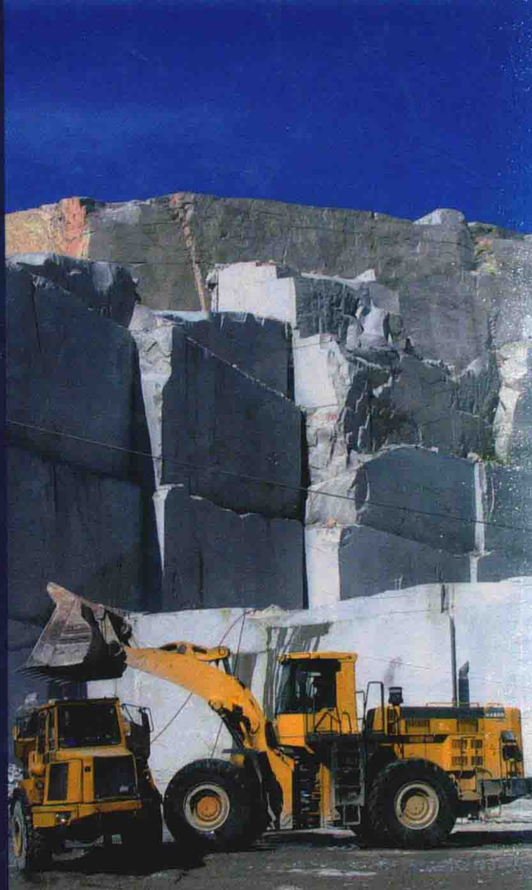
Soil and Rock Description in Engineering Practice

2nd Edition



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Soil and Rock Description in Engineering Practice

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To Susan
The rock without parallel

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Preface

Geoscience graduates are routinely sent out on site with little or no training to carry out logging of soils and rocks as part of a site investigation. It is assumed that they have been taught how to carry out a systematic description in their university courses, but this is generally not the case. For this reason we established a course in Soil and Rock Description (SARD) at Soil Mechanics Limited in the mid-1980s. It arose from the critical review that I and colleagues carried out of Section 8 of BS 5930:1981 which led to our published recommendations (Norbury, Child and Spink, 1986). These courses which have now been delivered within Soil Mechanics over 100 times to date varied in length from half a day to four days, but it generally takes about three days to cover the material satisfactorily when practical sessions are included. This compares with the few minutes briefing and perhaps a few more minutes at the core box that most young graduates are given.

This book represents a distillation and refinement of the material assembled for the SARD course over the last 30 years. During this period, the standards framework has changed significantly. BS 5930 was revised in the 1990s to accommodate the experience gained in implementing the first version. At the same time, an ISO committee was drafting international practice which has since been published as normative EN ISO Standards around the world. These Standards introduced changes to descriptive terms which have had to be accommodated into practice. This led to the amendment of Section 6 of BS 5930 in 2007 and 2010 and culminated in the further revision of BS5930 in 2015.

The aim of this book is to provide practical guidance for those having to go out in the field to undertake engineering geological logging of the soil and rock samples and the exposures that are available. The systematic and codified approach is different from any other geological logging that most will have been taught and so care is required to ensure that the right terms are used in accordance with the definitions. A standard word order is provided not, as many believe, merely for the sake of it, but because if the descriptors are used in a consistent format life is much easier for all, mistakes are less likely and better communication is achieved.

The guidance within this book is not only for the young practitioners learning their craft however. It is also aimed at their seniors and mentors, including the responsible expert who is signing off the logs and reports on behalf of the company. These individuals have often been logging for many years, although in practice they may not have got their hands dirty for a while. They also need to catch up on the precise details of the current approach and the changes that have been introduced if they are to avoid mistakes which could be costly.

SARD is an art form in that the aim is to convey to the reader the key features of the ground that were visible in the exposure as though they were also present to carry out the inspection. This is important because the soil samples are not usually inspected by any party other than the driller and logger and in any case these deteriorate quickly and are thrown away within a few weeks or, in the case of trial pits, within an hour or so. The field logs therefore provide the only record of the ground that is available to the designer and contractor later in the construction process.

I would like to note my thanks and debt to a number of individuals with whom I have worked in establishing and evolving the descriptive framework described in this book. In the early days, I acknowledge the input of Geoff Child and Tim Spink as we reviewed the 1981 Standard and prepared our paper for the Guildford conference in 1984. The in-house course was then developed with Tim and Dick Gosling. In particular, it was Tim who sketched out a number of diagrams and figures, which have evolved into figures within this text. Ever since the first course in 1988, these two colleagues and I have collaborated closely in preparing and delivering courses and in the preparation of national standards. Without their collaboration over two decades or more, the subject of soil and rock description would not have reached its current refined state. This collaboration and evolution will continue over the coming years as there is still work to be done to remove inconsistencies which remain.

There are also the helpful comments and assistance provided by other SARD teachers and delegates within Soil Mechanics and beyond who are too numerous to mention individually. The people who have attended the courses have helped over the years by challenging notions. This has required the preparation of substantiated responses. Finally, and far from least, thanks are due to Matt Wolsey for preparing all the line drawings in a form suitable for publication.

Preface to Second Edition

In the five years since we published the first edition of this book I have been overwhelmed by the enthusiastic response expressed in reviews and feedback from friends and colleagues around the world. In particular, the publication engendered further discussion on the subject and so, although it might be thought that this is a mature subject and that there is nothing more to develop or say on the matter, I have found it necessary to continue to evolve how we describe soils and rocks.

To this end, the UK standard has been revised as Chapter 6 on soil and rock description within BS 5930:2015, the code of practice for ground investigations. At the time of writing we are actively engaged in updating the three EN ISO Standards (14688-1, 14688-2 and 14689-1); these matters move more slowly in the international arena, but I am hopeful that we will agree the amended texts in 2016 and then move towards publication in late 2016 or early 2017.

I hope you find the improvements to the guidance on soil and rock description given in this edition in order to keep up to date with the Standards is helpful. I do welcome continued feedback and discussion on these matters, but rest assured I do not have plans for further revisions in the immediate future.

David Norbury

Definitions

The EN ISO standards start by providing definitions of many of the terms used in the standards. Provision of clarity at an early stage of the document is very useful. This lead is followed here and definitions of some key terms relevant to the description of soils and rocks are given below.

Description of soils and rocks is the reporting of the material and mass characteristics seen in the exposure or sample. The description is carried out in the field and does not require test results to be completed. Descriptions are presented as a major component of the field log and should be an interpretation which represents the in situ condition of the ground at the investigation position before any disturbance caused by the formation of the exposure or the taking of the sample. Description can also be carried out in the laboratory in which case this interpretative element is not possible.

Classification is a process that follows description and uses the geological succession, the variability of the engineering characteristics of the succession and the results of tests to place the soil or rock into pre-defined classes which are of uniform character and this assists in the evolution of the ground model. Classifications are not normally explicitly presented on field logs, but are used to present and discuss the ground conditions within the report and on plans and sections of the site.

Soils are assemblages of mineral particles and/or organic matter in the form of a deposit which can be separated by gentle mechanical means and which include variable amounts of water and air (and sometimes other gases). They include naturally deposited sediments and organic materials. Soils can be considered in terms of soil material and soil mass and display relict structure or fabric features when weathered in situ. The difference in properties between the material and the mass is not as large as in rocks, although the discontinuities in soil can also be critically important to the overall behaviour.

Rocks are naturally occurring assemblages of minerals which are consolidated, cemented or bonded together so as to form material of greater strength than soils. Rocks are composed of the **rock material** which is present between the discontinuities and the **rock mass** which is the whole rock together with the discontinuities and weathering profile. The discontinuities dominate the behaviour of the rock in engineering terms.

Rockhead is the boundary between materials that are described or classified as soil and those that are considered as rock. There are a number of definitions of rockhead, which can be based on strength, stiffness, structure or fabric, geological origin or specification clauses applied to the site works. In field description the identification of both the geological and engineering rockhead is usually necessary.

Anthropogenic ground is the collective name for those soils which are laid down by man and are composed of either natural or man-made materials.

Marl is a calcium carbonate or lime-rich mud or mudstone which contains variable amounts of clays and aragonite. Marl was originally a term loosely applied to a variety of materials, most of which occur as loose, earthy deposits consisting chiefly of a mixture of clay and calcium carbonate, formed under freshwater conditions. The term is today often used to describe indurated marine deposits and lacustrine sediments which are probably more accurately named marlstones. Marlstone is an indurated rock of about the same composition as marl, more correctly called a clayey argillaceous limestone. It tends to have a blocky sub-conchoidal fracture and is less fissile than shale.

Loam is a soil composed of sand, silt and clay in proportions typically of about 40-40-20% respectively, and is generally considered ideal for gardening and agricultural uses. Loams are gritty, moist and retain water easily. In addition to the term loam, different names are given to soils with different proportions of secondary constituents including sand, silt and clay (see Chapter 13.1.1).

The **nature of the soil grains** refers to their particle size grading, shape and texture or, if appropriate, their plasticity, together with special features such as organic or carbonate content. The nature of a soil does not usually change during civil engineering works. Nature can be described on disturbed samples.

The **state of the soil grains** is their packing, water content, strength or relative density and stiffness. The state of a soil usually changes during civil engineering work; the description of the soil state requires undisturbed samples or exposures.

The **fabric** or **structure** of a soil or rock comprises the large scale spatial interrelationship of elements and can include folds, faults, or the pattern of discontinuities defining the soil or rock blocks. The structure includes features that are removed by reconstitution, that is fabric or microfabric features, such as layering, fissuring or cementing. Structure is often destroyed by large distortions and so can be observed only in the field on natural or artificial exposures or, to some extent, in an undisturbed (Quality Class 1) sample.

Texture is the size, shape and arrangement of the grains (sedimentary rocks) and the crystals (igneous rocks).

Particle size grading is the proportion of particles of each size fraction by weight. Size fractions are defined on the basis of a range of particle size. Examples include clay or sand. The range of soil particles is divided into a number of size fractions. These range from boulders which are larger than 200 mm, through cobbles, gravel, sand and silt to clay. The individual particles in silt and clay fractions are not visible to the naked eye. Some size fractions are subdivided into coarse, medium and fine.

The **matrix** is the finer grained component of the soil or rock which fills or partially fills the voids between the grains which can also be called clasts or crystals. Soils or rocks with a range of size fractions can be either clast or matrix supported, indicating which size fraction is present as a continuum and which will therefore control the behaviour.

Discontinuities are the mechanical breaks which intersect the soil or rock material and break it up into fissure or joint bounded blocks. Examples include fissures (a term used in soils), joints, shears, faults and cleavage. The term discontinuity is synonymous with the term **fracture.**

Bedding planes separate different beds and represent changes in the depositional sequence. Bedding can be indicated by colour or material changes, but the latter are usually more important in engineering logging. Bedding planes are not necessarily a plane of weakness and therefore may not be a fracture.

Bedding fractures occur along bedding planes. Identifying whether a bedding fracture is induced by the sampling process or is naturally present in the ground can be very difficult.

Joints are breaks of geological origin in the continuity of a body of rock along which there has been no visible displacement. A group of parallel joints is called a set and joint sets intersect to form a joint system. Joints can be open, filled or healed. Joints frequently form parallel to bedding planes, foliation and cleavage and may be termed bedding joints, foliation joints and cleavage joints accordingly.

The spacing of joints tends to decrease with stress relief and weathering, that is as the depth of burial decreases. Fissures are exactly the same as joints but the term is usually reserved for such features in soil. This distinction between joints in rock and fissures in soil is not standardised, but has grown as a common practice.

Cleavage fractures occur along the preferentially aligned minerals that make up cleavage. Care needs to be exercised in recording the spacing of cleavage fractures. Cleavage is a penetrative foliation and so the number of fractures present will tend to change with time. A freshly recovered core could well be recovered as a complete intact cylinder without any fractures being observable. As the core responds to the removal of the surrounding stress, dries out and is mechanically disturbed, fractures start to appear, such that within a few days the core will split into discs and these will become progressively thinner as more and more fractures appear.

Incipient fractures are natural fractures which retain some tensile strength and so may not be readily apparent on visual inspection.

Induced fractures are those created by the drilling, sampling or excavation process, which were not fractures in the ground. The assessment of these fractures is often not straightforward. The standard logging convention is that induced fractures are not described and are not included in assessment of the discontinuity state.

Faults are fractures or fracture zones along which there has been recognisable displacement, from a few centimetres to a few kilometres in scale. The walls are often striated and polished resulting from the shear displacement. The rock on both sides of a fault can be shattered and altered or weathered, resulting in fillings such as breccia and gouge. Fault widths may vary from millimetres to hundreds of metres. Faults can comprise single shear surfaces or multiple surfaces which combine to create a fault zone. The intervals between individual surfaces in a **fault zone** can be filled with **fault gouge** which is comminuted host material.

Shear surfaces are joints across which displacement has occurred. Shear surfaces tend to be smoother than joints and may have polished surfaces. Depending on a combination of confining pressure, grain size and joint spacing of the rock, and the amount of movement, shear surfaces can be striated.

The **discontinuity features** that should be routinely described in rock mass assessment are outlined in Chapter 11 and include:

- Orientation – attitude of the discontinuity described by the dip direction (azimuth) and dip of the line of steepest declination in the plane of the discontinuity.
- Spacing – perpendicular distance between adjacent discontinuities. Normally refers to the mean or modal spacing of a set of joints.
- Persistence – length of a discontinuity observed in exposure. May give a crude measure of the areal extent or penetration length of a discontinuity. Termination in solid rock or against other discontinuities reduces the persistence.
- Roughness – inherent surface roughness and waviness relative to the mean plane of a discontinuity. Both roughness and waviness contribute to the shear strength. Large scale waviness may also alter the dip locally.
- Wall strength – strength of the walls of a discontinuity. May be lower than rock block strength owing to weathering or alteration of the walls. It is an important component of shear strength if rock walls are in contact.
- Aperture – perpendicular distance between adjacent rock walls of a discontinuity, in which the intervening space is open or infilled, see below.
- Infilling or filling – material that separates the adjacent rock walls of a discontinuity and that is usually weaker than the parent rock. Typical filling materials are sand, silt, clay, breccia, gouge, mylonite. Also includes thin mineral coatings and healed discontinuities, e.g. quartz, and calcite veins.
- Seepage – water flow and free moisture visible in individual discontinuities or in the rock mass as a whole.
- Number of sets – the number of joint sets comprising the intersecting joint system. The rock mass may be further divided by individual discontinuities.
- Block size – rock block dimensions resulting from the mutual orientation of intersecting joint sets and resulting from the spacing of the individual sets. Individual discontinuities may further influence the block size and shape.

Contents

1 Introduction

A site investigation lives or dies by its field logs

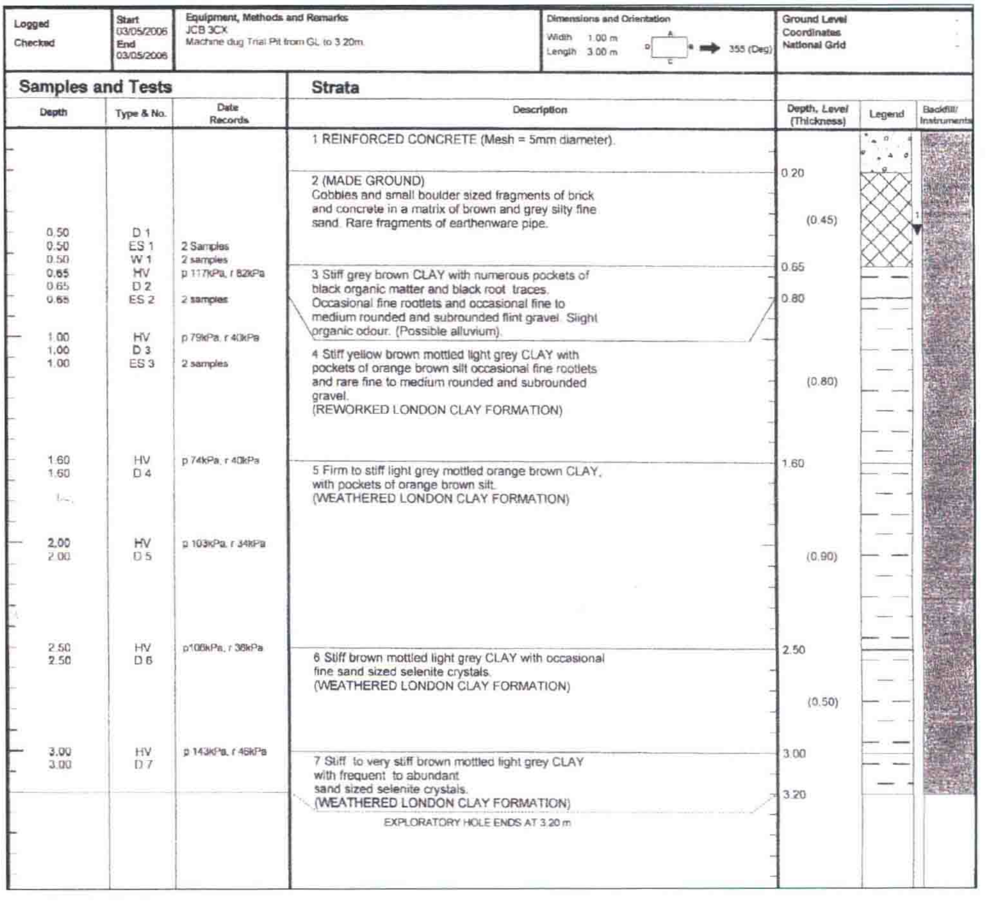
—Dick Gosling, personal communication

The description of soils and rocks in engineering practice forms a major and hugely significant input to one of the fundamental components of an investigation of the ground, namely the field log. The field log should record the materials and strata seen in a borehole, trial pit or any other type of investigation hole, or record an exposure such as a cliff or quarry face. The record presented as the field log (see Figure 1.1) or the digital data behind the field log includes descriptions of the strata encountered and a range of other field observations which provide additional information to that presented within the description alone. The descriptions within the field log are a basic element of the factual information that underpins the entire understanding and interpretation of the ground conditions at the site. The field log is therefore a basic building block in the compilation of the ground model. The field log is also all that remains after the investigation has taken place, the trial pit has been backfilled and the borehole samples or cores are no longer available. The field log therefore has a life well beyond that of the investigation report.

The purpose of this book is to provide the background and framework for the recording of exposures (which can include samples, cores, trial excavations or exposures) and for the communication of this record to the reader or user of the information. The users of field logs include clients, designers and contractors.

The descriptions contained within a field log are used in a number of ways and at various stages of the investigation:

- They provide the designers with information to guide the scheduling of field and laboratory tests.
- They provide a framework used in the interpretation of those test results and in the lateral and vertical interpolation or extrapolation of those results to the whole site.
- In many cases, the description is relied upon, because test results are either not available or cannot be used since representative samples may not be available or recoverable.
- The descriptions are a key element in the preparation of the permanent works design in terms of providing information that helps in understanding how the ground will behave and interact with the structure.
- The field logs and descriptions also provide information that is critical to the contractors who have to carry out the works. The aspects that a contractor will be interested in may centre on the site preparation or the temporary works so their interest will include aspects of how the ground will respond to



Logged	Start 03/05/2006	Equipment, Methods and Remarks	Dimensions and Orientation	Ground Level
Checked	End 03/05/2006	JCB 3CX Machine dug Trial Pit from GL to 3.20m.	Width 1.00 m Length 3.00 m 355 (Deg)	Coordinates National Grid

Samples and Tests			Strata			
Depth	Type & No.	Date Records	Description	Depth, Level (Thickness)	Legend	Backfill/ Instruments
			1 REINFORCED CONCRETE (Mesh = 5mm diameter).	0.20		
0.50 0.50 0.50	D 1 ES 1 W 1	 2 Samples 2 samples	2 (MADE GROUND) Cobbles and small boulder sized fragments of brick and concrete in a matrix of brown and grey silty fine sand. Rare fragments of earthenware pipe.	(0.45) 0.65		
0.65 0.65 0.65	HV D 2 ES 2	p 117kPa, r 82kPa 2 samples	3 Stiff grey brown CLAY with numerous pockets of black organic matter and black root traces. Occasional fine rootlets and occasional fine to medium rounded and subrounded flint gravel. Slight organic odour. (Possible alluvium).	0.80		
1.00 1.00 1.00	HV D 3 ES 3	p 79kPa, r 40kPa 2 samples	4 Stiff yellow brown mottled light grey CLAY with pockets of orange brown silt occasional fine rootlets and rare fine to medium rounded and subrounded gravel. (REWORKED LONDON CLAY FORMATION)	(0.80)		
1.60 1.60	HV D 4	p 74kPa, r 40kPa	5 Firm to stiff light grey mottled orange brown CLAY, with pockets of orange brown silt. (WEATHERED LONDON CLAY FORMATION)	1.60		
2.00 2.00	HV D 5	p 103kPa, r 34kPa		(0.90)		
2.50 2.50	HV D 6	p106kPa, r 38kPa	6 Stiff brown mottled light grey CLAY with occasional fine sand sized selenite crystals. (WEATHERED LONDON CLAY FORMATION)	2.50 (0.50)		
3.00 3.00	HV D 7	p 143kPa, r 46kPa	7 Stiff to very stiff brown mottled light grey CLAY with frequent to abundant sand sized selenite crystals. (WEATHERED LONDON CLAY FORMATION)	3.00 3.20		
			EXPLORATORY HOLE ENDS AT 3.20 m			

Figure 1.1 Example of a field log.

excavation, whether the materials are suitable for re-use, whether any ground treatment is needed and if so what sort might be appropriate and what support needs to be provided in the construction works.

For all these reasons it can be seen that complete and accurate description of the soils and rocks underlying a site is fundamental to all investigations. Compilation of the descriptions that appear on a field log is carried out by a field logging geologist or engineer. The completeness and correctness of the investigation report can therefore only be as good as this logger.

Despite the great importance which should thus be attached to field descriptions, this activity is usually carried out by the youngest members of staff, the newly qualified graduates. This is usually blamed on the need for a low price investigation. Whether this economy is false or genuine can be debated, but the true question is whether we as the investigation industry are providing our clients with a complete and professional service. All too often the answer to this question tends to be in the negative. Whilst many clients do not help themselves in this matter with their attitude to the cost benefits that can be achieved from an appropriate and professional site investigation, the industry should educate clients and manage the client's expectations.

Graduate staff who are deployed under this illusion of apparent economy may well have not received significant engineering geological training, or at least not in systematic description. The investigation industry tends to presume that these youngsters are trained and capable and expects them to launch immediately into description in the field. This presumption is usually made without reference to course curricula.

Even if these staff are geology graduates, they will probably not have received training specific to this most important activity, that is the engineering geological description of soils and rocks. The requirement of site investigation is for the systematic and accurate recording of all the samples or exposures using defined terminology in a standardised manner. Few undergraduate courses teach systematic description in a way that is sufficient for the investigation industry. There are exceptions, of course, but even these more enlightened establishments rarely teach the description of both soils and rocks.

Given these conditions, it is necessary for the requisite training to be provided after graduation and within industry. Until recently there have been no courses teaching soil and rock description on the open market and few companies provide formal in-house training courses. A large proportion of industrial training in this area is necessarily provided by one-to-one supervision or mentoring by more experienced members of staff within companies. Although this is a reasonable approach, it is far from certain that these staff have themselves received any formal training. The possibility that the young graduates will, therefore, be taught bad or even incorrect practices from the outset is significant and does happen. This is not helped by those individuals who believe that the best way to learn is by making mistakes. If this philosophy is invoked in soil and rock description (SARD) activities, the mistakes are quite likely to find their way into the field log on which the design work and the contractor's price are based.

The intention of this book is to provide a practical guide to carrying out soil and rock description in an engineering context for these juniors who do not have the necessary training or background experience. It also aims to fill gaps in the general level of knowledge about soil and rock description for the juniors and their seniors who check their work and sign off the reports and field logs that they include. In addition to the now current systematic practice, changes to practice that have taken place over the last 40 years and those that are taking place at the time of writing are highlighted. These changes are not all advances in descriptive practice, but they are now in normative standards and have to be followed until such time as those standards are revised and improved.

Throughout this book the process of the recording of exposures through description is given in detail. These exposures can vary from in situ material, such as a cliff face or trial pit or other in situ exposure, to continuous or intermittent individual samples recovered from a borehole and which are described remote from the field location. These samples can include disturbed and supposedly undisturbed samples and rotary drilled cores. The description of a number of such samples, be they large or small, leads to the compilation of a field log of the ground conditions. One purpose of this book is to provide guidance on the process of transferring the visual observations at the point of logging to the field log. This field log will be used by others and will remain as a record of the ground long after the samples have been discarded or the exposures covered up.

The reader should be aware that throughout all logging activities, there is a difference between the level of detail and the level of quality. A simple log is not detailed but can be of high quality because all the information that really matters is presented accurately. All field logs should be of high quality, but the level of detail to be recorded will vary depending on the nature of the ground and the requirements of the investigation. It is not appropriate to record the maximum level of detail in all investigations. The selection of the right level of detail requires experience together with a thorough understanding of the proposed works and how they and the ground will interact.

This book begins with a summary in Chapter 2 of the historical background to codification in soil and rock description over the last 50 years. This history is important as the terms and definitions in use have not remained unchanged and some terms have been recycled. Anyone using old field logs needs to be aware of these changes. In Chapter 3 the procedure for carrying out descriptions (which has not changed) is given, together with the standard word order which forms the basis for the systematic approach to this activity.

Description of soils and rocks is split into the description of the material features, which is the natural ground without discontinuities, and the mass which includes the discontinuities and the effects of weathering. Details of the description of the material are given in Chapters 4 to 9 in the same sequence as the standard word order. The description of the mass aspects of the ground is covered in Chapters 10 to 13.

The distinctions that have to be made to identify different classes of soil and rock, between coarse and fine soils and between inorganic and organic soils and between natural and anthropogenic soils is the first important step within a systematic description. The procedures for making these distinctions are outlined in Chapter 4, which provides guidance on the naming of the soils and rocks that are being described. Having named the material, description is then carried out in a sequence in accordance with the standard word order previously given in Chapter 3. The next chapters provide guidance on each aspect of the description in turn. Descriptions of the terms relative density, consistency and strength are given in Chapter 5 where the differences for each class of material require different approaches. Chapter 6 covers the description of the structure of the soil or rock, either through the description of fabric in soils, or of structure, fabric and texture in rocks. The brief Chapter 7 is devoted to colour although for many this may overstate its importance. However, the need for accurate description of the colour is just as great as any other aspect of the material being described.

The behaviour of all soils and rocks is modified by secondary and tertiary constituents of the material, which need to be assessed in the field and reported. This is not always easy and although descriptions can be verified against subsequent laboratory test results, it is, of course, important that the constituent fractions are correctly assessed and described in the field. Guidance on this aspect of the description is provided in Chapter 8. The description of the soil or rock material is concluded with the identification of the geological unit and guidance on this aspect is given in Chapter 9. This is a relatively straightforward step, but care still needs to be exercised to get it right and not to overstate the confidence in the name assigned.

The mass features of all soils and rocks should be described because these aspects have a major influence on the behaviour of the ground in response to the engineering works. The description and classification of weathering is considered in Chapter 10. The logging of discontinuities in the mass is given in Chapter 11 with definitions