GEOLOGY AND CIVIL ENGINEERING

2nd Presidential Address to the East Midlands Geological Society

by

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Summary

An account is given of the importance of geology to the civil engineer, and the process of site investigation is outlined. A personal complaint is made against the narrowing and consequent handicapping of geological studies by reason of the loss by default of some parts of the discipline. Some examples of geology in aid of the civil engineer are given.

The Civil Engineers' interest in geology

The geological work which is done in aid of the civil engineer bears a different emphasis from the more academic studies with which the amateur is probably familiar. It is more closely concerned with the physical condition of the rocks as they are found, and less with their stratigraphical or genetic significance. This is because the rocks are, for the civil engineer, the most fundamental factor in the design and construction of his structure, be it a dam, a bridge, a tunnel, a roadway, or a large building. With every other material the engineer can exercise a choice, or can to some extent specify its properties, but the rocks on or in which he builds are beyond his control and he must take them as he finds them. He must rely on the geologist to give him the fullest account possible of the rocks, without the equivocation which is normally inseparable from such descriptions, based as they are on incomplete data.

The compilation of a geological report is a progressive process based on the geological map, showing the types of rock in the area of the proposed work and their distribution (see for instance Knill and Jones, 1965). The engineer has learned from experience that some rock-types particularly cause him trouble. Sands and silts are unconsolidated and non-cohesive, and when they contain groundwater under pressure may be 'fluidised' into the quicksand condition. The strength of clays is profoundly affected by their moisture content, and their behaviour in this respect is complex, possibly showing thixotropy, so that apparently solid material may be caused to flow by sudden shock or disturbance. Amongst the solid rocks, the solution cavities in limestones have caused unexpected failure and leakage, and the weakness along the schistosity planes of mica schist was one of the causes of the failure of the Malpasset Dam (Walters, 1962).

In all cases the engineer is interested not in the stratigraphic position of the rocks or contained fossils, but in their strength and homogeneity. Rocks lie in many attitudes, and these may profoundly modify their behaviour under load, as well as controlling their distribution. Rocks vary too in their condition; they may be fresh or weathered, dry or water-bearing, massive or jointed. Different rock types will be separated by discontinuities, including bedding planes, contacts, faults, unconformities, and cleavage or schistosity planes. All these features will have developed in a chronological order which is the history of the area. The engineer may show little concern for this aspect of the geology until it is pointed out that earthquakes, recent fault movements, and landslips in the recent past may warn him of future catastrophes, and that the glaciation of the area may have formed otherwise unsuspected buried channels filled with sands beneath the bed of a river. This particular feature of the River Thames held up Brunel himself for seven years during the driving of the Rotherhithe Tunnel. Perhaps the most important function of the geological map for the engineer is to isolate those critical locations where more detailed investigations are required.

Beyond the geological map

The geological map is normally based on surface observations, and any subsurface findings are extrapolations. The second stage of the investigation employs direct subsurface measurement derived from boring and geophysics. Boring is merely a method of obtaining rock samples and a section to amplify the information gained during mapping. Geophysical methods of revealing subsurface structures and conditions are regarded by some, including geologists, as a mystery, or else as unreliable and unworthy of consideration, but they are only a further extension of the mapping process (Eve and Keys, 1956). Whereas normally rocks are recognised by some such feature as their colour, texture, grain size, or bedding, geophysically they may be recognised, both on the surface and underground, by other bulk physical properties such as their density, seismic velocity, magnetic susceptibility or electrical resistivity. Naturally the recognition of rocks from these unfamiliar properties requires some ingenuity, but should come within the work of the geologist. To leave such a function to the unaided physicist or mathematician, who may be unaware of the extreme vagaries of rocks, can lead to error.

The electrical resistivity method recommends itself particularly to the civil engineer. It is cheap, it detects water content which can affect rock behaviour adversely (so that alternatively it can be used to find supplies of groundwater) and it is sufficiently accurate not to solve problems alone, but to corner them so that the drill can solve them directly. Boring and geophysics are completely complementary, and either alone has serious limitations.

Having mapped the ground, carefully placed his boreholes and geophysical traverses, and interpreted the results, the geologist should now be able to give a good account of the subsurface conditions likely to be of interest and significance to the engineer. The samples from the boreholes are representative of the rocks that can cause trouble, and the nature and seriousness of this trouble can often be revealed by the physical tests which are grouped together under the names Soil and Rock Mechanics (Terzaghi and Peck, 1948). There are valid reasons for dropping the word 'soil' altogether in this context, and calling the techniques Rock Mechanics, for soils are rocks in the geological sense, and in any case many of the engineers' soils are not soils geologically.

The tests applied to a sample vary with the type of rock and with the particular physical property which stands in doubt. Unconsolidated rocks are regarded as a continuous series between clays, or cohesive soils, where moisture content is all-important, and sands, or non-cohesive soils, where moisture content hardly affects the physical strength, but the influence of the confining pressure is the important factor.

Rocks are widely heterogeneous as well as very variable in physical behaviour. The synthesis of mechanical properties from petrological data is very far from possible, and soil mechanics tests are as a result empirical in nature. The triaxial compression test attempts to simulate the stress conditions endured by the material underground and observes the result. The end result of all the many tests is to determine a value of the strength of the material under the known or postulated conditions which will exist under the structure to be created. Rock Mechanics, in the sense of tests on consolidated rocks, is a relatively new development, but it is largely an extension of the Soil Mechanics tests on materials where higher stresses are needed to produce deformations, and where elastic as well as elasto-plastic behaviour is important.

Width of interest in geology - some lost opportunities?

Here I would like to put in a personal note. This is that the geologist should keep hold of these techniques of Exploration Geophysics and Rock Mechanics. Our science is one where cross reference from one part may prove very valuable in another, for instance the applications of palaeomagnetism in the continental drift question. No part of the whole science should be allowed to become the preserve of other disciplines, so that geology becomes more exclusive, but rather the distinctions between studies should become vague and in the end non-existent. That parts of geology have been lost in the past is plain. Pedology is a closed book to most geologists; photogeology appears mostly in the geographical, engineering, and surveying literature; hydrogeology is not of immediate concern to most geologists, and geomorphology is mainly the concern of geographers. Rock Mechanics and Exploration Geophysics, which are after all only a study of the physical properties of rocks,have been handed over by default of geological interest to the civil engineers, physicists and mathematicians. By all means let us solicit help from all who can, but many of the results of these studies, which can be of assistance in stratigraphy, structural geology, and petrology, are at the moment neglected. It is to be hoped that the present move towards schools of Earth Sciences will succeed in averting the prospect of geologists arguing together in an ever more exclusive vacuum.

Some examples

I would now like to turn to a number of examples of civil engineering work where the geologist,using the techniques outlined above,has been able to provide the engineer with a sounder knowledge of the site than he would otherwise have. The first of these examples is the Channel Tunnel, (Bruckshaw, Goguel, Harding and Malcor, 1961). This project has been the subject of discussion, hesitation, and delay for over 160 years. From 1957 to 1960 the idea was under intensive study and the geology came in for a share of attention. Three routes were known to be possible, and they were named after the geological formations that each would traverse - the Kimmeridgian, the Cenomanian, and the London Clay routes. The first was known to be the most variable in rock type, containing limestones, clays, and sands, some water-bearing, and it had already caused some trouble in a tunnel at Boulogne. The London Clay was well known as a tunnelling formation as most of the London Underground was excavated in it, and it was expected to be continuous across the Channel. It was not, of course,water-bearing, and the few faults expected would probably not carry water either. The Clay would have to be worked from within a moving shield, and a tunnel within it would need a lining to be placed immediately behind the shield. This technique was, however, well known. The Lower Chalk, although harder than the London Clay, provided a shorter route, and was almost ideal as a tunnelling material. The jointing which carries water so abundantly in the Middle and Upper Chalk was absent, so that tunnelling could be expected to be dry, and the slight clay content of the Lower Chalk would assist this. Flints, which would certainly impede mechanical tunnelling machines, were very rare. The strength of the rock was such that it could stand for a long period without lining, so that this could be done after the tunnelling machines had passed on.

The investigation followed the conventional and logical pattern outlined above. The land and submarine geology on and between both shores was mapped and the short trial tunnels that exist on both sides were re-examined. Borings were then put down to show the exact depth and thickness of the Lower Chalk, and a seismic profiling method was used to provide linking between the control boreholes. The seismic profiles showed only the sea bed, the upper surface of the Chalk, and phantom horizons within it. These are reflecting surfaces within the formation which show the attitude of the bedding planes, but which do not correspond in depth with those recognised in the boreholes. The profiles only penetrated about 60 or 70 metres into the Chalk, and so could not generally show its base, but they revealed a small fault at about mid-Channel. This situation exemplifies the interdependence of geophysical and boring methods, where the limitations of one are compensated by the nature of the other. The exact stratigraphical horizons of the borehole and drop-sampler specimens were identified by their contained microfossils. From these diverse sources the section of the Lower Chalk was built up, and it was confirmed that this formation offers the best route for a tunnel.

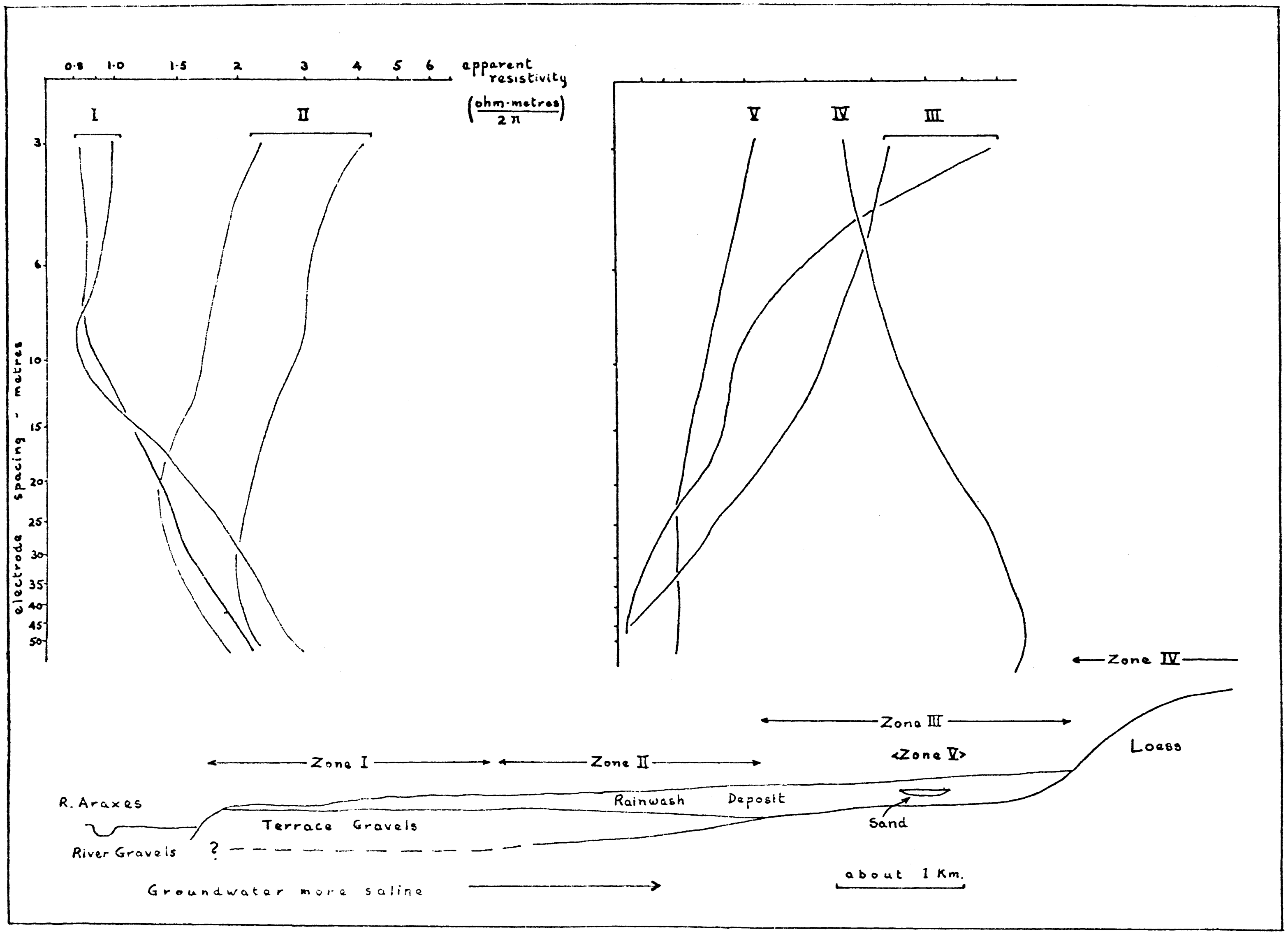
The Clyde Tunnel (Haswell,1963),a new cross-river link 3 miles downstream from Glasgow,was opened by the Queen in June 1963. It is 2,500 feet long, is 29 feet in diameter, and carries a roadway and separate cycle and pedestrian tracks. The ground in which it lies is of Upper Carboniferous sandstones and shales, not easy rock to tunnel, but made worse by the presence of overlying glacial and alluvial sands, gravels and clays. Part of the tunnel is entirely within these unconsolidated rocks; in addition to working in compressed air, it was necessary to form a 'box', through which the tunnel could be driven, by grouting the loose rocks with cement pumped into them under pressure . The tunnel could then be driven from within a shield and finally lined with cast iron rings.

The new Blackwall Tunnell (Hammond, 1965), slightly larger than the Clyde Tunnel, is 2,844 feet by 31 feet; here again trouble was caused by the nature of the rocks, which were silts in the Woolwich and Reading Beds. Resins, based in this case on resorcinol and formaldehyde, are a new development in engineering materials. They have the advantage over cements, sodium silicate, and clay minerals sometimes used,that the liquid, as it is pumped in, retains a low viscosity, and can therefore penetrate the formation thoroughly, and only afterwards will it start to set and consolidate it. Grouting here reduced the permeability of the troublesome material to a hundredth of its natural value, and formed a shell round the tunnel axis through which the driving shield could work.

An unusual example of geology in aid of the civil engineer is provided by the Teheran Hilton Hotel (Anon, 1963). This luxury hotel of 15 storeys stands in an earthquake region and has been designed to resist earthquake shocks. The design had to take into account the maximum expected intensity, and the corresponding horizontal and vertical ground accelerations,which depend to a great extent on local rock and soil conditions. Considerable work on such problems has been done by those nations most likely to suffer from earthquakes, namely the Americans and the Japanese (Neumann, 1962). They have found that earthquake intensity at a point is a complex concept, compounded of frequency spectrum, vertical and horizontal ground acceleration, and foundation rock type; to this must be added a consideration of the resonance response of the projected building. Earthquake shocks may contain frequencies from 10 cycles per second to 2 cycles per minute, while ground accelerations, usually of the order of 0.06 g may rise to 0.3 g. and exceptionally above. It has been estimated too, that the intensities experienced on alluvium may be up to thirty times greater than those felt on solid rock. In the absence of a Seismological Field Survey such as has been set up in the western United States, the designers of the Teheran building had to estimate, from past non-instrumental experience, the expected intensity in the area; at least in the short run their estimates have proved reasonable, for the building has already survived,unscathed,a shock which was sufficient to slide furniture about on the polished floors. The building is able to resist horizontal accelerations of up to 0.2 g, twice as much as has been assumed in the past in similar circumstances.

An example nearer home is provided by the new Post Office Tower in London. When seen drawn to a scale, it is easy to be impressed by the apparently small size of the foundation. This, only 25 feet below surface for a 600 feet tower, is about 90 ft. square, yet carries a load of about 13,000 tons, and all on London Clay. Such a feat could only be made safe by a very close study of the properties of the clay, which has been the subject of a great amount of work in the past (see for instance Ward, Samuels, & Butler 1959). This is because it underlies a very large urban area; it is therefore penetrated by a great number of boreholes during foundation investigations, and also has been penetrated by the London Underground. It shows (Skempton & Henkel, 1957) remarkably consistent values in water content, Atterberg limits,density, shear strength,and coefficient of consolidation over a large area of central London.

I turn now to the construction of dams. These structures, more than any other, are able to improve the material lives of those persons they serve. Dams prevent floods and at the same time conserve water to be used in a later dry season for irrigation,and so make thousands of acres fertile. The same dam may



Text-fig. 1. Dashte Moghan, Iran; Groundwater Zones as defined by Apparent Restitivity curves also provide power. None of these uses is exclusive, and some dams fill all three roles. The Warragamba Dam functions as a flood control on the Warragamba River in New South Wales, supplies Sydney with water, and produces 50 MW of power when excess water is available (Nicol, 1965). It is a straight concrete gravity dam and stands in a gorge cut out through Triassic sandstones and shales. The rocks were porous and permeable, faulted and crushed in some places, and not regarded as strong enough to take the side thrust of an arch dam. In addition, during the excavation of the site, the unloading of the rocks caused them to expand elastically upwards. The variable strength (sometimes less than 3,000 lbs./sq. in.), low modules of elasticity, extensive jointing, and high permeability of the rocks in the dam site all caused concern, but by preliminary grouting with concrete and by suitable design of the dam itself, all these were countered. The half-completed dam was flooded several times, once for 76 days, because the period of construction corresponded with a series of unusually wet years; it was completed in 1962 after 14 years work.

The Backwater Reservoir for water supply for Dundee is another example of the influence of geology on the design and construction of a dam (Scrimgeour, 1965). An apparently ideal site, where a short earth dam would contain a wide reservoir, was chosen close to Bridgend of Lintrathen in Perthshire. The site was covered by extensive glacial deposits; when boreholes were put down in the positions of the dam abutments, although solid rock was found 25 feet below one of them, no solid rock was found beneath the other even though the hole was continued to 186 feet below surface. The site had to be abandoned. A seismic survey at another site nearby showed no solid rock less than 300 feet below surface. Boring, however, showed that these results were misleading, and that the valley was floored by solid rock covered by shattered rock, and by a complex of boulder clay, sand, and gravel. Such misleading results are not unknown in glacial material and arise from their relatively unbedded and heterogeneous nature. Investigations of rock type and permeability indicated that, even in such unpromising material, a grout curtain might be constructed. Accordingly a test block was injected with clay/cement and silicate mixtures by the 'manchette' process, and the permeability was reduced to a low value, comparable with that of rolled clay. The dam is still under construction and is due to be completed in 1968.

I would like to conclude with an example from water supply work in which the geologist was able to offer advice. It concerns the groundwater supply of a number of villages in Northern Persia. The population of Persia includes a number of nomadic Turkoman tribes who live by herding sheep. Their standard of living is very low and the Persian Government wished to persuade them to abandon their wandering existence, but in order that they might be converted to agriculture, new villages had to be built. The area chosen for settlement was irrigated by diverting waters from the river Araxes over a wide piece of valley floor known as the Dashte Moghan, but as the irrigation water could not be relied on as potable water, boreholes were to be put down to provide a supply for each village. The geological section through the valley floor is shown in the figure. The loess hills at the valley side contained groundwater, but this was known to contain too much gypsum for drinking, and only near the river was the groundwater of good quality.

The river side section and two well sections showed that the terrace gravels of the river extended some way under the loess of the plain, thinning as they approached the valley sides, and their contained groundwater quality appeared to deteriorate as it became merged with that of the loess. This appreciation of the conditions was achieved by an examination of the geology and some testing of the existing few wells. Resistivity curves (showing changes of apparent resistivity with depth) were observed along several lines across the plain and included the family of curves shown in Text-fig. 1. It became apparent that the different curve shapes were due to the variations in gravel thickness and also to variations in the salinity of the contained groundwater. The existing wells provided fixed points in the progression from thick, near-river, fresh water bearing gravels to thin, near valley side, saline water bearing gravels; and, on the basis of the curve shapes, zones of groundwater quality were plotted. It was then possible to achieve the best distribution of boreholes to take the best water and hence to locate the villages.

Conclusion

I trust that I have shown the nature of the connection between the work of the geologist and that of the civil engineer. The work of the civil engineer becomes yearly more exacting, and the geologist who supplies an essential part of his basic information must also advance in technique and concept. The assistance is not all one-way, for there is, and could increasingly be, a 'fall-out' of information and methods of use in purely geological problems.

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Manuscript received 16th May 1966