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GEOLOGY AND SITE INVESTIGATIONS IN THE VICINITY OF THE GOLIATH PORTLAND CEMENT COMPANY'S WORKS — RAILTON, TASMANIA

by I. B. Jennings.

INTRODUCTION

To understand the problems which may be encountered in carrying out large scale quarrying operations in this area it is desirable to first investigate the general geological history of the district. From this we can proceed to a more detailed examination of the weathering history of the limestone and to a study of the geological significance of the various rocks present, their lithology, structure and genesis. For the purpose of this report all rocks and rock structures older than basal Ordovician need not be considered. Once the broad geological conditions are understood it will then be possible to design the investigation programme more confidently.

REGIONAL GEOLOGY

Geological History

At the beginning or Ordovician times, marine sedimentation of sands, silts and some clays occurred in this area. The sediments have since been consolidated into an 800 ft. thick formation of quartzites, ferruginous sandstones and clays, locally referred to as the Caroline Creek Sandstone. This formation was laid down under rather shallow water, inshore conditions and typical life forms of the time, e.g., trilobites, gastropods and brachiopods, were incorporated into the sediments and have been preserved as fossils. The resuiting fauna is locally abundant, and easily dated; it is referred to the Tremadocian age, the very base of the Ordovician. Thus, although the overlying Gordon Limestone is here poorly fossiliferous we can determine fairly closely the age of the rocks which lie immediately beneath it and therefore estimate the age of the base of the limestone itself.

Following the deposition of the Caroline Creek Sandstone, changing climate and environment initiated the building up of huge thicknesses of limestone detritus which has since recrystallised to form the well-known Gordon Limestone. The lack of recognisable bioherms and the general paucity of well preserved fossils in the limestone suggest that the main coral reefs lay outside the Railton district and that the limestone beds here generally represent transported reef detritus. This detritus accumulated to thicknesses estimated at between 1200 and 3000 feet; such thicknesses indicate a steady, continuous rise of sea level relative to the land of about this figure, during the time represented by the deposition of the Gordon Limestone. The estimates so far made of the thickness are based upon general geological grounds, from structure and from correlations with nearby areas but because of the lack of limestone outcrops they cannot be regarded as authoritative. Further structural work now in progress is designed to test these estimates, but again the lack of outcrop renders any purely geological approach to this problem liable to error.

Evidence from elsewhere in the State suggests that the deposition of Gordon Limestone was followed by a long period of sedimentation extending up to the Lower Devonian. During this time, many thousands of feet of sandstone and shales were laid down over the limestone, but they have all subsequently been removed by erosion. However, relics of these formations still occur, overlying the Gordon Limestone at Mole Creek, Liena and Gunn's Plains.

This long period of sedimentation was halted by an intense period of diastrophism in Devonian times. All the sediments were strongly compressed, folded, faulted and raised up into fold mountain ranges well above sea-level. Erosion of these newly formed mountains commenced immediately, and deposition in the area was halted until the mountains were eroded to sea level, or until the sea-level rose high enough to engulf their eroded fragments. It was during this period that the sediments overlying the limestone were removed.

By late Carboniferous or Lower Permian times, sedimentation recommenced and horizontal beds of new sediments were laid down upon the upturned and eroded limbs of the folded beds of Gordon Limestone.

The Permian sedimentation consisted of about 2000 feet of predominantly marine conglomerates, mudstones and pebbly mudstones. Some of the conglomerates were of glacial origin, but near the base of the Permian sequence there is an important interruption of the marine facies by estuarine conditions during which abundant spore beds accumulated locally, resulting in the formation of the Tasmanite oil shale beds. The marine deposition was also interrupted for a while by fresh water conditions during which the coal beds of the Mersey Coal Measures were deposited.

Evidence outside this area suggests that the Permian sequence was terminated upwards by the onset of further fresh water conditions initiating some coal deposition and followed during the Triassic by thick sequences of interbedded fresh water sandstones and shales. However, none of these Triassic rocks has been preserved in the vicinity of Railton.

The next main geological event was intrusion of large masses of dolerite through the basement of limestone and into the Permian and Triassic rocks. Fissures for the emplacement of this magma must occur at several places but so far none has been located near Railton. The dolerites spread out as vast sheet-like bodies into the Permian and Triassic rocks, and as numerous, but usually small, local intrusions along the unconformity at the base of the Permian. Subsequent erosion has left the dolerite sheets as protective caps on several hills in this vicinity, notably Long Hill and Bonney's Tier (formerly Brown Mountain).

These intrusions were accompanied by uplift of the land masses, the thickness of the intrusions probably contributing to much of the uplift. Erosion of the uplifted blocks has continued unabated in this area until the present day and all the rocks which formerly covered the limestone (Permian and Triassic sediments and the dolerite) have been removed. Erosion was considerably speeded up during the Tertiary by further strong uplifts, accompanied by vast outpourings of basaltic lava. The basalts flooded the existing topography, filling the river valleys and covering their stream gravels beneath lava fields. The volcanic outpourings were spread over a long period so that as the early flows disrupted the existing drainage system, temporary streams and lakes were formed into which the newly uplifted land poured sediments and these in turn were covered by further lava flows. The volcanism was in places foreshadowed by the uplift of the land along numerous faults which also severed the drainage lines and initiated lakes. Thus, under and between the basalt flows we now find old lake and stream deposits in abundance.

Since the Tertiary uplifts and outpourings of lavas, normal erosional processes have moulded and sculptured the existing topography. Stream erosion, frost action, rain and solution weathering have all been active in this area. During the Pleistocene, glaciation of the central highlands and its accompanying more rigorous climatic conditions temporarily accelerated some of these processes.

Perhaps for a while during the melting of the icecap and retreat of the valley glaciers stream erosion became dominant, but with the amelioration of the climate the same erosional processes which we can see at work today have been slowly carving the present topography.

Geological History and Weathering of the Gordon Limestone

Since the time of deposition of the Gordon Limestone some 400,000,000 years ago, as long as ground water has moved through the limestone beds, solution and re-deposition have occurred. We have seen how it was uplifted during the Devonian and how all the overlying rocks were removed by late Carboniferous so that surface erosion of the limestone occurred at that time. As indicated previously, it was subsequently covered again by sediments, only to be uplifted once more, and by the Tertiary, once again exposed at the surface. Whenever the limestone came within the zone of circulating ground water it was subjected to solution weathering.

To appreciate the complicated relationships between the limestone and its overlying mantle of residual clay and gravels we must, then, envisage these millions of years of slow, inexorable solution. As the ground water percolated downwards it continually dissolved away the surface of the limestone bedrock. Caves were formed where the descending ground waters encountered crushed zones, joints or more soluble bands of limestone. These caves were connected to the surface by sink holes and into some, the underground streams washed surface clay and gravels which choked the cave outlets at depth and then filled the caverns. As the general level of solution descended the cavern walls themselves were dissolved away, leaving the insoluble residues of the limestone, which slumped down after the retreating parent rock. Thus these ancient cave fillings still remain above the bedrock surface, engulfed and incorporated into the residual clays above.

The solution of limestone by ground water is very slow and during this process every small irregularity of composition, texture, porosity and structure is etched out. Slightly more resistant patches will withstand for a while the downward front of erosion and, like a resistant capping to a hill, leave jagged pinnacles of limestone projecting up into the overlying clay.

Where caverns encountered more soluble bands or structures at depth, the front of solution would spread out laterally, dissolving out caverns well beneath the general limestone surface and leaving great masses or rock unsupported. These masses would then collapse into the caves beneath in a pile of broken and disoriented limestone blocks enclosed in a clay matrix. Such collapsed structures are exposed at several points in the quarry today and more can be interpreted in the residual clays above, following solution of these brecciated masses.

The residuum of the solution process is the overlying residual clay. This forms only a small portion of the volume occupied by the parent rock, thus it is common to find polished, gliding faces in the clay, formed as it slumped downwards after the limestone, or as it followed the collapse of limestone masses into caves beneath.

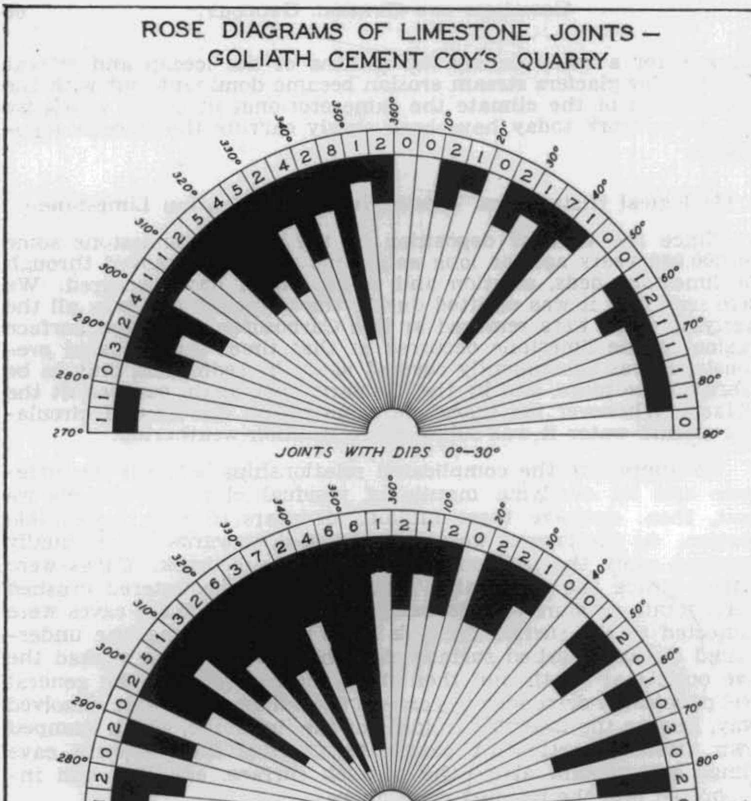


FIGURE 13.

5 cm

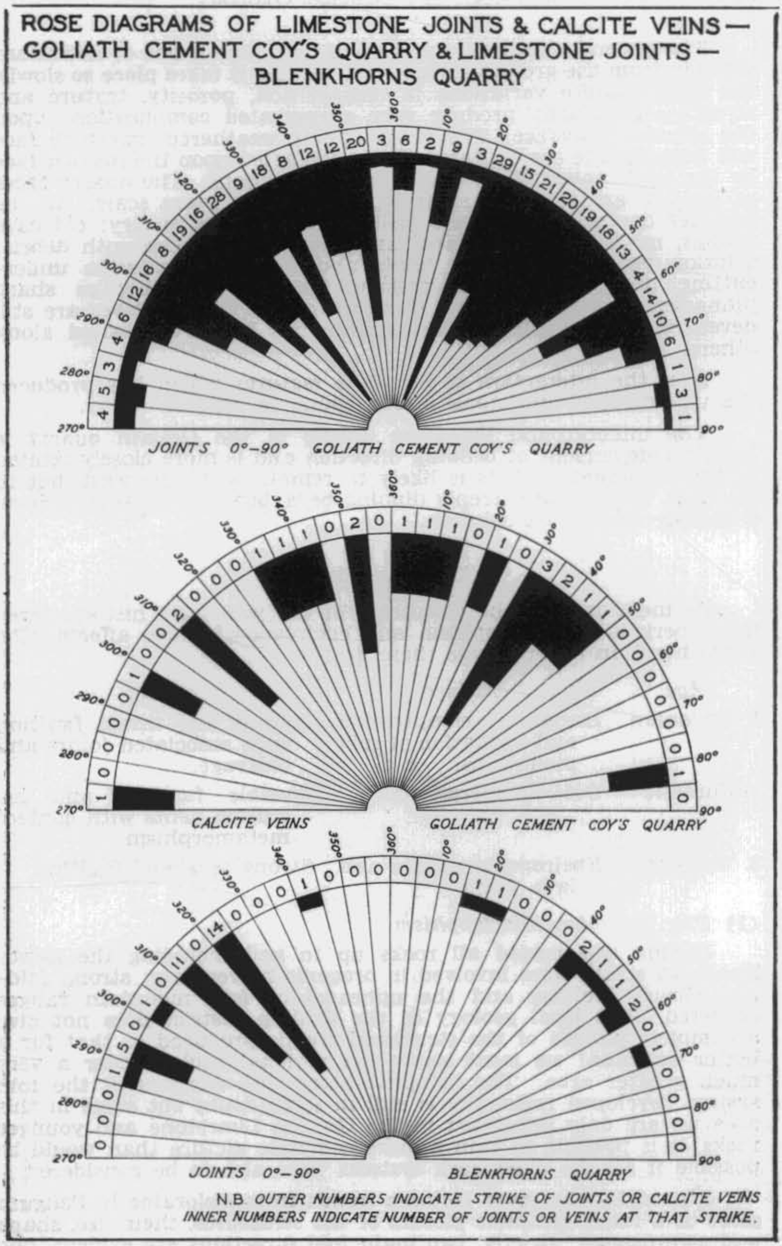
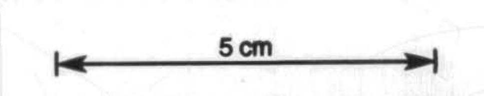

ROSE DIAGRAMS OF LIMESTONE JOINTS & CALCITE VEINS — GOLIATH CEMENT COY'S QUARRY & LIMESTONE JOINTS — BLENKHORNS QUARRY
JOINTS 0°–90°
GOLIATH CEMENT COY'S QUARRY
CALCITE VEINS
GOLIATH CEMENT COY'S QUARRY
JOINTS 0°–90°
BLENKHORNS QUARRY
N.B. OUTER NUMBERS INDICATE STRIKE OF JOINTS OR CALCITE VEINS
INNER NUMBERS INDICATE NUMBER OF JOINTS OR VEINS AT THAT STRIKE.

FIGURE 14.


5 cm

The general weathering process of limestone is one of downward solution from the ground surface, yet because it takes place so slowly, the most minute variations in composition, porosity, texture and structure eventually produce very exaggerated complications upon the solution interface. The study of any weathered limestone face will demonstrate the delicate sculpture effected upon the rock surface by the preferential solution of minute variations. The quarry faces at Railton exhibit these same variations on a giant scale. All the features described above are visible today in the quarry; oid cave fillings, newly developed caves and caves half choked with debris; solution penetrating along joints and structures, solution undercutting limestone masses; resistant patches standing as sharp pinnacles, and weak patches dissolved out at depth. Caves are still developing along joints whilst calcite has been redeposited along others.

It is the interaction of all these features which has produced the underground limestone profile found at Railton today.

The underground limestone profile in the Goliath quarry is largely independent of bedding direction and is more closely related to the topography. This is likely to remain so to the west, but to the east, in the more steeply dipping beds, bedding is likely to have a greater control on solution.

Tectonic History

As mentioned in the discussion of the geological history, three main periods of diastrophism and epeirogenesis have affected the rocks here. In order of age these are:—

Age.	*Nature.*	*Effect.*
1. Devonian	Strong compression and formation of fold mountains.	Folding and thrust faulting with associated joints and cleavage.
2. Jurassic	Dolerite intrusions.	Possible faulting and intrusion vents with contact metamorphism.
3. Tertiary	Epeirogenic uplifts and lava flows.	Strong tensional faulting.

(1) *The Devonian Diastrophism*

During this period all rocks up to and including the Lower Devonian strata were involved in orogenic movements; strong folding, thrust faulting and the upheaval of fold mountain ranges occurred. The local geology of the Railton district does not give a complete picture of the structural trends produced so that for a better appraisal we must study the regional geology over a very much greater area. The complete structural analysis of the fold system developed regionally is still in some doubt but since in this area we are only interested in the Gordon Limestone and younger rocks, it is possible to gain a more complete picture than would be possible if all the older rock systems were also to be considered.

A study of the main tectonic trends from Deloraine to Penguin gives us a fairly complete picture of the structures, their size, shape and significance. Briefly, two main fold directions are evident, one roughly easterly and the other roughly north-westerly. Both of these systems are major tectonic units, the main first order folds being some miles in wave length. The major easterly structures are shown by the great syncline running from near Golden Valley to Chudleigh, Mole Creek and Liena and by the south flank of the next anticline to the north which runs from Red Hills through Mounts Magog, Gog, Roland, Van Dyke and Claude.

The main north-westerly trending folds are the Railton syncline, the Badgers-Round Hill syncline and a series of folds in the Cambrian rocks at Beulah, Barrington and other localities. The intersection of these two great fold systems forms a complex, roughly oval-shaped, domal structure about 50 miles long and 30 miles wide, trending from the Golden Valley district to near Penguin.

Within this main structure the Railton syncline forms the east-north-east limb. At first sight it would seem that the Railton syncline is a fairly regular north-north-westerly trending fold plunging gently in that direction. However, it is unwise to ignore the effects which the easterly cross folding may have upon the plunge of this fold. The complicated trends in the Badgers north of Sheffield demonstrate that although the easterly folding is dying out towards the east it clearly extends as far as the Badgers and probably continues on into the limestone of the Railton district. Thus, although the rock distribution south of Railton indicates a closure of the structure there, and therefore a north-north-west plunge in that area, this may not be so for all parts of the syncline. At Blenkhorn's quarry the cleavage/bedding relationships, though poorly exposed, suggest either no plunge or a slight plunge to the south. The minor structures in the Goliath quarry are so poorly developed that no positive indications of the plunge of the fold can be interpreted from them. A reversal of plunge between the Goliath quarry and the hills south of Railton township is in accord with the nature of the cross folding exposed on the Badgers and in general agreement with the position of the axis of the main cross folds mapped in this area.

The regional tectonics indicate that the easterly trending folds die out east and north of Railton. Thus we may expect that their effect upon the plunge of the Railton syncline will be small and will die out along the axis of the fold to the north-west. These predictions are borne out generally by the observed minor structures and rock distribution. The Caroline Creek Sandstone never appears along the axis of the fold north-west of Railton and the chances of plunge in that direction seem to be small.

Axial plane cleavage is not strongly developed in the Goliath quarry but it is the major structural feature in Blenkhorn's quarry. In both cases it dips to the south-west at about 70°. This, together with the observed dips, suggests that the syncline is asymmetrical with a tendency to overturn towards the north-west. The Round Hill synclinorium, the only major north-westerly trending fold system which has been mapped in detail, also proved asymmetrical in the same sense.

From the foregoing discussion we can now estimate the tectonic setting of the Goliath quarry. The quarry is sited near the axis, on the east limb of a major north-north-west trending syncline at a point where the north limb of an easterly trending syncline crosses the Railton structure. This cross structure is dying out rapidly to the east and north.

Extension of the Goliath quarry should, then, show the following bedding relationships:—

1. To the north-north-west. Flattening south plunge to gentle north-north-west plunge. Dips west as at present.
2. South-south-east. Possible increase in south plunge. Dips to the west as at present.
3. West-south-west. Dips flatten and eventually become easterly.
4. East-north-east. Westerly dips steepening to 40-45°, possible increase in axial plane cleavage.

(2) *The Jurassic Dolerite Intrusions*

The only complications which these intrusions could bring upon the company's operations are:—

(*a*) The dolerite may cause inconvenience as it is a source of large talus blocks which occur in the overburden south and west of the present quarry.

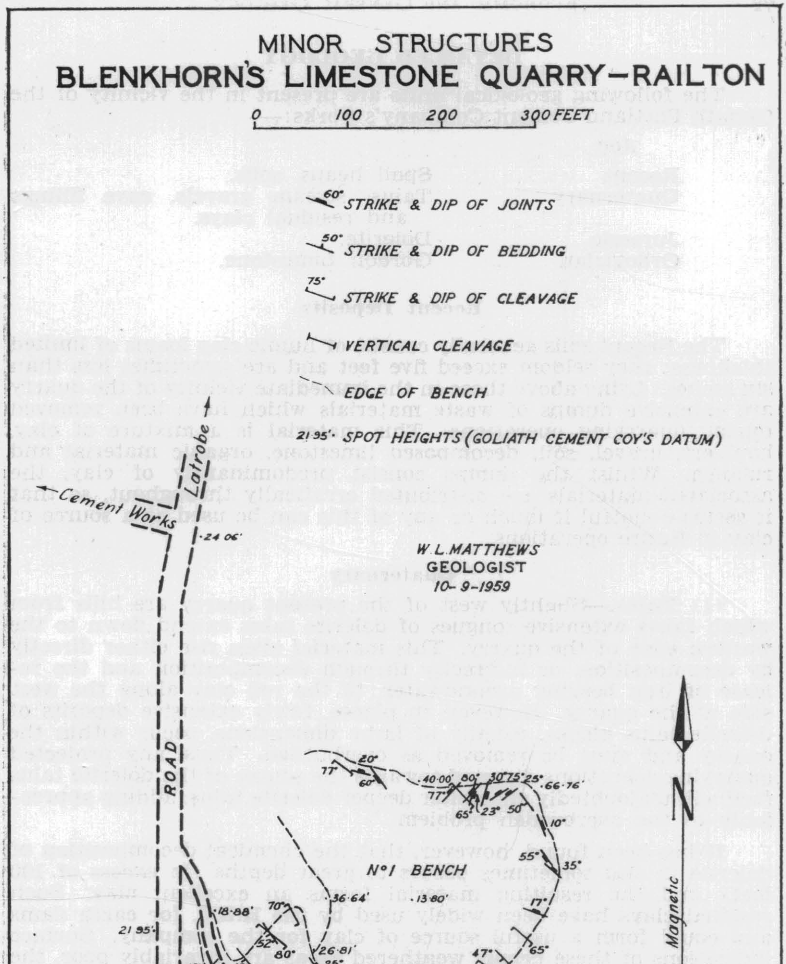
(*b*) Quarry extensions towards the dolerite areas, or new quarry sites near dolerite masses, could intersect dolerite feeders through the limestone. This is so unlikely here that no investigation for such features is warranted without further evidence. Such an intrusion vent could produce contact metamorphic effects along joints and cleavage planes in the limestone which would serve as a warning.

(3) *The Tertiary Faulting*

The whole State is strongly broken along fault lines related to the Tertiary uplifts. In this district a Tertiary fault strikes along the east side of the Badgers and separates these hills from Bonney's Tier. Several other faults of this period have been mapped on the hills to the south of Railton township.

The Tertiary faults are generally tensional and the fault planes are usually near vertical. Although their trends in detail may be complicated, in this area they appear to occur in two sets which trend roughly north-north-west and north-east. It seems probable that many of them here follow structural lines established in the basement rocks during Devonian diastrophism. Perhaps the Tertiary faulting is a late stage of the Devonian folding, representing the old fold cores still slowly emerging.

No minor structures directly related to this period of faulting have been proved in the present quarry but they are probably present. Since the surface rocks surrounding the quarry are completely obscured by superficial deposits we have no means of predicting the presence of such faults in the near vicinity. However, regionally, there is no evidence for Tertiary faults of sufficient magnitude to completely dislocate the limestone in this area. If such faults existed we might reasonably expect to find geological or geomorphological evidence of them. Thus, it is reasonable to assume that, whilst small faults producing crush zones in the limestone may well be encountered in future quarrying, there is no evidence whatsoever to suggest that faults with movements sufficient to displace the limestone entirely, will be encountered in the immediate works area.


MINOR STRUCTURES
BLENKHORN'S LIMESTONE QUARRY—RAILTON
0 100 200 300 FEET
60° STRIKE & DIP OF JOINTS
50° STRIKE & DIP OF BEDDING
75° STRIKE & DIP OF CLEAVAGE
VERTICAL CLEAVAGE
EDGE OF BENCH
21·95· SPOT HEIGHTS (GOLIATH CEMENT COY'S DATUM)
Cement Works
Latrobe
ROAD
Railton
W. L. MATTHEWS
GEOLOGIST
10-9-1959
Magnetic
N
Nº1 BENCH
Nº2 BENCH
·24 06·
21 95·
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36·64·
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38·32·
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50·53·
20·88·

FIGURE 15.

DETAILED GEOLOGY

The following geological units are present in the vicinity of the Goliath Portland Cement Company's works:—

Age.	
Recent	Spoil heaps, soils.
Quaternary	Talus, stream gravels, cave fillings and residual clays.
Jurassic	Dolerite.
Ordovician	Gordon Limestone.

Recent Deposits

The Recent soils generally consist of humic clay loams of limited thickness; they seldom exceed five feet and are sometimes less than six inches. Lying above these in the immediate vicinity of the quarry are extensive dumps of waste materials which have been removed during quarrying operations. This material is a mixture of clay, boulders, gravel, soil, decomposed limestone, organic material and rubbish. Whilst the dumps consist predominantly of clay, the associated materials are distributed erratically throughout, so that it seems doubtful if much or any of this can be used as a source of clay in future operations.

Quaternary

(1) *Talus.*—Slightly west of the present quarry are hills from which fairly extensive tongues of dolerite talus extend down to the western edge of the quarry. This material gives rise either directly by decomposition, or indirectly through decomposition and the release of iron bearing groundwater, to the red clay along the west side of the quarry. However, in places, fairly extensive deposits of dolerite talus blocks, usually of large dimensions, occur within the quarry and must be removed as overburden. Thus, any projected quarrying operations directed towards the source of the dolerite talus field will undoubtedly encounter deeper dolerite talus, adding appreciably to the overburden problem.

It has been found, however, that the chemical decomposition of dolerite in situ sometimes occurs to great depths (in excess of 100 feet) and the resulting material forms an excellent clay. Such residual clays have been widely used by the H.E.C. for earth dams and could form a useful source of clay for the company. Surface indications of these deeply weathered areas are invariably poor, the ground above many of the H.E.C. borrow pits being occupied by the typical dolerite soils intermingled with large boulders. Seismic work would give an indication if extensive areas of deep weathering do occur in the dolerite here.

(2) *Stream Gravels.*—Beneath the soil cover, and overlying the residual clays there is throughout the Railton district, a variable thickness of stream gravels. Sometimes the dolerite talus appears to overlie these gravels but elsewhere the gravels can be found intermingled with huge dolerite blocks. Commonly, in the underlying layer of residual limestone clay, irregular and sometimes large pockets of these gravels also occur. These are discussed later. The gravels consist of highly polished pebbles, varying from almost perfectly rounded to somewhat angular in shape but even the most angular pieces still retain the sheen on their surface. The gravel

material ranges in size from a quarter of an inch up to 18 inches across and if, as may be correct, we include the dolerite boulders in this category then the upper limit of the grain size may be increased by more than 10 feet.

The pebbles are included generally in a clayey matrix and where the horizon is well exposed it is common to find the gravels exhibiting a highly disrupted framework, i.e., the pebbles are sparsely distributed through an abundant clayey matrix and they are not in contact with one another. Frequently the bottom layer of gravel appears to be resorted, with much of the matrix washed out, leaving the pebbles in contact with one another. The disrupted framework characteristic of this deposit is generally in contrast to the fabric of the pockets of gravel incorporated in the residual clays.

Probably the best exposure of the soil horizon, the gravels and the gravel-residual clay contact, is on the south-east corner of No. 1 bench about 100 yards east of the "Chinaman". The widespread nature of these gravels is shown by their occurrence all around the quarry, and at Blenkhorn's quarry, and their presence has been reported in the drill holes north of the quarry. Where exposed, the contact between the gravels and the underlying clays is clear and sharp. Their distinctively polished surfaces are probably due in part to the polishing action of the surrounding clay matrix. Where the stream gravels occur in areas remote from the dolerite talus they consist largely of quartzite pebbles and apparently contain no dolerite fragments. As mentioned previously, gravels and dolerite boulders occur mixed together along the west side of the quarry. This may be due to mixing during slumping and landslips.

It is considered likely that these pebbles, the dolerite excepted, are recycled pebbles from Permian conglomerates. They have no economic value and indeed they represent a hindrance to quarrying operations since they occur widespread and erratically throughout the residual clay, interfering seriously with clay borrowing operations.

(3) *The Residual Clays and Cave Fillings.*—The residual clays are the yellow clays which overlie the limestone everywhere and have been used extensively by the company in their cement making operations. The use of the term "residual" in connection with these clays requires explanation, the meaning is somewhat different from that given elsewhere with reference to the residual dolerite clays, which are the end product of chemical leaching of dolerite in situ. Such clays possibly represent as much as 70% by volume of the original rock; they retain faithfully all the original rock structures and to a marked degree the original texture. They are "sensitive", i.e., the shear strength of the undisturbed clays is very much higher than the shear strength of the remoulded clay. Thus, in designing stable slopes in residual dolerite clays it is necessary to use the value of the shear strength of the remoulded samples, for when such clays are allowed to move slightly, they immediately remould and behave in accordance with the lower shear strength. The extensive slips now occurring in the red clays along the west side of the No. 1 bench may be due in part to this feature as it seems probable that some of this material at least is derived from dolerite rather than limestone.

The limestone residual clays are the residue of the limestone after all the solubles have been leached out but, as is well known, they represent as little as 10% of the original rock volume. They appear to be highly compact and examination of the clay faces in the quarry suggests that they are stable at a very much higher angle than the dolerite clays. Examination of the limestone residual clays reveals pronounced shearing which seems at first to be inherited from the parent limestone. Indeed, in portion of Blenkhorn's quarry where the limestone is of relatively low grade, this conclusion is inescapable. At selected points there, it is possible to trace these shear planes from the clays into decomposed limestone and then into unweathered limestone. At the company's quarry, however, because these clays represent such a small proportion of the original rock volume they cannot retain the whole fabric of the original rock.

This sheared appearance, so strongly reminiscent of the parent rock, appears to be due to settlement which occurred as the clays slumped after the limestone had dissolved away beneath them. As the limestone began to decompose, the rock structures were, for a while, preserved in the products of decomposition. Thus, when the clays were forced to slump because of decreasing volume, they inherited from the limestone a set of shear planes along which this movement could take place.

In many places within the residual clays other highly polished gliding surfaces may readily be found. These surfaces probably indicate where rapid settlement of the clays has taken place following collapse of the rocks beneath them.

Within residual clays extensive lenses and pockets of the highly polished gravels may be found and at first their occurrence is somewhat puzzling. The limestone itself does not contain conglomerate bands which could have given rise to these accumulations. Also, the attitude of these gravel pockets is most irregular and seldom, if ever, conformable with strike and dip of the limestone beds; if any generalisation could be made they would appear to have a near vertical attitude. The gravel lenses are surrounded on either side and at depth by sheared residual clays, but they usually lack this shearing themselves. In places they are associated with finely bedded clays which dip irregularly at high angles, show slump structures, and are quite unconformable with the prevailing strike and dip of the limestone in the quarry. Between the gravels and their associated beds of clay on the one hand, and the residual clays which surround them, we frequently find some of the best preserved polished gliding faces.

Taking all these observed facts into account it seems that the gravel pockets represent old cave fillings. The clay beds associated with the gravels dip roughly in conformity with the old cave walls. The polished interface between these and the residual clays is due to contraction in volume as the cave walls were dissolved away and the resulting residual clays slumped around the cave fillings to counteract the difference in volume between the limestone and their residuum.

Caves which are at present exposed within the quarry are in the process of being filled with deposits of gravel and residual clay washed in from the surface above. The size of these old cave fillings would simply be controlled by the size of the original caverns. Since chemical decomposition produces no change in volume of the cave fillings but is pronounced in the surrounding clays, the cave fillings come to represent a very significant proportion of the volume of the residual clays.

In a similar manner to the preservation of the old cave fillings, the brecciated masses of limestone formed by collapse structures have been preserved by the delicate action of solution weathering. Where large enough caverns were dissolved out beneath limestone masses, the removal of support rendered huge masses of rock unstable and in time they eventually collapsed in a jumbled mass of disoriented, angular blocks. Then as the groundwater penetrated these masses they were dissolved away in situ. Where the weathering has not yet become complete the original brecciated texture is still discernible. In some cases conglomerate-like masses of fairly fresh limestone can be found in the residual clays.

Jurassic Dolerite

As mentioned earlier, the hills immediately west of the quarry are composed in part of dolerite. Except that they contribute to the overburden in the quarry area and may possibly contain reserves of residual clay suitable for cement making they are of little interest to the immediate quarrying operations. Developments of the quarry to the west may intersect larger thicknesses of dolerite talus and it would be useful to map the boundary of dolerite talus in areas of potential interest.

The Gordon Limestone

In the Goliath Portland Cement Company's quarry this formation consists of thick, massive beds of high-grade limestone. The upper beds which have been worked average about 8% $CaCO_3$ and are locally referred to as low grade. Beneath these are 80-100 feet of limestone which averages over 90% $CaCO_3$. Because of the prevailing westerly dips the high-grade stone occurs in the eastern and lower benches whilst the lower grade limestone occurs on the upper and western benches.

Apart from these two main grades, no noticeable variations in composition seem to occur within individual beds which have been worked in the quarry so far.

Average analyses of several samples of high grade stone from the quarry show the following composition:—

$CaCO_3$	88·29%
MgO	1·29%
SiO_2	5·3 %
Fe_2O_3	1·19%
Al_2O_3	2·21%

Average composition of the Gordon Limestone throughout the State is indicated by the following table:—

	(1) %	(2) %	(3) %
$CaCO_3$	87·91	89·5	65·99
MgO	1·38	1·36	0·74
Acid Insoluble	7·62	6·04	27·56
Fe_2O_3	1·52	1·39	2·99

Column (1) is the average analysis of 125 samples from all parts of the State. Column (2) represents 110 samples all containing more than 75% $CaCO_3$. Column (3) is the average of 10 samples of low-grade limestone all below 75% $CaCO_3$.

These figures show that the stone at Railton is comparable to the average high grade Gordon Limestone elsewhere in Tasmania. They also show that where important percentages of impurities are found these consist chiefly of silica rather than aluminium or magnesium. The acid insoluble fraction of these figures includes roughly 80% SiO_2, the remainder being mainly Al_2O_3. Other impurities which have been recorded from various localities are:—

(a) P_2O_5—generally from a trace to less than ·1%.
(b) SO_3—generally below ·1%.
(c) TiO_2—present at Flowery Gully as 1% or 2% but not recorded elsewhere.

In addition to these, small amounts of MnO_2, Na_2O, K_2O and FeS_2 have been recorded from some areas and may occur generally.

The limestone is a very dense, impermeable, blue-grey rock, occurring in massive beds 25-30 feet thick. On freshly broken surfaces bedding laminations are rarely, if ever, discernible, but because of the delicate solution effects, the weathered surfaces often show fairly clear bedding.

Many fossils have been found in the quarry throughout its life, particularly by the quarry foreman, Mr. R. Best, but on the whole, the limestone at Railton is only sparsely fossiliferous. Again, on weathered surfaces, fragments of corals and gastropods are occasionally found etched out by weathering. The age and faunal relationships of the fossils from this area have been discussed in several Mines Department publications and an up-to-date account of the palaeontology of the Gordon Limestone in this and other areas is included in Geological Survey Mineral Resources No. 10, 1957.

Sedimentary structures generally are lacking, or at least not evident, on the exposures in the quarry. Tectonic structures, however, are strongly developed but coarsely spaced. Several major joint systems are present and some of these are clearly related to the Railton syncline, but the origin of others is still obscured. Axial plane cleavage is only locally developed in the Goliath quarry; it has been offset by small-scale thrust faulting related to the main syncline. In Blenkhorn's quarry, on the other hand, axial plane cleavage is very strongly, though crudely, developed. In all but a few instances it masks the bedding. The bedding there dips south-west at from 45-50° whilst the axial plane cleavage dips south-west at 70°.

The limestone is brittle and has a tendency to a conchoidal fracture where the cleavage is not strongly developed. Freshly broken surfaces are sometimes covered by a film of bituminous material and it seems probable that at an earlier stage of its geological history this limestone has been an oil bearing horizon. Stylolites are common. The tensional joints are invariably filled with abundant calcite, whilst along other joints solution and redeposition of calcite has taken place. The master joints frequently carry small streams of water but none yet encountered has been more than a nuisance to quarrying operations.

Outcrops are rare away from the quarry sites and the limestone generally has been dissolved to from 20 to 60 feet below the present ground surface. The limestone is cavernous but not abundantly so. Most of the caves which are exposed in the quarry are wholly or partially filled with clay and/or gravels. There seems to be a tendency for caves to develop most strongly along the major joints with more profound solution being controlled by the intersection of these joints with certain beds; crushed zones also are picked out more readily by solution. However, the irregularity of the caves and the limited number of exposures, render any strict generalisation as to their localisation liable to error. Solution openings have been located in drilling to depths of almost 200 feet below the ground surface.

Groundwater Hydrology

It is not proposed in this report to give a complete account of the principles of groundwater hydrology but it is desirable that the general classification of groundwater and the broader aspects of its movements in limestone areas should be discussed briefly.

Classification of groundwaters.

The following types of groundwater may be present in any area:—

A. Soil water. This is limited to the soil layer and is within the reach of roots.

B. Pellicular water. This is the water adhering to rock surfaces in the zone of aeration. It is not moved by gravity but may be abstracted by evaporation and transpiration.

C. Gravity or vadose water. This is the main body of water moving through the material above the permanent water table. It moves downward under the influence of gravity.

D. Perched water. This occurs locally in the vadose zone above an impervious layer.

All these waters occur above the permanent water table and are known as suspended waters, occurring in the vadose zone (sometimes called the under-saturated zone or the zone of aeration).

The following types of groundwater may occur below the permanent water table in the saturated zone:—

A. Free water. This occurs below the water table and is bound by the first effective confining stratum.

B. Confined water. Occurs beneath a confining stratum.

C. Fixed groundwater. Occurs in sub-capillary openings and is not moved by gravity.

D. Connate water. This is water which was entrapped in the sediments at the time of their formation.

Of all these it is only the vadose water, the perched water, and the free water which are important in this area. The perched water may be important where permeable layers, pockets, or lenses occur in the residual clays or in the limestone. Once the impermeable substratum is pierced by excavations, erosion or drilling, the perched water immediately begins to descend along any available openings to the permanent water table.

If the lenses which contain this perched water are of highly permeable material then the flows from them may be high initially, although the total volume of water in them is limited by their size. At Railton such lenses may occur in the old cave fillings, the limestone and the talus accumulations. Their size will therefore be extremely variable and unpredictable. Generally the cave fillings consist of gravels with a clayey matrix which probably has a low permeability. However, more open gravels could well occur along the old courses of the underground streams.

Perched water may occur in cavities in the limestone if the outlets from these have become choked. If they were intersected, such bodies of water could produce very high flows into excavations. The vadose or gravity water is that which finds its way underground through cavities, joints and fissures in the rocks and superficial deposits, under the influence of gravity. It is this water which is most effective is dissolving away the limestone. At Railton many small streams of vadose water occur at various parts of the quarry.

The free water is that which occurs in the super-capillary openings below the groundwater table. The movement of this water is controlled by the slope of the water table. It is not necessarily static or nearly so. Under favourable conditions where the water table gradient is steep, free water may move at comparatively high velocities, particularly in limestone country. Variations in geological structure, confining strata and the height of the area above sea level all have significant effects upon the shape and slope of the water table surface. Some limestone districts have enormous underground storages of groundwater, whilst in others the groundwater escapes readily and little underground storage is available. In some limestone districts the water table is almost flat and very low, whilst in other districts it is highly irregular. Such variations reflect the extent of underground solution, the total quantity of water available to the groundwater system, the topography and the geological structure.

Normally the movement of groundwater through rocks is controlled by D'Arcey's Law but this is not applicable to rocks having openings of large size. The difficulty in limestone areas is that the openings available for the movement of groundwater are so large that turbulent flow is likely. Some of the largest springs in the world are found in limestone areas.

The acquifers are solution conduits and caverns formed along fractures and joint systems and are connected to the surface by sink holes. Solution channels at and below the water-table discharge water-table streams or confined flow from sub-water-table conduits. The underground drainage may be considered as a subsurface stream system, or if the conduit is below the water-table, as sub-water-table flow. As an indication of the kind of flows which do occur in limestone areas, the following list shows data obtained from major springs in limestone country:—

1. The Vaucluse Spring in Southern France—After heavy rains this is probably the largest ground-water stream in existence but it fluctuates markedly with climatic conditions. The spring has reached a volume of over 4,000 cusecs.
2. The Silver Springs, Florida—Discharge 500 to 800 cusecs.
3. The Blue Spring, Florida—Discharge 300 to 700 cusecs.
4. Wakulla Spring, Florida—Discharge 300 to 850 cusecs.

(1 cusec. = 1 cubic foot per second).

These springs, of course, occur in regions having an enormously larger catchment and intake area than is possible in Tasmania. It is not suggested that springs aproaching these magnitudes would be encountered in the Railton district. The figures are cited merely to ilustrate the capacity of limestone to transport immense volumes of water along solution openings.

There is a general difference between the groundwater encountered in flat lying, impervious limestone and that encountered where the beds are inclined. In the inclined, impervious limestones, such as at Railton, the vadose water is not held above impermeable barriers but sinks straight to the water-table or moves down the inclined beds to the saturated zone. Within the limestone the first important barrier is the water-table and at this level caverns are dissolved out regardless of the dip of the beds. The stoppage and sudden drainage of such openings may produce flows of stored water of destructive character. An example quoted records:—" There is every indication that when the flood left the cave it did so with violence, tearing down loosened rock, hurling stalactites to the ground and felling huge columns like trees in a tornado's path ".

Solution is possible to considerable depths below the water-table. Rapid flow in openings below the water-table brings quantities of under-saturated water into contact with the limestone and solution thus proceeds, enlarging the fractures.

Openings in limestone country may deflect all the surface water underground, to be stored in solution openings and to be ultimately discharged by perched, underground streams, by water-table rivers or by flows from sub-water-table conduits.

SITE INVESTIGATIONS

Investigations to Date

Although some years of normal development can be expected from the present quarry it is clear that at some future date, a decision must be made between further developments of this quarry and opening up a new quarry. Just how soon this decision must be made should appear during the course of the forthcoming investigations. On a long term view the present quarry suffers restrictions due to the proximity of the works, the railway, old dumps, roads, rising ground and houses. These lateral restrictions also tend to limit the economic depth of the present cut if reasonable access is to be maintained. A more definite restriction may be the depth of the permanent water table. From these factors it is clearly wise policy at this stage to consider the long term development so that the company's activities may proceed without interruption.

With the exception of the works and possibly the railway line none of the above restrictions is necessarily prohibitive. The problem is simply to provide sufficient information so that the management can decide whether it is more economical to plan for extension of the present quarry or to open a new quarry. With this in view a drilling programme, at three points north of the works, was carried out to determine the depth of limestone beneath the surface and its grade. The existence of limestone outcrops at the surface in that area encouraged the view that the bedrock would be found at no great distance beneath the surface. However, this drilling has shown that conditions likely to be encountered there would be similar to, or worse, than those encountered during the early development of the present quarry. The following points became clear after a study of this drilling and of the present quarry area:—

1. Small, surface outcrops of limestone do not necessarily indicate the presence of extensive masses of stone at shallow depths in the near vicinity.
2. Everywhere the sub-surface interface between the limestone and clay is very complicated.
3. A number of drill holes are needed in each area to determine the configuration of the top of the limestone and its physical structure.
4. Clay seams, and their accompanying solution openings, exist to considerable depths below the surface (at least 150 ft. and possibly more than 200 ft.).
5. The limestone is always covered by the following formations (*a*) a soil layer, (*b*) a gravel layer, and (*c*) a layer of mixed residual clay and gravel.
6. The conditions faced in opening up a new quarry are likely to be the same or worse than those encountered in opening up the present quarry.
7. Diamond drilling to determine, in detail, such a complicated profile as the top of the limestone may be economically prohibitive.

It was decided to approach the Bureau of Mineral Resources regarding the possibility of attempting geophysical surveys, chiefly seismic refraction, to obtain more quickly and economically, a wider picture of the bedrock conditions. In doing so it was realised that the problem presented some difficulties to a seismic approach and that it may not be possible to confidently interpret the results obtained. The Bureau however, after consideration of the problem, has agreed to carry out seismic and resistivity surveys in the coming summer. They have requested that certain sampling and testing be carried out in preparation for these surveys, and this work is in hand.

In conjunction with these schemes the author commenced a geological mapping programme to record all the exposed structures. Whilst such an approach is unlikely to provide any detailed information as to possible future quarry sites it does give us a more complete picture of the geological conditions and weathering pattern than was previously available. This study will provide a useful background against which further investigations can proceed. The geological mapping has been undertaken along three main lines:

(1) Analysis of the regional maps of a wide area surrounding Railton to gain a better understanding of the tectonic setting.

(2) A stadia survey of the quarry area and the limestone outcrops in this vicinity, as far as Blenkhorn's quarry. Levelling of known outcrops and drill holes. This will enable us to produce geometrically constructed sections incorporating all the available outcrop data with a view to determining the overall thickness of the limestone, the shape of the folds, the minor structures and the grade of stone at various localities.

(3) Mr. Matthews has made a detailed stadia survey of the minor structures in the quarry. This plan is useful for record purposes and to provide information for possible quarry extensions. In conjunction with this

we have studied the limestone and its superficial deposits in some detail to obtain a better understanding of their genesis, age and space relationships.

This study is almost finished and as much of this information as possible has been incorporated into the geological section of this report, which is submitted in some detail so as to provide a background for future workers and to give a reasonably complete geological picture for the Bureau's geophysicists. As more information becomes available further reports will be made.

A diamond drilling programme is now in progress in the present quarry to test the quality and condition of the stone at depth and to enable a study of the permanent water table to be carried out.

Further Investigations Programme

Broadly speaking, the problem here is to decide whether to (*a*) plan for extensions of the existing quarry, or (*b*) plan on opening up a new quarry.

It is therefore necessary to carry out such investigations as will enable us to determine which of these propositions will provide us with the required quantity of high grade limestone at the cheapest rate, in some years' time. It is also desirable to design these investigations in such a way that:—

1. The programme can be carried out within the time and economic resources available to the company.
2. As much relevant information as possible on the selected sites is obtained to aid in future detailed planning of quarry operations.
3. The final selection will provide sufficient quantity of limestone to allow long range planning of works areas and dumping grounds, &c., to proceed unhindered.
4. They will add appreciably to the general fund of knowledge concerning the structure and grade of the limestone in this district generally.
5. The groundwater hydrology will be thoroughly understood and groundwater will present no major hazard in the future.

By careful planning, therefore, it should be possible to use each drill hole to obtain information concerning three or four aspects of the overall problem.

Possible Developments of the Present Quarry

The following developments of this quarry as a long term project seem feasible.

1. Development at depth, with lateral extension to the southwest across the Railton-Works road. The obvious problems involved in this are:—

(*a*) Realignment of the road.
(*b*) Removal of some dump material.
(*c*) Possibility of encountering the permanent water table.
(*d*) Possibly endangering one or more of the company's staff houses.

2. Development at depth and eastwards across the railway line. This involves:—

(*a*) Tunnels and/or support, or realignment of the railway line.

(*b*) Removal of some dump material.

(*c*) Possibility of encountering the permanent water table.

3. Development at depth and towards Railton. This involves:—

(*a*) The removal of extensive dumps. This is almost certainly uneconomic.

(*b*) Possibility of encountering the permanent water table.

4. Development at depth combined with underground mining from selected sites in the present quarry.

The major factor in this is the cost of underground mining. This is probably prohibitive. However, a quick comparison of probable mining costs would easily determine whether this scheme is competitive with the other developments suggested. If this scheme were competitive then the overall problem would be reversed. We should be faced with the prospect of searching for a clay pit instead of a limestone quarry.

Assuming that (4) is ruled out after a comparison of mining costs and that development (3) is uneconomical, the other alternatives have many problems in common. These are:—

A. The ground water table. This may well be the basic problem in any extensions planned for the present quarry. In all possible extensions it would obviously be desirable to proceed to a greater depth with the existing cut. A drill hole put down from No. 4 bench indicates that either the limestone is almost completely impermeable or else the level of the permanent water table lies just below the surface of No. 4 bench. Further drilling and measurements of the water table, together with a search for caverns at depth will be made to determine positively the depth of the ground water table under the present quarry floor. If it can be shown to lie close beneath the quarry floor, then it would be unwise to consider development to greater depths because of the ever present risk of encountering caverns.

Below the permanent water table a single cave, similar to those exposed in the present quarry, if encountered unexpectedly, could produce uncontrollable flows of water into the lower benches. By carrying out detailed investigations during quarrying it may be possible to minimise such a risk but it would always be present. Thus, a basic step necessary before any other decision is possible is to determine the level of the water table and to begin regularly recording any fluctuations in this level.

Whilst the problem of the permanent water table may appear to be formidable and to involve the company in some danger and expense due to the incursion of underground water on the quarry, it is likely that in the long run this study will prove of advantage to the company. The limestone has been shown by drilling and quarrying to contain fairly large underground cave systems and if these were encountered below the level of the water table they would certainly drain embarrassingly large quantities of underground water into the cut. By the same token, if it can be shown that the water table lies some distance beneath No. 4 bench then there is every reason to expect that surface water could then be drained away into cavernous ground. Thus, it is possible that the drilling costs involved in this hydrological study will, over a period of years, be repaid in the saving on pumping charges. The search for caves beneath No. 4 bench is an urgent part of any future investigation programme. Before any large scale drainage takes place it will first be necessary to ensure that no domestic ground water supplies would be in danger of pollution.

B. The spoil heaps. Most of the alternatives of future development of the quarry seem to require the removal of at least some dump material. It is therefore necessary, at an early stage, to determine the quantity of material which must be moved to allow development to proceed in any given direction. To do this it will be necessary to prepare a detailed contour map over such parts of the dump areas as may be involved in any projected development. The contour interval should be of the order of five feet. If the company officers consider that parts of these dumps which are to be moved may contain workable pockets of clay, it would be desirable to sample these areas with earth augers. It would certainly be unwise to plan on redumping material which may be usable in the works.

C. Topographic surveys. It is suggested that similar contour plans be prepared for areas which are beyond the dumps and which are likely to be included in future developments or in new quarries.

D. Grade of the limestone. The core from all drill holes should be tested for grade. Provided we can demonstrate that the grade is consistent along the various limestone beds we can, within limits, predict the grades which will be encountered at depth and at various places around the quarry. An investigation then, of the constancy of grade in the present quarry is warranted. As a generalisation it can be said that if the grade is constant, extensions of the quarry along the axis of the main syncline (i.e. to N.N.W. or S.S.E.) will encounter stone of similar grade to that now showing in the quarry. To the west the lower grade stone encountered on Nos. 1 and 2 benches will descend and new untested stone will appear in the upper benches. To the east the high grade stone will persist, and stone of the grade encountered in the 200 ft. bore from No. 4 bench will appear at depth and in the eastern benches.

E. Quarry design. A balanced design for the proposed quarry should be prepared. Company records probably indicate the percentage of usable clays in the overburden to date. As investigations proceed it should be possible to determine the shape and depth of a balanced face of the quarry so that the correct proportions of limestone and clay will be won as the quarry advances. For the time being we can assume that the proportion of usable clay in the overburden in all directions around the quarry is roughly similar to that which has been encountered up to the present.

At the same time it would be useful to compare the cost of a balanced design as above, against the cost of developing a predominantly limestone quarry with external clay resources. Consideration may also be given to the value of sampling the overburden in likely areas to test the percentage of usable clay present and to design stable batters for the proposed excavations.

F. Overburden. It is essential in this area to determine as accurately as possible the depth and configuration of the clay/limestone interface at selected sites around the quarry. To do this drilling and geophysical methods must be employed. At this stage it is impossible to assess the value of the proposed geophysical survey; at the best, the results obtained will solve this problem completely, or at the worst we may get no worthwhile results at all. However, it is reasonable to expect that we should at least get an overall picture of the level of the sound bedrock surface over a reasonably wide area. If some drill hole information is available to 'tie' in the geophysical results, so much the better. The more drilling available, the more accurate the geophysical work is likely to be.

At present several possible areas of interest could well be investigated in the work proposed for this summer. I feel that it would be better to concentrate on one, or at the most, two, areas rather than to attempt to carry out a limited amount of this work in several areas. With this in mind some effort should be made to analyse the engineering and geological problems involved in the various proposals so that we can concentrate this work upon what seems to be the most promising area.

The Bureau would probably be able to indicate how long the geophysical team will be available in this area and what length of traverse could be expected in the time available. This will enable us to decide whether it is worthwhile dividing this effort among two areas or whether to concentrate on a single site.

In providing drilling information for correlation by the geophysicists the object would simply be to locate the depth of the bedrock. This could probably be done much more quickly and economically with a percussion plant than with a diamond drill, and at the same time it may well provide more information on the nature of the overburden. Such percussion drilling will not, of course, give any indication of the grade or structure of the bedrock but the grade can be predicted generally from the known geology and the seismic work would give an indication of the soundness of the bedrock.

Development of the Present Quarry Across the Railway Line

From a purely topographic point of view, assuming the bedrock conditions to be similar everywhere, the most attractive development of the quarry seems to be towards the east across the present railway line. However, it has generally been held that such development would be uneconomic on account of the cost involved in moving the line. It therefore seems promising to consider the alternative of crossing the line by either (1) a bridge over the railway line with a high level road to the works, (2) a tunnel immediately under the railway line, probably in clay (provision would need to be made for support of the line) or (3) a low level tunnel from the bottom economic limits of the present quarry.

The choice of the scheme to be followed is very largely an engineering consideration.

The proposal involves virtually a new quarry. The first proposition leads to consideration of the stable slopes which must be left on either side of the railway line as well as the possibility of moving a limited amount of dump material. The second will involve much the same problems, constructing a relatively cheap tunnel (or two) in the clay and providing support for the railway line. The third alternative involves a tunnel two or three hundred yards long in limestone but would eliminate the necessity for permanent support of the line or for bridging. If this were done the tunnel could be connected by a rise to the upper benches of the quarry and the stone handled to this chute by bulldozers. In order to bring any of these proposals into action, careful planning would be necessary to balance the clay/limestone requirements of the works over a period of some years during the transition from one quarry to another. The estimation of clay and limestone requirements over the time involved in this transition is an integral part of this plan.

The advantages of the alternatives above, provided that solid limestone can be proved in that direction, are:—

1. It is the nearest new quarry site to the existing works.
2. As it is virtually an extension of the present quarry fewer assumptions regarding conditions of groundwater, structure and grade need be made.
3. Geological information at present available suggests that high grade stone will be present in that direction. An analysis of the core from the deep hole from No. 4 bench will provide further evidence of the grade in that direction.
4. Abundant dumping areas are available.

Disadvantages which are evident in these proposals at present are:—

1. The cost of bridging or supporting the railway line.
2. The limestone at the point closest to the line is cavernous and unstable. It would therefore be necessary to investigate the tunnelling and/or support conditions most carefully. However, this may not be the most desirable point or depth to effect the tunnelling when the present quarry is fully developed. It remains to be seen if these unstable conditions extend further to the east, and south and to depth.
3. Stable ground must be left for some distance on either side of the line.

Factors Influencing the Development of a New Quarry

A new quarry (apart from that outlined above) will involve new groundwater conditions, longer haulage, high initial development costs and some uncertainty as to grade and structure of the stone available. Experience suggests that even with the most careful investigation it is difficult to predict completely all new conditions which will be found underground.

However, it is necessary to assess carefully the costs likely to be involved in a new area and to balance these against the costs of further developments around the present quarry. Only by doing this, by assessing carefully all the costs of each proposal, by allowing for the extra cartage, the increased overburden ratio, the removal of old dumps and the many other factors, can we be in a position to weigh the relative merits of each proposal. Some of these factors are geological, some hydrological and others engineering. There are economic factors and there are doubtless other factors of which the company officials alone are aware. All of them should be included in the final analysis.

The following are the major problems which the writer envisages in opening up a new quarry away from the known ground:—

1. Overburden: This is the most important factor and investigations as to the depth and composition of the overburden must be undertaken similar to those discussed earlier with reference to extensions of the present quarry. That is, we must employ some diamond drilling, perhaps percussion drilling, and geophysical surveys to give us as complete a picture as possible of the underground topography.

2. Groundwater conditions: As with the present quarry an investigation of this problem is desirable. The water table investigations which will be carried out in the present quarry together with such other information as can be accumulated, will doubtless serve as a guide to the groundwater conditions in other areas provided that they are not too remote from the works. Obviously the permanent water table is initially not so important in a new quarry since it would not be encountered in the early stages of development. However, it is necessary to learn as much as possible about the underground water behaviour in all possible areas so as to plan for underground drainage at an early stage. In a new area some attention should be paid to the possibility of encountering appreciable quantities of water in perched water tables in the overburden. In the geological report I have discussed the occurrence of ancient cave fillings in the residual clay. These, and the tongues of talus which extend down from the higher ground to the west may well contain considerable bodies of such underground water. It is anticipated that we should be able to drain off this water into the underlying limestone through drill holes and that no heavy pumping costs should be involved, but it is desirable to know of the existence of any considerable body of such water in advance, so that drainage will be available where and when it is required.

3. Grade: In any new quarry site advance knowledge concerning the grade of stone is essential. Thus the cores from the three holes put down last year should be sampled and all future drilling should be similarly tested as a routine measure. As mentioned earlier, it should be possible to make general predictions of grade in advance but to do this we need to accumulate all possible evidence from drilling and to investigate for significant changes of grade along the strike of the limestone beds.

4. Transition: As mentioned earlier it is desirable to prepare such information as would be necessary to plan for the transition from one quarry to another and thus perhaps avoid unnecessary dumping and rehandling of clay. Accurate contours of the bedrock surface, a working estimate of the limestone/clay requirements some years ahead, an estimate of the ultimate life of the present quarry, and sampling of the overburden for the new quarry, are all inherent in this study.

5. Cartage: To truly compare any new quarry site with the present one we must determine the economic limits of cartage and debit the extra haulage against the new quarry site. The real extent of the investigations to be carried out in the search for new quarry sites will be governed by this factor. It is desirable to establish now the maximum distance for economic carting to the works.

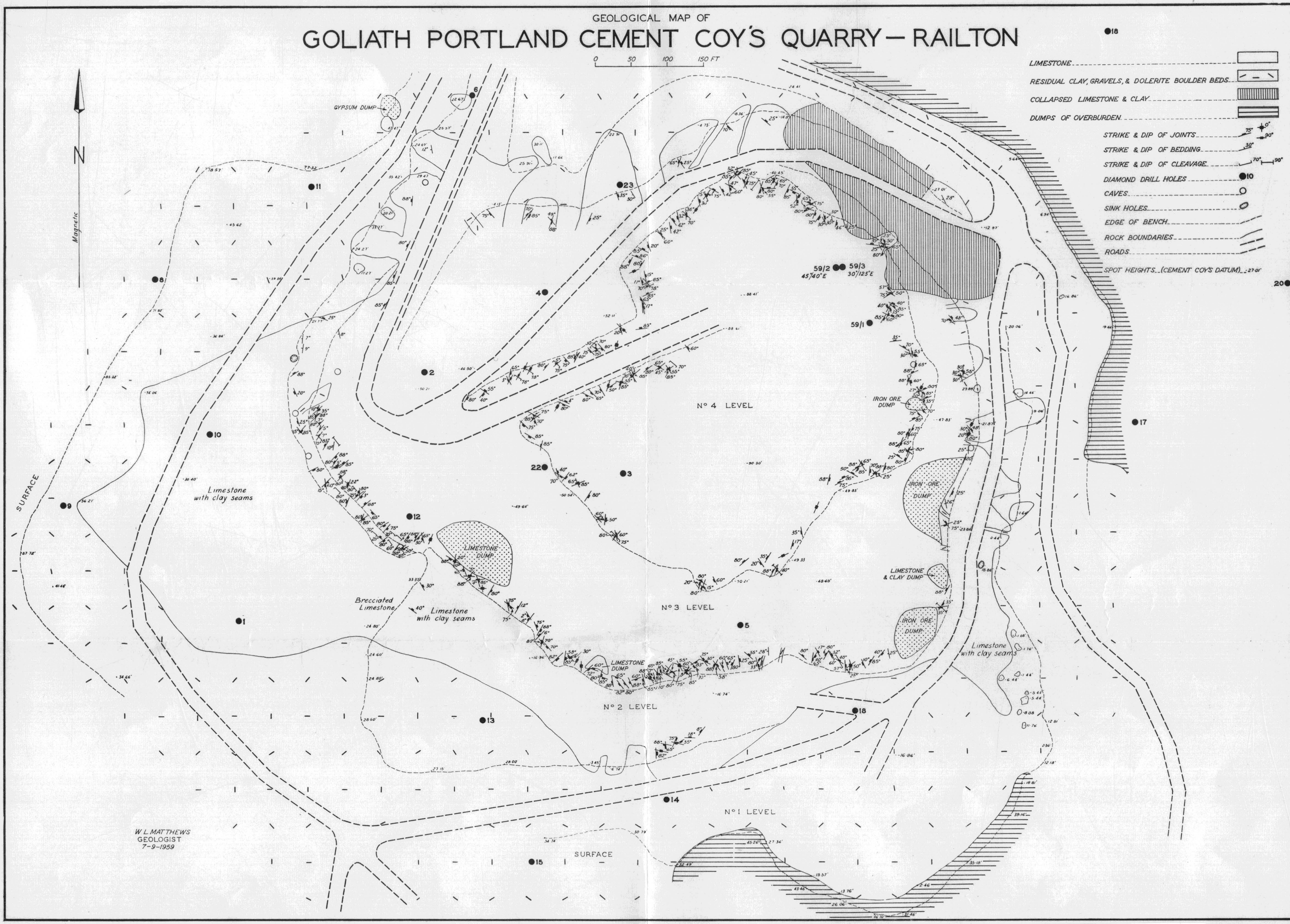

FIGURE 23.

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5 cm

Future Drilling Programme

The cost of diamond drilling is a very important part of any investigation and the programme should be carefully studied to assure that the maximum amount of information is obtained from each hole. It would, of course, be quite simple to lay down a grid of holes over areas of possible interest but such a rigid programme may not produce the most useful results for the cost involved.

For this reason I think that it would be wiser policy to carefully consider all aspects of the investigations as each hole is planned. There must be no question of the driller being held up for want of a new drill site, but at the same time it should be possible to retain the utmost flexibility without causing any delays of that kind.

The present drill hole from the quarry floor will give information on:—

(*a*) the depth of the water table;

(*b*) the structure and grade of the limestone;

(*c*) the physical condition of the stone at depth and to the east;

(*d*) the tunnelling conditions at depth under the railway line;

(*e*) caverns into which the quarry drainage may be diverted.

Thus, even if this drilling shows that development of the quarry to depth is undesirable, the holes will provide information which will be needed to assess the possibility of quarry extensions on the present level, towards or across the railway line.

The present programme should be continued to establish and explore the water table and to search, if it proves practicable, for drainage sites. After this, when the engineering aspects have been studied, drilling could be diverted to the area which appears to be most promising for either a new quarry or for extensions of the present quarry.

SUMMARY OF REQUIRED INVESTIGATIONS

(1) Geological Investigations

(*a*) Complete present mapping programme and construct geological cross sections of the area.

(*b*) Map the boundaries of the main areas of dolerite talus.

(*c*) Record all grades available and test for variation of grade along the strike of the limestone beds.

(*d*) Estimate the cost of underground mining of limestone on a large scale.

(*e*) Record all caves located in drilling to date, and in future drilling, for possible uses as drainage holes.

(2) Hydrological Investigations

(*a*) Establish the depth of the permanent water table below the present quarry.

(*b*) Provide facilities and initiate a system of regular recording of fluctuations in this level.

(*c*) Investigate the problems of perched water tables in the overburden.

(*d*) Search departmental bore records for information regarding groundwater levels in the Railton district generally.

(3) Drilling Investigations

(*a*) Test for cavernous ground in north-east of No. 4 bench, for foundation conditions under railway and as possible site for drainage holes.

(*b*) Drill holes in quarry floor for hydrological survey.

(*c*) Drill test holes for investigation of depth of overburden and for grade and condition of limestone beneath proposed extensions of present quarry and at proposed site or sites for new quarry. These are also to be used as control for the geophysicists.

(*d*) Check the desirability and availability of percussion plants for testing the depth and nature of the overburden and for control holes for the geophysicists.

(*e*) Further holes as may be required for drainage.

(*f*) Augering of dumps for samples if necessary.

(4) Geophysical Survey

(*a*) Request an estimate of the probable coverage to be expected from this seismic work, stressing that the company desires as much as possible within the time available to the Bureau.

(*b*) Enquire as to the complications likely to be encountered in seismic work over the dump areas.

(*c*) Enquire as to the possibility of establishing the permanent groundwater profile by geophysical methods as a check on 2 (*b*).

(*d*) Arrange for the necessary surveying.

(5) Topographical Surveys

(*a*) Contour all or selected areas of the dumps.

(*b*) Contour areas of projected quarry extensions.

(*c*) Contour possible new quarry site.

(6) Clay and Rock Testing by H.E.C. Testing Engineer

(*a*) In situ sonic tests of rock and clay.

(*b*) Tri-axial shear tests of undisturbed residual clays, remoulded residual clays and if necessary, of dump material.

(7) Engineering Investigations

(*a*) From 5 (*a*) calculate volume of dumps to be moved.

(*b*) Estimate removal cost of dumps.

(*c*) Investigate whether the material to be moved is worthwhile sampling for clay.

(*d*) Consider the advisability of testing the overburden in proposed areas in advance—by means of earth augers, and/or percussion drilling.

(*e*) Investigate the most economical quarry design.

(*f*) Investigate the relative merits of a balanced clay/limestone quarry against a predominantly limestone quarry with independent clay pits.

(*g*) Estimate the relative costs in crossing the railway by the various methods suggested, or by any other likely methods.

(*h*) Estimate the costs of road re-location if the present quarry is extended to the south-west across the Railton road.

(*i*) Prepare a working estimate of the clay/limestone requirements over the next 5-10 years.

(*j*) Estimate the dumping areas likely to be required over a long period for (i) extension of the present quarry; (ii) a new long term quarry.

(*k*) Estimate the increase in haulage costs of stone, brought from new quarry sites and determine an economic limit for cartage.

(*l*) From the above considerations attempt to make an early assessment of the most promising area or areas so that the seismic work can be concentrated there.

Recommendations

The full implementation of the foregoing investigation programme will obviously take some time and cannot be completed before the projected geophysical survey this summer. It is therefore necessary to plan this programme in stages and to determine roughly the priorities for the various investigations. It should be realised however, that whilst such priorities can be established fairly well at this stage, as investigations proceed various aspects will assume more or less importance and the programme can thus be amended accordingly.

Stage 1. To be completed before the commencement of the geophysical programme.

Geology (a).
Hydrology (a), (b), (d).
Drilling (a), (b), (d), (e).
Geophysics (a), (b), (c), (d).
Clay and Rocks tests (a).

Engineering—Make a careful and preliminary appraisal of all these points as far as possible, to guide the siting of the geophysical programme.

Stage 2. To be commenced immediately, independent of the geophysical work.

Geology (c), (d), (e).
Drilling (c), (f), (g).
Topographic surveys (a).
Clay and Rock tests (b).
Engineering (c), (d), (e), (f), (g), (h), (i), (j), (k).

Stage 3. To follow the geophysical survey.

This phase involves all the items not previously dealt with.

Such a programme will enable the company to make a calculated decision as to future quarrying practices. It may be found that not all of this work is necessary. For instance, if it is found that the permanent groundwater table lies close to the level of No. 4 bench then it would be fruitless to continue investigations concerned with the development of the present quarry to depth. Likewise, drilling and geophysical work may show areas where the overburden extends to prohibitive depths and further exploration therefore would become unnecessary.

The programme should be flexible enough to take advantage of all new information as it becomes available. Constant supervision, collection and recording of all data as it comes to hand is essential to the success of this kind of investigation programmme.