah descent, heights in meters are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

Relationship Between the Overall Height and Jv

In the analysis of rock slope stability, the overall height is used in the following equation to calculate the normal stress acting on the plane of failure.

$$\sigma_n = \gamma \times H$$

where γ is the unit weight of the rock material, and H is the height measured from the plane of failure to the slope crest. Since the plane of failure is not planar and it contains interlocking blocks of solid rock, hence, the overall height should also reflect a correlation with the Jv.

To study this relationship, the overall slope heights were plotted against their respective Jv for every studied slope in the two descents, together with the remedial and support measures (Fig. 8 and 9). Since the total overall heights range between 8 and 40 meters, the data were clustered on a log-log plot. This made the trend detection difficult and therefore the data were replotted on a semi-log plot. The two figures were subdivided horizontally into three zones, each zone being characterised by its supporting system. Similar to the basis of subdividing Fig. 2 and 3, Fig. 8 and 9 were subdivided into acidic rocks (Fig. 10 and 12) and basic rocks (Fig. 11 and 13).

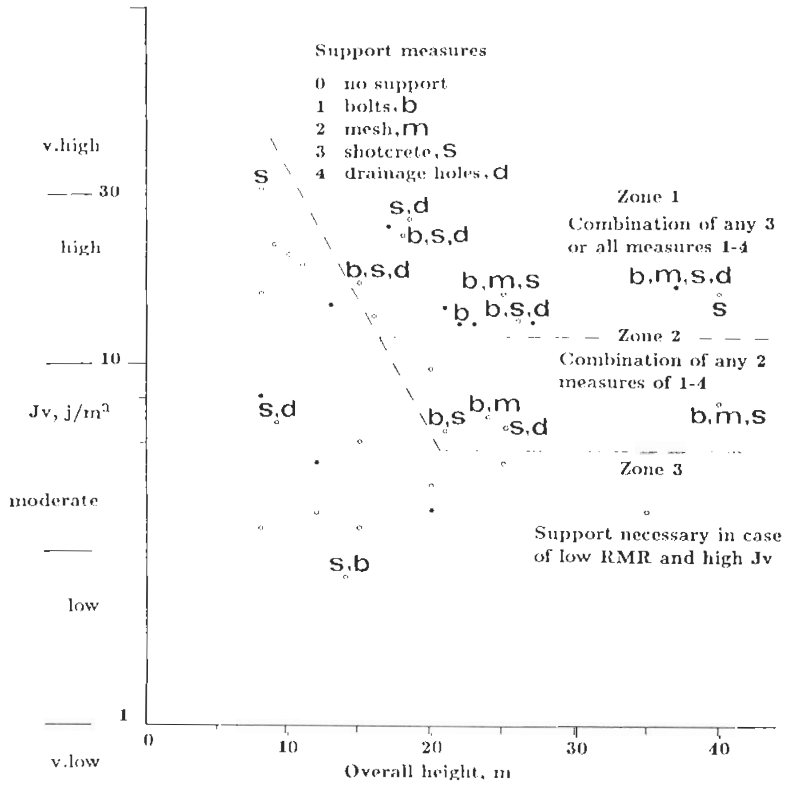

FIG. 8. Chart for designing and protecting rock slopes cuts, for a given height and Jv at Al-Dilaa descent.

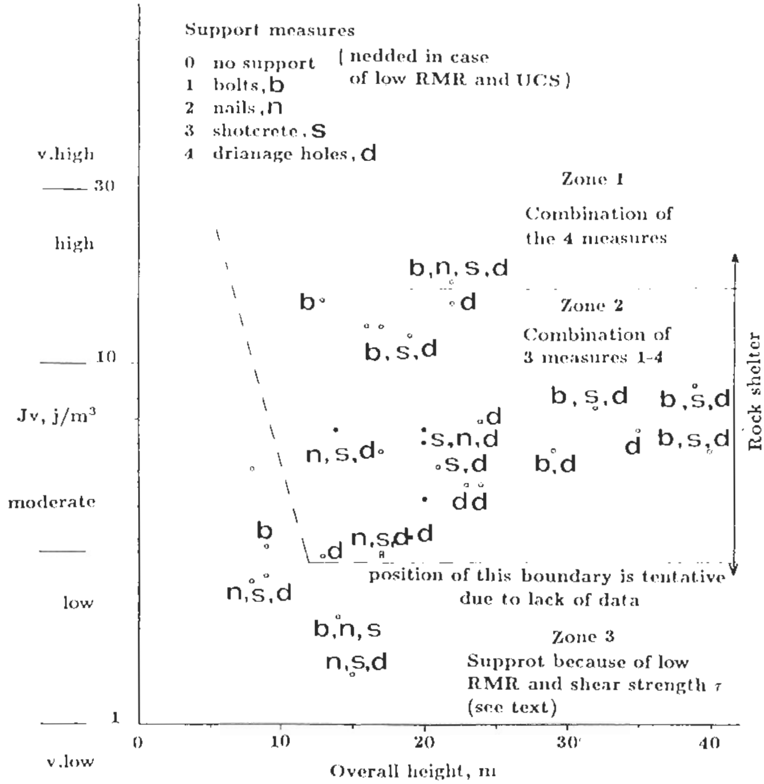

FIG. 9. Chart for designing and protecting rock slopes cuts, for a given height and Jv at Al-Juwah descent.

Acidic Rocks: Al-Dilaa

At Al-Dilaa descent, the acidic rocks (Fig. 10) have an overall height between 8 and 38 metres, and a Jv value between 2 and 8. The general trend is negative rather than a scatter. Some failures were experienced at 20 and 8 metres where wedge failures occurred. Other failures were experienced at heights of 38 and 12 metres. Even at low Jv, failures took place due to the effect of the flash rain on the escarpment.

Basic Rocks: Al-Dilaa

The basic rocks at Al-Dilaa descent (Fig. 11) show a negative trend relationship, ranging between overall heights of 8 to 40 metres, and a Jv value between 2 and 31. The failures are scattered between the extreme values, but it is noted that all rock slopes of no support in zones 1 and 2 are failed, and all of them have high heights and high values of Jv. Figure 8 shows that rock slopes of high Jv are preferably to be supported irrespective of the height, and the support measures are necessary for rock masses of low RMR in zone 3.

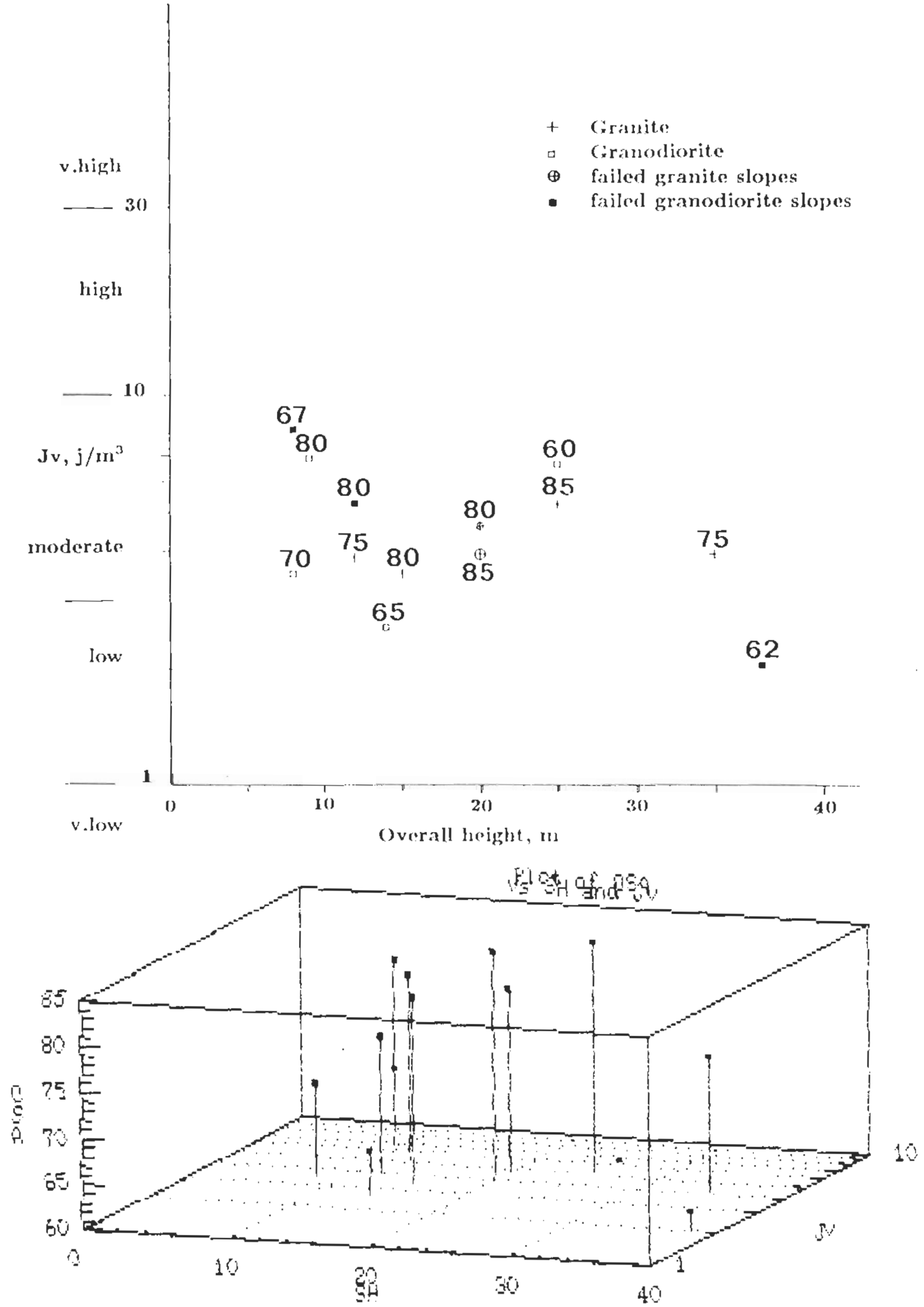

FIG. 10a & b. Log Jv versus overall height for the acidic rocks at Al-Dilaa descent, overall slope angles are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

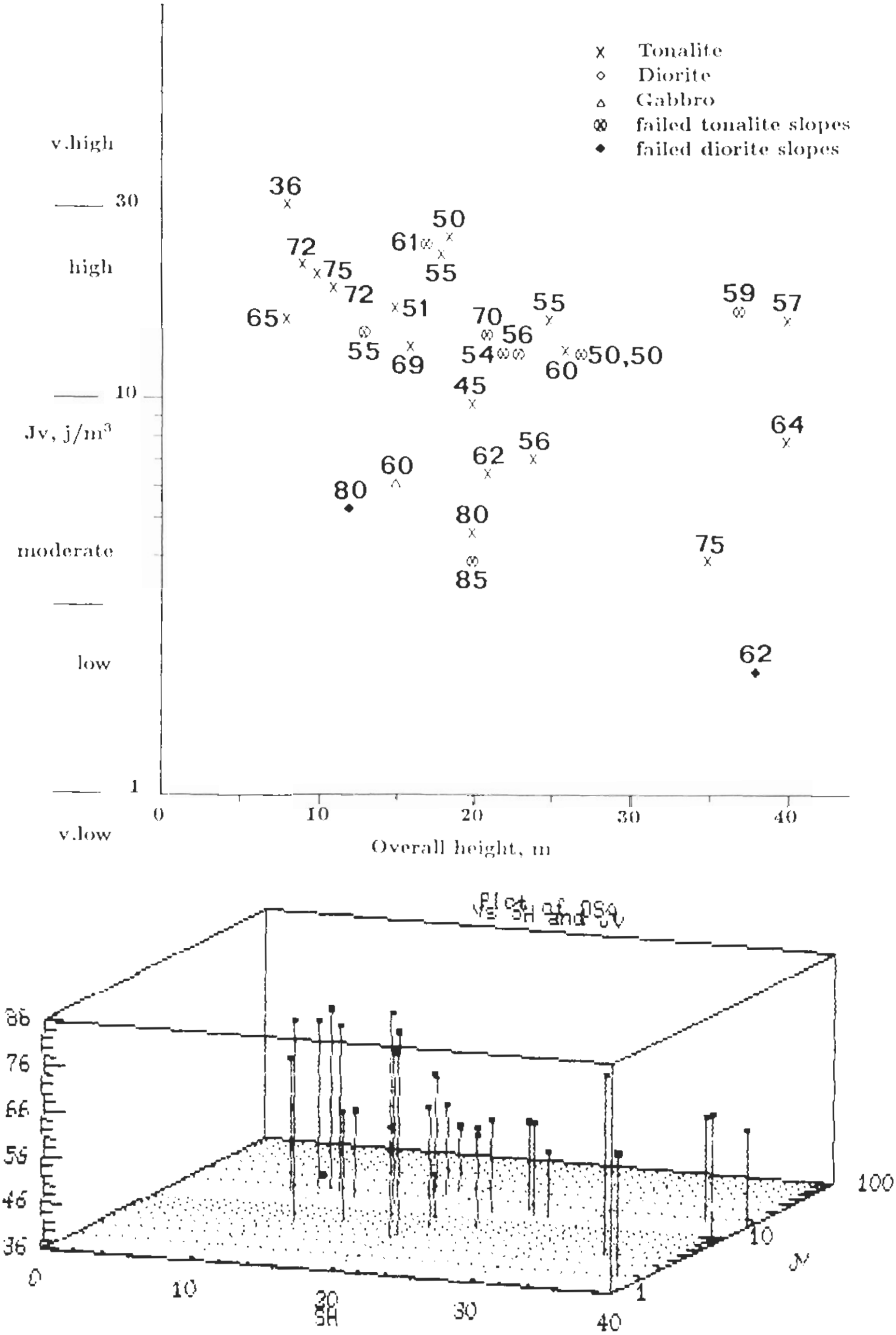

FIG. 11a & b. Log Jv versus overall height for the basic rocks at Al-Dilaa descent, overall slope angles are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

Acidic Rocks: Al-Juwah

At Al-Juwah descent, the acidic rocks (Fig. 12) show a positive trend relationship, where overall heights increase as Jv increases in the presence of support measures. Failure was experienced at slope heights of 19 and 20 metres where supports were not used. Stable slopes were lying in zone 2 (Fig. 9). The slopes in zone 3 were supported because of low RMR and UCS, although their position on the Jv-height graph suggests that the support was unnecessary.

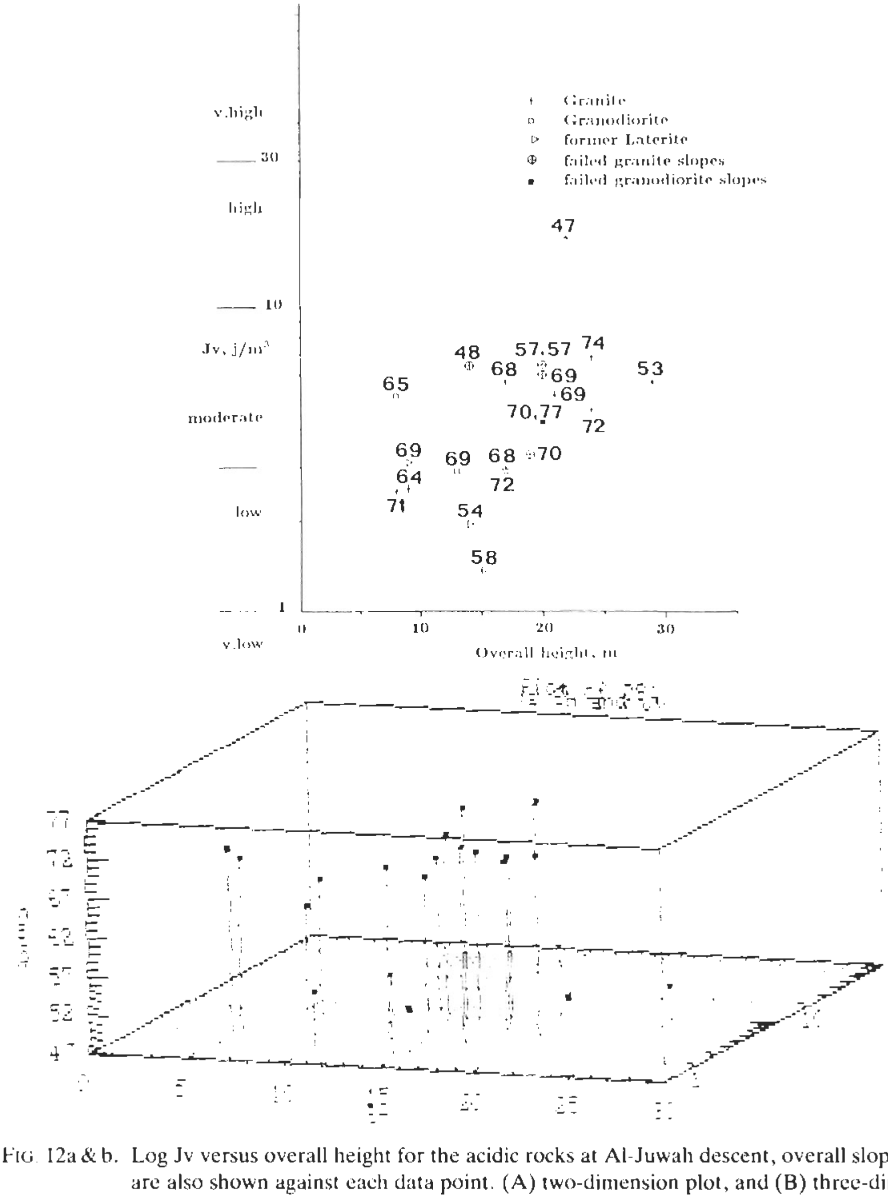

FIG. 12a & b. Log Jv versus overall height for the acidic rocks at Al-Juwah descent, overall slope angles are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

Basic Rocks: Al-Juwah

The basic rocks (Fig. 13) show a clear negative trend. All slopes in zone 2, Fig. 9, are stable because they are supported correctly, except for two slopes of 16 and 17 metres height and slope angles of 64 and 65. Due to their relatively low heights and better joint distributions, they are not supported.

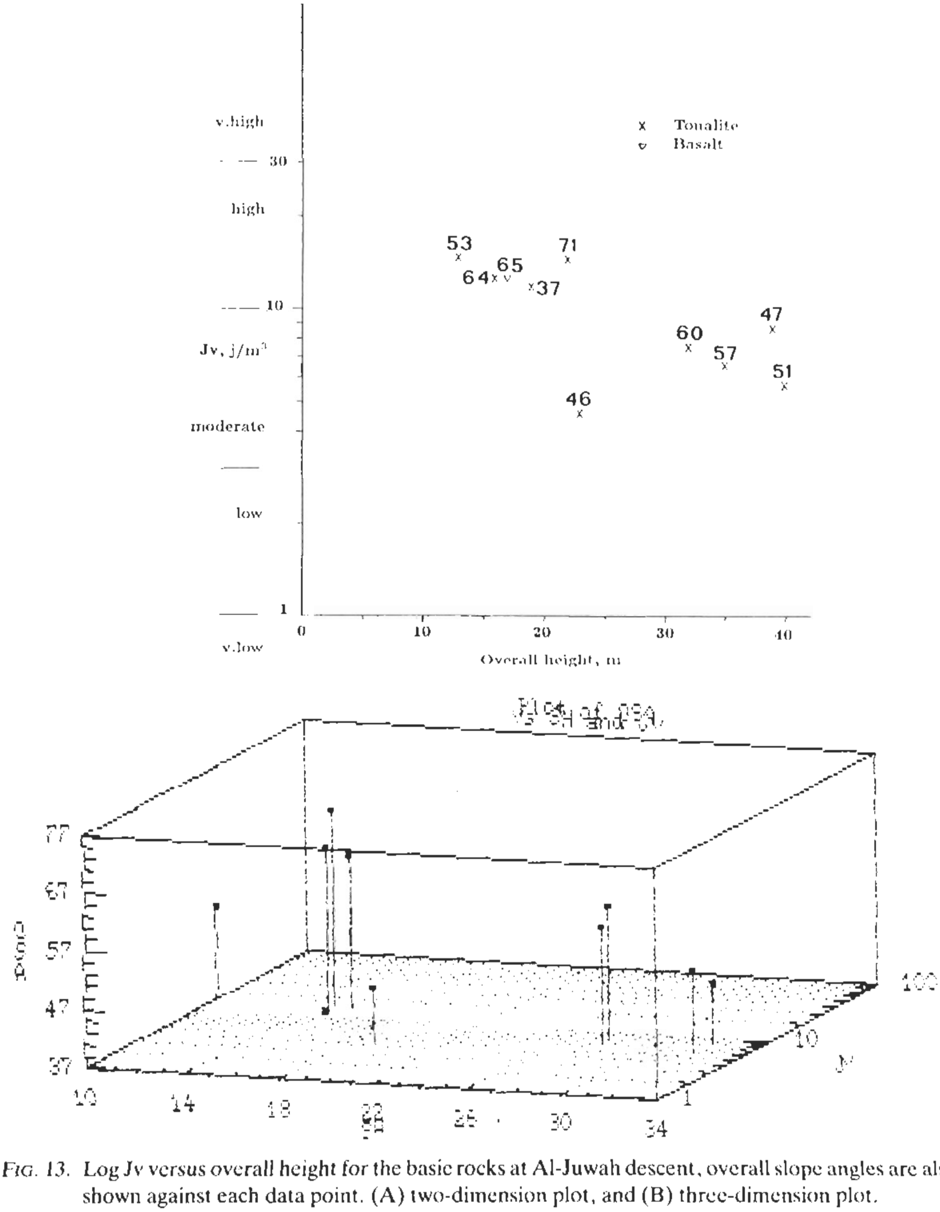

FIG. 13. Log Jv versus overall height for the basic rocks at Al-Juwah descent, overall slope angles are also shown against each data point. (A) two-dimension plot, and (B) three-dimension plot.

Relationship Between RQD Range and Jv

The RQD measured in one direction represents one dimension of the Jv calculation, indicating that the RQD is, to some extent, representative of the Jv. As the intensity of jointing increase, the RQD decreases. For a given rock mass, the RQD has a range between two extreme values. The Jv is sensitive to the overall slope angle and overall slope height; it is expected that it is also sensitive to the RQD range. Plots of Jv against RQD are shown in Figures 14 and 15.

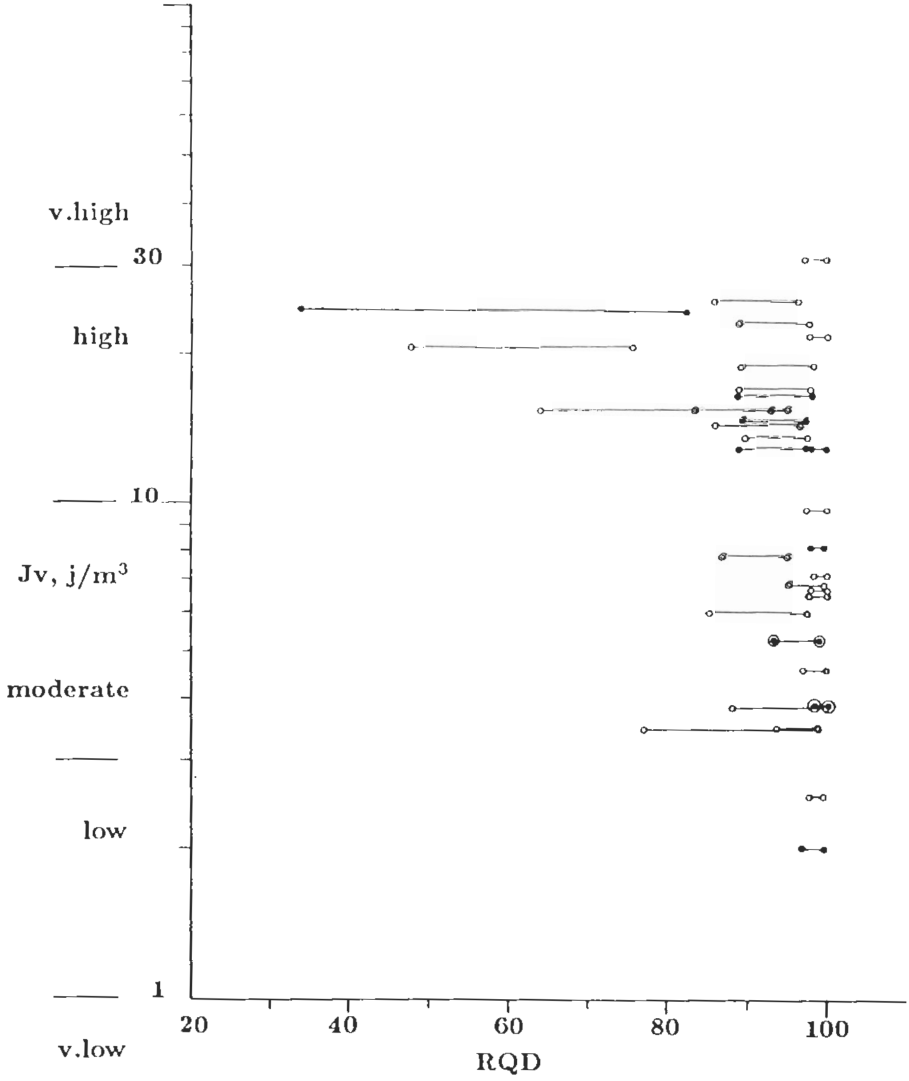

FIG. 14. Chart of RQD at a given Jv at Al-Dilaa descent.

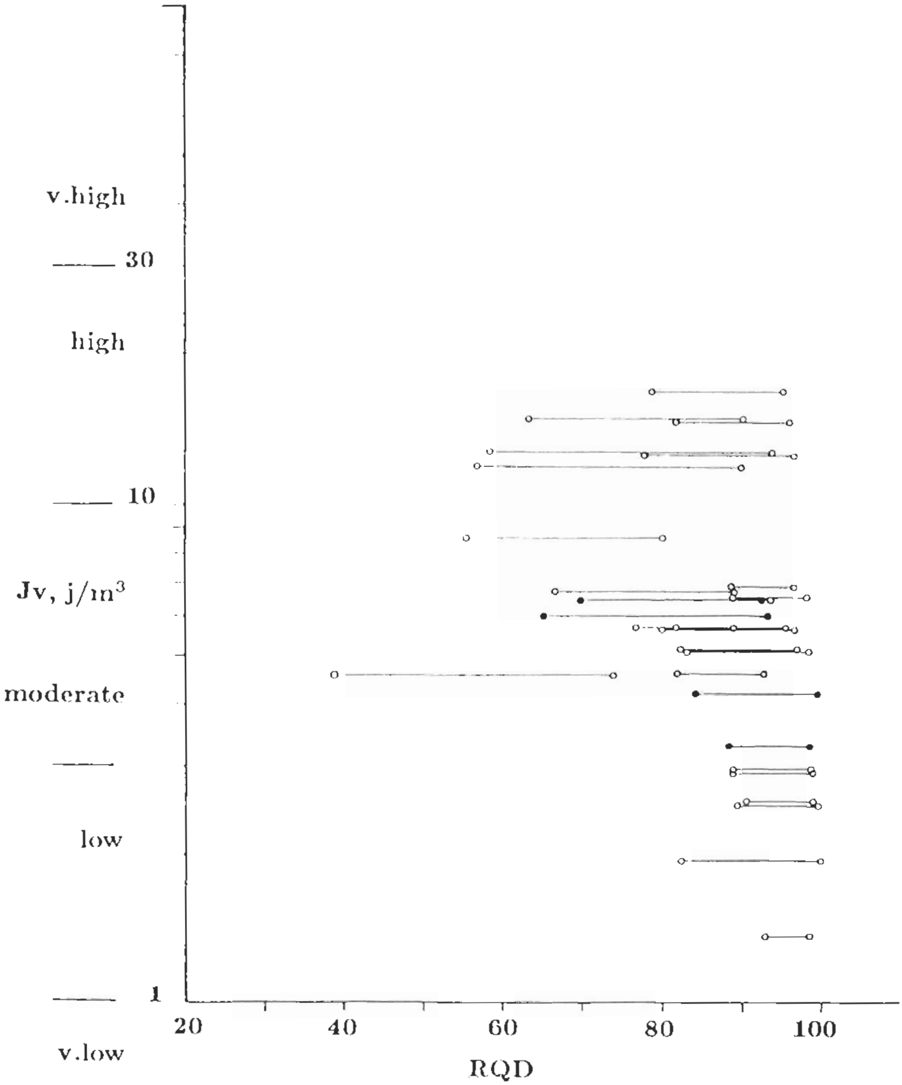

FIG. 15. Chart of RQD at a given Jv at Al-Juwah descent.

At Al-Dilaa descent (Fig. 14), the RQD range varies between 96 to 100 and 33 to 82. It shows a curvilinear relationship with Jv; as Jv decreases the RQD range becomes smaller, and as Jv increases the RQD range gets bigger.

The acidic rocks at Al-Dilaa descent, (Fig. 16) show very narrow ranges of RQD, except for three slopes; the Jv values range from 2 to 8. Figures 8 and 2 show that all slopes, except one slope where the Jv is of 6.7, lie in zones where support is not required.

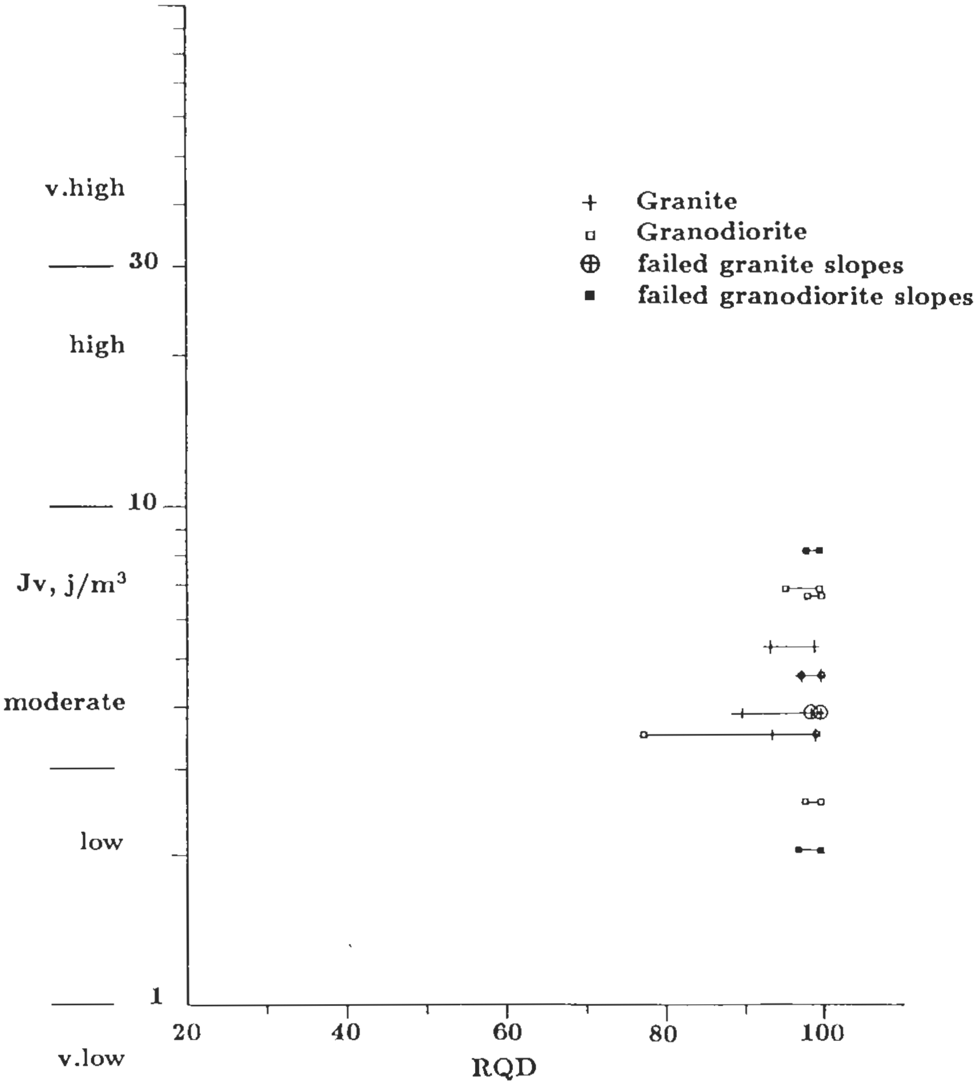

FIG. 16. RQD range versus log Jv for the acidic rocks at Al-Dilaa descent.

The basic rocks at Al-Dilaa descent (Fig. 17) show wider ranges of RQD, and higher Jv values, up to 31 in some cases. Figures 8 and 2 show that slopes in Fig. 17, with Jv more than 5.2, need different combinations of support. At Al-Juwah descent (Fig. 15) the RQD range varies between 93 and 98.5 and 39 to 74, and it shows a similar trend to that shown by the rocks of the Al-Dilaa descent, Fig. 14.

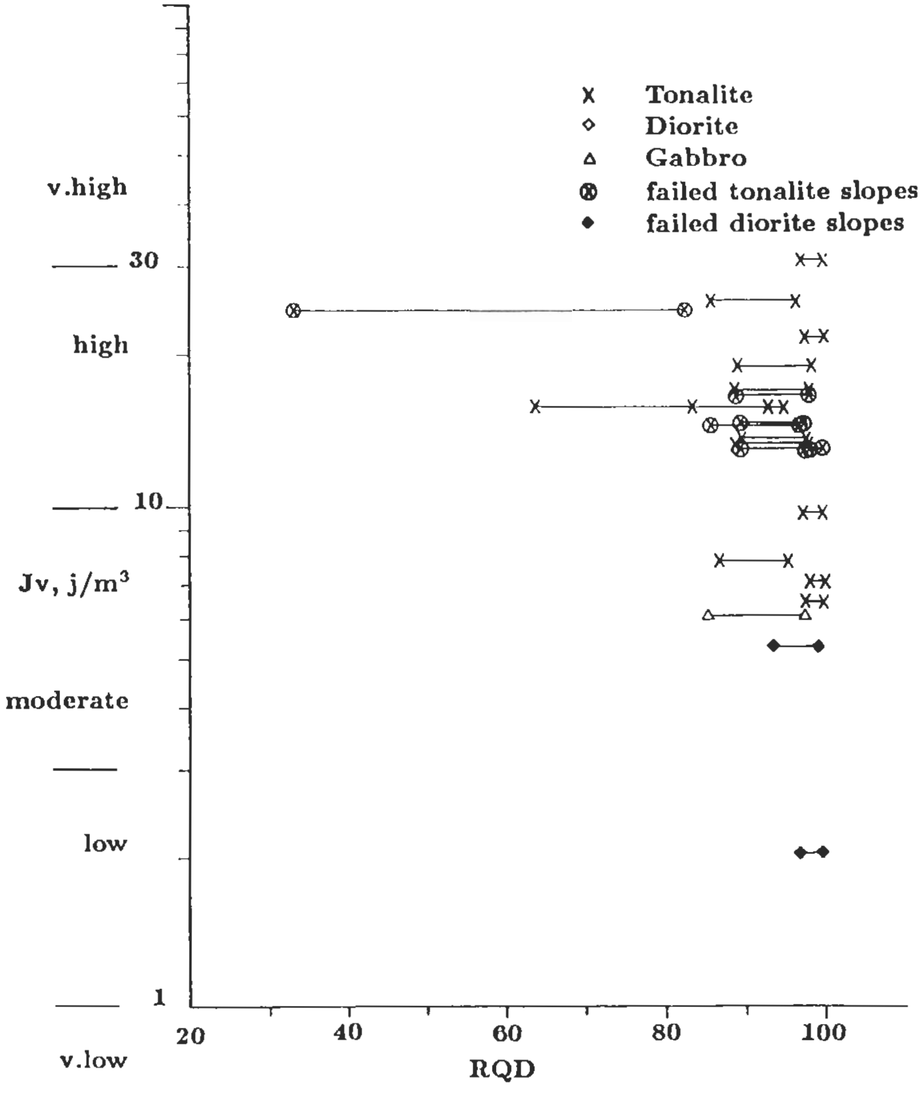

FIG. 17. RQD range versus log Jv for the basic rocks at Al-Dilaa descent.

The acidic rocks at Al-Juwah descent (Fig. 18) show wider ranges of RQD than the corresponding rocks at Al-Dilaa descent. Compared to Al-Dilaa descent, more slope failures took place at Al-Juwah descent where the RQD range is larger at moderate Jv values, and where support protection had been used.

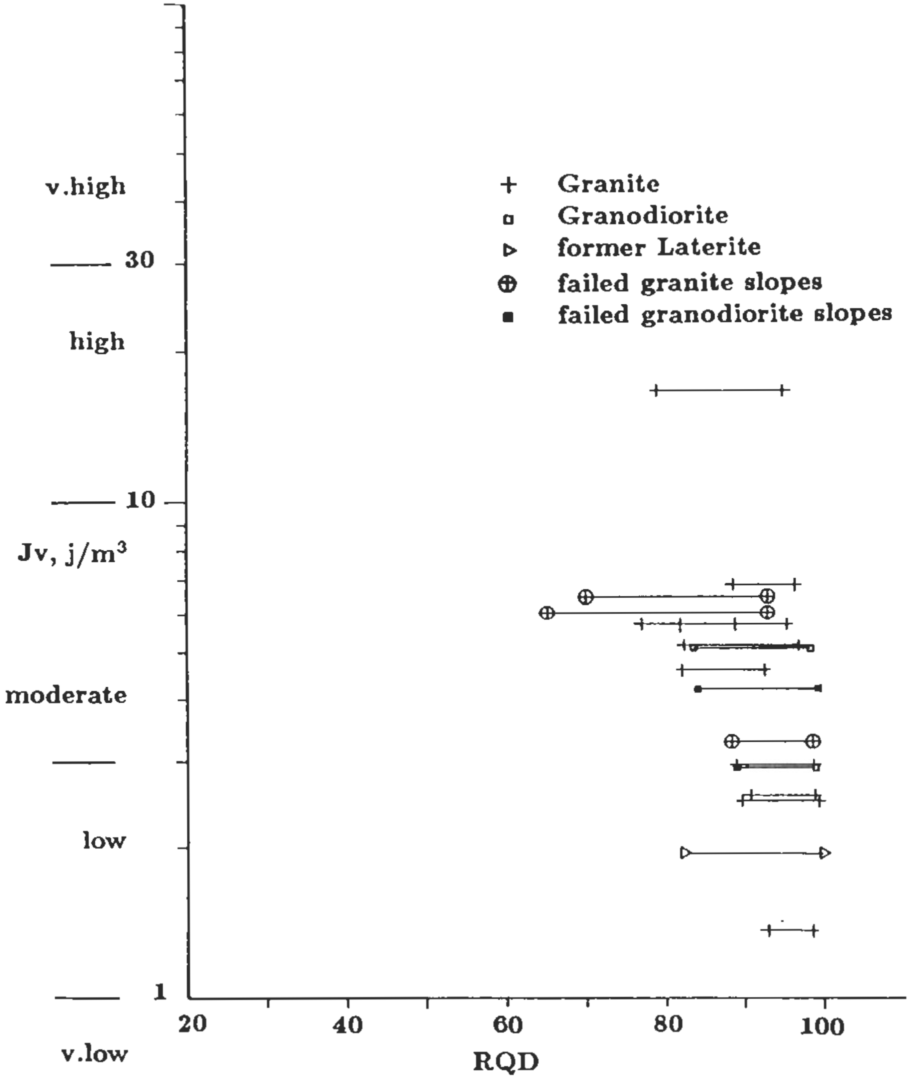

FIG. 18. RQD range versus log Jv for the acidic rocks at Al-Juwah descent.

The basic rocks at Al-Juwah descent (Fig. 19) have higher Jv and a wider RQD range with no failures, because the majority of slopes were supported correctly.

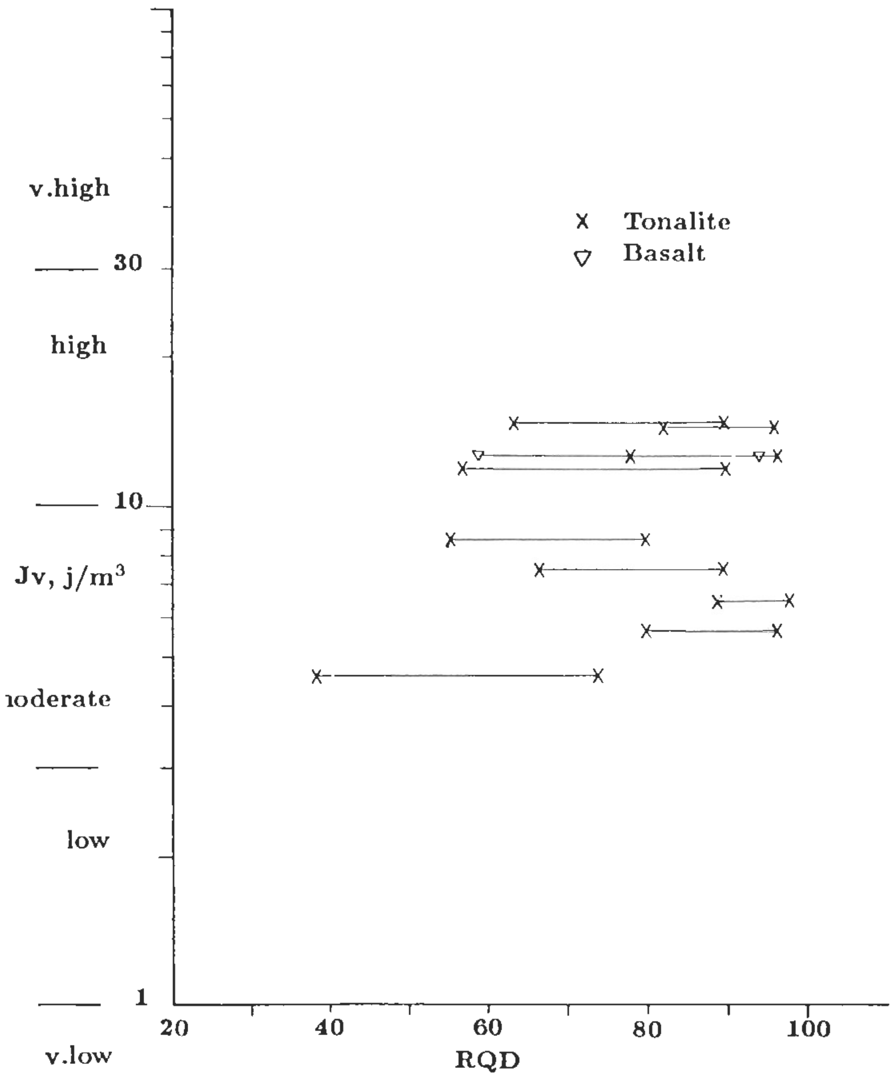

FIG. 19. RQD range versus log Jv for the basic rocks at Al-Juwah descent.

Discussion and Conclusions

A direct comparison between the behaviour of the granites and the tonalites can be made studying the design charts. These reflect clearly the fact seen in the field that the first and second order irregularities along the joint surfaces in granites are both increasing the peak shear strength τ of the granites, and decreasing the support requirements for their slopes. The irregularities are acting in an opposite way in the tonalites. In the study area, where the granites and tonalites have an average UCS of

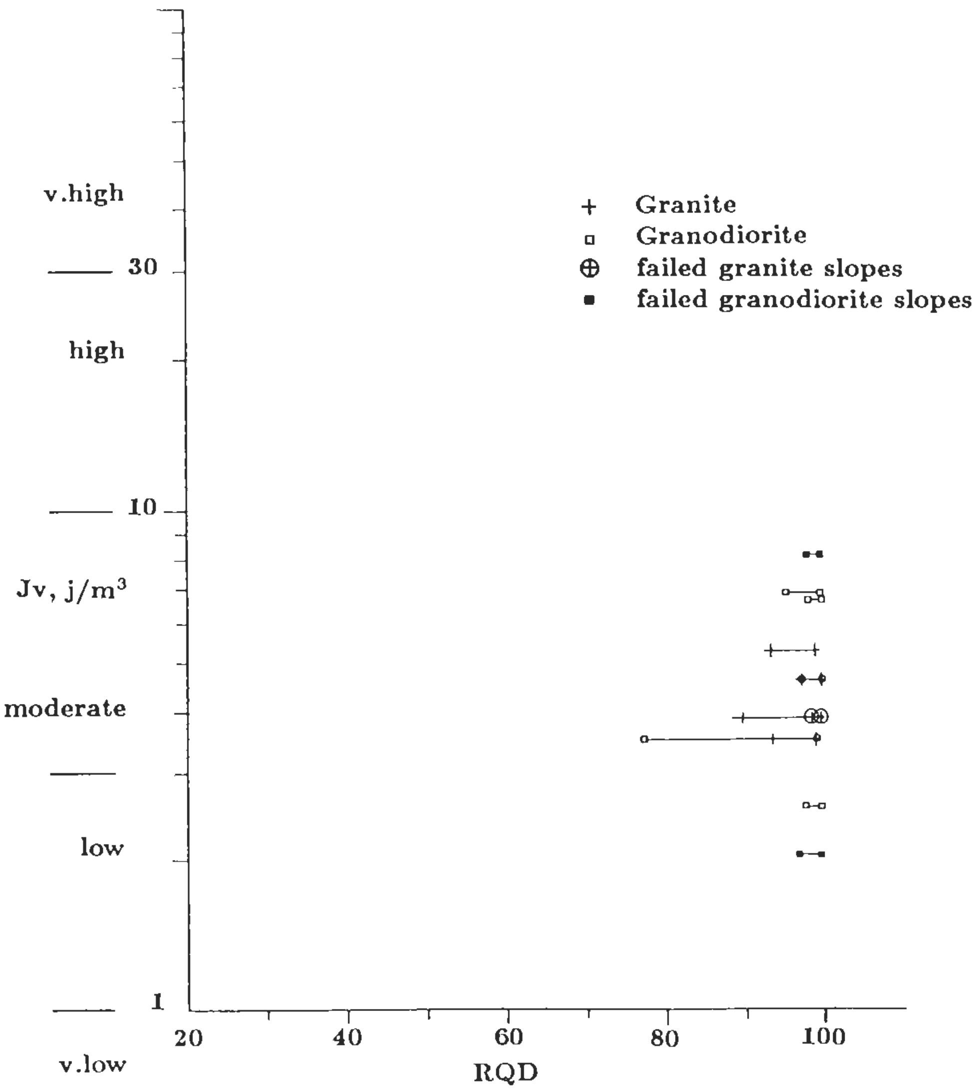

FIG. 16. RQD range versus log Jv for the acidic rocks at Al-Dilaa descent.

The basic rocks at Al-Dilaa descent (Fig. 17) show wider ranges of RQD, and higher Jv values, up to 31 in some cases. Figures 8 and 2 show that slopes in Fig. 17, with Jv more than 5.2, need different combinations of support. At Al-Juwah descent (Fig. 15) the RQD range varies between 93 and 98.5 and 39 to 74, and it shows a similar trend to that shown by the rocks of the Al-Dilaa descent, Fig. 14.

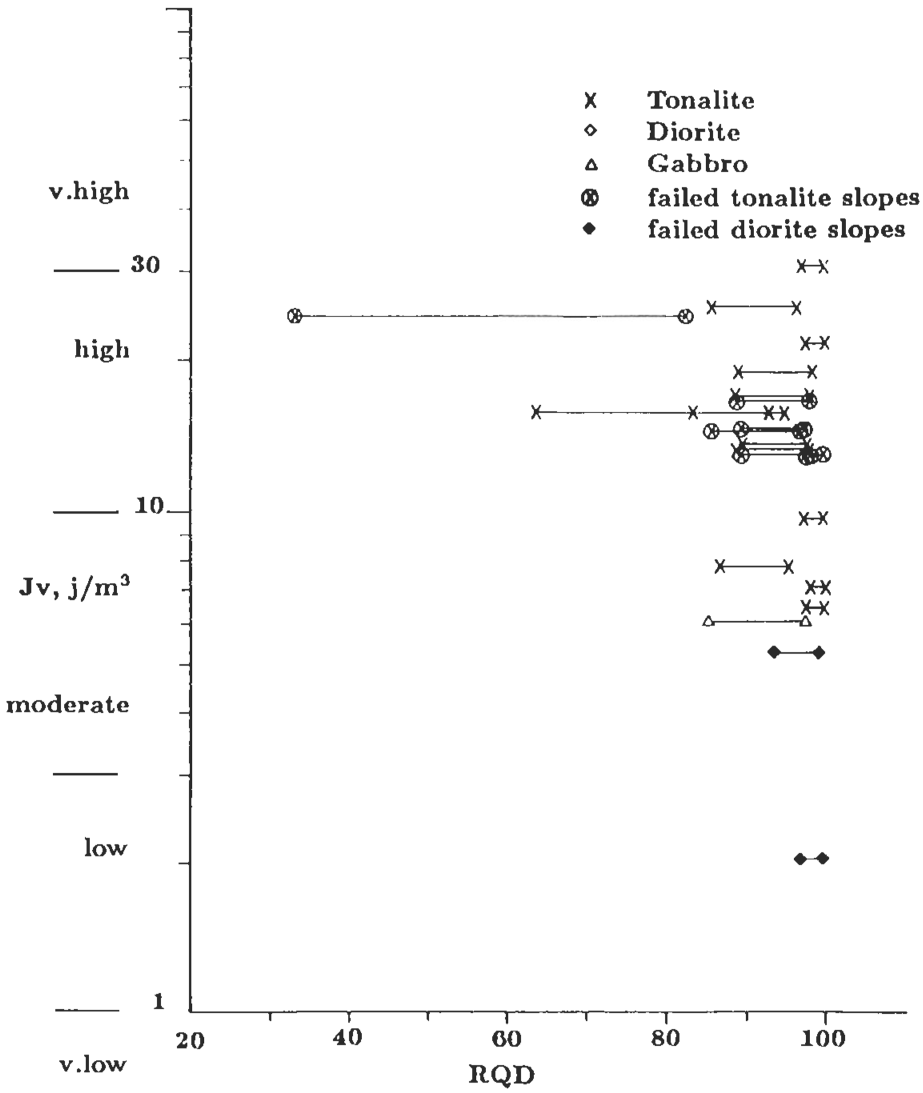

FIG. 17. RQD range versus log Jv for the basic rocks at Al-Dilaa descent.

The acidic rocks at Al-Juwah descent (Fig. 18) show wider ranges of RQD than the corresponding rocks at Al-Dilaa descent. Compared to Al-Dilaa descent, more slope failures took place at Al-Juwah descent where the RQD range is larger at moderate Jv values, and where support protection had been used.

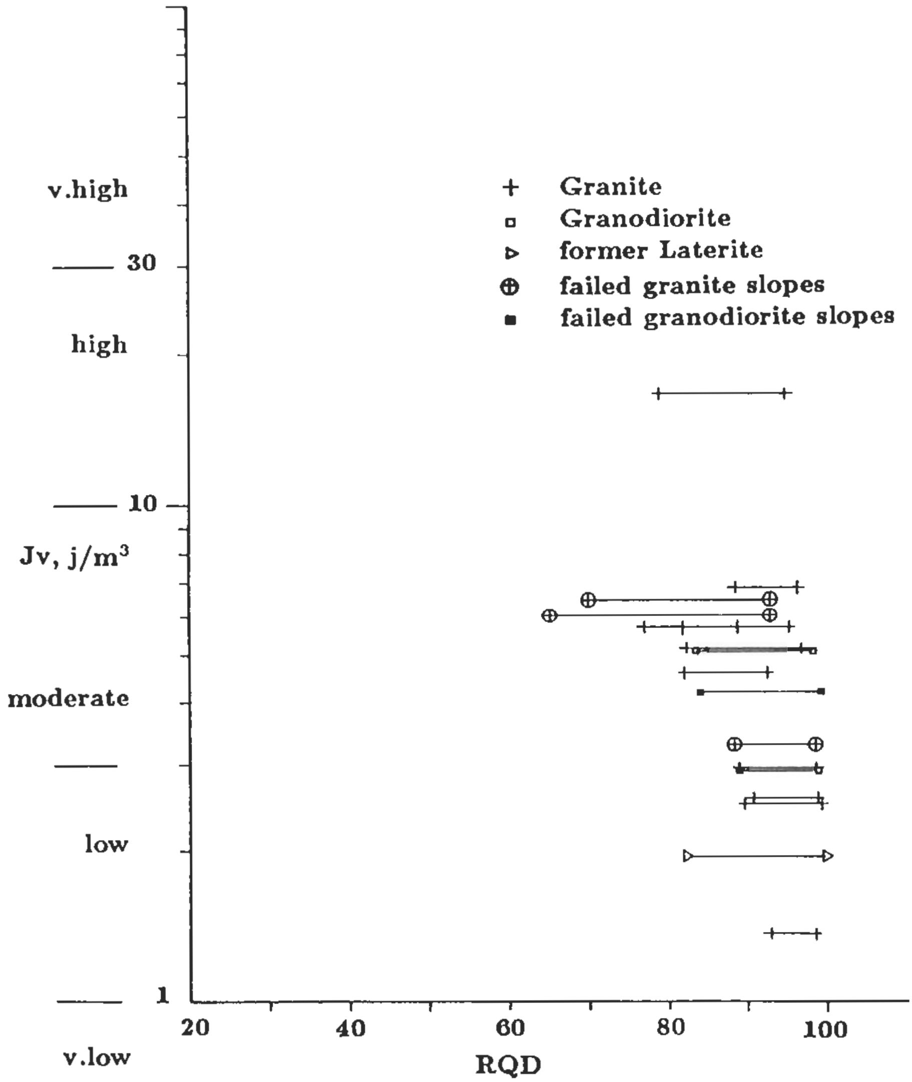

FIG. 18. RQD range versus log Jv for the acidic rocks at Al-Juwah descent.

The basic rocks at Al-Juwah descent (Fig. 19) have higher Jv and a wider RQD range with no failures, because the majority of slopes were supported correctly.

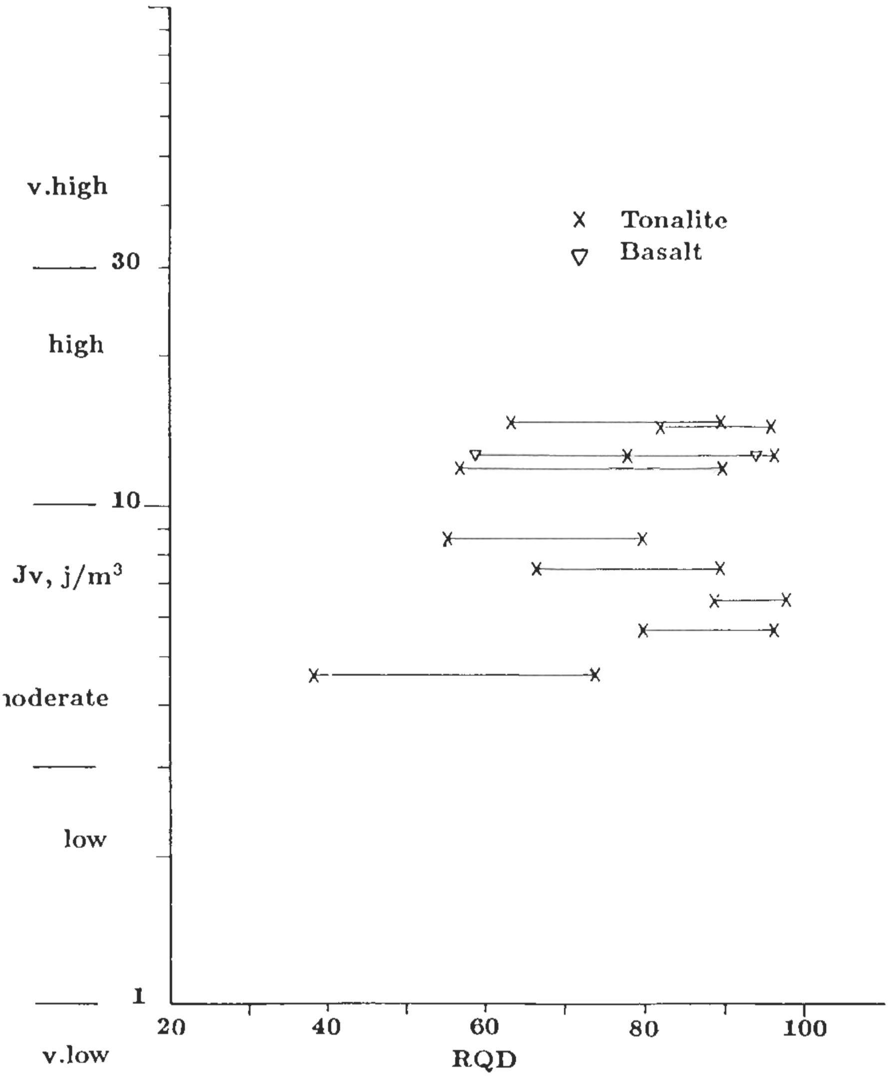

FIG. 19. RQD range versus log Jv for the basic rocks at Al-Juwah descent.

Discussion and Conclusions

A direct comparison between the behaviour of the granites and the tonalites can be made studying the design charts. These reflect clearly the fact seen in the field that the first and second order irregularities along the joint surfaces in granites are both increasing the peak shear strength τ of the granites, and decreasing the support requirements for their slopes. The irregularities are acting in an opposite way in the tonalites. In the study area, where the granites and tonalites have an average UCS of

100 and 67 MPa, respectively, the tonalites need more support than the granites due to their lower JRC values, and where their system of jointing is of schistose and metamorphic origin, while the jointing system in the granitic rock is of brittle and tensile origin. Furthermore, the volumetric joint count (Jv) values in the tonalites are much higher than those of the granites.

1. It is obvious from Fig. 1 and 2 that all rock slopes at Al-Dilaa descent of different slope angles and Jv above 5, have drainage holes as basic protection, due to the effect of water pressure in destabilizing the slopes and decreasing the factor of safety of the slope cuts along the road. The design of slopes is more careful at Al-Juwah descent, the drainage holes are drilled even for Jv values of 1.5. At Al-Juwah descent there are seven failures along an eighteen kilometres-long motorway, while at Al-Dilaa descent there are fourteen failures along an eleven kilometres-long motorway. Therefore, it is concluded that drainage holes are essential for all slopes designed at any angle and at any Jv value in this region of sudden and heavy rain.

2. In case of no possible failure resulting from the attitudes of joint set within the rock mass, slopes of high heights and low Jv could withstand the heights normally encountered maintaining their original cohesion and shear strength characteristics, but the negative effect of running water in the form of flash rain could increase sharply the water pressure causing failures rapidly, especially if it is combined with an unfavourable joint set attitude with respect to the slope face attitude. On the other hand, all the slopes heights over 34 metres, of Jv above 6 and very steep slope face need support by any means.

3. The overall slope height and overall slope angle are sensitive to the volumetric joint count, Jv.

4. From Fig. 14 to 19, it is concluded that, as the value for Jv decreases the RQD range is smaller, reflecting excellent quality rocks, and vice versa. Nevertheless, a certain range of RQD values does not predict adequately a certain value of Jv; this depends on where the scanline of the RQD was taken in respect to the rock mass, and how long it was.

5. At Jvs higher than 10, the chances of failure become more possible at slopes of wide ranges of RQD, these chances will be eliminated if the slopes are supported as indicated by the design charts.

6. To a large extent, the rock type determines the value of Jv and consequently the support requirements of the rock cut slope. Thus, the lithology and the weakness zones, are the prime factors influencing the stability of rock slopes. This result is in agreement witb the conclusions reached by Terzaghi (1962) and Ross-Brown (1979).

7. The design charts in Fig. 2, 3, 8, 9, 14, and 15 may be used both to fit the observed data of rock slope design and to predict it. Fig. 2, 3, 8, and 9 set the limits of designing a safe slope of certain overall height and slope angle. If the overall height and slope angle exceed such limits without taking any support measure, failure would be eventually expected.

8. In the rainy seasons, January to April in the southwestern region, the possibility of rock slide and rock falls increases sharply, due to the destructive effect of the

water pressure in joints. This effect could be eliminated by either driving drainage holes in the rock slopes or covering part of the slope surface with a layer of shotcrete to prevent the accumulation and infiltration of water, or by constructing gullies in the rock slope faces for water to drain away.

These design charts, show that the requirements for a basic design of a rock slope in a strong rock, especially in a difficult terrain can be met by using values for variables that are easy to obtain in the field, such as a joint spacing, overall slope height, and slope angle. On the light of this study, it might be concluded that it is extremely difficult (and not yet achieved by any researcher), to put together all the geotechnical, geological and geomorphological key parameters along with the engineering and support requirements in a single design chart, so as to design a rock slope-cut with a reasonably derived factor of safety.

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Appendix 1: Notations

H	=	Slope height,
JRC	=	Joint Roughness Coefficient,
RMR	=	Rock Mass Rating,
UCS	=	Unconfined Compressive Strength.
σ_n	=	Normal stress,
γ	=	Unit weight,
τ	=	Shear strength.

رسومات تصميمية لقطوع المنحدرات الصخرية على الطرق الجبلية في جنوب المملـــكة العربيـــة السعوديـــة

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مستخلص . تصف هذه الورقة العلمية مجموعة جديدة من رسومات التصميم الفني البيانية والتي صنفت للمساعدة في عمليات التخطيط والتحليل المبدئي لتصميم منحدرات الصخور في المملكة العربية السعودية . وقد جمعت معلومات هذه الرسومات من عقبتي الضلع والجوة . كل من المنحدرات المستقرة وغير المستقرة قد قيم بوساطة تصنيفات الكتل الصخرية والتخريط الأساسي والاختبارات الدالة ، والتي بوساطتها أمكن تمييز الخصائص الجيوتقنية الأساسية لمختلف الكتل الصخرية المستقرة وغير المستقرة . وقد أضيفت إلى هذه المعلومات قياسات الاستقرار الصخري وكذا طرق العلاج والتثبيت وذلك لتحقيق استقرار المنحدرات .

أظهر عامل عدد الشقوق الحجمية (JV) أنه حساس للغاية لأداء صخور المنحدرات في المملكة العربية السعودية ، ويمكن أن يضم إلى كل من الارتفاع الكلي للمنحدرات وزاوية ميل المنحدر الكليه فيزودنا بمجموعة مفيدة من رسومات تصميم المنحدرات الصخرية . هذه الرسومات التصميمية يمكن أن تُقسَّم إلى مناطق ، كل منطقة تنسب إلى مجموعة مؤتلفة من طرق العلاج .

ولعلنا نتوقع أن يكون لهذه الرسومات التصميمية أكثر من تطبيق أشمل مما أجرى في عقبتي الضلع والجوه ، ولعلها تكون وسيلة لعمل تقويم سريع لتصميم وبناء وصيانة وطرق علاج انحدارات القطوع الصخرية في المناطق الجبلية الوعرة في المملكة العربية السعودية على طول ساحل البحر الأحمر .