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27. The engineering properties of Tasmanian dolerite, with particular reference to the route of the Bell Bay Railway.

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In order to appreciate the range and scale of engineering properties and problems associated with the dolerite it is necessary first to understand something of what the dolerite is, what it contains and the forms it takes.

The dolerite is an igneous rock, that is a rock initially molten (1,100°C - Edwards, 1942; McDougall, 1962) and injected as a fluid into older water-laid sedimentary rocks. It was injected under a pressure head of at least 700,000 g/cm² (Leaman, 1970a) and caused severe disruption of pre-existing geological features. As the initially hot fluid was forced into cold sediments, severe thermal gradients were produced during the period of injection and cooling. The importance of the thermal history of the dolerite to its present physical and chemical properties is discussed later. A body of such injected material is termed an intrusion.

Dolerite is composed of two essential and several accessory minerals. The two essential minerals; termed plagioclase feldspar and pyroxene, compose together 60-80% of the rock. Plagioclase is a white or colourless, prismatic silicate mineral containing sodium and calcium in the proportion of about 40:60. The pyroxenes (more than one member of the pyroxene family of minerals is usually present), are greenish-black silicate minerals containing iron, calcium and magnesium. The accessory minerals are quartz, orthoclase, chlorite and magnetite. Magnetite may constitute 3-5% of the rock and quartz+orthoclase+chlorite 20-40%. The mineralogy of the dolerite is closely related to the form of the intrusion and the thermal history. Further information on the petrology of dolerite is given by Edwards (1942), Joplin (1957, 1971), Spry (1962) and McDougall (1962, 1964).

Intrusions normally take the form of large slab-like bodies, which may parallel the regional dips of the intruded sedimentary rocks. The thickness of these bodies varies somewhat but is at least 300 m in a major intrusion. The horizontal dimensions significantly exceed the vertical and thus the form in true scale is a thin wafer. Details of intrusion form are given by Leaman and Naqvi (1968), Leaman (1970a), Longman and Leaman (1971) and Leaman (1972b).

Crystallisation of the minerals from the fluid commenced upon injection (Edwards 1942) and once the slab of fluid was emplaced strong thermal gradients were established perpendicular to the upper and lower surfaces. The chilled margin of the dolerite is thinnest at the top due to combination of the rapid marginal chilling process and a temperature gradient through the slabs. Convection and crystal movement play a part in the disposition of the isotherms. The lower margin also shows a strong chilling effect but the gradation of grain size from the margin to the centre of the slab is very slight. At the margins where chilling has occurred the rock is almost glassy and very fine-grained. The last point to solidify is two-thirds to three-quarters up from the base of the slab. The time taken for solidification was about 1,000 years, (Jaeger, 1958; Leaman, 1970a). The longer the cooling time the coarser in grain and the lighter in colour the rock became. The lighter colour is due to more plagioclase, quartz and orthoclase as the final phase is very rich in the last two minerals. Each intrusion with a simple thermal history (i.e. only one injection) will show a textural layering: fine (at the base), fine-medium, fine medium-coarse, very coarse, medium-fine (fig. 46,A). Aspects of the thermal history of dolerite are discussed by Jaeger (1958, 1961).

The joint frequency is in part related to the cooling time and grain size and the weathering properties are related to grain size and mineralogy. Thus much of the variability of dolerite is inherent in its original thermal history. However, joint frequency is also partly related to crustal stresses subsequent to intrusion and the extent of weathering is largely dependent on such induced joints. The extent of weathering may also be controlled by physiographic relief and climate past and present. These points are dealt with in detail in the following sections.

JOINTING

Three main types of joint are developed in dolerite. The relative dominance of any one type may significantly affect any cut in the material.

Joints related to cooling

Joints of this type are most commonly observed near the boundaries of the intrusion. Normally the joint pattern is developed normal to isotherms and is rectangular and regular and tends to produce a platiness or slaty look in the rock. Most joints of this type are incipient, i.e. they appear as slight lineal depressions in the rock but are tightly closed. The overall joint frequency (including incipient joints) is about one per centimetre. The frequency of the principal joints of this type is about 10-12 per metre.

The grain size coarsens away from the chilled margin of the intrusion and the joint frequency decreases slightly although the joint pattern retains its rectangular form.

The above comments apply only to the lower 60-90 m and the upper 30 m of the intrusion. In the core of the intrusion a very massive columnar structure is produced with a frequency, in the horizontal plane, of 2-3 or less per metre. The columnar structure may be broken by a number of steeply dipping and sub-horizontal joints to produce a rather blocky form. The frequency of jointing in the vertical plane may exceed that in the horizontal plane. A joint phenomenon known as fan jointing, where a distinct fan pattern is visible, is of debatable origin but may be related to thermal history. Such joints are generally found in the finer grained rocks near the margins of an intrusive body.

Joints related to crustal stresses (tectonic forces)

Fracturing is induced in all materials near the free surface due to earth movements of crustal scale. A thin, brittle slab of material such as dolerite is very susceptible to this type of fracturing. Normally a general warping movement produces a rectangular fracture pattern. However, depending on the orientation of the slab and the cooling features already in it the new stress field may either superimpose closely on the 'thermal' stress field and simply open pre-existing joints or potential joints, or a completely new set of fractures may be produced. Local structural or compositional variations may cause deviations from one mode to another.

Locally faulting may be very significant in joint control. As a fault is a surface along which rather violent impulsive movement has taken place, and even although the movement may be small and only a few centimetres, a zone of shattering is normally present in the near vicinity. This zone may be up to several metres wide, and the joint frequency within it may exceed 25 per metre. Depending on pre-fault jointing any new fractures will be either parallel to or normal to the fault surface.

Joints related to elastic response of unloading

A distinctive suite of joints is produced by the simple effect of erosion. Within a hill which has active erosion proceeding on either side the load on the material is decreasing and the outward stress component is nil. The result is a series of sub-horizontal joints which increase in dip as the ground surface is approached but which are always shallower in slope than that surface. Such joints are always major and continuous. However, there are rarely more than 3 or 4 of any significance and none are obvious at depths of more than 5-6 m.

WEATHERING

There are two principal processes: physical weathering and chemical weathering.

Physical processes involve the simple breakdown of rock into smaller pieces. Fracturing due to crustal stress and unloading is of major importance. Other processes include temperature effects, water erosion and the action of plant roots. Alternate heating and cooling of dolerite, which has a relatively high thermal conductivity, results in a series of smaller expansion and contraction joints. Although this is only a near-surface effect it increases the efficiency of chemical weathering by exposing a greater surface area to decomposition. The force exerted by growing plant roots is several tonnes per square metre and makes a significant contribution to fracture extension. Physical processes alone contribute to simple rock falls on various scales.

Chemical processes are responsible for soil production and what is normally considered the weathering profile of a rock. The products of the processes acting may control slope and reduce stability. The processes acting include aqueous oxidation (rain or other water plus oxygen), reduction (derived chemicals in solution at deeper levels), hydration (inclusion of hydroxy radicals in deficient or less rich minerals) and carbonation (water and carbon dioxide). All such processes act together and dominance of effect is related to mineral composition and to very particular and very local conditions in the rock (including joint frequency, openness, general distribution, relation to surface and orientation). The ability of water to circulate easily from the surface and as groundwater is fundamental to the weathering process.

Plagioclase minerals break down to form carbonates of sodium and calcium and hydrated silica and clays. Pyroxene minerals decompose to yield carbonates of calcium and magnesium, oxides of iron and clays. The carbonates of sodium and in part magnesium (as hydrogen carbonate) are lost to the system although some of the cation radicals may be adsorbed by the clays. The remainder of the calcium and magnesium carbonates form a white semi-amorphous material which is called travertine when abundant. The clay minerals are generally illite and montmorillonite, although chloritic forms are not uncommon. Iron oxides may form thin coatings on joints or thick fillings. Extreme weathering is normally related to coarse-grained dolerite which contains more iron rich pyroxene and more quartz and orthoclase. Orthoclase decomposes readily to form clay and quartz. The original magnetite contributes to the iron oxide products.

It is also not uncommon to find medium- and coarse-grained dolerite in which the pyroxenes are either completely replaced by or altered to, chlorite and chlorophaeite. This alteration may be original due to some concentration of hydrous phases in the magma at the time of injection, so that pyroxenes

were not formed. Alternatively, extensive and somewhat selective weathering of the pyroxenes may have occurred. The eventual results of this change is to form a rock in which each joint and cavity is filled with chloritic clays and which as a whole is deeply decomposed. The rock is friable and subject to simple failure as the chloritic material is very waxy. Close examination of such rock in cores will confirm that movements have occurred between blocks of less affected rock. Dangerous conditions will occur in cuts in which much of this material is encountered. The overall colour of dolerite in this condition is a dark green with white flecks.

Thus assuming no climatic irregularities, to be discussed later, a whole range of weathering styles and products are to be expected; these are discussed below. When fresh, and viewed at a distance of more than 2 m, the dolerite appears to be blue or blue-black in colour, the lighter colour being associated with coarser grain sizes. The following comments refer to rock and do not refer to the soil zone which is commonly less than 0.5 m and rarely more than 2 m thick. The weathering profile in dolerite is usually very shallow and abrupt.

Marginal or chilled dolerite. The rock is fine-grained and has a high joint frequency. As the rock is fine-grained it is more resistant to chemical attack, and although the joint frequency is high most joints are tight. The amount of separation along any open joints is very slight. Unless the rock has been shattered by tectonic forces little weathering effect is noted other than a very thin (<1 mm) yellow, brown or red coating of iron oxide on each face or air and water exposed joint.

Lower third of an intrusion. The rock is fine-medium grained and the joint frequency moderate. Similar comments apply as for marginal dolerite.

Centre of an intrusion. The rock is medium-grained and the joint frequency moderate to low. Weathering is rarely deep, but joint coatings may average 2-5 mm. Where a large face is exposed rock kernels surrounded by fragmental products, normally with little clay, are usual. 'Kernelisation' is common only in medium-coarse grained rock as only then can the hydration process produce enough expanded hydroxy products that result in a layering and subsequent peeling of the surface layers of the rock.

Upper quarter of the intrusion but below upper marginal zone. The rock is coarse to very coarse-grained and the joint frequency commonly low. Joints are much more open than elsewhere in the intrusion. The dolerite is very light in colour and rich in iron oxide and accessory minerals. Weathering may often be very deep and sometimes produces a gritty, gravelly product with grain units of some 5 mm. 'Kernelisation' is a common process.

Rock weathering may produce isolated basins or troughs of deeply weathered material which are surrounded by quite fresh rock. The nature of the jointing, especially its pattern and intensity, will determine whether a basin or trough is formed (see also Enslin, 1944). Basins are rarely more than 6 m across. As such features are produced by chemical weathering which is only significant, on a whole-rock scale, above the water table (Thornbury, 1954) basins rarely extend below this level. Because of past fluctuations in the level of the water table, the depth of weathering may not be related to the present level. Trough weathering is commonly associated with the fracturing near faults or major joints and may extend to great depths (fig. 46,B).

Significant apparent horizontal stratification of dolerite also occurs due to layering of rock in different stages of weathering. It is not unusual

to find profiles such as soil, fragmented rock, fresher rock, fragmented rock, discoloured rock, fresh rock. It will often be noted that such layering is related to the levels of the major sub-horizontal joints since these mainly determine the water circulation. As a result the rock above such a joint is often markedly weathered while that below is not since the water with the dissolved active chemical constituents is transferred to other parts of the system or the surface.

An important aspect of all weathering is the presence or absence of open joints (fig. 46,B,C). There may be a history of openness: following initial cooling, when a network of contraction joints was formed, but while the dolerite was still warm (100-700°C) some late stage magmatic fluids were often introduced; sometimes these were rich in calcium carbonate (calcite) or calcium silicates (zeolites) the result being that many joints were sealed. Both calcite and most of the common zeolites are white although some are pink or green. Zeolites have a characteristic radiating needle-like crystal form. Following perhaps further contraction or tectonic stress some of the original contraction joints may be reopened or others formed. Weathering products including calcite, iron oxides or chloritic clays (chlorophaeite, nontronite) may then seal the joints. In the case of the iron oxides and clays shrinkage may occur permitting a flakiness to develop thereby reopening the joint. All variations may be observed in one locality. Fault shattering creates a mass of open joints which lead to a zone of deep weathering.

The presence of much travertine in the soil is a good indicator of extreme weathering. Detailed descriptions of the weathering processes are given by Holmes (1965), Hem (1959), Goldich (1938), Bond (1964), Enslin (1944). The relation between weathering and water transfer is discussed by Leaman (1965). Other aspects of dolerite weathering are discussed by Hale (1958) and Spry and Hale (1964).

Climate plays a vital part in the entire process, the humidity and temperature being critical. In the present climatic conditions much of the weathering is due to physical processes and chemical action is somewhat retarded. However this has not always been true as the climate in the near-recent past was warmer and wetter. Thus in low-lying areas where present day active erosion is not occurring there is often a thick soil cover with zones of deep weathering. Such a cover of thick weathering products should not be confused with the rubble, boulders, soil and clay which may collect at the foot of a currently eroding and exposed hill. Deep red soils and weathering products reflect past weathering and are related to more humid times.

Physiographic relief is a significant factor in determining the form and depth of weathering (fig. 46,D). Its relation to jointing has already been discussed, and the collective effects of slopes are mentioned above. At the present time active erosion is occurring on the exposed portions of the hills, especially the tops. The rock fragments, soil and wash generally collect on the concave parts of the slope, as near the base. Due to deeper cover and non removal of weathering products near the base of the slope deeper weathering will be found in this position while bare rock exposures appear elsewhere on the hill. The exact range of products and effects are related to the factors of jointing and composition. The slope deposits are discussed below.

There is one other major factor not yet mentioned. It has been assumed throughout the above discussion that the intrusion is a simple slab resulting from one injection of material. This need not be so, and if not can result in great and apparently wild changes in properties due to the non systematic

grain and compositional variations (fig. 46,A). It should be noted that faulting could have the same effect horizontally while maintaining the same series vertically but at different elevations when referred to a common base.

SLOPE DEPOSITS

Slope deposits are produced as a result of erosion from more exposed areas with subsequent deposition of material in more sheltered areas. Slope deposits fall into three main categories; soil, scree and talus. The general form of the deposit is a wedge at the change of slope (fig. 46,D).

Soil accumulations are very common on the lower slopes of dolerite hills, or where there are distinct steps in the topography. Consolidation is normally very slight and fragments of travertine and weathered rock may be present. Such deposits are porous and although piping may occur in them they are stable at relatively high cut angles (30-40°) (fig. 46, D,E). Some dolerite soils are sensitive (Evans, 1958).

Scree is defined as an accumulation of rock fragments, pieces and boulders, which are commonly quite fresh and may vary in size from a few centimetres to more than a metre across; with little or no clay or soil. Such deposits are unstable at almost any angle and movement of a few boulders may cause mass failure; rock slides are common.

Talus is defined as an accumulation of fragments, pieces or boulders with at least 10% of its volume made up of soil and clay. Normally the soil and clay content is 40-60%, but may vary greatly. Where the proportion of soil is low the deposit may be stable in cut less than 3-4 m high. However, as the soil content increases the likelihood of slips also increases. The water content is critical as it converts the soil component to a mud: slips normally follow heavy and persistent rains. Good drainage trenches upslope are essential as the failure is partly initiated by surface sheet overflow and partly by shallow underflow. All cuts in this material should be as shallow as possible, preferably benched and sown down with deep rooting plants. An example of failure in talus is discussed by Leaman (1970b).

OUTCROP EXPRESSION

A wide range of soil and outcrop conditions occur in dolerite areas. In many cases, particularly in areas of gentle relief, only brown, black or sometimes grey soil will be seen. Although such soils may suggest deep soil cover this is not usual, although deeper weathering will certainly be present. Soils are rarely more than one metre thick. Where rock pieces are exposed at the surface a detailed examination of their joint directions and texture will be necessary in order to gain an indication of whether or not such pieces represent actual outcrop. The size of the pieces is also a good indicator. Consistency of joint directions does not necessarily confirm outcrop as large boulders commonly tip or creep down slope maintaining the joint directions. Even the largest boulders may appear as outcrop. A seismic survey can easily determine whether the rocks represent outcrop.

The proportion of outcrop or near outcrop will give a good indication of the nature and often the depth of extreme weathering. If there are nearly continuous exposures of rock then there is usually little doubt about the state of the rock. This will normally only be the case in exposed areas such as slopes, hill tops and actively eroding valleys. Where there is a reasonable doubt as to the nature of the surface exposures, a seismic survey should be undertaken. Should the result remain ambiguous due to velocity overlaps (rarely a problem) some shallow boring will be needed (see later).

SITE INVESTIGATION REQUIREMENTS

The particular requirements of exploration in dolerite areas depend on the type of project under consideration. Only cuttings are discussed in this report since tunnels and foundation works are not required in connection with the railway. Two preliminary studies should be undertaken and the information gleaned from these will determine the need for further work.

A reconnaissance geological survey of the area should be undertaken to establish the dolerite type and form, to gain some idea of weathering both from soil products and the amount and type of outcrop, and to obtain a general idea of jointing conditions. This should be followed by geophysical work, preferably by a seismic survey, although other methods may give useful information. Depending upon the results, bore holes may then be required to test problem areas. In each case geophysical results will eliminate the need for some drilling and provide better control for further investigation.

Where a series of cuttings is needed, little drilling will be required since calibration of the seismic data by the results of the first few bore holes will enable predictions to be made along the length of the route and only minor subsequent drilling will be required.

SITE INVESTIGATION METHODS

The first examination of a site should be reconnaissance geological survey. This may be followed by geophysical work to provide subsurface information. Three geophysical methods are applicable to dolerite terrains; refraction seismic, magnetic and resistivity. Geophysical work should be regarded as a means of adding physical information to qualitative observation and also of providing specific targets for drilling. The aim of geological-geophysical investigation of this type should be to produce a detailed appraisal more economically since geophysical work is cheaper than drilling. This does not mean that drilling is without value, but the siting of the bore holes must be properly controlled to ensure that the maximum information may be gained.

Seismic methods enable predictions to be made concerning the state of the rock and the depth of soil and weathering. Some information can be obtained on joint anisotropy where some joint trends are more pronounced than others. For examples of such surveys see Longman (1969a,b). Where multi-component geophones are used information on the elastic moduli of the rock can be obtained.

Magnetic methods can be used to locate zones of fresher rock. Dolerite has a high magnetic susceptibility and remanent magnetisation. However, when weathered there is a significant decrease in the magnetic field due to disorientation of the magnetite. To be successful very close spacing of observations is necessary and as a consequence only areas of less than a hectare can be covered easily.

Resistivity methods can be used to give either a depth profile similar to a seismic survey since differing values of resistivity are related to each different weathering states. It is also possible to traverse an area to locate major vertical discontinuities such as crush zones or major joints. Such features cannot be defined easily by seismic methods (Leaman, 1968a,c).

A combination of methods may be required depending on the particular problems encountered.

CUTTINGS AND THEIR STABILITY

Dolerite cuttings pose problems in excavation, stability and maintenance; all of which are related to some aspect of jointing and weathering. Some of the main points are listed below (see also fig. 46,E).

Excavation

Soil and weathered rock is simply removed by mechanical excavators. In general only about 1-3 m of material may be removed in this manner. Blasting will be required thereafter, and selection of major joints as blast points will facilitate the collapse of a face. The siting of charges in major blocks should be avoided, if possible, as it is wasteful because most energy is spent shattering the rock and not in the removal of material from the face. A watch should be kept on exposed faces to ensure unintentional rock falls do not occur. Potentially dangerous material should be cleared at the appropriate excavation level. Weathered zones should be stripped from a face to ensure the stability of that face. Such zones can be deceptive in that the rock may look more decomposed than it really is and only restricted zones of weathering may be present. The greatest danger occurs when large blocks are isolated by restricted weathering zones; with more complete weathering only small fragments are involved.

Stability

The stability of a dolerite face depends partly on its age (see later). Of more immediate importance as such aspects as jointing and weathering. The frequency of jointing and the orientation of that jointing with respect to the cut are crucial to its stability. The smaller the joint blocks the more likelihood that a collapse will occur. Crush zones should be unloaded as much as possible; if such zones are parallel to the cut, the material between the crush zone and the cut should be removed or suitably benched. Crush zones dipping towards the cut will need to be selectively removed or benched. Similar comments apply for major joints.

Good upslope drains are essential. All drains should be as deep as possible and certainly cut to the top of reasonable quality rock (the limit of excavation with mechanical shovels).

If inclined joints are present, with dips toward the cut, an asymmetrical cut will be required with the up-dip face cut well back (fig. 46,Ea). It must be noted that the vibrating effect of heavy traffic may eventually loosen many blocks and result in a major failure.

Weathering serves only to emphasise the above effects in that it reduces the total rock strength and particularly the adhesion between adjacent blocks - especially if other factors such as joint dip and direction would favour collapse.

The design of each cutting will be different due to the varying importance of the factors affecting stability.

Small cuts less than 4-5 m high, will stand vertically, or nearly so, provided that the face is cleared of suspect blocks and zones. Larger cuts will need benching and no cut should exceed 10-15 m without at least one bench. In most cases each step in the cut might be nearly vertical and each bench perhaps 2-4 m deep. A special examination of each cutting will be necessary because of the large number of factors affecting stability. It is advisable to have deep and wide table drains because minor block falls,

especially in wet weather, are almost unavoidable. Some drainage trenching should be considered in association with either deep cuttings or deep weathering as running water aggravates the problem.

Maintenance

Nearly all dolerite cuttings require periodic maintenance. This may take the form of removal of material from the base of the face or removal of occasional blocks from the face. The frequency at which maintenance will be required will vary according to the nature of the dolerite and depth of cutting; most of these considerations have been discussed above. Deep and wide table drains are strongly recommended.

A face weathers and fragments with time. The age of a face is generally of little consequence in dolerite where only physical processes apply but may be important when rapid weathering also occurs, as with the coarser rocks.

SEISMIC DATA AND WORKABILITY

The following table summarises the general properties of the dolerite in relation to the seismic velocity and Young's modulus.

An important control on the compressional velocity is the presence and amount of clay, soil or joint fillings. In the case of talus, scree or gravel the boulder fragments may be very fresh and in themselves capable of transmitting energy very rapidly. However, as in the case of scree, the areas of contact between adjacent boulders are small and the seismic velocity is directly proportional to contact area. Where soil and clay is present, as in the case of talus or very weathered dolerite the contact areas of relatively solid material will be even less and the seismic velocity is directly related to the inter-block material.

Material	Seismic velocity m/s	Young's modulus MPa
Soil	0- 300	
Scree and talus	300-1,000	1,000- 2,500
Dolerite gravel	800-1,500	
Weathered dolerite	800-2,000	
Close jointed dolerite	2,000-2,500	7,500
Fractured and, or, partly weathered dolerite	1,500-4,000	
Jointed or fractured dolerite; some fracture filling	2,700-4,500	10,000-40,000
Unweathered dolerite, slightly fractured but sealed with calcite or zeolites	4,000-6,000	40,000-80,000
Massive, fresh dolerite	5,000-7,000	50,000-100,000

Dolerite, or dolerite-derived material, with a seismic velocity of less than 2,000-2,700 m/s may usually be ripped or dug with a back hoe. In some cases where wide joint separations and large massive blocks are present in a weathered mass there may be some restriction on ripping even though the seismic velocity may be as low as 1,500 m/s. A seismic velocity of 2,000 m/s should be regarded as a general cut off value. Dolerite with a seismic velocity above 2,700 m/s, cannot be dug without the aid of blasting. Further comments on use of seismic data are given in the following section, where complete interpretation of the condition of the material is discussed.

BORE CORE FEATURES AND THEIR INTERPRETATION

Cores of dolerite clearly demonstrate most of the joint and weathering features outlined in preceding sections. All joints, including incipient types, are clearly shown. Joint fillings and weathering films are also obvious. However, the colours seen in joint fillings will be generally unlike those seen in rock exposures. Green chloritic and clay minerals are common. A typical core log is shown in Figure 47.

A drill core gives only a minute sample of the rock and many of the inferences that may be made from an examination of the core could be invalid. Herein lies the advantage of geophysical (especially seismic) methods which can provide data on a large volume of material and permit an estimate of its workability and general condition. In many cases a drill core gives a depressing outlook for two reasons. Firstly the core is often broken, either due to natural jointing, the drilling process or by the requirement to fit it into boxes. Secondly, weathering and joint fillings dominate the appearance of the rock more than they affect its real condition.

Consider the sample core log (fig. 47). In the zone marked 'A' recovery was very poor and represents the soil horizons. In seismic terms a velocity of about 300 m/s would be observed. Zones B to E represent various weathering conditions. In general oxides of iron are obvious and except for zone C the rock is shattered. Only in some larger pieces of core will sealed joints be apparent, perhaps containing calcite and chlorophaeite. In the process of drilling many of these joints will be broken and pieces of the filling material will be noted adhering to various core sections. Apart from zones B and E the rock is not generally affected by weathering and only the joints and material within 3-6 mm of them are altered. The core losses which occur in zones B and D probably represent thicker joint fillings which have been ground away and removed from the hole by the circulation of the drilling fluid. Where material similar to that in zones B to E has been noted in core the seismic velocities are very informative. If for example the neighbouring rock is in similar condition the velocity might be 2,400 m/s. However, if the hole is near a major fracture zone - this being the cause of the increased fracturing in B to E - then the surrounding rock will be fresher and more massive with the result that the velocity might be 3,500-4,000 m/s. A similar result would be obtained if the bore hole is unfortunately placed in a local zone of weathering. In the first case the velocity would suggest a just ripplable material. Zone B would certainly be ripplable from core indications but zone C might well be too massive to permit further excavation without blasting. In the latter two cases the seismic velocity would suggest immediate use of explosives as only very limited use of ripping equipment would be possible. Thus the seismic velocity picture is of more overall use than a few restrictive bore holes which taken alone could give a wrong impression. Zone F core is generally massive and, except for a small region at about 18 m, unbroken. This broken zone shows oxide weathering implying groundwater circulation from higher levels. Such a fractured zone will normally appear very messy in the core but will in no way affect the overall stability of zone F. The seismic velocity would be of the order of 6,500 m/s and would reflect the very massive nature of the rock.

In summary, bore holes are useful in that the conditions of weathering and fracturing can be directly observed. However, this information may in no way be related to the actual overall physical state of the rock which would determine the method of excavation. The information from a bore hole can be used to help resolve some of the ambiguity of a seismic interpretation where the velocities obtained could be produced by two rock conditions (only true of very fractured and weathered material). In general, well controlled

and calibrated seismic interpretations will provide most of the information required for costing and excavation within the limitations outlined earlier. Seismic results are considerably upgraded by a small amount of drilling information. Movements on fractures are indicated by slickensides, the polishing and grinding of the filling material. Such effects are easily observed in the core and indicate nearness to a fault or major fracture. Slickensides are commonly observed in the chloritic coatings which may be extensive in some local areas (see earlier). The joint coating and indications of movement may often be seen only in bore core as the materials containing the necessary evidence are quickly removed upon exposure to the elements.

SOIL MECHANICS

To date very few samples have been taken for analysis. The following results give an indication of the character of dolerite soils. For other geotechnical information see Evans (1958).

Plasticity index:	44	53	42	27	44	39
Liquid limit:	61	79	59	51	59	56

The soils consist mainly of kaolinite with some illite, metahalloysite, quartz or montmorillonite. Many of the values for plasticity index and liquid limit given by Evans are lower than those stated above, but many of the above data are from samples collected in the Hobart area from the thick black soils. The thinner red and grey soils of the highlands may well be less plastic and sandy as indicated by Evans.

OTHER PHYSICAL PROPERTIES

Density. 2,700-3,200 kg/cm³ (average: 2,900-2,950 kg/cm³). The lowest density is associated with the coarse grained light-coloured dolerite.

Poisson's ratio. 0.02-0.10 in weathered rock.
0.3-0.4 in fresh rock.

Uniaxial compressive strength. 40 t/m² in fresh rock.

Apparent resistivity. 10-100 Ω-m in weathered rock.
100->5,000 Ω-m in unweathered rock.

Bulk modulus. 5,000-30,000 MPa in weathered rock.
90,000-100,000 MPa in fresh rock.

Rigidity modulus. 10,000-50,000 MPa.

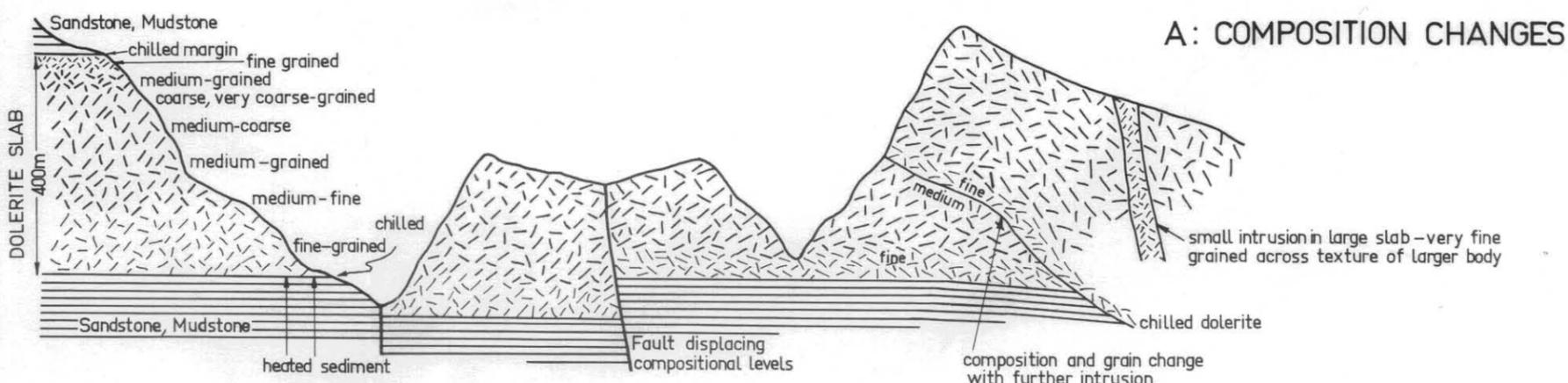
Porosity. About 1%.

Fracture permeability. 0-200 m/yr (est.)

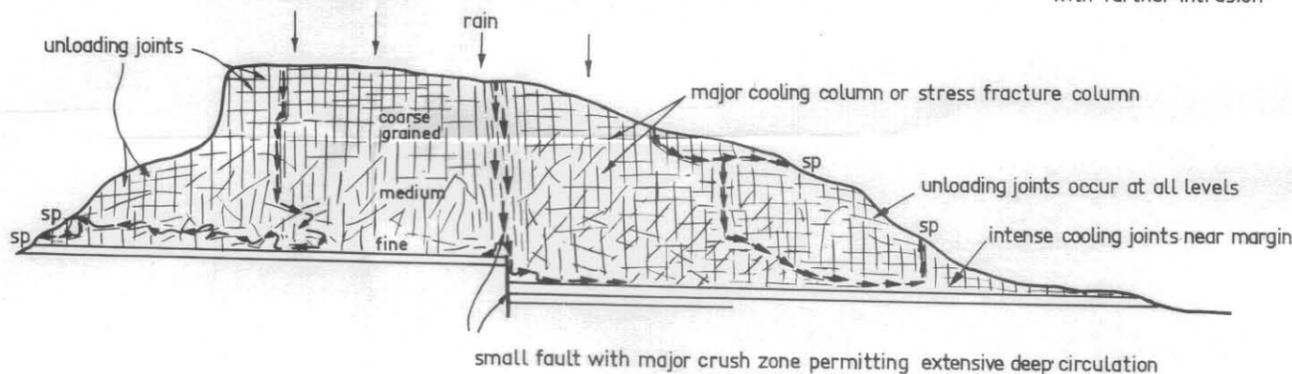
A summary of the engineering properties of dolerite is also given by Leaman (1972) for the Hobart area.

CONCLUDING COMMENT

Most of the problems associated with working in dolerite are faced by a contractor and are rarely appreciated by those involved in design. The following quotation is taken from A.M. Muir Wood's article 'An art for humble men' (*Tunnels and Tunnelling*, March 1971, p. 99): 'The contractors' problems

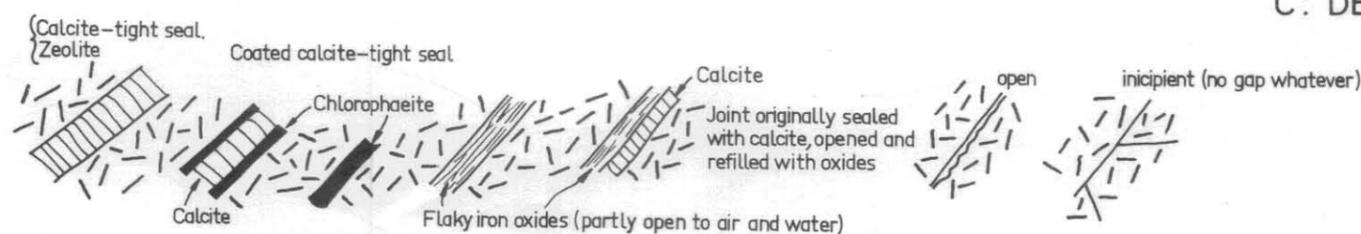


A: COMPOSITION CHANGES

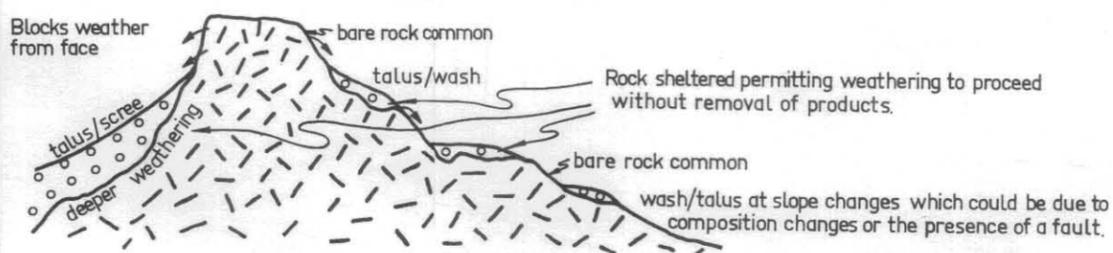


B: JOINTING & WATER TRANSFER

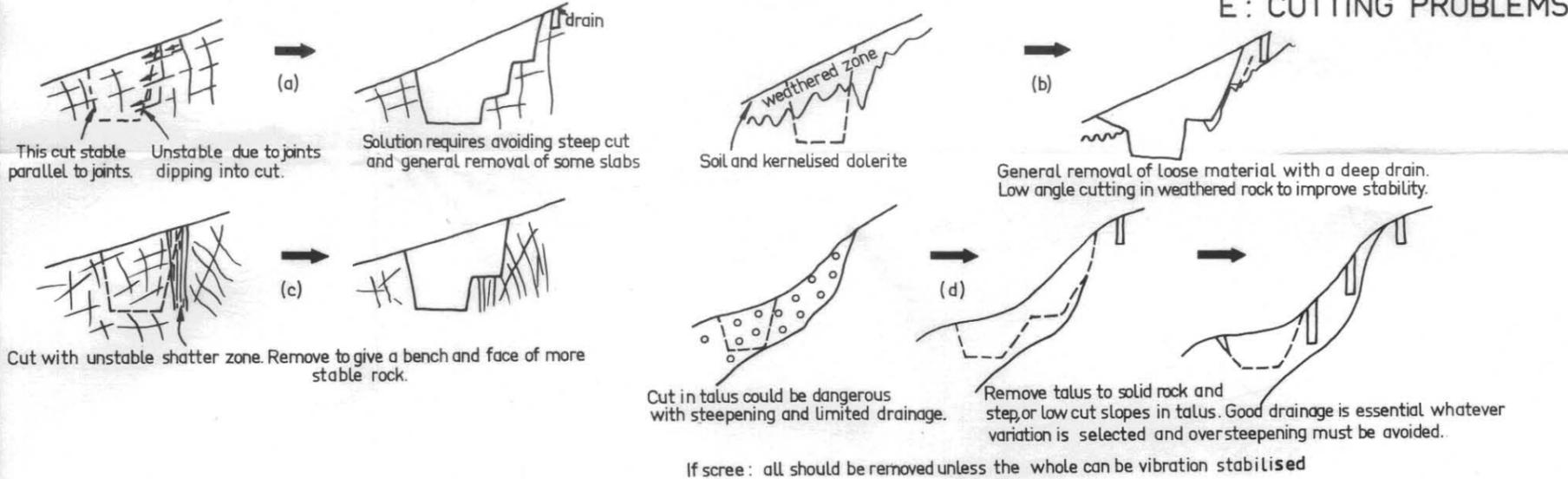
Springs may occur where a continuous fracture system with a water supply reaches the surface. Water may circulate to great depth, or alternatively be restricted to small fracture systems depending on openness, scale and continuity of joints.



C: DEGREE OF JOINT OPENNESS



D: TOPOGRAPHIC EFFECTS



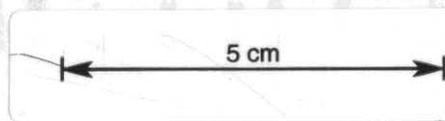
DOLERITE-ENGINEERING PROPERTIES

GEOLOGIST : D. E. LEAMAN

Drawn : H. Mackinnon

PROGRESSIVE DEPTH (M)	DEPTH (M)	CORE DRAWN (M)	CORE LENGTH (M)	CASING	RECOVERY			GRAPHIC LOG	JOINTS NO. PER. METRE	FLUID RETURN GROUND WATER	REMARKS
					20 %	40 %	100 %				
A	2.4	0.6	2.4								0-1m soil. Coarse dolerite fragments; no solid core lengths; Fe oxide weathering with white fibrous calcite deposits.
	5.2	0.7 0.15 0.7 0.4	0.8 0.4 1.2 0.4					X/X/X	60 120 30 60		Dolerite shows whole rock weathering - principally to limonite. Fe oxide coating on joints up to 1.5mm thick. Shatter zone with green chlorophaeite. Weathering 3mm into rock from joint. Joints mostly at 30-60° to core, some horizontal.
C	7.2	2	2					X/X/X	12		Joints at 60°, 20°, 0°, 75-80° in order of frequency. Most weathering on 20° joints. Rock absolutely fresh within 6mm of joint. Some 75° joints open. Some joints contain calcite, most are iron coated. Medium-coarse dolerite.
	8.8	0.15 0.7	0.8 0.8					X/X/X	?		Very weathered highly oxidised shatter zone
F	10										Massive coarse-very coarse dolerite. Joints sealed with calcite and green chlorophaeite at 8.9, 9.3, 10.4, 12.5, 13.2m. Joints predominantly at 30-45° to core
	12								3-6		
	14										
	16	14	14								14.3m, mineralised joint-pyrite.
	18							X/X/X	30		Shattered medium dolerite with some Fe oxide weathering.
	22								3-6		Massive dolerite, joints sealed with calcite and chlorophaeite.

Figure 47 Specimen log of dolerite core.



and his consequent costs [which it might be noted affect the whole project cost - D.L.] depend to a great extent upon whether or not the tunnelling [or any other - D.L.] scheme presented to him by the engineer has been devised with a practical understanding as to how it is to be undertaken or even with any thought to the geology, the dominating factor. No amount of critical path planning will overcome such lapses nor solve the intricate problems of breaking out into variable ground'.

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APPENDIX 1: TAMAR VALLEY LOCALITY GUIDE

Locality 1

A low cutting on the road to Batman Bridge and Rowella at a point 4.75 miles from Rowella and between the road junction to Rowella/Batman Bridge and the reflectorised sign indicating this junction [DQ912369].

The dolerite is very deeply weathered and red in colour. The weathering probably occurred during a previous climatic period and the rock has almost been reduced to a soil. Drainage is critical to the stability of this material and failures have occurred at this point.

This weathered material has a seismic velocity of 485 m/s and is up to 15 m thick. It overlies rock with a seismic velocity of 1,400 m/s. These velocities are typical of deeply weathered dolerite.

Locality 2

The main cutting immediately west of the Batman Bridge [DQ925366]. The dolerite in this cutting is seen to be very variable; there are massive kernels of fresh, blue rock and zones of weathered and intensely shattered rock. The soil is thin and brown and most weathering products are either yellow or brown, the implication being that the weathering is comparatively recent.

The usual seismic velocities range from 1,000 to 1,500 m/s, although velocities of up to 2,400 m/s were recorded from certain zones. The cut is relatively stable except where running water erodes the clay fillings surrounding kernels; the unsupported kernels frequently fall on to the road. A wider and deeper table drain is needed in the west side of this cutting.

Only some of the material in this cutting could be ripped. This situation would be expected from the range of seismic velocities recorded.

Locality 3

Near diamond drill holes 2 and 8, east of the wood pulp plant [DQ946428]. The condition of the dolerite exposed in this area is extremely variable. The range of seismic velocities was 900-1,800 m/s indicating generally very weathered material. More detailed seismic work will be necessary in this area because of the erratic occurrence of more solid dolerite.

Locality 4

Site of bridge of East Tamar Highway [DQ936447]. The distribution of exposures in this region implies a considerable degree of weathering as most rock exposures are on the steeper slopes nearby and there is a significant depression on the hill at this point.

The seismic velocity range was 2,750-3,500 m/s below about 3-4 m, and about 500 m/s above it.

Locality 5

The centre of a cutting in weathered and kernelised dolerite 35 km north of Launceston on the East Tamar Highway [DQ959429]. The dolerite appears to have been deeply weathered in recent times, but has a thin soil cover, preserving rock texture, joint traces and other rock structures.

Rock in the top 3 m has a seismic velocity of about 700-1,400 m/s and below this of 3,300-4,000 m/s. Most of the material in the cut wasrippable.

Locality 6

Public Works Department lower quarry, Mt Direction [EQ016346]. The dolerite is fine-grained and generally fresh with a very thin coating of iron oxide on joints. Significant weathering effects are restricted to the top 2 m (seismic velocity: 800 m/s). Below this depth the seismic velocity recorded was 4,500 m/s from west to east and 6,000 m/s from east to west. The difference is related to the sub-horizontal elastic response joints, which dip westward, slowing energy transmission. The real interjoint (response type) velocity should be regarded as 5,500-6,000 m/s. Rock of this type is firm and stable, will stand vertically in cuts up to 7-8 m high but should be benched thereafter on 2-3 m wide steps.

Locality 7

A cutting in jointed dolerite on the East Tamar Highway 34 km north of Launceston [DQ961424]. The average seismic velocity was 5,500 m/s, but velocities of 4,000 m/s were recorded for more highly jointed zones. The latter need to be examined closely for stability; falls have occurred in this cutting. Thicker weathering coatings can be seen in those places where falls have occurred.

Locality 8

A cutting in talus-type material on the East Tamar Highway at Mt Direction at the junction with the road to Pipers River [EQ014338]. The seismic velocity in the talus was 1,000-1,250 m/s. The talus is more than 25 m thick and overlies rock with seismic velocities of 5,500-6,000 m/s. The

talus exposed in this cutting consists mainly of boulders with little clay and soil; it is quite stable. Good drainage is essential, especially where more clay is present.

Locality 9

Hill spur and small cut with a quarry immediately south of the bridge over Four Mile Creek on the East Tamar Highway [DQ915460]. There are widely separated exposures of fresh rock. The small quarry shows that clay zones are the reason for the gaps in outcrop. The near surface (to 2.75 m) seismic velocity is 900 m/s whilst below this velocity is 4,000 m/s. This suggests that although the rock appears solid and stable, deep but joint restricted weathering and clay fillings are present.

Locality 10

Dilston Magazine Road on the dolerite bench approximately 1 km east of the old farm house at the right-angled bend [EQ051305]. Dolerite crops out as widely separated, large flat slabs. The near surface seismic velocity is 1,800 m/s suggesting that the dolerite is only present as kernels in a deeply decomposed matrix. In view of the size of some of the exposures it is unlikely that ripping will be generally possible. At about 15 m the velocity rises to 5,000 m/s and the dolerite below this depth is massive and solid with insignificant weathering.

Between 2.5 and 3.5 m a layer with a seismic velocity of 975 m/s overlies a layer of about 2,000 m/s at a depth of about 3 m. The upper 'slab' layer represents the surface clay and the 'fast' layer is probably fresh but fractured dolerite. At 2.5 m in Bruce Street, an area where the groundwater is known to be very near the surface, seismic velocities of 1,500-1,800 m/s were observed corresponding to clay or soft sand, and no further rock was detected to a depth of about 2.5 m.

RESISTIVITY RESULTS

No water table was detected from the resistivity measurements, a finding consistent with the predominantly clayey nature of both the sediments and dolerite. Gravels containing free water were rare or at least very thin and were only detected at 2.5 m, 3.5 and possibly at 1.5 and 1.0 m.

CONCLUSIONS

The bedrock has an effect on the groundwater in the area; the dolerite outcrops are very heavily weathered and generally only isolated boulders in a matrix of clay and the sediments consist largely of clay with only minor amounts of sand and gravel.

The fact that water is carried deep in the clay by some thin sand or gravel layers is borne out by the Council's experience that French drains 2 m deep were not effective.