# CLASSIFICATION AND ZONING OF MARBLE SITES

GEO REPORT No. 29

Y.C. Chan

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
HONG KONG

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A. W. Malone
Principal Government Geotechnical Engineer
April 1995

# FOREWORD

This report records the development of a system for the zoning and classification of marble sites. It describes the details of and the rationale behind the system. It has applications in the interpretation of karst morphology, planning of detailed ground investigation and design of foundations.

The system was developed by Mr Y.C. Chan under the supervision of Mr M.C. Tang. Mr W.K. Pun performed most of the computation involved.

The drafting services provided by Special Projects Division is gratefully acknowledged.

M.C. Tang
Ag Chief Geotechnical Engineer/Mainland West

# CONTENTS

## 1. INTRODUCTION

In January 1989, the Mainland West Division of the Geotechnical Control Office started a search for a system of classifying or zoning marble sites. This report records the work done and the details of the proposed system as illustrated by case examples.

## 2. AIM

The aim of the exercise is to develop a system of classifying or zoning marble sites based on borehole data to :

(i) obtain an indication of the difficulty of designing and constructing foundations.

(ii) gain a better understanding of the geology.

Regarding (i), there are two levels of engineering applications. The first level is to classify sites from the preliminary stage ground investigation. The site classes should allow the engineer to decide on the potential foundation problems and solutions and hence to plan a good stage 2 ground investigation with a good idea of what to look for. The second level is to assist interpretation of all ground investigation data to decide on a site class from which the engineer can draw precedent cases with regard to the choice of foundation types, founding levels and supervision requirement.

By plotting the site classes on a geology map, we may be able to correlate site classes with geology. This would in the future allow identification of potential difficult sites from known geology features and vice versa. This is however a secondary aim that may only realise after data from sufficient number of sites are collected.

## 3. CONSULTATION

The Resident Consultant Geologist, Messrs Dames & Moore (HK) and Dr A.C. Meigh, all of them are GCO consultants serving on the marble study project, were approached for assistance. Dr A.C. Meigh provided a series of useful thoughts.

In addition, the author is in debt to Dr R.L. Langford for his surface karst concept.

## 4. KARST MORPHOLOGY

### 4.1 Factors Affecting Karst Dissolution

Marble or limestone is sparingly soluble in water with dissolved carbon dioxide. The following formula summarises the reaction involved.

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{++} + 2HCO_3^-$$

For the dissolution of $CaCO_3$ to continue, there must be a continuous supply of carbon dioxide and water.

The supply of carbon dioxide to the part of water in touch with the limestone depends on a number of factors in a complicated manner e.g. pH value, temperature, partial pressure of $CO_2$ in the air adjacent to the water surface, mechanism of distribution of $CO_2$ from air/water interface to the water/marble interface. In general, low temperature, high partial pressure and turbulance in the water would all encourage high $CO_2$ concentration at the marble/water interface.

Whilst the $CO_2$ concentration can vary within a certain range, the amount of water available to dissolve the calcitic rock mass can vary tremendously and is the main controlling factor. It depends on the hydrology of the area, the location and the characteristics of the rock mass.

## 4.2 Hydrology of a Marble Rock Mass

Water travels in a marble rock mass mainly along joints and fractured zones. This water flow would dissolve the joint walls hence widening the joints. As a result, the permeability of a marble rock mass would increase with time. Likewise the contrast in permeability within the rock mass would also increase with time hence exaggerating any initial difference in conditions.

Figure 1 shows the different possible paths of water flow in a marble rock mass.

Marble rock mass is relatively permeable. Part of the rainfall would infiltrate into the rock and travel down along joints. The flow volume would depend on joint width and spacing. Hence, the flow is much larger in a fractured or fault zone.

Depending on the rainfall intensity, some of the rainfall may collect on the marble as surface runoff and drain towards local depressions to form temporary ponds or swamps. Joints daylighting in or adjacent to the depression would have strong flow because of better supply of water.

When two or more fractured zones intersect, a linear belt of very fractured rock will form. It would tend to collect water from the fractured zone to flow in a lateral direction.

Rainfall on a non-marble rock would collect along surface streams. When such streams meet marble, water would infiltrate into the marble and move on as concentrated flows along the marble/non-marble interface as a result of low permeability of the latter. Likewise, when water conducting joints meet less permeable dykes, the water would collect to contribute a concentrated flow at the dyke interface.

This flow pattern would in the end control the form and pattern of karst features in the rock mass as explained below.

4.3 Karst Features in Yuen Long

The following karst features have been interpreted from detailed ground investigations on building sites in Yuen Long. Their relations with the hydrology of the marble rock mass are shown in Figure 2.

(a) Surface Karst

This is at the rockhead where the marble rock mass is seriously weakened and dissected by dissolution channels. It is usually 5 m thick but may be up to 15 metres. The more developed surface karst are usually found at depressions where the continuous supply of water was more effective in dissolving marble. The depressions might have been swampy in which case the higher partial pressure of carbon dioxide would increase the rate of dissolution drastically and contributed to a much more developed surface karst.

(b) Overhangs

The solution channels might undercut the rock mass leaving a cap of good quality marble on top. These are named as overhangs.

(c) Dissolution Joints

These are joints locally opened by dissolution. The joint wall remains in contact at most locations. The effect of these affected joints on the rock mass strength is not significant.

(d) Deep Cavity Zone

This registers the location of concentrated water flow in the geological past. It is usually in form of series of medium to small size cavities in a zone 10 m or more thick.

(e) Underground Channels

This is found at points of concentrated flow along fractured rock mass where the many joints facilitated dissolution and collapse of small cavities to form a few large cavities.

(f) Underground Cavity

At the marble/non-marble boundary, surface stream along the non-marble would direct concentrated flow into the rock interface. This would encourage dissolution of the rock mass. If the flow velocity is sufficiently large, it would also erode the decomposed non-marble rock. Such erosion would leave a very large underground cavity.

Features (c) to (f) are regarded as deep karst features in the subsequent part of this report.

## 4.4 Effect of Dissolution on Rock Mass Quality

The immediate effect of marble dissolution is a redistribution of stresses. The result is fracturing of the rock mass as shown in Figure 3.

The lost of insitu stresses at the surface karst zone and adjacent to the small cavities would cause the joints to open. The effect on rock mass quality is small. However, large shear and tensile stresses would be induced in the vicinity of cavities of large extent and in the pinnacles. This would cause the rock to fracture reducing the rock mass strength and rigidity.

# 5. RQD AND DISSOLUTION

The Rock Quality Designation (RQD) is an indirect measure of the fracture spacing in a rock mass. Since fractured rock is favourable to dissolution, low RQD values imply the potential existence of cavities in the rock mass being examined. This is also true if the fractures are induced by karst features as explained in Section 4.4.

From an engineering point of view, an underground cavity is important if there is a mechanism for the adjacent rock mass to move into it under stress. RQD value is a good measure of rock mass strength against such movement.

# 6. PARAMETERS FOR THE CLASSIFICATION SYSTEM

## 6.1 Basic Parameter

The Rock Quality Designation (RQD) value has been adopted as the basic parameter for the classification system. In addition to the reasons given in Section 5, RQD also presents the advantage of being a relatively reliable parameter recorded in logs not prepared under close supervision or with detailed description of dissolution features. It would therefore allow wider application of the classification system.

## 6.2 Defined Parameter

The Marble Quality Designation (MQD) has been defined as :

MQD = Average RQD x Marble Rock Recovery Ratio (MR)

$$\text{Average RQD} = \sum_{L_1}^{L_2} \frac{r_i \times l_i}{(L_2 - L_1)}$$

$$\text{MR} = \sum_{L_1}^{L_2} \frac{l_i}{(L_2 - L_1)}$$

where $l_i$ is the length of core of RQD value $r_i$.

$L_1$ is the top elevation of the section of core being considered.

$L_2$ is the bottom elevation of the section of core being considered.

$(L_2 - L_1)$ is usually 5 m.

Figure 4 illustrates the definition.

It can be seen that the MQD is a combined measure of the effects of dissolution voids and the physical and mechanical implications of fractures on a cavity affected rock mass. Furthermore, the rock masses can be classified according to the following range of MQD values.

| Marble Class | MQD Values (%) | Description |
|---|---|---|
| I | 75.1 - 100 | Very good quality marble mass consisting of rock with widely spaced fractures and unaffected by dissolution. |
| II | 50.1 - 75 | Good quality marble mass consisting of rock slightly affected by dissolution or slightly fractured rock essentially unaffected by dissolution. |
| III | 25.1 - 50 | Fair quality marble mass consisting of fractured rock or rock moderately affected by dissolution. |
| IV | 10.1 - 25 | Poor quality marble mass consisting of very fractured rock or rock seriously affected by dissolution. |
| V | 0 - 10 | Very poor quality marble mass consisting of rock similar to class IV marble except that cavities can be very large and marble continuous. |

In this system, Class I and II marble masses are definitely good for foundation purpose. Class IV and V marble masses are definitely unsuitable. The implication of Class III rock would however require some elaboration.

In one extreme, the Class III rating may purely be a result of rock joint spacings in which case the rock mass should be able to stand the usual range of foundation stresses (5 MPa) unless it is close to other cavities.

In another extreme, the Class III rating may be a result of large cavities in a widely jointed-rock. If the MQD is calculated for sections of 5 metres, the largest cavity that can be found in one section of Class III rock is 2.5 m. This may not be critical to stability if the cavity is separated from the foundation by say 5 m of Grade I, II marble masses. If Class III marble exists in two consecutive sections, the largest possible cavity is 5 m. This would have serious implications on foundation stability. Hence Class III is a marble mass of marginal rock quality and requires detailed examination of borehole records to assist interpretation of its effect on the foundation design.

## 7. The CLASSIFICATION SYSTEM

### 7.1 The MQD Values and Rock Mass Classes

The first step in the marble site classification system is to calculate MQD values for the marble cores recovered from each borehole and assign the rock mass class for each section of the rock cores according to the method in Section 6.2. To facilitate subsequent application, the MQD values are best calculated for 5 m sections of the same reduced level, e.g. -40 mPD to -45 mPD, -45 mPD to -50 mPD and so on. The section location will be designated by the top reduced level of the section.

At the rockhead, where the top section is shorter than the standard 5 m but longer than 3 m, the average will be calculated for the exact length and designated as a full 5 m section. If the top section is shorter than 3 m, it will be grouped into the section immediately below.

Figures 5 and 6 are some examples of this process.

### 7.2 Borehole Rating

To facilitate identification of unfavorable karst features from the marble mass classes, the rock masses can be rated according to the following scheme.

| | | Rating |
|---|---|---|
| (i) | Surface karst (a zone of Class III, IV, V marble mass at rockhead). | 0 |
| (ii) | Overhang (5-10 m of Class I, II marble mass capping the surface karst). | 5 |
| (iii) | Class III marble separated by $\geq 5$ m of I, II marble mass from the surface karst. | 10 |
| (iv) | Class IV, V marble separated by $\geq 5$ m of I, II marble from the surface karst. | 20 |

The ratings are applied separately to all parts of the borehole logs. The sum of the ratings becomes the borehole rating.

Figure 7 illustrates the rating schedule.

Boreholes with zero rating imply good quality rock and the ground in its vicinity is good for foundation. A borehole rating of 5 implies some obstruction to piling to good foundation material. It can affect the building layout or piling method if this obstruction is extensive on plan. Boreholes of rating 10 to 15 imply potential foundation problems if it is adjacent to holes of higher rating. Borehole rating exceeding 15 would indicate difficult ground condition requiring detailed ground investigation on the geology and trend of the cavity or cavity zones. Special designs are required to suit the building layout and ground conditions.

## 7.3 Site Zoning and Classification

If the borehole rating and the base level of the surface karst is plotted on a plan, it is possible to zone the site into areas of similar rating, as illustrated in Figures 8 and 9.

Figure 8 shows a site where most of the holes are with zero rating. The bottom level of the surface karst zone is at -35 to -45 mPD. A continous overhang caps the southern part of the site. In general, the site is easy to develop. However because of the possible lateral continuity of the overhang, its effect on foundation design and construction would need detailed consideration.

Figure 9 shows a site where most of the boreholes are again with a zero rating. However, at the east and west of the lower part of the site, there are 3 holes with rating greater than or equal to 10. In particular, hole DH18 shows 10 m of Grade III rock at a depth corresponding to the deep karst at DH20. DH19 is too short to reach this depth so that it is very likely that the deep karst at DH18 and DH20 are connected. From the picture, it would be advisable to avoid the southwestern corner of the site. Otherwise, the nature and extent of the deep karst at DH18 and DH20 should be examined in detail.

Based on the percentage site area underlain by overhangs or deep karst, the sites can be classified as follows.

| Percentage of area with borehole rating $\geq 5$ | Site Class | Description |
|---|---|---|
| 0 - 10 | A | Easy site |
| 10 - 25 | B | Fair site |
| 25 - 50 | C | Very Difficult site |
| 50 - 100 | D | Extremely Difficult site |

Hence, both sites at Figure 8 and 9 are classified as easy sites.

For a large site, zones can be delineated to contain the minimum of obstructions, solution channels and deep karst features. These zones can be classified separately. An example is shown in Appendix B.

## 8. APPLICATION

### 8.1 Initial Ground Investigation

For sites less than 1,000 $m^2$ in area, the initial ground investigation should consist of at least 4 drillholes down to -80 mPD and located in a triangular grid. For sites in excess of 1,000 $m^2$, the number of hole should be proportionally increased and be positioned in a regular grid pattern.

The borehole ratings should be assigned according to Section 7.2. The percentage of holes with borehole rating greater than zero should be calculated and compared with the site classes at Section 7.3 for an initial indication of the site condition. Initial zoning can also be done on large sites at this stage to allow concentration of subsequent investigation efforts.

In the subsequent investigation, boreholes should be sunk around those initial boreholes with rating greater than zero. The purpose of these holes is to trace the extent of the karst features (overhang, deep channels etc) being investigated. The investigation should best be flexible and supervised by a geotechnical engineer or engineering geologist with experience in karst morphology and foundation on karst marble. However, as a rough guide, holes may be sunk around the initial hole with high rating at a grid of 7 to 10 m centres to a depth of approximately 20 m below the bottom of the karst feature being investigated.

Boreholes in other parts of the site may be sunk along a grid or at points of concentration of piles to a depth of 20 m into rock.

During the course of the detailed ground investigation, the drillhole cores and logs should be continuously reviewed so that the investigation programme can be modified in time to investigate new karst features intercepted.

### 8.2 Design Guidelines

On completion of all ground investigations, the site can be classified and zoned according to Section 7.3.

For easy sites, driven H-piles of heavy sections would be the best foundation type. These piles can penetrate the surface karst easily. A nominal redundancy of 10-20% would be adequate for the piles. The exact percentage redundancy depends on the thickness of the surface karst as well as the nature and extent of the overhangs or deep karsts.

Driven H-piles may still be most appropriate for fair sites. The percentage redundancy of the piles should be 20-30%. Bridging over or penetration of obstructions by predrilling should be considered. It would also be appropriate to locate the building to avoid the problem areas.

No simple rules exist for very difficult and extremely difficult sites. The extent, nature and geological background of the problematic karst features must be known. The rock mass quality around these features should be assessed and a suitable foundation design can then be attempted. This may be in form of deep bored piles to penetrate the zone, bored piles underpinned by grouting or micropiles, micropiles alone, floating piles or floating raft.

## 9. CASE EXAMPLES

Appendix A illustrates the application of the classification system on a site in central Yuen Long. This is a site where piling has been completed. Appendix B is an application on a site in the eastern part of Yuen Long town. This case illustrates site zoning from preliminary ground investigation results.

## 10. SUMMARY

A classification system for marble sites has been developed basing on some knowledge of karst processes and common karst features in Yuen Long. The system utilises RQD as the basic parameter. Five steps are involved in the application of the system.

(a) Calculate the Marble Quality Designation (MQD) values for sections of 5 metres according to the reduced levels.

(b) Assign the marble rock mass classes according to the MQD values.

(c) Calculate the borehole ratings according to the rock mass class patterns.

(d) Plot borehole ratings on plan to identify problem zones.

(e) Assign site classes according to the percentage area of the problem zone.

Based on limited experience on design and construction of foundations on karst marble in the Yuen Long area, some tentative guidelines on ground investigation and foundation design have been associated with the site classes. This would be the immediate application of the classification system.

## 11. POTENTIAL DEVELOPMENT

With some practice, engineers and geologists may use the borehole ratings to assist interpretation of the karst morphology of the sites. This may turn out to be the real strength of the system as illustrated by Chan & Pun (1994).

As a follow up, this system will be applied to sites in the Designated Area with good ground investigation results. The system would then be reviewed for improvement.

## 12. REFERENCES

Chan, Y.C. & Pun, W.K. (1994). The Method of Karst Morphology for Foundation Design (GEO Report No. 32). Geotechnical Engineering Office, Hong Kong. (Under Preparation).

# LIST OF FIGURES

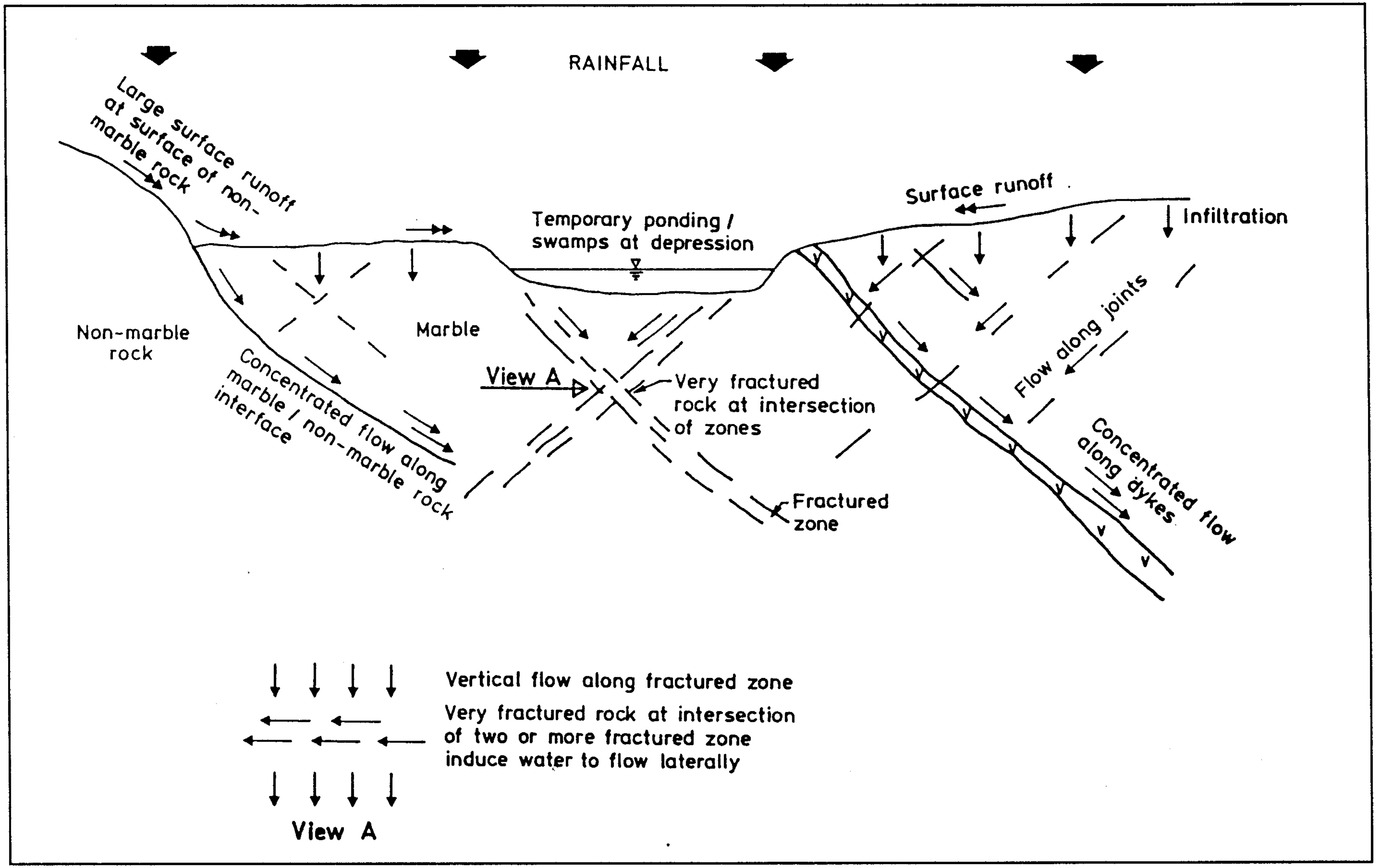


Figure 1 - Hydrology of a Marble Site

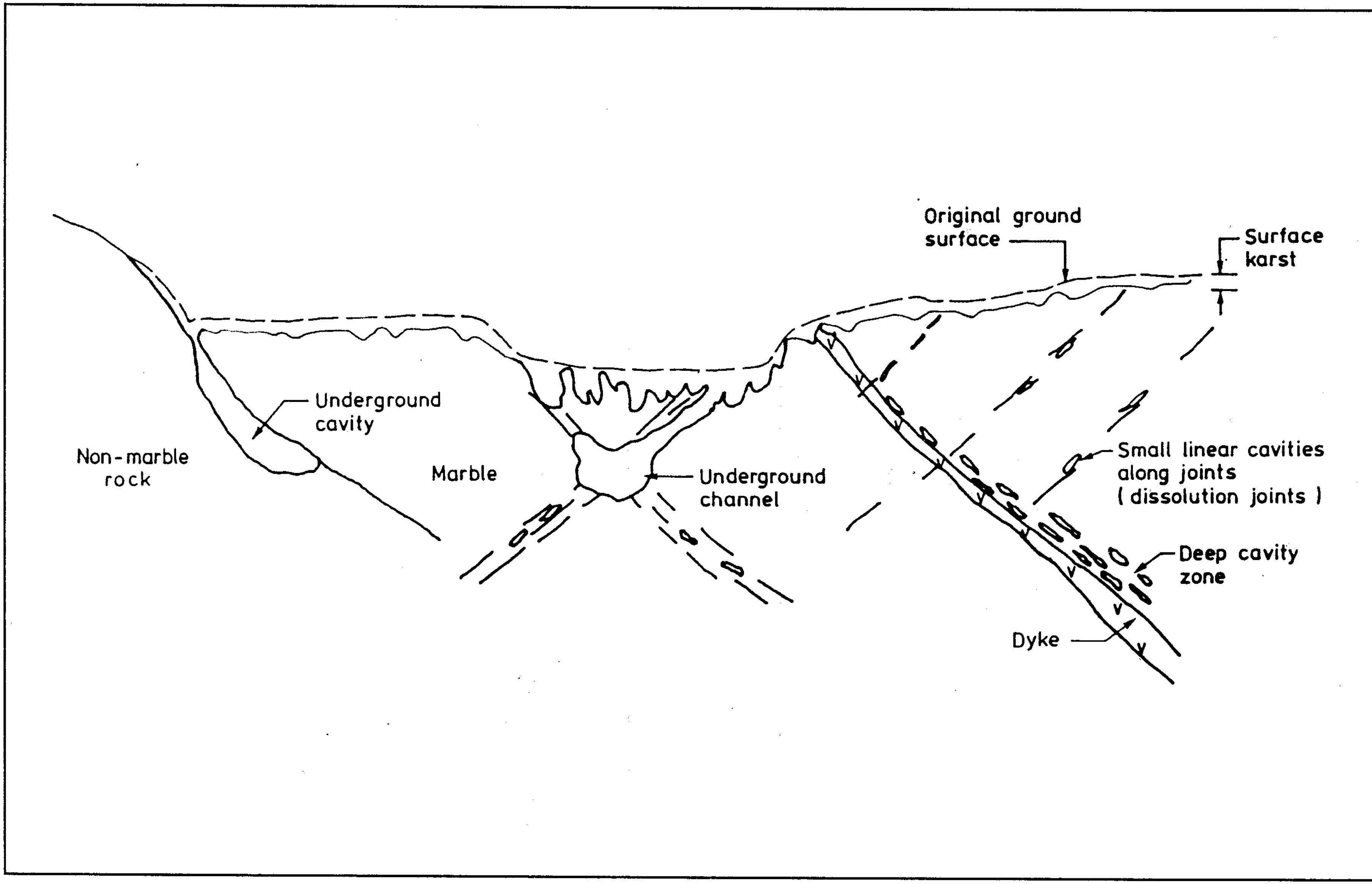


Figure 2 - Karst Features in Marble

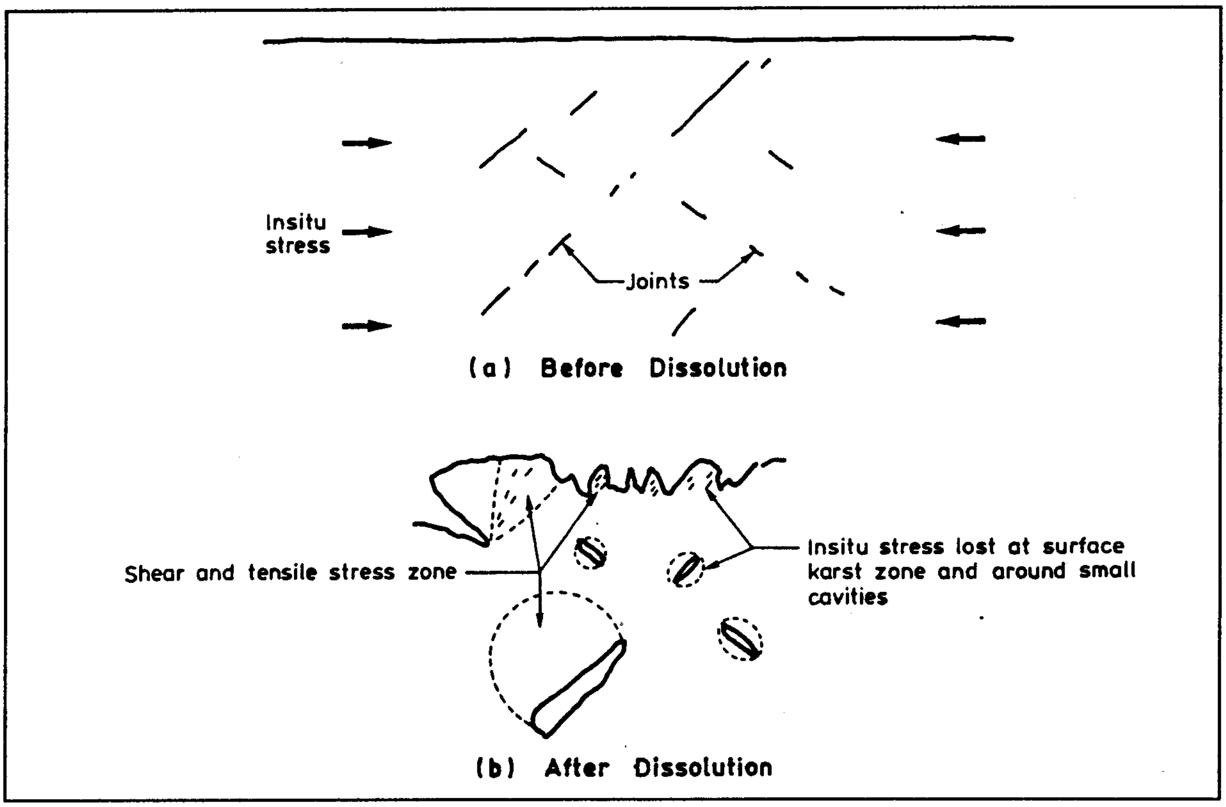


Figure 3 - Effect of Dissolution on Rock Mass Quality

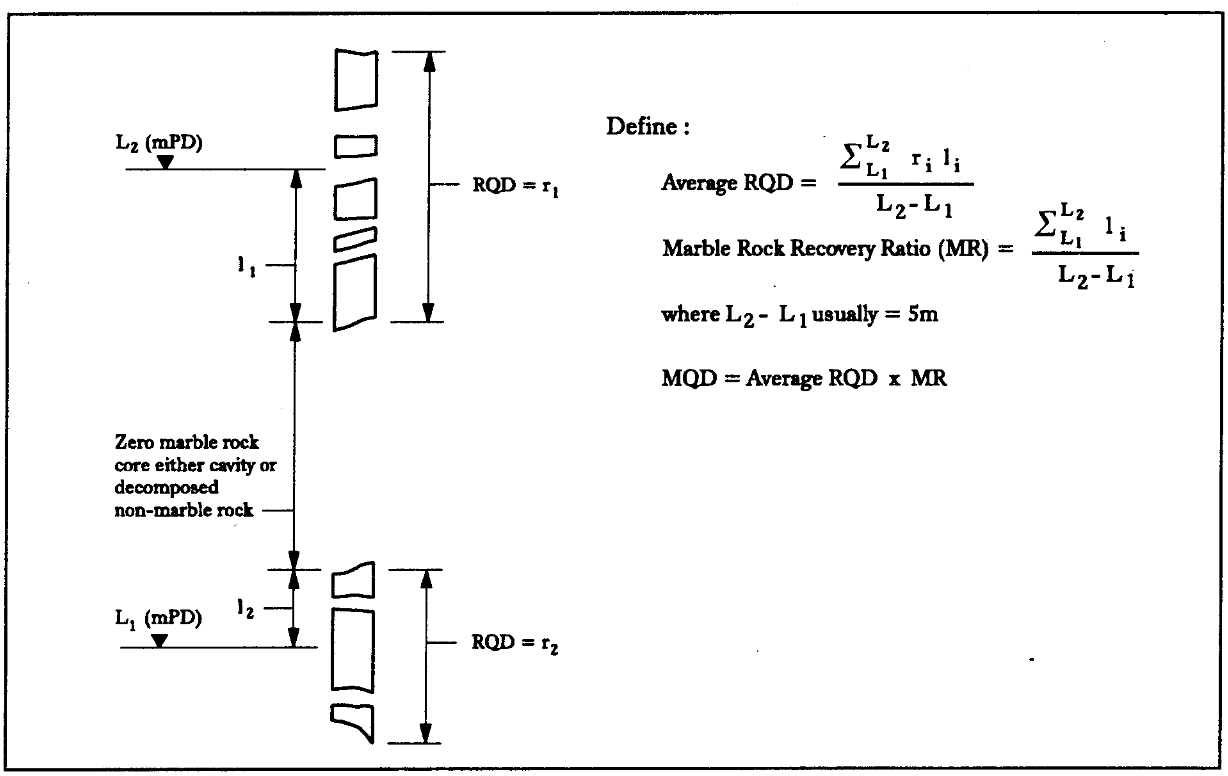


Figure 4 - Definition of Marble Quality Designation

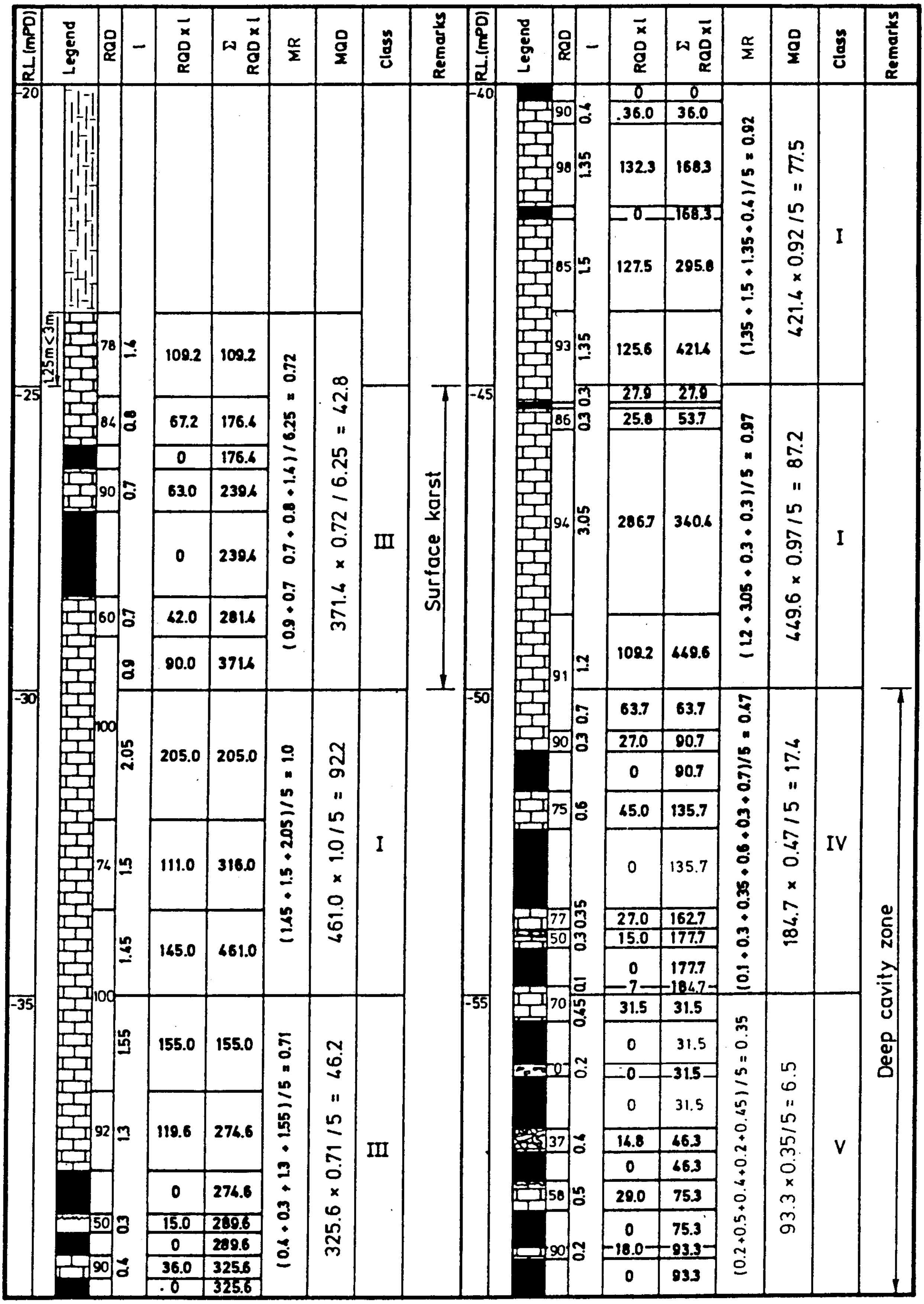


Figure 5 - Assignment of Marble Mass Classes Example 1

| R.L.(mPD) | Legend | RQD | l | RQD x l | Σ RQD x l | MR | MQD | Class | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| -30 | | | | | | (0.3 + 0.7 + 1.3)/3.8 = 0.61 | 178.7 × 0.61/3.8 = 28.7 | III | |
| | | 82 | 1.3 | 106.6 | 106.6 | | | | |
| | | | | 0 | 106.6 | | | | |
| | | 70 | 0.7 | 49.0 | 155.6 | | | | |
| | | | | 0 | 155.6 | | | | |
| | | 77 | 0.3 | 23.1 | 178.7 | | | | |
| | | | | 0 | 178.7 | | | | |
| -35 | | 60 | 0.4 | 24.0 | 24.0 | (0.5+0.5+0.6+0.2+0.9+0.5+0.4)/5 = 0.72 | 198.0 × 0.72/5 = 28.5 | III | |
| | | | | 0 | 24.0 | | | | |
| | | 88 | 0.5 | 44.0 | 68.0 | | | | |
| | | | | 0 | 68.0 | | | | |
| | | 90 | 0.9 | 81.0 | 149.0 | | | | |
| | | | | 0 | 149.0 | | | | |
| | | 70 | 0.2 | 14.0 | 163.0 | | | | |
| | | 40 | 0.6 | 24.0 | 187.0 | | | | |
| | | | | 0 | 187.0 | | | | |
| | | 22 | 0.5 | 11.0 | 198.0 | | | | |
| | | | | 0 | 198.0 | | | | |
| | | 0 | 0.5 | 0 | 198.0 | | | | |
| -40 | | | | 0 | 0 | (0.5 + 0.5 + 0.8 + 1.5 + 0.7 + 0.2)/5 = 0.84 | 328.2 × 0.84/5 = 55.1 | II | |
| | | 60 | 0.2 | 12.0 | 12.0 | | | | |
| | | | | 0 | 12.0 | | | | |
| | | 86 | 0.7 | 60.2 | 72.2 | | | | |
| | | 90 | 1.5 | 135.0 | 207.2 | | | | |
| | | 45 | 0.8 | 36.0 | 243.2 | | | | |
| | | 90 | 0.5 | 45.0 | 288.2 | | | | |
| | | 80 | 0.5 | 40.0 | 328.2 | | | | |
| -45 | | | | 0 | 0 | (0.6 + 1.3 + 1.2 + 0.2 + 0.2)/5 = 0.7 | 295.6 × 0.7/5 = 41.4 | III | |
| | | 50 | 0.2 | 10.0 | 10.0 | | | | |
| | | | | 0 | 10.0 | | | | |
| | | 100 | 0.2 | 20.0 | 30.0 | | | | |
| | | | | 0 | 30.0 | | | | |
| | | 80 | 1.2 | 96.0 | 126.0 | | | | |
| | | 100 | 1.3 | 130.0 | 256.0 | | | | |
| | | | | 0 | 256.0 | | | | |
| | | 66 | 0.6 | 39.6 | 295.6 | | | | |

3.8 m > 3 m

| R.L.(mPD) | Legend | RQD | l | RQD x l | Σ RQD x l | MR | MQD | Class | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| -50 | | | | 0 | 0 | (0.9 + 0.5 + 1.0)/5 = 0.48 | 214.0 × 0.48/5 = 20.5 | IV | |
| | | 0 | | 0 | 0 | | | | |
| | | | | 0 | 0 | | | | |
| | | 0 | | 0 | 0 | | | | |
| | | | | 0 | 0 | | | | |
| | | 90 | 1.0 | 90.0 | 90.0 | | | | |
| | | | | 0 | 90.0 | | | | |
| | | 95 | 0.5 | 47.5 | 137.5 | | | | |
| | | | | 0 | 137.5 | | | | |
| | | 85 | 0.9 | 76.5 | 214.0 | | | | |
| -55 | | 100 | 1.7 | 170.0 | 170.0 | (0.4 + 1.7)/5 = 0.42 | 198.0 × 0.42/5 = 16.6 | IV | |
| | | | | 0 | 170.0 | | | | |
| | | 70 | 0.4 | 28.0 | 198.0 | | | | |
| | | | | 0 | 198.0 | | | | |
| -60 | | | | 0 | 0 | 0/5 = 0 | 0/5 = 0 | V | |

Figure 6 - Assignment of Marble Mass Classes Example 2

| Reduced Level (mPD) | BH1 | | | BH2 | | | BH3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Class | Feature | Rating | Class | Feature | Rating | Class | Feature | Rating |
| -20 | | | | | | | | | |
| -25 | I | Overhang | 5 | I | | | | | |
| -30 | V | Surface karst | 0 | II | | | IV | | |
| -35 | II | | | III | Marginal rock mass at depth | 10 | V | Surface karst | 0 |
| -40 | I | | | III | | | III | | |
| -45 | I | | | II | | | I | | |
| -50 | III | | | II | | | I | | |
| -55 | V | | | | | | I | | |
| -60 | V | Deep karst | 20 | | | | III | Marginal rock mass at depth | 10 |
| -65 | V | | | | | | III | | |
| -70 | V | | | | | | I | | |
| -75 | | | | | | | III | Deep karst | 20 |
| -80 | | | | | | | IV | | |
| | | | Σ = 25 | | | Σ = 10 | | | Σ = 30 |

Figure 7 - Examples of Borehole Ratings

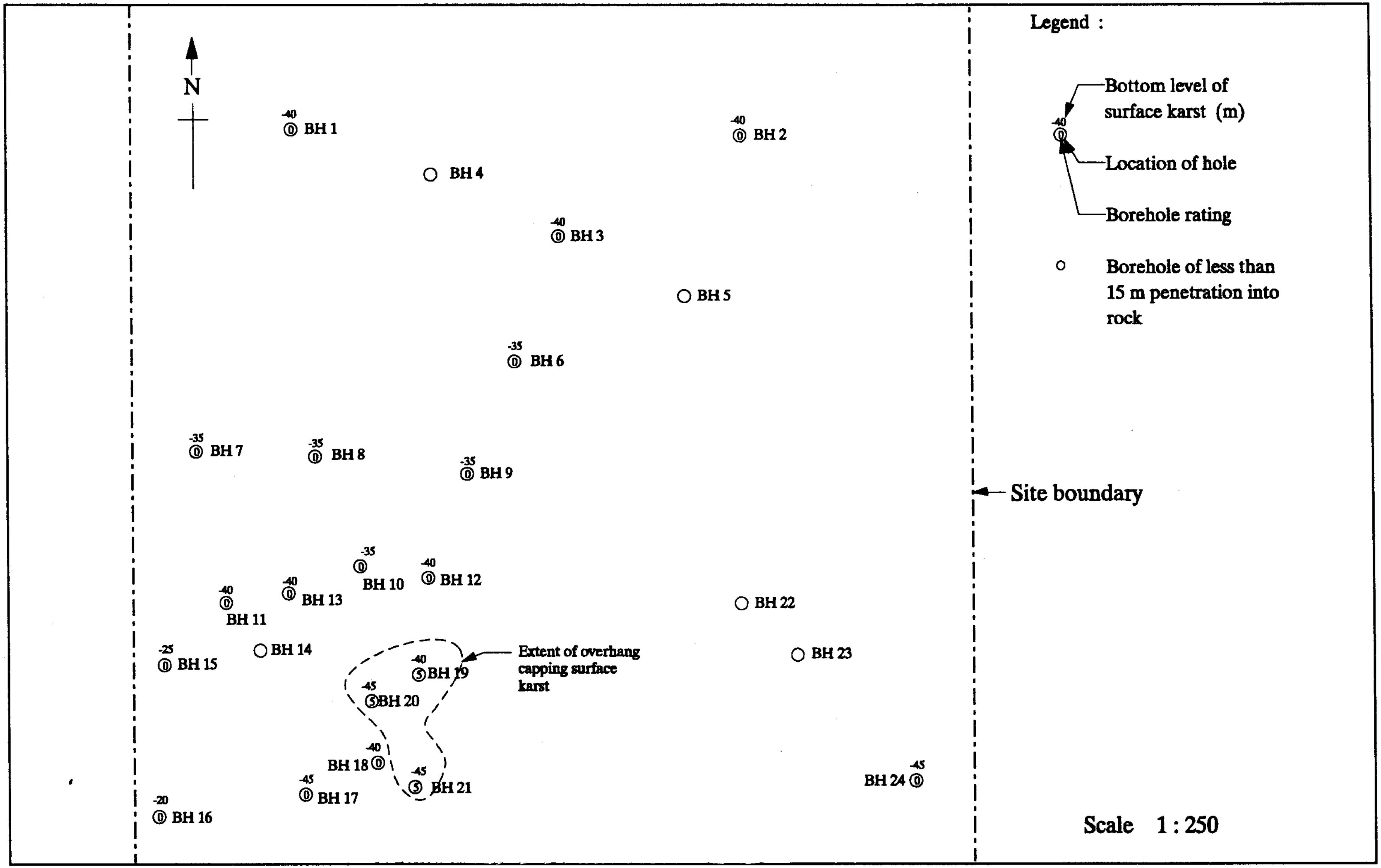


Figure 8 - Site Zoning and Classification Example 1

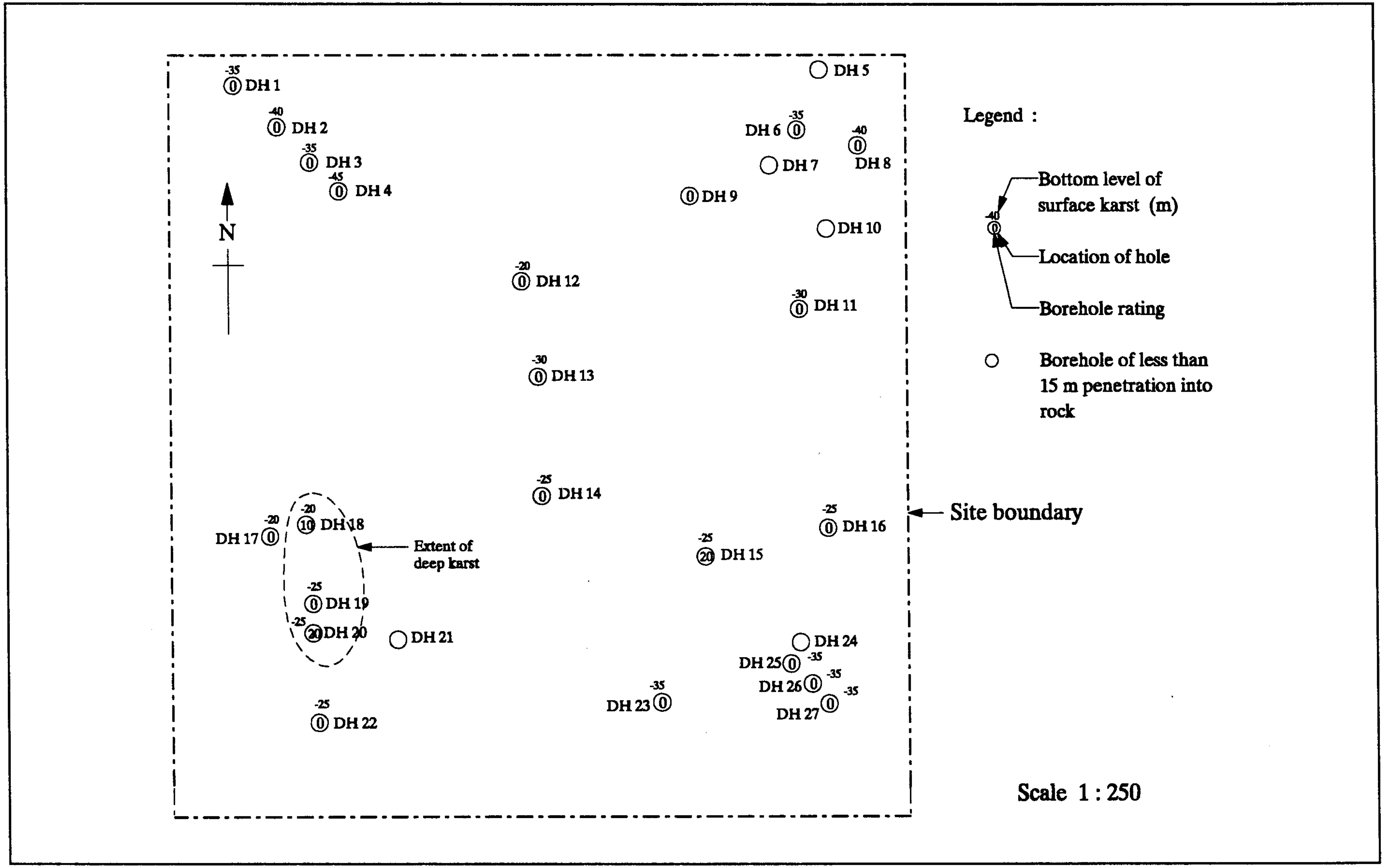


Figure 9 - Site Zoning and Classification Example 2

# APPENDIX A

## CLASSIFICATION OF MARBLE SITE - SITE A

A.1 SITE A

Table A1 lists the MQD values of all the boreholes. Figure A1 shows the borehole ratings and the bottom levels of the surface karst.

Contouring of the bottom levels would highlight two depressions along a east west trend.

Between the two depressions are boreholes of rating ≥ 5. Close examination of the MQD values at Table A1 would show that this represents a deep cavity zone connecting the two depressions. From the engineering point of view, the site is easy to develope but some attention would be required for the part of foundation above the deep cavity zone at the middle-northern part of the site.

## LIST OF TABLES

## Table A1 - MQD Values and Marble Mass Classes for Site A

**Section Starting (mPD)**

(a) MQD Values

| Borehole | −20 | −25 | −30 | −35 | −40 | −45 | −50 | −55 | −60 | −65 | −70 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BH1 | | 18.5 | 90.8 | 16.2 | 88.0 | 89.5 | | | | | |
| BH2 | 95.3 | 96.0 | 78.0 | | | | | | | | |
| BH3 | 81.5 | 10.6 | 7.1 | 63.6 | 93.4 | 100.0 | | | | | |
| BH4 | 82.2 | 2.4 | 2.3 | 51.0 | 48.1 | 93.4 | 81.8 | 86.6 | | | |
| BH5 | 87.9 | 94.6 | 100.0 | | | | | | | | |
| BH6 | 68.0 | 12.9 | 100.0 | 100.0 | | | | | | | |
| BH7 | 5.9 | 100.0 | 88.5 | | | | | | | | |
| BH8 | 0.0 | 93.5 | 65.5 | 97.1 | 96.1 | 94.7 | 100.0 | | | | |
| BH9 | | 0.0 | 7.1 | 78.0 | 75.0 | | | | | | |
| BH10 | | 51.1 | 76.1 | 89.7 | 77.0 | | | | | | |
| BH11 | 55.1 | 35.1 | 83.0 | 72.8 | | | | | | | |
| BH12 | 75.3 | 82.3 | | | | | | | | | |
| BH13 | | 72.2 | 94.8 | 85.6 | 69.8 | 93.0 | 98.3 | 98.0 | | | |
| BH14 | | 19.7 | 36.4 | 27.4 | 20.3 | 66.2 | 89.9 | 95.0 | | | |
| BH15 | 94.1 | 95.2 | 95.5 | | | | | | | | |
| BH16 | 95.4 | 97.3 | 97.1 | 100.0 | | | | | | | |
| BH17 | | 24.3 | 96.9 | 63.2 | 84.8 | 76.4 | 73.7 | 92.7 | 96.3 | 100.0 | |
| BH18 | 15.6 | 0.0 | 11.1 | 40.3 | 70.0 | 91.6 | 54.4 | 84.8 | 91.3 | | |
| BH19 | 73.3 | 5.8 | 98.3 | 84.3 | 98.5 | 100.0 | | | | | |
| BH20 | 70.0 | 79.7 | 71.6 | 93.1 | 95.6 | 89.0 | | | | | |
| BH21 | 23.2 | 50.4 | 92.6 | 40.6 | 66.3 | 56.3 | 90.6 | | | | |
| BH22 | 93.9 | 12.0 | 6.0 | 84.9 | 38.7 | 80.3 | 85.5 | | | | |
| BH23 | 78.7 | 25.9 | 8.9 | 8.0 | 63.9 | 97.9 | | | | | |
| BH24 | | 50.4 | 26.4 | 70.9 | 86.3 | 54.5 | | | | | |
| BH25 | | 46.7 | 73.5 | 45.8 | 84.2 | 95.4 | 98.0 | | | | |
| BH26 | | 79.4 | 87.8 | 93.0 | 91.9 | 89.9 | 100.0 | | | | |
| BH27 | 27.9 | 63.6 | 76.5 | 85.9 | 88.2 | | | | | | |
| BH28 | 10.4 | 74.2 | 66.9 | 85.3 | 88.7 | 87.5 | 89.9 | 97.9 | 74.0 | | |
| BH29 | 80.0 | 98.0 | 82.5 | 95.7 | 90.6 | 90.0 | | | | | |
| BH30 | 89.7 | 95.4 | 83.1 | 87.1 | 94.6 | 94.0 | | | | | |
| BH31 | 67.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | | | | | |
| BH32 | | 96.5 | 100.0 | 100.0 | 100.0 | | | | | | |
| BH33 | | 75.8 | 100.0 | | | | | | | | |
| BH34 | 23.3 | 97.5 | | | | | | | | | |
| BH35 | | | 95.3 | | | | | | | | |
| BH36 | | 69.0 | | | | | | | | | |
| BH37 | 75.2 | 90.4 | | | | | | | | | |
| BH38 | 6.5 | 90.2 | | | | | | | | | |
| BH39 | | 85.1 | 83.0 | | | | | | | | |
| BH40 | 94.6 | | | | | | | | | | |

(b) Marble Mass Classes

| Borehole | −20 | −25 | −30 | −35 | −40 | −45 | −50 | −55 | −60 | −65 | −70 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BH1 | | IV | I | IV | I | I | | | | | |
| BH2 | I | I | I | | | | | | | | |
| BH3 | I | IV | V | II | I | I | | | | | |
| BH4 | I | V | V | II | III | I | I | I | | | |
| BH5 | I | I | I | | | | | | | | |
| BH6 | II | IV | I | I | | | | | | | |
| BH7 | V | I | I | | | | | | | | |
| BH8 | V | I | II | I | I | I | I | | | | |
| BH9 | | V | V | I | II | | | | | | |
| BH10 | | II | I | I | I | | | | | | |
| BH11 | II | III | I | II | | | | | | | |
| BH12 | I | I | | | | | | | | | |
| BH13 | | II | I | I | II | I | I | I | | | |
| BH14 | | IV | III | III | IV | II | I | I | | | |
| BH15 | I | I | I | | | | | | | | |
| BH16 | I | I | I | I | | | | | | | |
| BH17 | | IV | I | II | I | I | II | I | I | I | |
| BH18 | IV | V | IV | III | II | I | II | I | I | | |
| BH19 | II | V | I | I | I | I | | | | | |
| BH20 | II | I | II | I | I | I | | | | | |
| BH21 | IV | II | I | III | II | II | I | | | | |
| BH22 | I | IV | V | I | III | I | I | | | | |
| BH23 | I | III | V | V | II | I | | | | | |
| BH24 | | II | III | II | I | II | | | | | |
| BH25 | | III | II | III | I | I | I | | | | |
| BH26 | | I | I | I | I | I | I | | | | |
| BH27 | III | II | I | I | I | | | | | | |
| BH28 | IV | II | II | I | I | I | I | I | II | | |
| BH29 | I | I | I | I | I | I | | | | | |
| BH30 | I | I | I | I | I | I | | | | | |
| BH31 | II | I | I | I | I | I | | | | | |
| BH32 | | I | I | I | I | | | | | | |
| BH33 | | I | I | | | | | | | | |
| BH34 | IV | I | | | | | | | | | |
| BH35 | | | I | | | | | | | | |
| BH36 | | II | | | | | | | | | |
| BH37 | I | I | | | | | | | | | |
| BH38 | V | I | | | | | | | | | |
| BH39 | | I | I | | | | | | | | |
| BH40 | I | | | | | | | | | | |

**Legend :**

| Code | MQD Range |
|---|---|
| I | 75.1 – 100% |
| II | 50.1 – 75% |
| III | 25.1 – 50 % |
| IV | 10.1 – 25% |
| V | 0 – 10% |

# LIST OF FIGURES

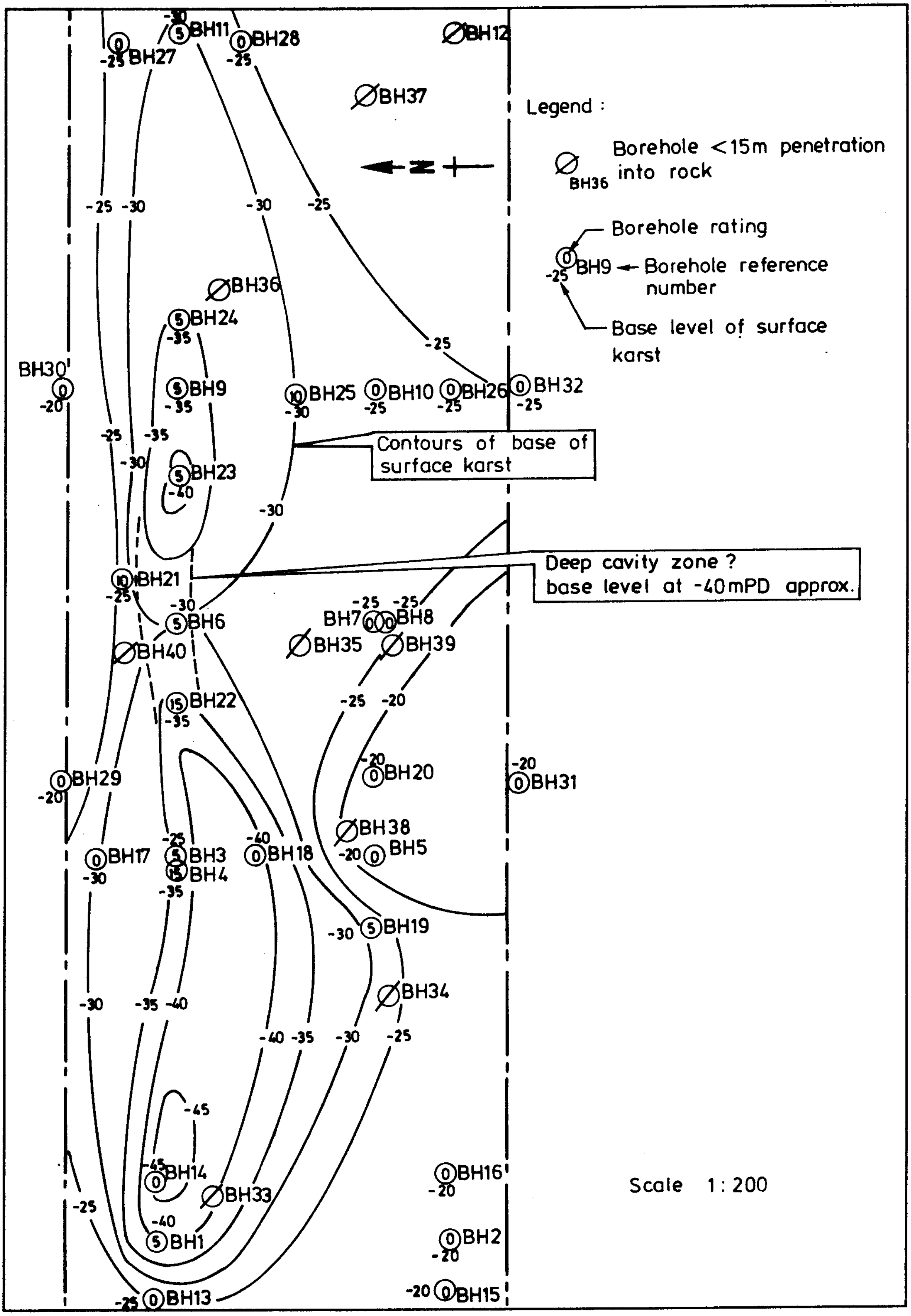


Figure A1 - Karst Morphology of Site A

# APPENDIX B

## CLASSIFICATION OF MARBLE SITE - SITE B

## B.1 SITE B

Only the preliminary ground investigation has been completed on this site.

Table B1 lists the MQD values of the boreholes.

Figure B1 shows the borehole rating and the bottom levels of the surface karst.

Due to widely spaced borehole information, the reconstruction of the karst morphology is not possible. However, out of the 31 boreholes plotted, 35% (11 holes) are with rating ≥ 5. The site would therefore be classified as "very difficult", implying the need for very detailed ground investigation and probably building reorientation to avoid difficult ground.

A NE-SW line can however be drawn across the site. The lower half of the site is cavity free. The upper half of the site would have 55% of its holes (10 out of 18) with borehole rating ≥ 5. This half of the site would be classified as "extremely difficult" with all its engineering implications.

## LIST OF TABLES

## Table B1 - MQD Values and Marble Mass Classes for Site B

(a) MQD Values

| Borehole | Section Starting (mPD) −20 | −25 | −30 | −35 | −40 | −45 | −50 | −55 | −60 | −65 | −70 | −75 | −80 | −85 | −90 | −95 | −100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH1 | | | 49.6 | 96.9 | 100.0 | 65.2 | 86.3 | | | | | | | | | | |
| BH2 | | | | 9.5 | 25.4 | 70.9 | 97.6 | 93.4 | 90.1 | 74.2 | 85.3 | 98.5 | | | | | |
| BH3 | | | 92.1 | 89.4 | 89.5 | 88.4 | 95.7 | 76.8 | 90.1 | 88.6 | 81.0 | | | | | | |
| BH4 | | 51.4 | 44.3 | 80.4 | 67.7 | 98.4 | 98.1 | 100.0 | 98.7 | 100.0 | 45.6 | 88.7 | 100.0 | 100.0 | | | |
| BH5 | | | 13.2 | 23.4 | 75.9 | 84.2 | 76.8 | 96.7 | 40.6 | 45.9 | 77.4 | | | | | | |
| BH8 | | 76.8 | 81.3 | 75.4 | 92.7 | 100.0 | 99.2 | 94.5 | 70.0 | 81.4 | 96.2 | 98.2 | 82.6 | 95.0 | | | |
| BH9 | | 47.8 | 6.3 | 41.3 | 85.1 | 100.0 | 42.0 | 81.4 | 100.0 | 100.0 | 100.0 | 100.0 | 96.0 | 100.0 | | | |
| BH10 | | 46.8 | 77.9 | 78.9 | 85.2 | 80.8 | 99.2 | 100.0 | 100.0 | 100.0 | | | | | | | |
| BH11 | | | 24.0 | 1.1 | 70.2 | 49.2 | 23.5 | 0.0 | 0.0 | | | | | | | | |
| BH12 | | | | | 13.7 | 82.1 | 7.2 | 34.0 | 21.1 | 87.2 | 96.8 | | | | | | |
| BH13 | | 95.6 | 26.7 | 0.0 | 2.3 | 23.9 | 3.1 | 79.9 | 77.7 | 89.2 | 95.0 | | | | | | |
| BH14 | | | 3.1 | 2.7 | 0.7 | 57.0 | 72.0 | 81.6 | 99.8 | 86.7 | 94.3 | | | | | | |
| BH16 | | 36.0 | 68.4 | 90.1 | 98.1 | 99.8 | 99.1 | 99.8 | 96.6 | 98.6 | 100.0 | | | | | | |
| BH17 | | 95.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 81.4 | 89.4 | 87.4 | 100.0 | | | |
| BH18 | | | 48.6 | 29.2 | 16.2 | 74.0 | 98.5 | 2.8 | 0.0 | | | | | | | | |
| BH19 | | | | | | | | | | | | | 47.8 | 13.0 | | | |
| BH20 | | | 14.9 | 31.0 | 81.3 | 1.6 | 80.9 | 97.4 | 48.6 | 3.3 | 0.0 | 57.3 | 66.3 | 64.6 | 78.1 | 76.4 | 68.3 |
| BH21 | | | 87.8 | 92.0 | 80.9 | 0.0 | 51.4 | 100.0 | | | | | | | | | |
| BH22 | | | 98.4 | 94.1 | 85.7 | 93.2 | 75.9 | | | | | | | | | | |
| BH23 | | | | | | | | | | 32.9 | 33.2 | 39.4 | 45.1 | 8.7 | | | |
| BH27 | | | 11.5 | 88.1 | 53.3 | 61.5 | 41.3 | 66.5 | 92.6 | 93.0 | 93.3 | | | | | | |
| BH28 | | | | 78.6 | 0.8 | 91.2 | 84.4 | 87.5 | | | | | | | | | |

(b) Marble Mass Classes

| Borehole | Section Starting (mPD) −20 | −25 | −30 | −35 | −40 | −45 | −50 | −55 | −60 | −65 | −70 | −75 | −80 | −85 | −90 | −95 | −100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH1 | | | S | I | I | II | I | | | | | | | | | | |
| BH2 | | | | V | III | II | I | I | I | II | I | I | | | | | |
| BH3 | | | I | I | I | I | I | I | I | I | I | | | | | | |
| BH4 | | II | III | I | II | I | I | I | I | I | III | I | I | I | | | |
| BH5 | | | IV | IV | I | I | I | I | III | III | I | | | | | | |
| BH8 | | I | I | I | I | I | I | I | II | I | I | I | I | I | | | |
| BH9 | | III | V | III | I | I | III | I | I | I | I | I | I | I | | | |
| BH10 | | III | I | S | I | I | I | I | I | I | | | | | | | |
| BH11 | | | IV | V | II | III | IV | V | V | | | | | | | | |
| BH12 | | | | | IV | I | V | III | IV | I | I | | | | | | |
| BH13 | | I | III | T | T | IV | V | I | I | I | I | | | | | | |
| BH14 | | | T | T | T | II | II | I | I | I | I | | | | | | |
| BH16 | | III | II | I | I | I | I | I | I | I | I | | | | | | |
| BH17 | | I | I | I | I | I | I | I | I | I | I | I | I | I | | | |
| BH18 | | | III | S | IV | II | I | V | V | | | | | | | | |
| BH19 | | | | | | | | | | | | | III | IV | | | |
| BH20 | | | S | III | I | V | I | I | III | V | V | II | II | II | I | I | II |
| BH21 | | | I | I | I | V | II | I | | | | | | | | | |
| BH22 | | | I | I | I | I | I | | | | | | | | | | |
| BH23 | | | | | | | | | | III | III | III | III | V | | | |
| BH27 | | | IV | I | II | II | III | II | I | I | I | | | | | | |
| BH28 | | | | I | V | I | I | I | | | | | | | | | |

**Legend :**

| **Code** | **MQD Range** |
|---|---|
| I | 75.1 – 100% |
| II | 50.1 – 75% |
| III | 25.1 – 50% |
| IV | 10.1 – 25% |
| V | 0 – 10% |
| T | Decomposed non–marble rock |
| S | Non–marble rock |

## LIST OF FIGURES

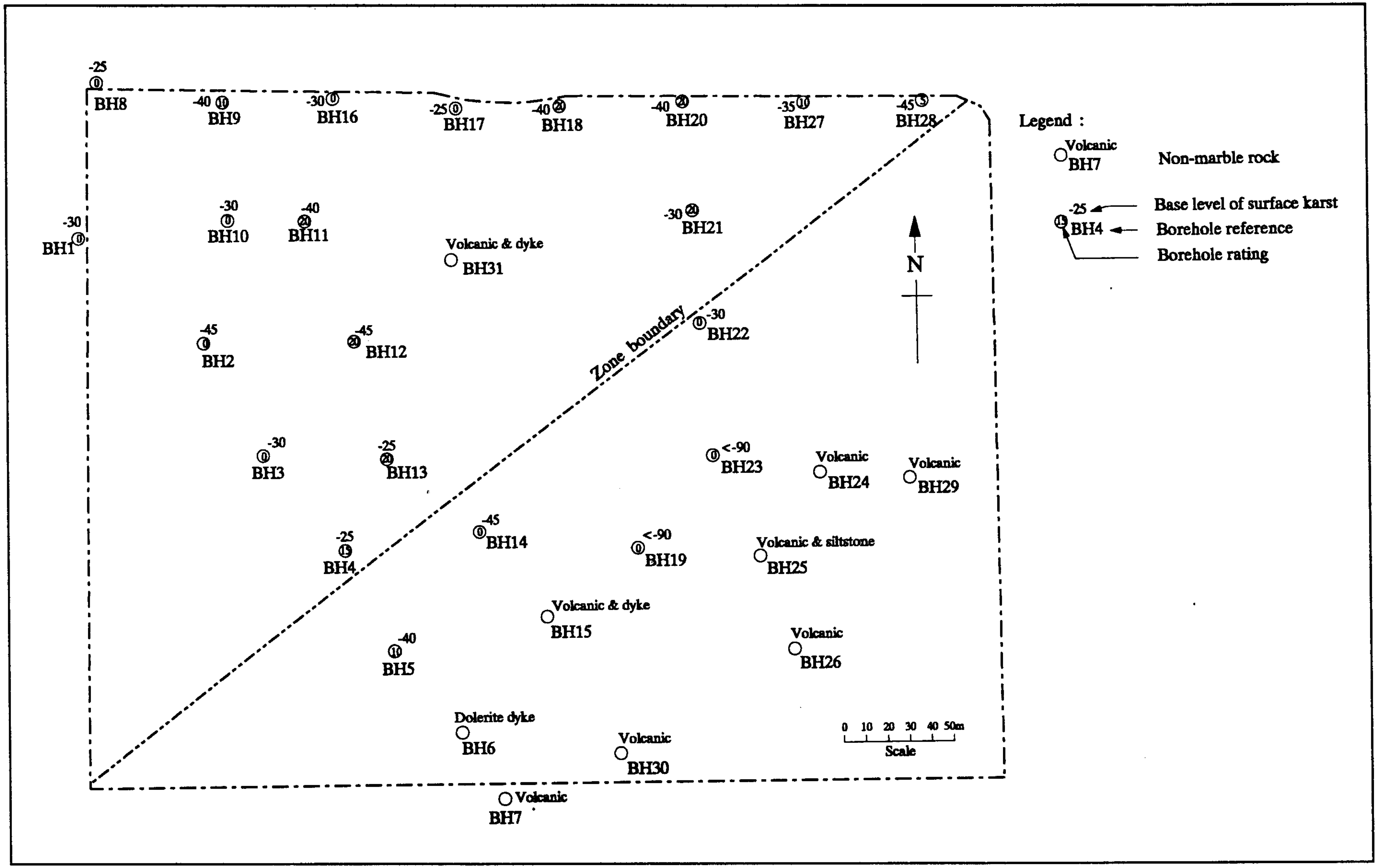


Figure B1 - Marble Site Zoning and Classification of Site B