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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 in 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'Arcy'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 aquifers 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 sub-surface 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 Spring, 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 approaching these magnitudes would be encountered in the Railton district. The figures are cited merely to illustrate the capacity of limestone to transport immense volumes of water along solution openings.

There is a general difference in the groundwater encountered in flat lying, impervious limestone to 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 3 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 (3) 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, etc., 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 south-west 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 5ft. 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 clay xxxxxxxxxxxxxxx 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 cimilar to that which has been encountered up to the present.

At the same time it would be useful to compare the comparative costs of a balanced design as above, against the cost of developing a predominantly limestone quarry with external clay sources. 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 limit 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 ore pass by bull dozers. 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. The 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 areal 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 new the maximum distance for economic carting to the works.

FUTURE DRILLING PROGRAMME

The cost of diamond drilling is a very important part of any investigation and the programme should by 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 ~~overall~~ 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) TOPOGRAPHIC 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 Rock 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).

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Engineering (c), (d), (e), (f), (g), (h), (i), (j), (k).

Stage 3. To follow the geophysical survey.

The remaining items.

This 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 programme.

(I.B. Jennings)
REGIONAL GEOLOGIST
13/10/59