Keeping the "Geo"; Why and How

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OPENING REMARKS

First, I thank the Society for this award, and point out that the great honour it represents must be shared with many engineers and geologists I have worked with and learnt from, during the past 44 years. I knew and admired Professor Jaeger for his contributions to the Snowy Mountains Scheme, and later enjoyed contact with him during planning for the 1973 National Symposium on Rock Fragmentation. He understood the practical importance of the "geo" part of geomechanics, and I believe he would approve of the objectives of this lecture, given in his memory.

The request for this lecture posed a difficult problem for me. It was suggested that "some exciting case histories" would be appropriate. This would be the easy option, but I could not forego an opportunity to put some views on educational requirements for geomechanics professionals.

1. ARE WE STILL LOSING THE "GEO"?

In "Let's keep the "Geo" in Geomechanics" (Stapledon, 1986) I looked critically at site investigation practice in Australia, and drew the following conclusion:

"Out of our ineffective education system has come a generation of geotechnical engineers, most of whom have been happy to use a set of soil symbols which are geologically ridiculous, and who have the attitude that geology is for geologists. I don't agree with this attitude, because even though site characterisation work is largely an exercise in geology, most of it is done by engineers."

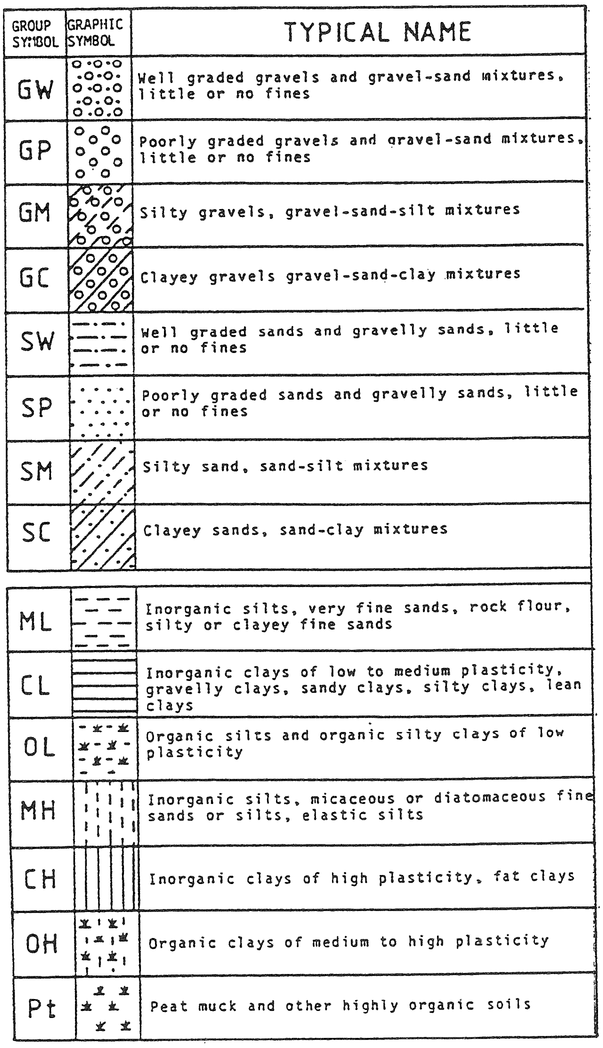
I also recommended :

"*...that the Society take positive steps to improve the standard of geology presented to engineers ....*"

and concluded :

"Otherwise, in the long term we will have in reality, a Mechanics, rather than a Geomechanics Society."

The "geologically ridiculous" symbols referred to were those in AS 1726-1981 (Standards Association of Australia, 1981), first seen in AS 1726-1975. I recommended that these symbols (Figure 1) be replaced by simple basic symbols (Figure 2) and presented Figure 3 and other examples to the symposium, to show that the standard symbols were not only inadequate, but misleading. No-one disagreed. The code was revised in 1993 (Standards Australia 1993), and the symbols were deleted, but unfortunately, not replaced. My research for this present paper (Appendix A) has shown that they are still being used by groups employing more than two thirds of Australia's geotechnical professionals.



GROUP SYMBOL	GRAPHIC SYMBOL	TYPICAL NAME
GW		Well graded gravels and gravel-sand mixtures, little or no fines
GP		Poorly graded gravels and gravel-sand mixtures, little or no fines
GM		Silty gravels, gravel-sand-silt mixtures
GC		Clayey gravels gravel-sand-clay mixtures
SW		Well graded sands and gravelly sands, little or no fines
SP		Poorly graded sands and gravelly sands, little or no fines
SM		Silty sand, sand-silt mixtures
SC		Clayey sands, sand-clay mixtures
ML		Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
OL		Organic silts and organic silty clays of low plasticity
MH		Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
CH		Inorganic clays of high plasticity, fat clays
OH		Organic clays of medium to high plasticity
Pt		Peat muck and other highly organic soils

Figure 1. Symbols for soils, from AS1726-1981. (From Stapledon, 1986).

Other conclusions in the 1986 paper included :

- the importance of graphic representation of data on logs of boreholes and excavations
- a caution abut the potential for errors when borehole logs are produced at places remote from the site, by computer
- more use should be made of surface geological mapping.

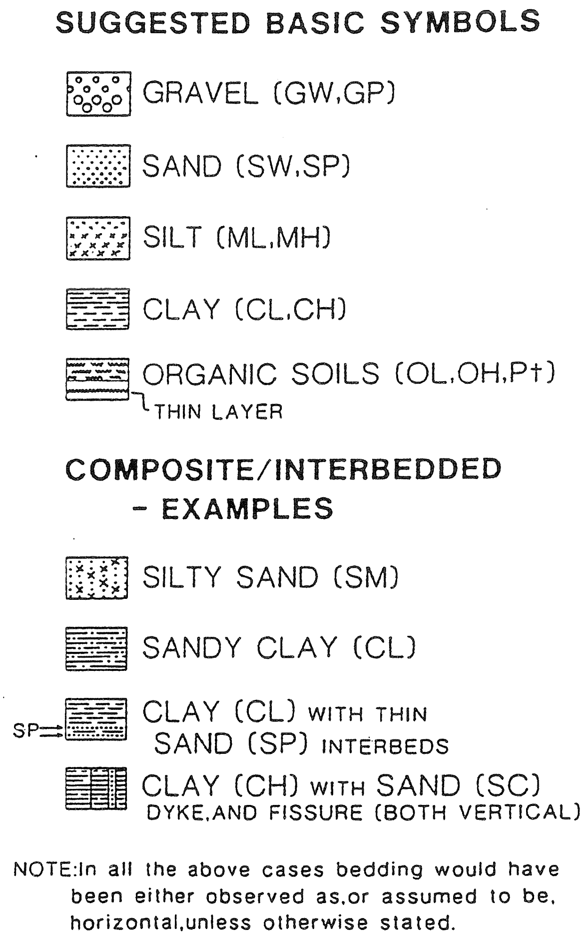


Figure 2. Suggested basic symbols to replace those in AS 1726-1981. (From Stapledon, 1986).

Since 1986 I have seen further examples of projects with troubles which could have been avoided by heeding some of the above advice. The following were the most disturbing :

In Case A, very expensive computer modelling was completed and reported on, using largely coded drill core data which had been entered by geologists onto cards, without preparation and interpretation of detailed graphic logs as part of their field logging. Later interpretation showed a vital aspect of the geological picture assumed in the modelling to be incorrect.

In Case B, a major, vital geological feature was missed by engineers, during an investigation involving a relatively large number of cored boreholes. This feature could have been inferred easily and cheaply from mapping of surface outcrops and topographic evidence at the site.

I have to conclude that little has changed since 1986, and we are still losing the "geo".

I have also thought about educational requirements for all geotechnical professionals. Throughout my career, I have made blunders, varying in severity, which have related at least partly to my lack of basic training in soil and rock mechanics.

Accordingly, the primary aims of this present paper are :

(i) to persuade all geotechnical groups to stop using the AS 1726-1981 or similar soil symbols, and to adopt improved practices for collection of basic geotechnical data, during logging of boreholes and excavations and
(ii) to discuss the needs for and availability of undergraduate and postgraduate education for geotechnical professionals.

2. THE SYMBOLS, WHY STOP USING THEM?

Figure 3, taken from the 1986 paper, shows graphic logs of the same borehole prepared using (a) my recommended symbols, which are very similar to those in BS 5930-1981 (British Standards Institution, 1981) and (b) symbols from AS 1726-1981.

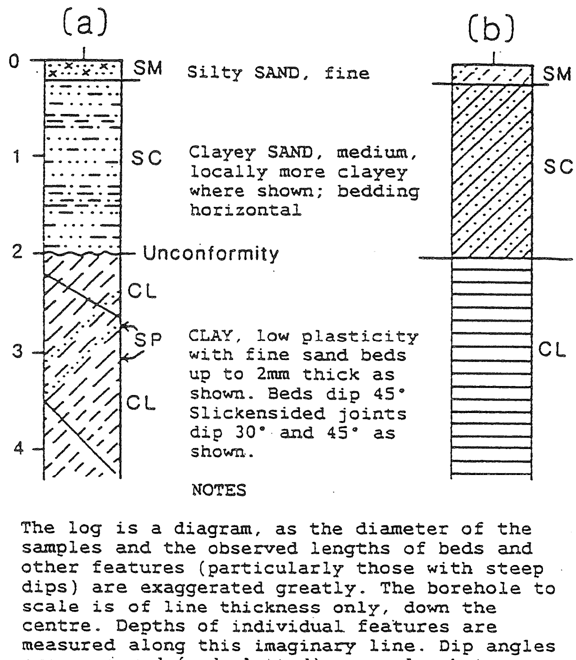


Figure 3. Borehole log prepared using different graphic symbol systems. (From Stapledon, 1986).

That figure was accompanied by the following text :

"Figure 3(a) shows portion of a borehole log, drawn up using the basic symbols on Figure ..... In its top 200mm the hole passed through a horizontal layer of fine silty sand (SM). This was underlain conformably by horizontally bedded clayey sands (SC) which varied in clay content at different levels. The horizontal bedding and the subtle variations in clay content are shown simply and clearly by the symbols. At 2 metres the hole entered a low plasticity clay (CL) bedded at 45 degrees, and containing fine sand beds (SP) at 2.75 and 3.05 metres. Slickensided joints (fissures) were met at 2.45 and 3.9 metres. All of these features are indicated clearly on the log, and hence only a small number of explanatory words have been required. The fact that the boundary at 2 metres is an unconformity is immediately obvious from the graphic log ......"

"Figure 3(b) shows a graphic log for the same four metres of borehole, prepared using Australian Standard symbols. It is not possible to show sensibly, the bedding orientations, the conformable boundary between the silty and clayey sands, the variations in clay content, the unconformity, nor the thin sand beds. Thus many more words will be required if these features are to be described."

With a Figure 3(b) type log or a log without any graphics, the logger who recognises the important geological features will have to spend time and effort compiling the extra words, and the user of the log will have to spend time and effort composing a mental picture of the ground, from the words. Apart from the inefficiency, the picture so obtained is unlikely to be as clear or accurate as one drawn directly from the ground, and the probability of incorrect interpretation or correlation must be increased.

It should be clear also that "dominantly words" approaches prevent or discourage engineers (and geologists) from drawing geological features that they see, and from the next step, trying to understand and interpret them. Therefore they are deprived of the most effective way to extend their knowledge and understanding of geology. This is particularly serious for today's civil engineering students and recent graduates, because as I will show later in this paper (i) most of them will receive, or have received, inadequate basic training in geology, and (ii) there is little or no opportunity to remedy this in postgraduate (MEngSci) programs, or short courses, in Australia.

2.1 A Set of Symbols for All Soils and Rocks?

Experience with many projects in a wide range of geological environments has shown that it is not sensible to try to develop a set of standard symbols for all soils and rocks. It is sensible to have sets of standard basic shapes, as in the upper part of Figure 2, and to use them "artistically" as in the lower part. Often the sizes, shapes or spacings of the symbol components need to be changed, to allow us to differentiate between different layers at the same site, which share the same group symbol. For example, a coarse GP comprising angular particles could be shown as large open angular shapes (rather than circles) and a fine GP comprising well-rounded grains could be shown as small circles.

3. THE TAIL IS WAGGING THE DOG!

A survey in early 1996 of 19 consulting groups employing 634 professional geotechnical staff (Appendix A) has shown that 416 of these people are in ten groups which still use the AS 1726 type symbols. Most are employed in four of the largest groups. When senior staff were questioned as to why they still use them, answers ranged from "we never really thought about it" to "we understand what you are saying, but they are on our computer program and so it will be very difficult to change them." One group employing 19 engineers does not use any graphics in logging of soils.

Some individuals in the largest groups have adopted the BS 5930 type symbols. They use the company computer logging system except for the graphic log, which they draw in the field and add to the final log in the office.

One large group and six of the smaller groups use geologically sensible symbols similar to BS 5930 and those on Figure 3(a).

As far as I know, the "artistic flexibility" described in 2.1 above cannot be achieved directly in the field, with any of the computer programs currently in use by groups involved in mineral exploration or geotechnical work. McMahon Associates (Appendix B) achieve it for major jobs, by hand drafting in the field and transfer by CAD in the office.

It is concluded that the introduction of computer produced logs is a major obstacle preventing change to sensible symbols. The tail is wagging the dog!

4. PRODUCING REALISTIC, EFFECTIVE LOGS IN THE FIELD, BY COMPUTER

4.1 Advantages of Producing Logs by Computer

The advantages of computer-produced logs are at least the following :

(i) large amounts of data are stored for future access, and
(ii) data can be selected and manipulated, to produce statistics, 3-D representations, enhanced pictures, etc. which can assist and accelerate the interpretation and presentation of the geological model.

It has been argued that computer produced logs can be more uniform in content than those produced manually, because of the discipline imposed by the rigid formats and limited choices of descriptive terms and graphics. In my experience this is not so: while reviewing reports and giving advice or evidence during more than 30 contractual disputes I have seen equally disastrous logs produced both manually and by computer. The key to getting uniformly good quality data from groups of field staff is training. Also needed are well designed log formats, which often need to be project-specific or site-specific. By restricting the operators to one format and a few inflexible standard symbols one is likely to get uniform mediocrity, at the best.

4.2 Requirements for Effective Logging by Any Method

Even in the simplest geological situations, it is vital for effective mapping or logging work, that the map or log is produced by the logger, in its final format, while he or she is on the ground or in the pit, doing the logging. This is because for each borehole or pit the logger must draw and describe the results of observations and tests, both in a progressive (piecemeal) manner, and by standing back and reviewing both the samples/ground and the log. The review periods are the "thinking time"; when the logger compiles a broad picture from the piecemeal (eg defines "homogeneous zones") and assesses the progress results in relation to the engineering questions, to the results of other holes and to an assumed or evolving site geological model. It is best practice to progressively plot and interpret the results of all holes on sections and/or a plan, in the field, during the logging period. The up-to-date interpretation enables immediate field decisions to be made e.g. on whether to proceed, and if so, on positions, depths and samples/testing needs for future holes.

4.3 Problems With Computer Logging as Currently Used

The computer logging programs currently in use in Australia either discourage or prevent engineers or geologists from following the above well-tested procedures. They do not allow logs to be produced in their final formats at the time of logging, and they are able to produce realistic graphic logs of only the simplest geological situations. Bedding and other near-planar geological features cannot be shown at measured angles, and irregularly shaped boundaries or defects cannot be plotted realistically.

Logging is in some cases done onto field forms quite different from the final log form, and data is entered in coded form (by means of letters and numbers. The final log is produced by a computer back at an office which is often remote from the site.

I first saw comparable "double handling of data" in 1951 in the Snowy Mountains Authority. In that case a draftsperson was manually rehashing the field data to produce the final log (rather than the computer and its operator, today). I was able to persuade the management, within 6 months, of the foolishness of that approach, by pointing out the time wasted in double handling and checking, the inevitable errors, and the fact that the system prevented the field geologist or engineer from seeing the complete log, graphically to scale, at the right time to apply geological or engineering judgement. I find it disturbing that this approach to logging, which effectively treats the field logging staff as "well trained monkeys", has returned in the 1980's as a reinvented square wheel.

Case A (see 1 above) is one of the three projects I know of which has suffered serious problems as a result of this approach to field logging.

4.4 Equipment and Programs Suitable for Logging

It would appear from 4.2 and 4.3 above, that the best system should be one which allows logs to be prepared directly at the site, by hand drawing and typing, and produces both a screen image and hard copies, at the site.

Computer geologist Grant Jacquier has suggested that currently there are 3 options available, 2 of which meet these requirements. The following descriptions of these options and comments on their advantages and disadvantages have been compiled largely from Jacquier (1996).

OPTION 1 - Pencil onto copy of final log form, with transfer to the computer, in the office.

The logger draws what he or she sees, using appropriate defined symbols, and then describes and interprets this picture in words (see 4.2 above). The results of field tests etc. are added as histograms or numbers, or both.

The field sheet is photocopied and either faxed or delivered to the office. Here the graphic log is transferred by CAD and the other data is keyed in. Alternatively, the graphics can be scanned.

Advantages

1. Field plotting is very rapid.
2. Allows effective logging as described in 4.2.
3. Reliable in all field conditions, e.g. dusty, hot, cold, or wet.

Disadvantages

1. Transfer of data in the office (especially the graphics by CAD) is slow.
2. Errors of transcription are inevitable.
3. Careful checking of the final log is needed and takes time.

OPTION 2 - Portable pen-based computer, at the drill site or in the excavation.

In the office, a programmer digitises the log form and transfers it to a pen-based computer as a template for data entry. The battery powered computer is taken to the site, where the graphic log is drawn using a stylus, and coded data and descriptions/interpretations are keyed in. A hard copy is printed out and checked against the samples or excavation sides, and later used as a backup copy. The completed log can be transmitted to a main office from a motel room or site office, by telephone or floppy disc.

Advantages

1. Allows effective logging as described in 4.2.
2. The final log can be completed and checked in the field.
3. It is possible to do some data processing in the field.
4. At the main office, the transmitted log is available immediately for processing

Disadvantages

1. Field logging will be much slower than with pencil and paper; the computer cannot keep up with the hand drawing, and keying in is slow.
2. There will be lots of downtime due to flat batteries (2 to 4 hours life), heat stress, etc.
3. High costs - estimated $10,000 to $15,000 for equipment, and extra for initial custom programming, and for any changes to forms.

OPTION 3 - A hybrid of paper/pencil and portable computer, and using a vehicle as a field office.

In this option, the field sheet has columns only for the graphic log and general descriptions. The power source can be plenty of dry cell batteries or the vehicle battery via a transformer which plugs into the cigarette lighter socket. The computer has a spreadsheet-like program attached for keyboard entry of coded data, against depth.

As the site, the graphic log is drawn by hand and the general descriptions are hand written/printed in their columns. The coded data are keyed in.

At the vehicle, the field sheet is fed into a fax scanner which scans the drawing and text and outputs these to the computer. The logger uses a customised CAD program to combine the scanned images and coded data already in the computer, to produce a draft log. A paper copy is printed out and carefully reviewed against the samples or excavation. This is vital because during the initial field logging the logger is unable to view and assess all of the data (graphic, text and coded). Amendments are likely to be made as a result of this review. A copy of the final corrected log can be sent to the main office by fax and mobile phone.

Advantages

1. The final log can be completed and checked in the field.
2. Allows effective logging as described in 4.2.
3. It is possible to do some data processing in the field.

Disadvantages

1. Field logging will be much slower than with pencil and paper - due to keying in data, the second site visit (review), and the CAD is slow.
2. Relatively high capital cost, around $8,000.

5. EDUCATION FOR GEOTECHNICAL PROFESSIONALS

5.1 Need for Geological Training; Opinions of Eminent Engineers

The importance of geology in the basic training of engineers who practice geomechanics in industry has been emphasised by eminent engineers who have been most successful in this field e.g. Skempton (1950), Terzaghi (1961a and b), Peck (1962) and Glossop (1968).

In his 1962 classic "Art and Science in Subsurface Engineering", Peck listed *"three attributes for the successful practice of subsurface engineering ......knowledge of precedents, familiarity with soil mechanics, and a working knowledge of geology."*

Expanding on geology, he wrote :

"..... *every interpretation of the results of a test boring and every interpolation between two borings is an exercise in geology. If carried out without regard to geological principles the results may be erroneous or even ridiculous."*

Glossop (1968) wrote, in the conclusions to the 8th Rankine Lecture :

"..... *but one thing is certain; the education of an engineer in this branch of science is incomplete until he has had much experience of geology in the field."*

It might be argued that changes effecting the profession since these statements were made have lessened the need for geological training. Such changes in Australia include :

(i) a decrease in the numbers of major infrastructure projects
(ii) an increase in the numbers of environment-related projects (impact statements, contaminant cleanup reports)
(iii) the developments in and increased use of rock mechanics, and
(iv) the introduction of computers.

It is suggested that any effects of (i) on the need for geological input would be compensated by the requirements introduced by (ii). Successful use of rock mechanics requires a greater geological input because the properties of most rock masses are governed largely by details of their geological structure. Also, because computers have enabled the analysis of much more complex geological situations (including anisotropic and 3-D) than in the 1960's, to use this power effectively calls for much better definition of the geology of sites.

Also, the outstanding successes of Australian mineral exploration geologists (Woodall, 1983, 1994) have led to several Australian mining companies becoming major operators on the world mining scene. This has increased the opportunities for geotechnical groups and individuals to contribute to mining projects both in Australia and overseas.

The need for substantial geological training for geotechnical professionals has not diminished.

5.2 Communication and Related Problems in the Geotechnical Business

Roberts (1963) compiled a thoughtful paper about the professional staff within Dames and Moore, one of the world's first multidisciplinary consulting engineer groups. The firm started out with "soils engineers", but by 1963 nearly one in four of their professionals had a degree or extensive training in geology. Roberts stated *"In recent years, the soils engineer has been introduced to other "cousins", the engineering geologist and geological engineer."* To compare the characteristics of staff with different academic backgrounds and experience, he used a series of matrix diagrams. He used part of his Figure 5, reproduced here as Figure 4, to illustrate one of the teething problems experienced when a "theoretical soils engineer" and "empirical engineering geologist" were supposed to be working together as a team.

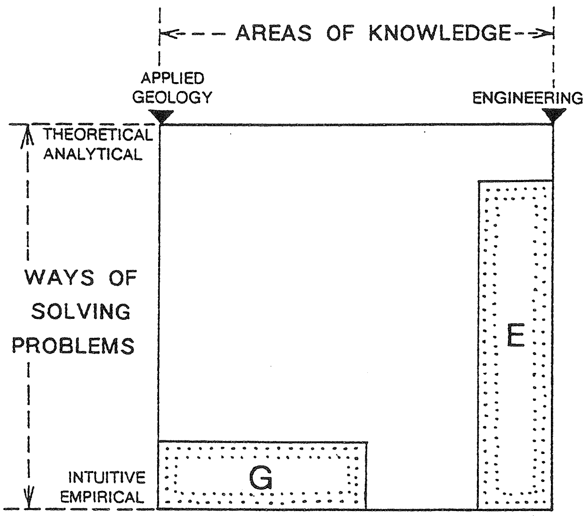


Figure 4. An ineffective team - empirical geologist and theoretical engineer. (from Roberts, 1963).

It shows the "void" or communication gap which existed between them due to their different academic backgrounds. Many at this conference will have experienced or observed situations like this. Roberts explains :

"The soils engineer may be very willing to make bold predictions based on a few borings, a few tests and limited analyses, yet have too limited a training in geological sciences to recognize the profound warnings or limitations which are more readily apparent to the engineering geologist.

By contrast, the engineering geologist may fail to communicate with the soils engineer because he lacks the ability to express his findings in technical terms which are familiar to a person with engineering training."

Figure 5 shows Roberts' "general yardsticks of value for individual consultants in geological-engineering fields." He points out that persons of Case I (too close to the corners) should be hired only as sub-consultants when needed, and that Case II (too-narrow training) should be avoided "if the consultant is to be responsible for answers in broad application of geological engineering fields." He calls Case III "the ideal consultant" with broad knowledge and flexibility in ways of solving problems. Such a person would be a highly qualified and experienced geological engineer.

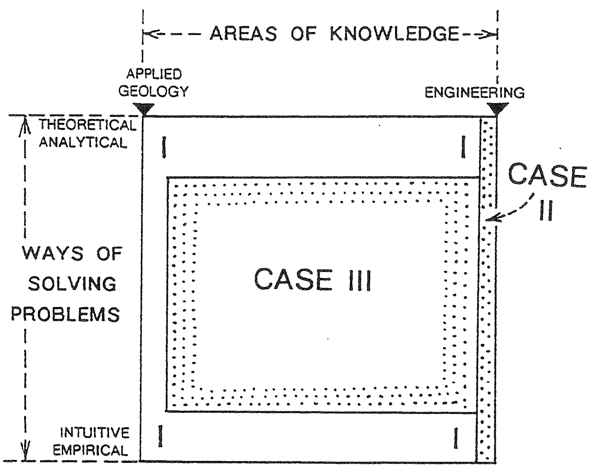


Figure 5. Yardsticks of value for individual consultants in geological-engineering fields. (From Roberts, 1953).

Roberts challenged the firm's staff to sketch their own "areas" on the chart, and "to work as individuals to grow both horizontally in fields of knowledge, and vertically in extending our ways of thinking or solving problems."

Since 1963 the part of the communication gap caused by poorly defined geotechnical language has been largely overcome, by the efforts of individuals within groups, and of local and international technical committees. Also, almost half of our engineering geologists now have formal qualifications in geotechnical engineering areas (Appendix A). I could name some who have got close to the Case III "ideal consultant" on Figure 5, and can realistically be called geological engineers.

With notable exceptions, geotechnical engineers seem to have difficulty moving towards the left, on Figure 5, I still see disasters like Cases 1 and 2, and teams with communication gaps resulting mainly from engineers (often senior) having no real understanding of what geology and geologists are all about.
I have been concerned about this for a long time. This concern provided the stimulus for Stapledon (1986), in which I put most blame *on "our ineffective education system*" and called for the Society ... "*to take positive steps to improve the standard of presentation of geology to engineers at all tertiary institutions, and to give special attention and support to those institutions who are making efforts to set up key centres for teaching and research in geotechnology.*"

5.3 Why Do Engineers Have Difficulty With Geology?

Terzaghi's basic education was in geology and mechanical engineering (Casagrande, 1960). He taught both soil mechanics and geology to engineers in four different institutions over many years, in Europe and USA. He recognised the difficulties engineers had with geology, the reasons for them, and the serious consequences when engineers practised without adequate geological understanding. He was greatly disturbed about these matters, and wrote about them at length. For example, in Terzaghi (1961a) :

"*It has been stated at the outset of this article that one of the principal functions of a course in engineering geology consists in focusing the attention of the student on the difference between the mechanical and hydraulic properties of the natural ground and those which he assigns to them on the basis of the results of subsoil exploration before he starts making his estimates and performance forecasts. This difference can be insignificant, considerable or very important, depending on the geological characteristics of the site. However, in order to be of any practical value, the knowledge of this difference must be combined with the capacity to adapt procedures and decisions to the possible consequence of the prevailing uncertainties. Unfortunately this capacity, like that for creative writing, cannot be developed by systematic training. It can only be stimulated by representative examples and some students may never acquire it. On account of this fact, combined with the educational background of the civil engineer, the teaching of the subject involves considerable pedagogical difficulties.*

In practically every one of his courses, the student in civil engineering is supplied with information, such as the equations required for computing the stresses in the members of framed structures, which can be applied to the solution of practical problems almost without any original thinking on his part. By contrast, in engineering geology, no such direct application of the information supplied to the student is practicable. Therefore the writer was not surprised to find that most courses on engineering geology fail to make any lasting impression on the students. As soon as the student has left his alma mater he again becomes blissfully unaware of the uncertainties involved in the assumptions on which *his computations in subsurface engineering are based, and the consequences are deplorable indeed."*

An important difference today is that students are supplied not only with "*equations*" but with "programs" which many seem to consciously or unconsciously believe are less fallible than the former.

Terzaghi recommended that to overcome the learning problems, the teacher should be acquainted with soil mechanics and foundation engineering as well as having adequate geological training. He also recommended that because "*Extensive practical experience can hardly be expected* ...." case records illustrating the role of geology should be presented by visiting lecturers with suitable qualifications.

In addition to the difficulties pointed out by Terzaghi, I have found that many engineers and engineering students find it difficult to visualise in 3 dimensions, and to imagine geological time and processes. Also, I consider it impossible to teach geology effectively to anyone, without a lot of time in the field where the real soil and rock are. This view is shared by most geologists and teachers of geology, and clearly, by Glossop (1968).

5.4 Availability and Quality of Geological Training for Engineers, in Australian Universities

5.4.1 Bachelor of Engineering (Civil) Courses

I believe that there has been a steady decline in the amount of time allocated to geology subjects in the BE (Civil) courses throughout Australia, during the last 40 years. Engineers who graduated in the 50's and 60's advise that they studied geology for 150-200 hours, with considerable field work. When I started teaching "geology for engineers" in 1978, the course at SA Institute of Technology covered about 70 contact hours, and I was able to spend 35 of these in the field with students on full-and half-days of observation, pit-logging and mapping exercises. The hours have been reduced progressively, and in 1995 were about two thirds of those values. The course is currently being reviewed and a reduction seems more likely than an increase.

To assess the current situation around Australia, I examined published BE (Civil) course data (mostly 1995 or 1996) from the 13 universities listed in Appendix C. In a few cases I got further details by telephone or facsimile. This survey showed that in most courses :

- geology (usually called "engineering geology" or geology for engineers") is presented as a single compulsory subject, usually in years 2 or 3
- total geology contact hours range from 21 to 70, and the subjects earn about 1 to 2 percent of the total course credit points
- there is little or no "hands on" teaching about both soils and rocks, in the field.

The notable exception is the University of Sydney, where the geology component totals 130 hours, 65 in each of Years 1 and 2. In each year the laboratory practical component is 39 hours. There is no field work in Year 1 but Year 2 "as approved for 1996" includes a full-day inspection of construction sites, quarries, etc. and another full day of demonstrations and hands-on experience of various geophysical methods. Also included are two projects each requiring about a half day of the student's own time (without staff supervision) in the field.

Although this program appears to have a more acceptable number of field hours, I suggest that the day on geophysics would be better spent on field exercises requiring observations and mapping, in both (engineering) soils and rocks.

I suspect that Terzaghi's teaching approach, and requirements for lecturers and visiting lecturers, are not being followed at many universities.

It is clear that most of the courses are nowhere near adequate to provide the required levels of competence in geological thinking and methods implied by Peck, Terzaghi and Glossop.

The decreases in sizes of geology subjects appear to coincide with increases in the amounts of time allocated to "geotechnical engineering" subjects under various names. I suggest that this may be due in some cases to dissatisfaction with the services provided by the geology departments, and in others to a perceived need to cover a much wider "geomechanics" area than that of the soil mechanics courses of the past. In any case, from the "geotechnical engineering" subject descriptions I consider it unlikely that they contribute much to the students' understanding of basic geology.

It is clear that most BE (Civil) graduates from Australian universities will not have enough geological knowledge and skills for successful general practice in geotechnical engineering, without some further training in geology. However, to my knowledge, very few presently practising geotechnical engineers have any formal qualification in geology. Also, having been "raised" in an almost geology-free environment, many recent and new graduates wanting to succeed in geotechnical consulting or research may not be aware of the need to obtain more (or some) knowledge and understanding of geology, until they are involved in something like Case 2.

Fell (1995) doesn't specifically mention geology, but considers *"the limitations in what can be taught in a BE degree"* as one reason why postgraduate qualifications are vital for engineers who are to work in geotechnical engineering.

The staff profiles in Australian Geomechanics (1995), assessed together with the results of my questionnaire about geologists, suggest that no more than 48% of geotechnical engineers have post-graduate qualifications (Appendix A). To assess the availability of further geological training for engineers within post-graduate programs I sent a questionnaire to 14 universities.

5.4.2 Post-Graduate and Short Courses Offered by Universities

From the 12 answers to my questionnaire (Appendix D) it appears that the only post graduate engineering course which includes significant geological content is the MEngSci offered by the Department of Geotechnical Engineering at the University of New South Wales. Most of the geological content in that program is provided in 4 optional subjects, each of 42 hours, presented by experienced engineering geologist Greg McNally of the Applied Geology Department, and by two experienced geological engineers (Robin Fell and Garry Mostyn).

Unfortunately, the geological options include no field work. Also, the subjects appear to lean heavily on applications. Normally, one might expect the latter, at post-graduate level, but as many students probably will have not done adequate basic geology or field work at undergraduate level I question the omission of these aspects.

At Monash, a final year elective subject (Rock Engineering) in the BE (Civil) course is offered to masters students. This subject of 52 hours includes about 6 hours in the field on rock joint mapping, presented by engineering geologist John Neilson and geotechnical engineer Chris Haberfield, both industry experienced.

The MEngSci course at Curtin University (Western Australian School of Mines), includes 3 to 4 hours of geotechnical mapping in the field presented by experienced geological engineer Barry McMahon.

Short courses such as "Mining Geotechnics" (Key Centre for Mines, 1995) are not aimed at providing participants with understanding of basic geology.

It is concluded that the opportunities are extremely limited in Australia, for BE (Civil) graduates to increase their geological knowledge and skills by means of post-graduate or short courses.

It seems we are producing engineers progressively closer to the upper right hand corner of Figure 5!

5.4.3 Bachelor of Geological Engineering Course

Referring to the lack of well funded MAppSci courses in Australia, Fell (1995) suggests that :

"*.....there could be an argument for combining these into Schools of Civil Engineering to train Geological Engineers.*"

The only course in Australia aimed at training geological engineers is the 4-year bachelor degree course offered by the Royal Melbourne Institute of Technology (RMIT). It has been presented since 1982 by the Department of Civil and Geological Engineering, and was re-accredited by The Institution of Engineers, Australia in 1992.

Some details of the course are given in Appendix E. It has a common first and second year with a 3-year course in Applied Geology, and some of the third year subjects are also common. Students can decide at the end of year 2 whether to proceed with the engineering or applied geology stream. The course includes 51.5 days of field work, of which 37 days are spent geologically mapping (surface and underground). The course leaders are Warren Peck and Graham Granger, both experienced geological engineers.

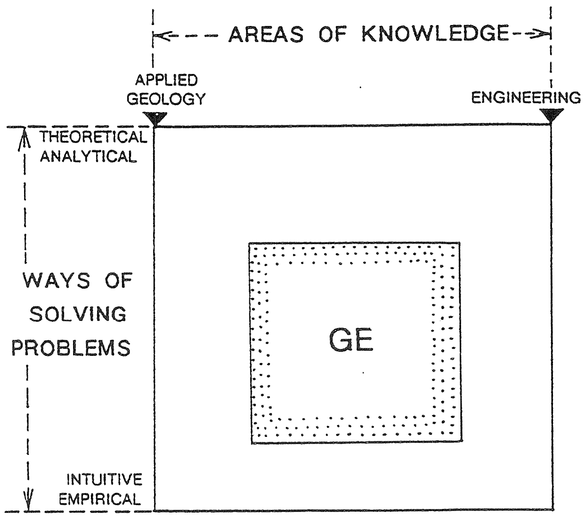


Figure 6. Typical "geological engineer" of Roberts (1963).

During the period 1993-96, there were fifty six graduates from this course. Warren Peck has advised that all obtained professional employment in the following areas, within five months of graduation :

EMPLOYMENT AREA	NUMBER	PERCENT
Mining	29	52
Environmental/ hydrogeology	13	23
Geotechnical	10	18
Miscellaneous (mainly post-graduate study)	4	7

I consider that this type of course should provide graduates with adequate geological knowledge and skills to enter and work in the field of geotechnical engineering. Located somewhere in the middle of the diagram of Roberts (Figure 6), graduates should be well placed to broaden their knowledge and skills bases towards those of the "ideal consultant" of Figure 5, using post-graduate and short courses of the types offered elsewhere in Australia.

5.4.4 Bachelor Degree Courses in Geology or Applied Geology

Another way for geotechnical engineers with BE (Civil) degrees to get geological knowledge and skills is to undertake one of these widely available courses (see 6.2 below). This may be considered by some as an "overkill". However, the benefits can be great. Those in doubt should look at the contributions to the profession by those who have degrees in both geology and engineering. Good examples are the many publications of Peter James, particularly James (1971a and b, 1980, 1992) and James and Wood (1984). Also MacGregor (1993) and MacGregor et al (1994).

The amount of commonality of subjects in courses at Sydney University enables students to obtain both BE (Civil) and BSc. (Geol) degrees in 5 years. This should be possible also at other universities. At RMIT (see Appendix E) it is possible to obtain both the geological engineering and applied geology degrees in 5 years. A program at the University of South Australia provides for completion of BE (Mining) and BAppSci (Geol) in 5 years.

6. EDUCATION OF AND FOR ENGINEERING GEOLOGISTS

6.1 What is Engineering Geology?

Engineering geology isn't a special kind of geology. In my view it has been best defined by Moye (1966) as simply :

"Geology which is useful in engineering".

To be useful to an engineering project the geology applied to it must be the facet or facets of "classical" or "basic" geology most appropriate for providing answers to the engineering questions raised by the project.

Our most successful engineering geologists have become so mainly because they have good understanding of engineering issues and are good at applying classical geology to assist in their resolution.

In the light of the above views I am not in favour of special courses in "engineering geology" at bachelor degree level.

6.2 First Degree Courses in Geology

Australian universities offer about 25 first degree 3-year courses including classical BSc(Geol) and applied (BAppSci) types. Both types concentrate on classical geology, but the applied courses usually have fewer optional subjects and include more mathematics and some introductory material on mining, mineral exploration and engineering.

Many graduates undertake a fourth year, usually comprising specialised study and a thesis, to obtain an honours degree.

In my view graduates of either course type can develop into equally good engineering geologists - the most important attribute of the graduate is his/her understanding of basic geology. This view is shared by McMahon Associates, one of our largest employers of engineering geologists (Appendix B).

6.3 Availability of Engineering Training for Geologists

As noted in 5.2, the answers to my questionnaire (Appendix A) showed that about half of Australia's engineering geologists have some formal qualification in a geotechnical engineering area. I understand that many have obtained these qualifications by undertaking all or parts of BE (Civil) courses, or one of the following master level "engineering geology" courses :

- MAppSci (University of New South Wales)
- MSc/DIC (Imperial College, London)
- MSc (University of Canterbury, New Zealand)

The main engineering components of each of these courses are presented by eminent engineers.

Also available to the geologists are short courses (eg. Key Centre for Mines, 1995) offered from time to time by several universities.

7. NEED FOR MORE SHORT COURSES AND GUIDELINES

Practising geotechnical people need to keep up-to-date with important subject areas developed by engineering geologists but often not covered at all, or adequately, in first degree geology or engineering courses. These include :

- geotechnical language
- geotechnical mapping, or "engineering geological" mapping
- geomorphological techniques and mapping
- logging of excavations, boreholes etc.
- rock weathering processes and products, and systems for description of products
- surficial geology and pedology
- terrain evaluation - air photo interpretation

Short courses in topics such as these would be useful. For some e.g. geotechnical language, and descriptive systems for rock weathering products, guidelines also are desirable.

It would be useful also to have guidelines or short courses for academics responsible for teaching geology to engineers. These people should in any case receive the guidelines on geotechnical language, as the undisciplined language of some geological academics has infected many engineering geologists and engineers.

8. THE FUTURE - STILL TEAM WORK

I predict that geotechnical work will continue to be carried out by teams of people. Even if everyone completed a geological engineering degree such as that offered by RMIT, not all would broaden out into the "ideal consultant" area of Roberts. Some would "migrate" towards the left side of Roberts diagram, and others to the right or towards the top right hand corner. Specialisation happens to some people because their employer or job requires it, and to others because they have a special interest or ability in a particular area.

I believe that it will be healthy for the geotechnical profession to receive "new blood" from a variety of engineering and geological courses. The essential requirement is that engineers and geologists become progressively better educated in each other's field. This will result in better communication, team work, results, and utilisation of staff. To this end I recommend the check list in Appendix F.

9. CONCLUSIONS AND RECOMMENDATIONS

1. The AS 1726-1981 graphic symbols for soils should not be used. AS 1726-1993 should be revised to include soil symbols like those in Figure 2, and notes for guidance about their use. A similar approach using basic symbols should be adopted for rocks.
2. Computer programs currently in use by most consulting groups cannot produce geologically realistic logs of boreholes or excavations. There is an urgent need for programs and equipment which will allow geologically realistic records to be produced directly at the site, by hand drawing and typing.
3. The use of inappropriate systems for collection of geotechnical field data for more than 20 years reflects failure of our education system to provide engineers with adequate understanding of geology, and a long-term decline in the quantity and quality of geology taught in BE (Civil) courses.
4. There appears to be an increasing emphasis on sophisticated analytical methods, in most civil engineering courses at bachelor and post-graduate levels. The analytical methods are being taught to students or graduates most of whom lack enough geological training to allow them to understand the limitations imposed on their computations, by natural site variability.
5. Geology should be taught to engineering students during the same semesters as geomechanics subjects, and related to them. Emphasis should be on basic geological principles and methods, and on illustrating how the histories of formation of soils and rocks cause variabilities in their compositions, fabrics and structure, and the limitations these place on many engineering analyses. Case histories (including local projects), and much teaching in the field, are needed. The geology lecturer should liaise with the lecturers in geomechanics when planning the program and presenting it.
6. The BE (Geological Engineering) course at RMIT is considered to be the only Australian course which includes geological content (including field mapping) appropriate for the basic training of geotechnical engineers for the consulting business.
7. For BE (Civil) graduates wishing to get a better understanding of geology, the only Australian post-graduate program offering significant geological material is the MEngSci at the University of New South Wales. Unfortunately the geological subjects include little basic geology and no field work.
8. Geology graduates are well-served with courses which provide knowledge and skills in engineering aspects. Almost 50 percent of engineering geologists have some formal engineering qualification; most are from master degree courses in Australia, New Zealand or the United Kingdom.

9. Short courses presented by industry people or industry-trained people are the best way to teach many of the practical field aspects of the geotechnical business. Companies should encourage competent senior people to contribute to such courses, and less experienced staff to attend as participants.

10. The Society should set up a working party to examine the issues raised in this paper and work out ways to get action to restore, and keep, the "Geo" in Geomechanics in Australia.

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APPENDIX A: SURVEY OF CONSULTING GROUPS

A.1 : Questionnaire re: Paper for 7th ANZ Geomechanics Conference

Dear ....,

I have been asked to write a paper for this conference. Among other things, I want to discuss the positions and roles of engineering geologists in geotechnical groups in Australia. I see from Australian Geomechanics 27, June 1995, that your group has .....% of its professional staff with first degrees in geology. I would appreciate it if you could advise me about the following, in relation to these persons.

1. The number of engineering geologists
2. The number with first class Honours degrees

3. The number with Masters Degrees
4. The number with Doctorates *
5. The number with formal "engineering" qualifications, e.g. in soil or rock mechanics or other
6. The number who are principals
7. The number of hydrogeologists
8. What duties are performed by your engineering geologists? Please indicate the numbers who perform work in each of the following categories:
   a) collection of geological/geotechnical data for others to analyse and report on
   b) collection and analysis of geological and geotechnical data to produce geotechnical models
   c) as for b) above but with full analysis, answering project questions and preparation of report
   d) other (please specify)

   It is appreciated that the answers to a) to d) will depend partly on the type of projects undertaken by your firm and the geological environments in which they are located. Your comments on this would also be appreciated.
9. How do you handle geophysics?
10. Do you use AS1726-1981 type graphic symbols for soils? If another system, can you fax me a copy please?

NOTE : Questions 9 and 10 were asked by phone in some cases.

A.2 : Groups Which Answered Questionnaire

ARUP Geotechnics

Australian Water Technologies

BHP Engineering

Barrett, Fuller and Partners

Coffey Partners Int.

Dames and Moore

Douglas Partners

Jeffery & Katauskas

Golder Associates

Gutteridge Haskins & Davey

Koukourou & Partners

Maunsell & Partners

McMahon Associates

Pells Sullivan Meynink

Rust PPK

SMEC Australia

Soil and Rock Engineering

Soils Surveys Engineering

Ullman & Nolan

A.3 : Results Of Questionnaire Plus Data in Australian Geomechanics 27 June 1995

	Number	Percent
Groups	19	100
Total professional staff in groups	668	100
Geotechnical Engineers	411	61.5
Engineering Geologists	129	19.3
Hydrogeologists	57	8.5
Geophysicists	3	0.4
Environmental scientists	68	10.2
Groups using AS 1726 symbols	10	N.A.
Total staff in groups using AS 1726 symbols	450	67.4
Staff in largest group	123	N.A.
Staff in smallest group	3	N.A.

A.4 : Profiles - Engineering Geologists Employed in 16 Groups

	Number	Percent
Total	129	100
With formal engineering qualifications	61	47
With first class honours*	26	20
With master degree**	55	43
With doctorate**	8	6
Total with master or doctorate	63	49
Principals	16	12
Data collection,*** analysis and report	79	61

* May include some with higher degree

** Highest degree for each person

*** This indicates only that 79 or 61% of the geologists conducted all these activities some of the time. The questions were not specific enough to indicate how often. It appears that 5 groups employing 49 geologists use most of their geologists frequently for the full range of activities. 13 groups sometimes use some of their geologists for data collection only.

APPENDIX B : EXTRACT FROM REPLY TO APPENDIX A QUESTIONNAIRE, BY McMAHON ASSOCIATES

We find ourselves working more and more on very large projects: large open pit and underground mines, tailings dams and water supply projects. In one recent project we had 6 large drills working 24 hours per day, 7 days per week for almost 4 months. At one stage our engineering geologists and engineers were orienting, logging, sampling and photographing close to 1000m of core per week. Without computers we could not hope to process, consolidate, communicate and evaluate such a flood of information. Things have changed since Geehi Dam when 30m of core was a good week's drilling.

In these major projects the costs of potential geotechnical errors far outweigh the cost savings of second rate documentation of the core. On these jobs, we use hand written logs drafted using a CAD package. Otherwise we lose details that don't fit into the preconceived pigeon holes that seem to be characteristic of the computerised systems we have come across. Where the cost of full logging cannot be justified we have used simplified computerised logs, which are quite inferior to the manual logs but provide about 80% of the information at about 20% of the cost. With good core photos to fill in the gaps, these have been adequate for specific projects.

We don't require any formal education in engineering geology for new hires and follow Dan Moye's advice and look for people who have a knowledge of and feeling for basic geology, including the engineers. We have found that even graduates of Master's programs in Engineering Geology don't know how to log core, classify soils and rocks, use a geologist's compass, use a Schmidt net, map a face, etc. although most can use a spreadsheet. We provide intensive training in these and similar skills.

Engineers and Geologists do the same work providing they have the required skills. Sometimes we have found that raw recruits are more valuable to us than people with long experience and what are, in our view, many bad habits.

APPENDIX C : UNIVERSITIES FOR WHICH DATA WAS OBTAINED ABOUT GEOLOGY IN BE (CIVIL) COURSES

University of Adelaide
University of South Australia
Monash University
Curtin University
University of New South Wales
Central Queensland University
University of Queensland
James Cook University
Sydney University of Technology
Wollongong University
Sydney University
Queensland University of Technology
Royal Melbourne Institute of Technology

APPENDIX D : SURVEY OF POST-GRADUATE COURSES

D.1 : Questionnaire re: Post-Graduate Courses for Engineers (or Geologists) Wishing to Specialise in Geological Engineering or Geomechanics

Dear ....

I am preparing the John Jaeger Memorial lecture to be delivered at the 7th ANZ Conference, and will be including some discussion on the opportunities in Australia for post-graduate training in the above areas. I would therefore appreciate receiving from your organisation, descriptive material with contact hours etc. for courses of the above type, which you offer.

1. In particular, do such courses include classical and/or applied geological mapping (as optional or compulsory subjects) and if so, how many hours and at what scales?
2. Does the mapping component cover several different geological environments, in different areas? Examples from past students would help me to get the picture.
3. Do you get assistance with this or any other aspect of the course(s), from the geology school or department within your university?
4. Do you get assistance with this or any other aspect of the course(s) from highly experienced person from industry?
   (a) geologists (b) engineers

With good wishes and thanks in anticipation - please use this fax sheet for answers to Questions 1 to 4.

D.2 : Answers Received From:

University of Sydney
University of Technology Sydney
University of New South Wales
Curtin University (Western Australian School of Mines)
University of Melbourne
University of Queensland
James Cook University
University of Adelaide
University of South Australia
University of Western Australia
Monash University
University of Wollongong

APPENDIX E : GEOLOGICAL ENGINEERING AT RMIT - EXTRACT FROM PROSPECTUS

Geology and Geological Engineering

General information

Two undergraduate degrees are currently offered: a three-year Bachelor of Applied Science (Applied Geology); and a four-year Bachelor of Engineering (Geological Engineering). Both are full-time or part-time courses.

These courses have a common first two years. The first two years of the courses are taken under the combined course 111092, Geological Science and Engineering. These first two years are designed to give students an appropriate education in geological science and basic engineering, and the necessary background skills in mathematics, computing, technical design, and contextual studies in fields such as sociology, politics, culture, and language.

By the commencement of the third year, students nominate the course area in which they wish to specialise, and select subjects from a core of appropriate major subjects supplemented by electives. Students selecting to specialise in Applied Geology receive their Bachelor of Applied Science degree after completing three years, whereas students wishing to specialise in Geological Engineering are required to complete third and fourth year programs for that degree.

In addition, there is the one year Applied Geology Honours course leading to the award of the Bachelor of Applied Science (Hons) Degree, available to students holding a first degree in geology.
Opportunities also exist for suitably qualified graduates to enrol in the degrees of Master of Applied Science or Master of Engineering by thesis. Details of these courses may be obtained from the Course Leader.

111092 Geological Science and Engineering
Upon completion of this two year course students may select to complete a degree program in either:

- 111006 Bachelor of Applied Science (Applied Geology) 3rd year; or
- 111007 Bachelor of Engineering (Geological Engineering) 3rd or 4th year.

Mode: Full-time or part-time.
Entrance requirements: See RMIT Undergraduate Prospectus and/or individual course brochures.
Experience requirements: All students selecting the Geological Engineering course are required to obtain a minimum of 12 weeks of approved practical experience to satisfy the requirements of the Institution of Engineers, Australia. Students are required to enrol in GE 900 to receive credit for their practical experience.

Course Structure

		Contact Hrs/Wk	*Credit Pts*
	First Year		
GE 100	Geology	5	20
GE 180	Field Geology Compilation & Design	2	8
GE 190	Intro. to Geological Eng.	2	8
CE 108	PBL Statics	2	8
CE 109	PBL Intro. to Solid Mechanics	2	8
CM 354	Chemistry 354	3	12
	One subject from:		
MA 251	Mathematics 251	4	16
MA 252	Mathematics 252	5	16
XX xxx	Electives* (see below)		

* Departmental approval is required for the elective subject combination selected by each student

	One subject from:		
GE 141	Earth Physics	2	8
GE 195	Environmental Issues in Eng.	2	8
PH 354	Physics 354	2	8
	Second Year		
GE 202	Applied Geophysics	2	8
GE 203	Petrology	3	12
GE 230	Sedimentology & Fluid Mechs.	2.5	10
GE 262	Structural Geology	3	12
GE 289	Field Geology Compilation & Design	2.5	10
GE 290	Geological Engineering Design	2	8
GE 291	Rock Mechanics	2	8
CE 182	Graphical Communication	2	8
CE 183	Tech. Computing for Engineers	2	8
CC xxx	Approved Context Curriculum Subject	2	4
CC xxx	Approved Context Curriculum Subject	2	4
	Third Year		
	All students must take:		
GE 302	Hydrology	2	8
GE 312	Geomathematics	2	8
GE 303	Ore Deposits & Mining Geology	2	8
GE 331	Land Contamination	2	8
CC xxx	Approved Context Curriculum Subject	2	4
CC xxx	Approved Context Curriculum Subject	2	4
	plus further subjects in their chosen field.		

111006 Applied Geology

GE 241	Sedimentary Petrology	3	6
GE 244	Palaeobiology	3	6
GE 315	Depositional Systems Analysis	2	8
GE 321	Appl. Geol. Mapping Project	1	4
	Electives, at least 6 hours/week from:		
GE 305	Speciality Topics in Geology	2	8
GE 304	Petroleum Geology	4	8

GE 314	Advanced Petrology	2	8
GE 370	Exploration Geology	3	12
GE 513	Remote Sensing	2	8
GE 591	Geophysical Well Logging	2	8
MT 112	Intro. to Mineral Processing	2	4
EV 220	Solid, Liquid & Gas Waste Management Unit 1	3	6
EV 261	Fate & Transport of Pollutants	2	4
AC 300	Accounting for Business Decisions	2	4
XX xxx	Approved Subject *or*	2	4

or

111007	**Geological Engineering**		
GE 320	Geological Engineering I	4	16
CE 341	Soil Mechanics 2	2	8
MA 003	Differential Equations A	2	4
MA 005	Differential Equations C	2	4
	Electives, at least 4 hours/week from:		
GE 305	Specialist Topics in Geology	2	8
GE 370	Exploration Geology	3	12
GE 513	Remote Sensing	2	8
CE 350	Civil Engineering Practice 2	1	
AC 300	Accounting for Business Decisions	2	4
EV 220	Solid, Liquid & Gas Waste Management Unit 1	3	6
EV 261	Fate & Transport of Pollutants	2	4
XX xxx	Approved Subject		

Fourth Year

	Geological Engineering only		
GE 432	Advanced Hydrogeology	2	8
GE 400	Design Project	6	24
GE 402	Geological Engineering 2	4	16
GE 900	Vacation Report	1	2
MA 019	Finite Element Methods	2	4
	Electives, at least 6 hours/week from:		
GE 304	Petroleum Geology	4	8
GE 315	Depositional Systems Analysis	2	8
GE 572	Mining Geology 572	3	8
GE 591	Geophysical Well Logging	2	8
CE 462	Construction Engineering A	3	6
CE 463	Construction Engineering B	3	6
CE 475	Civil Engineering Practice 3	2	8
EV 400	Environmental Policy & Law	3	6
EV 401	Environmental Eng. Ethics	2	4
CE 382	Risk Management	3	6
CE 373	Project Control	3	6
XX xxx	Any Approved Subject		

APPENDIX F : CHECK LIST FOR LEARNING MORE ENGINEERING OR GEOLOGY

INFORMAL

- Work closely with engineers (geologists)
- Share offices where possible
- Ask questions
- Follow up jobs, read and discuss final reports
- Observe and learn at construction sites
- Draw, photograph and get explained, features seen but not understood, in exposures or samples of soils and rocks
- Attend/give in-house talks/seminars

READING

- Geotechnical journals
- Construction magazines
- Symposium proceedings
- Textbooks
- Old reports

SOCIETY MEETINGS/TALKS - ATTEND AND CONTRIBUTE

- Geomechanics, Geological etc.
- At universities
- At conferences

FORMAL COURSES IN ENGINEERING (OR GEOLOGY)

- Short term (½ day, 2 day, week etc.)
- Part time
- Full time

From Moon (1996)