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Problem recognition index (PRI) applied to the Falset area

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ABSTRACT
A problem recognition index (PRI) for general mapping purposes on an engineering geological map has been developed during four years of research in Falset, province Tarragona, Spain. The index gives a numerical value which suggests the amount of problems expected within a mapping unit. The more points assigned to a mapping unit the fewer problems can be expected with any type of engineering use that might be made in or on the rock mass described by the mapping unit. The index considers intact rock strength, block size and block form, weathering profile and the presence of deleterious minerals.

1 Introduction

In the last decades the study of discontinuous rock mechanics has become more important. The development started in near surface rock engineering in applications such as slopes, foundations and shallow tunnels. For these constructions it was established that the discontinuities in a rock mass had a major influence on the engineering properties of a rock mass. This perception had major consequences for the assessment of rock mass quality. Descriptions, characterization, engineering geological maps and calculations for engineering structures in or on a rock mass have to include discontinuity properties. The number of discontinuities in a rock mass can be enormous even for a relatively small rock mass. Theoretically it is necessary to include the properties of the rock material and all discontinuities in descriptions of the rock mass as well as in calculations. Variations in properties can be considerable along the same discontinuity plane. As there may be hundreds of discontinuities in a rock mass, each with its own variable properties, these, taken together with inhomogeneities in the rock material, show that to describe the rock mass precisely a great deal of data is required. Laboratory and field tests are available to obtain discontinuity properties. However, testing in large quantities is expensive and troublesome. The definition of significant rock mass units and the comparison between different units are major problems due to the large number of different properties to be considered. The possibilities of giving a good description, characterization and clear representation of rock masses on engineering geological maps, including all properties of all discontinuities, are clearly limited.

Engineering geological maps should use mapping units that take characteristics of discontinuity systems into consideration. For a regional scale (1 : 10,000 to 1 : 100,000 scale) general purpose engineering geological map it is not feasible to do extensive testing programs. Thus the data should be gathered by other means, such as field characterization of units and simple field tests. Another problem is that representing extensive amounts of data on a single map makes the map unreadable. Alternatives are to present the data in a computer database or to try to represent the data in a single number by means of a classification system. This article describes the development of a classification system that may be used to indicate the expectation of encountering problems for any engineering application within a mapping unit.

2 Existing systems for engineering geological mapping

Many authors describe various systems to present engineering geological data and to characterize rock and rock mass data on a map (BS 5930, 1981, Dearman, 1991, ISRM, 1981, Keaton, 1984, Unesco, 1976, Williamson, 1984). These systems or recommendations for making engineering geological maps contain a series of standard tables for presentation of data (e.g., type of soil and rock, structural features, depth to bedrock; foundation depth, groundwater level, geodynamic features, etc.) on maps and on borehole logs. Characterization systems that also include some (limited) amount of classification have been proposed by various authors often with a strong emphasis on geomorphology of natural slopes rather than engineering geology (Selby, 1980). Numerous maps have been produced for urban areas with foundation recommendations. The articles and accompanying maps published regularly in the Bulletin of the Association of Engineering Geologists (USA) are notable, for instance Galster et al. (1991), Gates et al. (1992) and Woodhouse et al. (1991). Various maps and proposals for mapping systems have been published based on parameters obtained by remote sensing technics, e.g. aerial photography, satellite reconnaissance and image processing. Obtaining data in this way is obviously a major benefit for the making of smaller scale maps. Lately a development has started to include Geographical Information Systems (GIS) in the map making process and also the evaluation of the parameters within a GIS system (Akinyede, 1990, Westen et al., 1993, Shuk, 1994).

3 Classification systems

The disadvantage of the existing systems for general engineering geological mapping is that these are complicated and difficult to understand because all information relevant to every type of engineering use has to be shown on the map. Whether all such information can be shown depends on the scale of the map and the complexity of the rock mass geology. In many instances it is not possible because of limitation of printing. Then information has to be summarized or excluded. How and which data is summarized or excluded depends on the maker of the map and is often not or only partially reported. Other maps are designed to show the reaction of the rock mass to a particular engineering structure, such as foundation depth, settlement of buildings, etc.. These maps are then only useful for that particular purpose.
An alternative is grouping or classifying the information such that the 'quality' of a rock mass is indicated on the map (Sissakian et al., 1983, Rengers et al., 1990). The application of these classification systems has not always been entirely satisfactory and therefore a new mapping system has been designed. The system was developed during 4 years of field work in the Falset area, province Tarragona, Spain (Fig. 1), by staff and students from ITC and the Technical University Delft, and is directed towards the representation of geomechanical and geological factors of engineering significance by a single numerical value. A single value representation is necessary if a general engineering geological map is to be made suitable for different types of engineering projects.

4 The research area

The research has been mainly done in the area around Falset in the north-east of Spain, in the province of Tarragona (Fig. 1). The area is particularly suitable for the type of research described because:

1. The variation in geology, lithology and tectonic environments is large, giving different geological environments for the development and verification of the classification systems.
2. The topography is mountainous and vegetation is limited, exposing large areas of rock.
3. Access to the area and to rock exposures is not difficult.
4. Aerial and satellite images, topographical and geological maps at various scales are available.

In the Falset area the stratigraphy is composed of sediments of Devonian through to Quaternary age and intrusive rocks from Carboniferous through to Permian age. A generalized geology table, the lithology and the main engineering characteristics are listed in Table 1. The table only presents a broad impression of the geology, lithostratigraphy and engineering geological mapping units found in the area and is in no way complete. A further description is given by the geological maps of the area and accompanying legends (geological map sheets, no. 444, 445, and 471, of the area prepared at a 1 : 50 000 scale by the Instituto Geologico y Minero de España). Reference may also be made to the engineering geological map and accompanying report and legend (Price et al., in preparation). which will be published as the result of the research done in the area. The description of rock mapping units on the map will be based on the problem

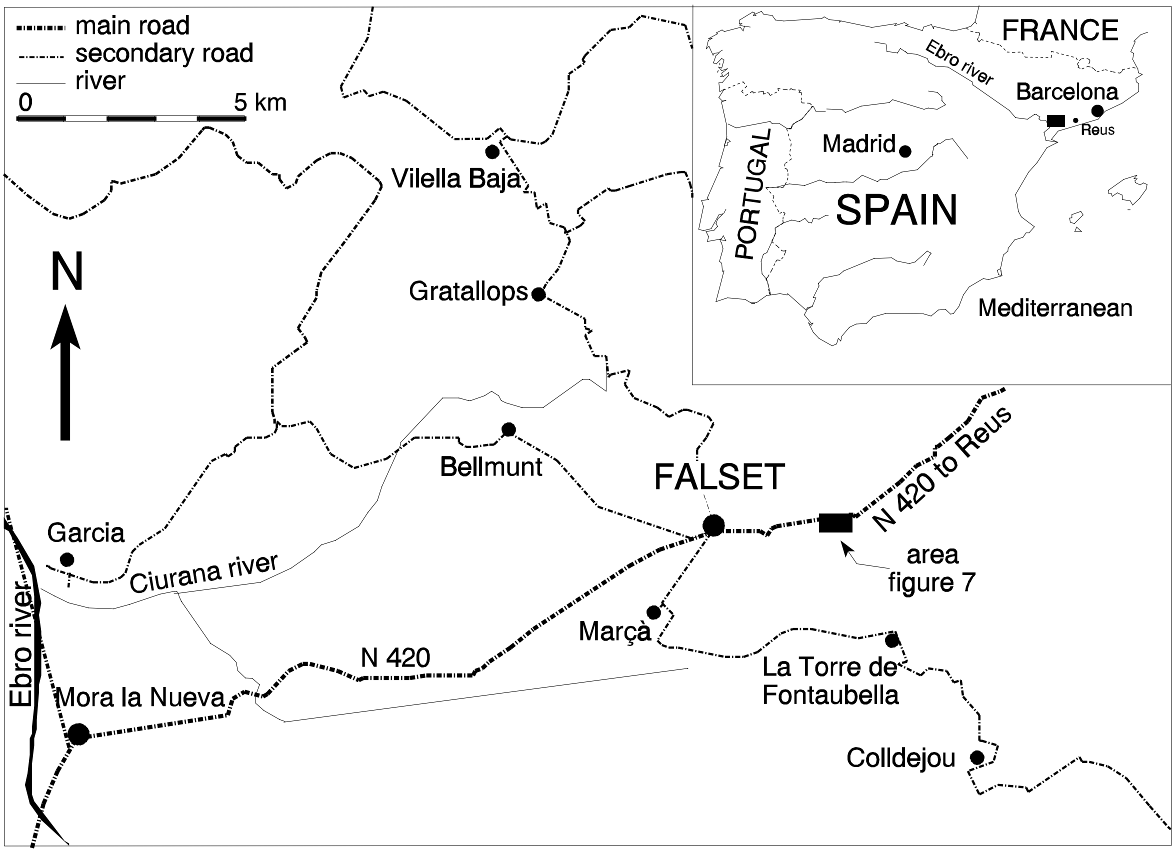

Fig. 1. Research area.

recognition index (PRI).

5 Background

The system is designed for use in engineering geological mapping. Its purpose is to aid the identification of those rock mapping units that may cause problems for engineering in those units. Before designing such a classification it is necessary to consider the basic causes of engineering problems which may stem from the geotechnical character of rock units. Most engineering geologists are able, as the result of past experience, to identify those rock mass units that could give problems for any particular engineering process. The factors that determine such judgements are considered by the authors to be the strength of the rock materials, the size and shape of the rock blocks, the degree of uniformity of the rock unit, particularly with regard to strength and weathering, and the presence or absence of deleterious minerals. The influence of these factors on various engineering processes is indicated schematically in Fig. 2. The influence of these factors on any particular engineering work will, of course, depend on the dimensions and orientation of the engineering work and the geological structure embracing the rock units, including disturbances caused by faulting, land sliding and so forth.
In engineering geological mapping, maps may be prepared by many workers so that any rock mass classification system should be simple enough to limit operator dependence. The mapping classification is based upon the general idea that for a generalized surface mapping the level of detail should be limited and that the final rating should also express the variation of particular parameters in a rock mass. The final rating is thus not only an expression for the quality of the rock mass at a particular spot but also an expression for the variation of the quality of a rock mass over a particular area. This allows for using the rating system as a regional mapping tool.

6 The system

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GENERALIZED GEOLOGICAL TABLE & DESCRIPTION AND MAIN ENGINEERING CHARACTERISTICS OF THE LITHOLOGY IN THE FALSET AREA(1)

CENOZOIC	Quaternary			Q	GRAVEL terraces along and in rivers; SAND/SILT/CLAY often on flat agricultural areas (also eolian origin).
	Tertiary(3)	Miocene, Oligocene, Eocene		T	Brown/yellowish, cemented, CONGLOMERATE layers (massive up to metres thickness) interbedded with brown/yellow, clayey SILT AND SAND layers, in top: LIMESTONE and calcareous silty SAND layers.
MESOZOIC (3)	Cretaceous	Upper Cretaceous(4)		C	Off-white/l.grey, argillaceous to arenaceous, medium bedded to massive, medium to v.large blocky, jointed, slightly weathered, LIMESTONE AND DOLOMITE, strong.
		Albian		C 16	Red/ochre, SANDS AND CLAYS, at some locations weakly cemented.
	Jurassic(4)			J	Off-white/l.grey, argillaceous to arenaceous, medium bedded to massive, medium to v.large blocky, jointed, slightly weathered, LIMESTONE AND DOLOMITE, strong.
	Triassic	Keuper		Tg3	Red/green/greenish blue/brown/yellow/off-white, argillaceous to fine arenaceous, thinly laminated to v.thin bedded, v.small blocky, jointed, often folded and deformed, slightly to completely weathered, calcareous sandy silty SHALES, v. to mod. weak, with (small) quantities of gypsum. Bottom: Interbedded with layers (20 - 100 cm) off-white/l.grey, argillaceous to fine arenaceous, v.thin bedded, v.small blocky, jointed, LIMESTONE AND DOLOMITE, mod.weak to mod. strong.
		Muschel-kalk	upper	Tg23	Off-white/l.grey/yellowish grey, argillaceous to fine arenaceous, thick laminated to massive, v.small to v.large blocky, jointed, slightly weathered, LIMESTONE AND DOLOMITE, mod.strong to strong.
			middle	Tg22	Red (occasionally greenish grey), argillaceous to fine arenaceous, thinly laminated to v.thin bedded, jointed, often folded and deformed, slightly to completely weathered, gypsiferous clayey sandy SILTSTONE, v. to mod. weak; large quantities of gypsum up to occasionally more than 80 %.
			lower	Tg21	Off-white/l.grey, arenaceous, medium to thick bedded, medium to large blocky, jointed, slightly weathered, LIMESTONE AND DOLOMITE (CALCARENITE), strong.
		Buntsandstone		Tg1	Red/brown, rudaceous (bottom) to fine arenaceous (top), v.thick bedded to massive, slightly weathered, SANDSTONE, mod.strong.
PALAEO-ZOIC	Carbonife-rous(2)			Hs, H	Thick sequences (> 100 m) of d.grey, argillaceous, thinly spaced cleavage, thinly bedded, small to medium blocky or tabular, jointed, folded, slightly to mod. weathered, SLATE, mod. strong to strong, interbedded with sequences (5 - 100 m thick) of grey/brown, thin to thick bedded, medium to large blocky, jointed, folded, slightly weathered, MICRO CONGLOMERATES, SANDSTONES AND SILTSTONES, mod. strong to extr. strong; folding 1 to > 10 m in slate and > 10 m in other. At two locations 10 to 50 m thick layer of black (with white 5 - 10 mm bands), medium grained, massive, fresh, GNEISS, v. strong to extr. strong.
	Devonian(2)			D	Layers (6 cm) of black, argillaceous, thinly laminated, schistose, folded, slightly to mod.weathered, ORGANIC SHALE, v.weak, interbedded with layers (10 cm) of off-white/brown, amorphous, v.small to small blocky, jointed, folded, RADIOLARIAN CHERT, v.strong; intensive multiple folding from 10 cm to > 10 m.
	Intrusives in Carboniferous	late Carboniferous through Perm		γη/ FO2	L. to d. grey, fine to coarse grained, small to medium blocky, jointed, slightly to highly weathered (also residual soil), GRANODIORITE (sometimes porphyritic), v.weak to extr.strong.
					D. grey, v.fine to fine grained, v.small to small blocky, jointed, slightly to mod. weathered, APLITIC DYKES, mod. strong to v.strong (intrusive in Carboniferous sediments and granodiorite).

Codes (Q, T, C16, etc.) refer to codes used on the geological map sheets, no. 444, 445, and 471, of the area prepared at a 1 : 50 000 scale by the Instituto Geologico y Minero de España. Only main codes are included. Notes:

1 Description for rock units according to BS 5930 (1981). (l. = light; d. = dark; v. = very; mod. = moderately; extr. = extremely)
2 Palaeozoic sedimentary rocks intensively folded under Hercynian orogeny (Carboniferous through Perm); folded on a scale of metres to 10's of metres.
3 Mesozoic folded under influence of the Alpine orogeny (late Cretaceous through Miocene); folding on a scale of 100 m to km's, Tertiary faulted and tilted.
4 Jurassic and Upper Cretaceous consist out of various formations with similar engineering characteristics.
5 Weathering indication characterizes the degree of weathering typically found in surface exposures.

Table 1. Geological table and description and main engineering characteristics of the lithology of the Falset area.

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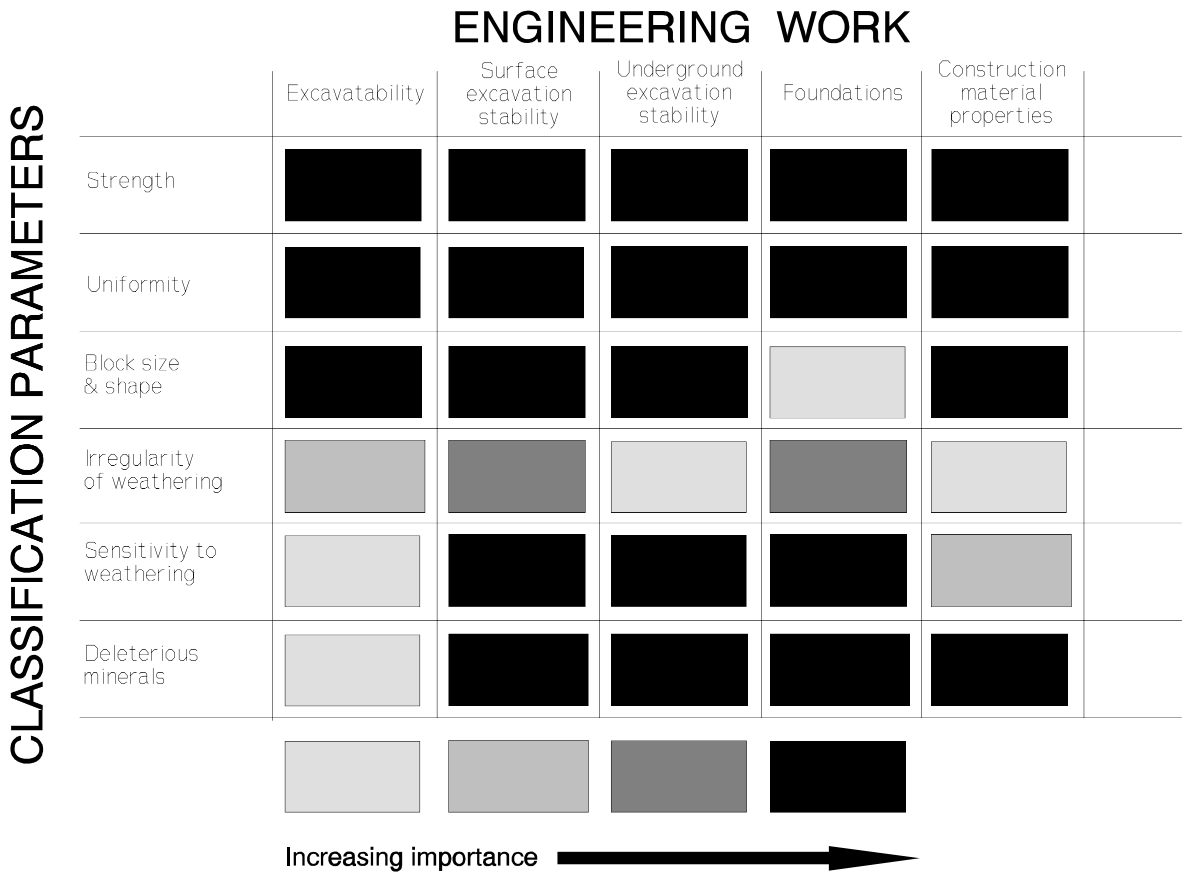

Fig. 2. Rock mass parameters and their influence on engineering works.

The system includes the following factors as separate measurements:

- Strength of the rock material (RSR)
- Uniformity of strength of the rock material within the unit (UR)
- Rock unit block shape and size (RS)
- Irregularity of weathering (UWP)
- Sensitivity : susceptibility to weathering and/or the presence of minerals which may be judged to be deleterious (S)

For classes and ratings see also the field mapping form (Fig. 3) and the calculation form (Fig. 4).

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ITC/TU ENGINEERING GEOLOGY	field form 1	ROCK MASS CLASSIFICATION MAPPING	
LOGGED BY:	DATE: / /1993	TIME: : hr	outcrop no:

WEATHER CONDITIONS		LOCATION	map no:	
Sun:	cloudy/fair/bright	Map coordinates:	northing:	
Rain:	dry/drizzle/slight/heavy		easting:	

METHOD OF EXCAVATION/DIMENSIONS/ACCESSIBILITY				
Size total outcrop: (m)	l:	h:	d:	Accessibility:
mapped on this form: (m)	l:	h:	d:	poor/fair/good

FORMATION NAME:

DESCRIPTION (BS 5930: 1981)					
colour	grain size	structure & texture (bedding thickness)	weathering	NAME	strength

LAYER STRENGTH (LS)

< 1.25 MPa	:	Crumbles in hand	: 1
1.25 - 5 MPa	:	Thin slabs break easily in hand	: 2
5 - 12.5 MPa	:	Thin slabs broken by heavy hand pressure	: 3
12.5 - 50 MPa	:	Lumps broken by light hammer blows	: 4
50 - 100 MPa	:	Lumps broken by heavy hammer blows	: 5
100 - 200 MPa	:	Lumps only chip by heavy hammer blows (Dull ringing sound)	: 6
> 200 MPa	:	Rocks ring on hammer blows. Sparks fly	: 7

direction	strength estimation	sample/test form number (Schmidt hammer/BPI)
perpendicular		
parallel		

DISCONTINUITIES (DS)	B=bedding	J=joint	
	.. 1	.. 2	.. 3
Dip direction [degrees]			
Dip [degrees]			
Spacing [metres]			

UNIFORMITY OF SURFACE WEATHERING PROFILE (UWP)

(tick number)
very irregular :1
irregular :2
uniform :3

DELETERIOUS MINERALS

Quantity: (tick)	none : 1.00					
	in intact rock (%)			fracture infill (mm)		
	< 5	5 - 25	>25	< 2	2 - 5	> 5
salts, easily soluble in water e.g. halite, etc.: (tick)	0.3	0.2	0	0	0	0
gypsum, anhydride: ,,	0.5	0.3	0.1	0.25	0.1	0.05
swelling clays: ,,	0.5	0.3	0.1	0.25	0.1	0.05

Fig. 3. Field mapping form for Problem Recognition Index (PRI).

6.1 Rock strength rating (RSR): Ratings from 10 to 100

Rock strength is an obvious parameter of considerable significance in most forms of engineering in rock. In tunnelling low intact rock strength often creates problems due to shearing along discontinuities (asperities on discontinuity planes are sheared off). In foundation engineering a low intact rock strength can cause settlement due to fracturing of intact rock. Also for slope stability intact rock strength is important. Anisotropy of intact rock strength is obviously a problem in construction materials, but anisotropy causes also problems in foundation and tunnel engineering.

Ratings assigned for intact rock strength vary from 10 for strengths less than 1.25 MPa to 100 for strengths greater than 200 MPa. In the field layer strengths are measured using a Schmidt hammer (Stimpson, 1965) or, for experienced observers by 'simple means' using, for example, the reaction to hammer blows as given in British Standard BS 5930 (1981, Burnett, 1975, Hack, 1996) (Fig. 3). An allowance is made for anisotropy by assessing strength in two orthogonal directions that, in bedded rocks, would be normal and parallel to the bedding. The intent is to indicate the fissility of the rock material. The ratio minimum/maximum strength is calculated and the maximum rock strength rating is multiplied by this ratio to give the final strength rating for the layer.

The estimation of intact rock strength by 'simple means' is discussed extensively in Hack (1996). One of the conclusions is that estimation of intact rock strength by 'simple means' is a suitable means of establishing intact rock strength and that estimates often lead to better results than unconfined compressive strength (UCS) testing. It was also concluded that the anisotropy of intact rock cannot accurately be estimated by 'simple means'. This is not important for the estimation of anisotropy in the problem recognition index as defined above. The important fact in the anisotropy rating is the percentage of anisotropy in the intact rock strength not the absolute values.

ITC/TU ENGINEERING GEOLOGY **calc. form** **ROCK MASS CLASSIFICATION MAPPING**

LOGGED BY:	DATE: / /1993	TIME: : hr	outcrop no:

LAYER STRENGTH

>200 MPa	200 - 100	100 - 50	50 -12.5	12.5 - 5	5 - 1.25	< 1.25 MPa
100	90	80	60	40	30	10 points

average layer strength (SR): (for conversion from MPa to points use table above)	MPa	=	points
minimum strength in any direction	MPa	ratio = minimum strength / maximum strength =	
maximum strength in any direction	MPa	(AF)	

LAYER STRENGTH RATING (LSR = SR X AF) = points

UNIFORMITY OF LAYER STRENGTH

LSR points measured within a radius of 50 m.

minimum:	points		
maximum:	points	percentage variation = maximum - minimum / average =	
average:	points		

< 10	10 - 25	25 - 50	50 - 75	> 75 %
50	40	30	10	0 points

UNIFORMITY RATING (UR) = points
(for conversion from % to points use table above)

SPACING

DISCONTINUITY SPACING (DS) =
(use figure 3.3 to determine the DS rating from the discontinuity spacings use the figure for mapping and not the figure for detailed classification).

WEATHERING

very irregular	irregular	uniform
0	25	50 points

UNIFORMITY OF SURFACE WEATHERING PROFILE RATING (UWP) = points
(use above table to determine the rating)

SENSITIVITY

slake durability (%):	< 70	70 - 95	> 95	slake durability: %
factor:	0.25	0.5	1.0	factor:

DELETERIOUS MINERALS (factor from field form 1)	factor:
Minimum of slake durability and deleterious minerals (S)	factor:

CALCULATION MAPPING ROCK-MASS RATING

ROCK MASS RATING = (LSR + UR + DS + UWP) x S =

preliminary index:
< 50(very poor), 50-150(poor), 150-250(fair), 250-350(good), > 350(very good)

Fig. 4. Calculation form for Problem Recognition Index (PRI).

6.2 Uniformity of rock strength (UR): Uniformity ratings from 0 to 50 based on percentage variation

The uniformity of strength within the rock unit is important. It is obvious that a large variation in the strength of the intact rock material implies a problem in many engineering projects. Consider the following examples. If a rock mass has to be excavated the locations with a high intact rock strength may have to be blasted, however, this causes overbreak in areas with a low strength. For construction materials a mixture of a high and low intact rock strength aggregate is nearly always unwanted or less economical. If a low intact rock strength is sufficient then a high intact rock strength causes excessive expensive excavation and crushers, whereas if a high intact rock strength is required the parts with a low intact rock strength are waste.
The uniformity may be judged by making a number of strength ratings in exposures in apparently the same lithology, within a 50 m diameter zone. This will lead to a form of a running average over the mapped area. The percentage variation may then be calculated on the basis of eq. [1].

$$\textit{percentage variation} = \frac{\textit{maximum strength rating} - \textit{minimum strength rating}}{\textit{average strength rating}} \qquad \textbf{[1]}$$

(*strength rating in points*)

Ratings are assigned to this parameter depending on the percentage obtained, less than 10% variation getting 50 points, more than 75% being awarded 0 points.

6.3 Rock unit block size and shape (RS): Ratings from 0 to 200

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Discontinuity spacing is important in that, for most engineering purposes, small rock blocks are a problem and large rock blocks offer fewer problems. Block shape is also important because tabular or columnar blocks cause greater problems than cubic. British Standard BS 5930 (1981) offers a description of rock blocks into blocky, tabular and columnar shapes and grades these into sizes ranging from very large to very small. However, the terms columnar, tabular and blocky are qualitative and BS 5930 does not prescribe a quantitative relation. Fig. 5 offers a rating system based on block size and form and, incorporating the basic idea that a rock unit composed of large cubic blocks is likely to give fewer engineering problems for most engineering works, gives the highest ratings for large cubic blocks. These then diminish as the blocks become smaller and change in shape from cubic to tabular and then columnar. The method of calculating the rating is given in Fig. 5.

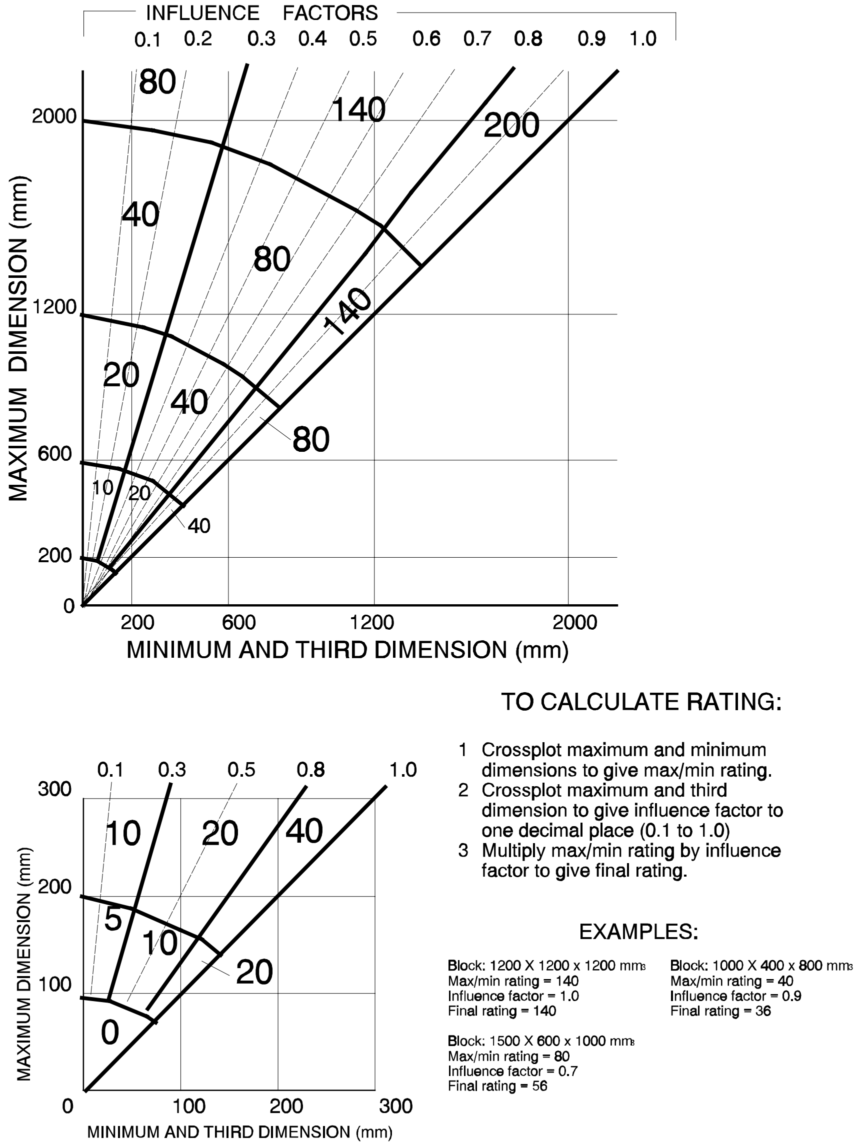

Fig. 5. The ratings system for block size and shape.

6.4 Uniformity of surface weathering profile (UWP): Ratings from 0 to 50

Weathering of the rock mass is important, particularly with regard to its uniformity. Experience suggests that highly irregular weathering profiles may give more problems for some engineering works than uniform profiles. For example, the construction of a shallow tunnel or tunnel portal in a rock mass with a very irregular weathering profile will be more difficult due to the variation in the rock mass quality caused by weathering. The different weathered parts may require different types of excavation and/or support. Similarly foundation problems may be a consequence of an irregular weathering profile. The end bearing capacity of bored piles with a standard length will vary all over a site if the weathering profile is very irregular. A constant end bearing is achieved only when the piles rest on sound rock but this requires the piles to vary in length which is more complicated engineering.

Three simple classes are proposed, namely 'very irregular' (rating 0), irregular (rating 25) and uniform (rating 50). Fig. 6 offers an indication of the 'irregularity' of the different classes. The uniformity of weathering should not be seen as a weathering classification but rather a an indication as to what extent existing weathering might cause problems when using the rock mass.

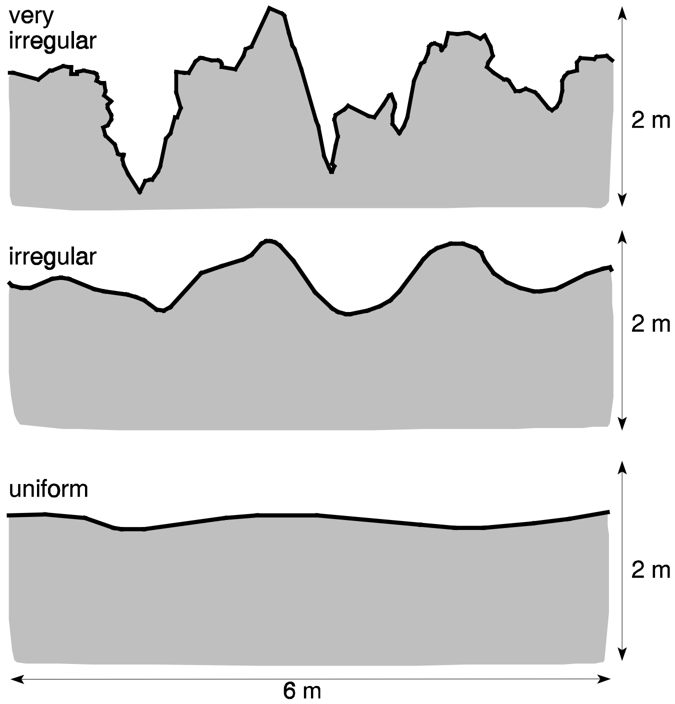

Fig. 6. Examples of weathering profiles.

6.5 Sensitivity (S): A multiplier on the sum of all previous factors; values 0 to 1

Some types of rock are more sensitive to weathering when newly exposed than others. This sensitivity may be established by local experience and observation or by tests, such as the slake durability test. Rocks may also contain particular minerals which may, in certain engineering processes, give problems. Minerals such as gypsum, anhydride, smectites, halite are examples. These problems are so important that instead of a rating a factor is introduced which is applied to the sum of all previous ratings. Factors range from 0.25 to 1 for sensitivity to weathering and from 0 to 1 for deleterious minerals. The lowest factor of the two is applied in the calculation for final rating.

6.6 End rating

The final numeric figure that expresses the amount of problems in or on a particular unit is dependent on the application and the scale of the map to be produced. For regional mapping purposes an end rating has been chosen that is likely to express the amount of problems per mapping unit in a general sense whatever the engineering application (eq. [2]).

$$PRI = (RSR + UR + RS + UWP) * S \qquad \textbf{[2]}$$

PRI is the Problem Recognition Index

The end rating is not truly a quality rating for quality must be judged against the application. Thus 'very good index' for foundation purposes could be 'very poor' in terms of difficulty of excavation. The end rating is intended to alert the user to potential problems. However, using the words commonly applied to judging rock mass quality a preliminary index division has been made and is presented in Table 2.

PRI	description
< 50	very poor
50 -150	poor
150 - 250	fair
250 - 350	good
> 350	very good

Table 2. Problem recognition index (PRI) classes.

With this definition of the problem recognition index (PRI), the best possible rock unit, for example an unweathered very widely jointed extremely strong isotropic granite, could give an end rating of:

$$PRI = 400 = (100 + 50 + 200 + 50) * 1$$

The end rating of 400 is equivalent to 'very good' meaning that none or very minor problems are expected for whatever use is going to be made of this unit. A very irregularly weathered, very weak, fissile shale containing bands of gypsum could give a rating of:

$$PRI = 2 = (5 + 0 + 5 + 0) * 0.2$$

This is equivalent to 'very poor' and it should be expected that any form of engineering that makes use of this unit could have severe and major problems during execution of the project and also that (major) maintenance of the completed structure might be necessary in the future. Of course, it should be appreciated that while this definition is appropriate for most engineering processes, it may be inappropriate for some. If is expected that a particular factor has a more severe influence on the engineering structure the weight for this factor can be increased. The index is intended as a guide to potential difficulty. However, a low rating could result from one of the factors, such as

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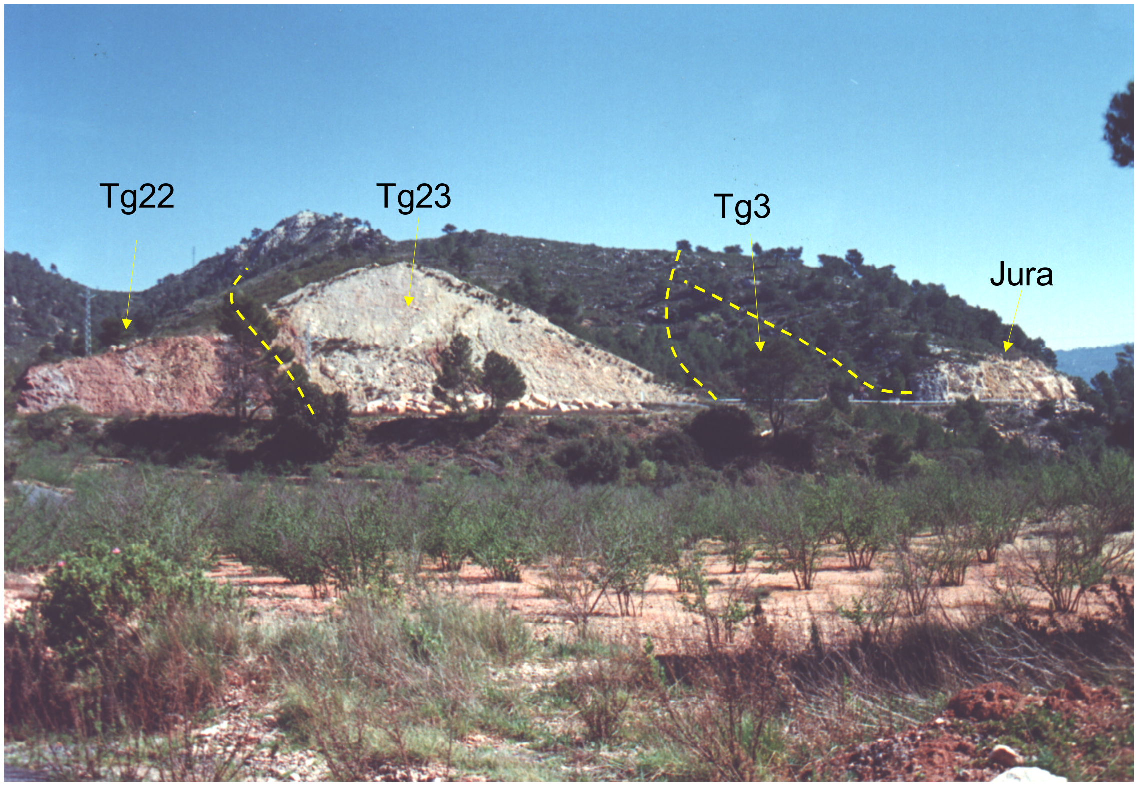

Fig. 7. Photo showing four different mapping units.

Price, D., Rengers, N., Hack, R., Brouwer, T., Kouokam, E., 1996. Problem recognition index (PRI) applied to the Falset area.
In: I Congrés del Priorat; resum de ponències i comunicacions, Gratallops, Catalunya, Spain, 13-15 December 1996. Adjuntament de Gratallops, Gratallops, Catalunya, Spain, p. 14.

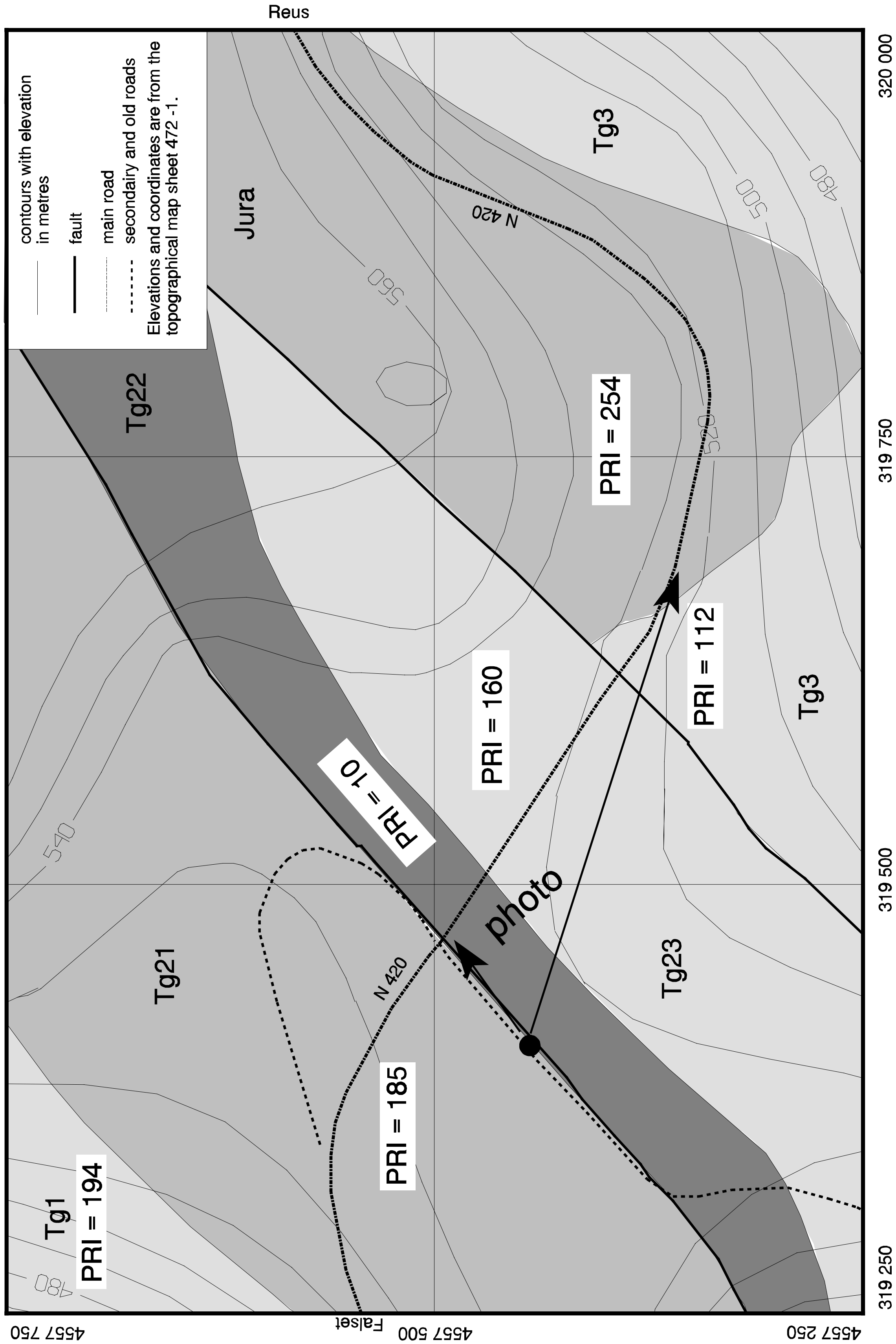

Fig. 8. Map with problem recognition index (PRI) of the area of Fig. 7.

UWP being low. This may or may not be significant with regard to the particular project. The alerted user must then look into the data base to find out how the index has been calculated. Any map produced showing these indices must be accompanied by a database.

7 Use

Examples of the field mapping form and the calculation form are given in Fig. 3 and Fig. 4. The problem recognition index (PRI) value resulting from the classification is plotted onto a map with the geological and structural boundaries. The combination of geological, structural and classification values results in the unit boundaries. The units depicted in this way are then characterized by a particular problem level. Within each unit it might be expected that seriousness of problems during the construction of an engineering work is then constant.

7.1 Operator independence

The problem recognition index (PRI) system parameters are reasonably operator independent. The only parameter that needs experience is the uniformity of weathering profile parameter. This parameter can easily be misjudged, leading to a PRI value that has a maximum error of 50 points.
Errors in the estimation of the presence of deleterious minerals or in the slake durability values lead to severe errors in the overall assessment of an unit. The sensitivity factor is a multiplier and has a very strong influence on the final PRI value for the mapping unit. It has been suggested to reduce the influence of the sensitivity factor or to change the multiplication in a subtraction with a maximum of 400 points for the deleterious minerals factor. Deleterious minerals are one of the main reasons for problems during execution of an engineering project and should thus have a major influence on the PRI. Therefore these suggestions have not been followed and the large sensitivity to errors is unavoidable.

7.2 Application

Fig. 7 shows a photo of an area which has 4 distinct different mapping units. Fig. 8 shows the geological map with classification values for the same area. A comparison of the PRI map values with the road engineering works displayed in Fig. 7 demonstrates the general validity of the system. The road cuts under low angle visible on the photo are in the units having low classification values whereas the high angle near vertical slopes are in mapping units with high classification values. The low angle slopes are in geological formations containing clayey silt and sandstones with in some places large quantities of gypsum (up to 50 %). The near vertical slopes are in mapping units of thick bedded limestones that are not expected to cause any problems in any type of engineering application.

8 Discussion and conclusions

Verification of an empirical classification system is always difficult. The problem inherent to verification of an empirical classification system is that the classification has been designed because parameters or factors could not be quantified or the physical and/or chemical processes that govern the behaviour of the mapping unit in an engineering application are not known or cannot be calculated due to lack of data or computation programs.
The radius used for the area uniformity rating is set to 50 m. The 50 m is tentative and it may well be that for other areas a different radius would be more appropriate.

The problem recognition index (PRI) is a classification system that attempts to quantify the severity of problems that could be expected by engineering applications in a mapping unit. The system is based on parameters that are thought to be important in engineering geology based on previous experience of the authors and of various other scientists and professionals who have been consulted during the research. The PRI system is not intended for design of engineering projects. The PRI system is intended as a help during planning stages of projects. In particular in long linear projects (roads, etc.) the system is expected to be useful. The system can be included in a Geological Information System (GIS). The GIS should include the geological and geotechnical boundaries. The values resulting from the system could be the reason to further divide the mapping units. Within a mapping unit an interpolation could be done of each of the factors of the classification system whereafter a calculation of the classification value can be done for each of the cells in a raster GIS system.

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