First among the instruments invented by Volta comes the electrophorus (1775), which followed as a natural consequence of the views expressed in his dissertation: “De vi attractiva ignis electrici ac phenomenis independentibus,” published in 1769. In the three years subsequent to the appearance of the electrophorus, Volta studied, both theoretically and experimentally, the influence of the form on the electrical capacity of a conductor and elaborated the conception of tension or electrical potential. These considerations formed the starting-point of a thorough investigation into the action of atmospheric electricity, this leading to the invention of the condenser, which is also numbered among the exhibits. While developing his ideas concerning electric meteorology and the origin of atmospheric electricity, Volta devised the very sensitive straw micro-electrometers and the electrostatic balance, reproductions of these being among the apparatus shown. The various forms of voltaic pile assembled by the inventor from such ordinary household articles as spoons, and water-vessels from bird-cages, are also included.

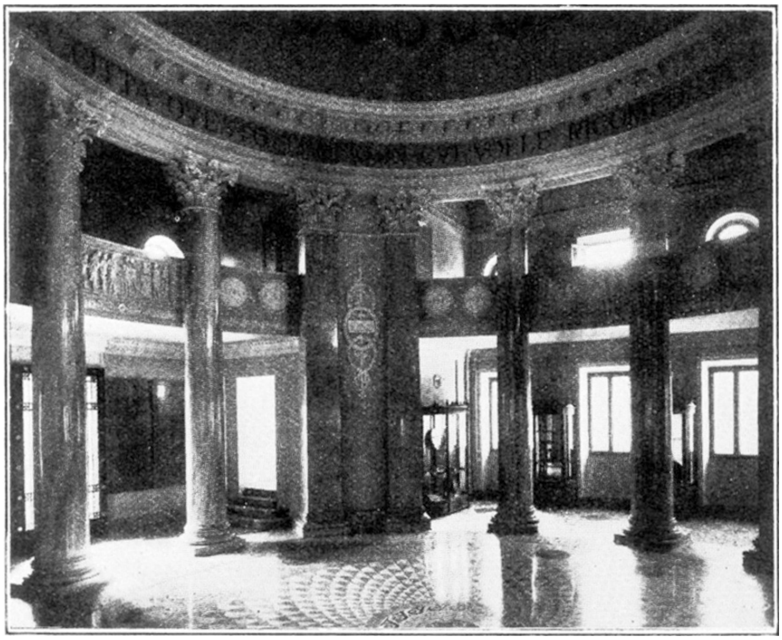
Photo.] [A. C. Gatti, Milan.

FIG. 2.—Interior of the Volta Temple.

The temple has been placed in the charge of Prof. Felice Scolari, in conjunction with the Royal Lombardy Institute, and has been generously provided, also by Somaini, with an endowment fund of 500,000 lire, the income from which is to furnish annual prizes of 5000 lire each, to be awarded to distinguished students of Como or of the canton of Ticino desirous of prosecuting studies in electrical subjects.

Physics in Relation to Oil Finding.[1]

By Prof. A. O. RANKINE.

EVIDENCE has accumulated during recent years that physical methods can be used under suitable conditions to facilitate the detection and location of minerals buried under the ground. This is a fact of considerable economic importance, having regard to the very great and wasteful expense of indiscriminate boring. Even the most careful geological survey often fails to fix with sufficient accuracy the points at which drilling is likely to be successful. Here, properly applied, physics may make its contribution to enhance the probability of success.

We are not now concerned with the divining rod and similar devices—similar, at any rate, in the respect that they can only be operated by persons specially endowed with certain obscure faculties. Sometimes the devices are dressed up to have the appearance of physical apparatus, and the methods are called geophysical; but all have this in common—that they are not capable of being independently checked, and for that reason may safely be ruled out of serious consideration. We are dealing with genuine physical methods which depend on the differences of physical properties of underground materials, and produce above the surface reliable indications, the measurement of which may provide valuable information regarding sub-surface structure.

It is important to emphasise at the outset that there is no question of physics being employed to the exclusion of geology. At the best the problems to be solved are extremely difficult, and the closest possible co-operation between the two sciences is essential. This alliance is implied in the term ‘geophysics,’ and for the successful development of this as a practical subject, geophysicists adequately trained both in physics and geology are the ideal personnel. Physics alone cannot solve problems of underground structure, whatever may be the efficiency of the method employed, for the unknown factors are far too numerous for a unique solution to be possible. The geologist must first indicate the kind of underground structure which is sought, and all the probable conditions under the region to be surveyed, before the physicist can even decide whether any available physical method

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[1] Substance of two lectures delivered at the Royal Institution on Feb. 21 and 28.

has a reasonable chance of being applied with success. Often, owing either to the absence of surface indications of a geological character, or to such indications being misleading because of 'nonconformability' of superincumbent strata, the geologist is unable to locate with precision the structures he is seeking. It is in such circumstances that physics has been able to join forces and help to define underground conditions more exactly.

With particular reference to the occurrence of mineral oil, geology provides the information that it is usually associated with salt-domes or anticlines, buried more or less deeply below the earth's surface. A typical salt dome, of which there are numerous examples in Texas, is a sort of underground plateau of rock salt, sometimes with a relatively thin covering of anhydrite, called cap-rock, the whole being below an overburden of sands and clays. The superficial area of the roughly circular top of the dome may be several square miles, and its depth may vary from a few hundred to several thousand feet. Oil may be located sometimes at the top of the dome, and sometimes at various levels down its flanks. The earth's surface above and around the dome is usually very flat, and there is little in the way of reliable geological indications to determine their positions.

On the other hand, limestone anticlines, such as occur in south-west Persia, are blunt limestone ridges, perhaps several miles in length and relatively narrow, covered, too, with a thin layer of cap-rock, underlying a mixture of alluvium, sand-stones, marls, gypsum, and salt. In the upper part of the anticline, just below the cap-rock, natural gas may be found ; farther down the flanks occurs the crude oil with much gas in solution, and still farther down the flanks salt water. Unlike the conditions relating to salt-domes, however, surface evidence of folding structure is abundant, the general direction of the strike being unmistakable. But, unfortunately, owing apparently to the plasticity of the overburden, these geological indications leave in considerable uncertainty the positions of the summits of the anticlines.

Here, then, is the problem of oil finding from the point of view of physics. It is to locate, within regions already roughly delimited by geological considerations, the position and extent of salt domes and limestone anticlines. Thus the search is not for the oil itself, but for the structures with which it is commonly associated. It is true that some claims have been made of locating oil as such by a method depending on its electrical conductivity, but this is very doubtful, and on theoretical grounds the method is distinctly unpromising. To find the oil itself is not asked of the geophysicist ; if he can locate the salt dome or the anticline with enough precision, it will always be worth while to drill.

The physicist thus has to consider what properties of these structures are likely to provide surface indications capable of physical measurement and interpretation. Caution is necessary in this respect, having regard to the unfortunate tendency to generalise geophysical methods. These have been enumerated in Prof. Eve's interesting article in NATURE last year.[2] Although various claims have been made, there exists no convincing evidence that magnetic and electrical surveys have assisted materially in the location of the structures under discussion. Moreover, the magnetic susceptibilities and electrical conductivities of salt and limestone differ insufficiently from those of the surrounding materials to give on theoretical grounds any real expectation of successful application. The only physical properties which have hitherto without doubt provided means of discrimination are the differences of density and elasticity as between the salt or limestone on one hand, and the superincumbent material on the other.

Remarkable success has been achieved by measuring local variations of gravity which depend directly on the differences of density of sub-surface materials. The approximate relative densities of salt and clay, for example, are 2·1 and 2·4, and of the cap-rock over a salt dome 2·9. Small though these differences are, the elegant and amazingly sensitive Eötvös torsion balance has been proved capable of measuring the corresponding gravitational effects in the neighbourhood of numerous salt domes in Texas and elsewhere, thereby locating and defining the limits of such domes, some of them deeply buried below the surface. For a lucid account of this beautiful instrument the reader may be referred to papers by Capt. Shaw and Mr. Lancaster Jones.[3]

The main purpose of this article is to give an account of a relatively new and less well-known successful method of locating structures likely to be oil-bearing, known as the seismic method. This method can be applied even in rough country, like that in the Persian oil-fields, where gravity measurements are too much distorted by surface effects to give reliable indications of underground conditions. It depends not only on the relative densities but also on the relative elasticities of the rocks encountered, or, what amounts to the same thing, the speeds of propagation of longitudinal mechanical disturbances in these media. In the salt dome structures of Texas, these velocities differ considerably, being about 5300 metres per second for the salt, and about 2000 metres per second for the clay and sand overlying the dome. For the limestone structures of Persia the difference is not so marked, the approximate figures being 4700 metres per second in the limestone and 3700 metres per second in the overburden.

One may perhaps digress for a moment to consider the possibility of using direct reflection from a clay-salt interface as a means of determining its depth. If a device similar to the remarkable depth-sounding machine[4] which has been so successful at sea could be used, the great advantage would accrue that the measurement of the time taken for the sound to go down to the interface and return by normal reflection would enable the local depth to be estimated. But the method is not

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[2] "Geophysical Prospecting." By Prof. A. S. Eve, NATURE, Mar. 10, 1928, vol. 121, p. 359.

[3] *Proc. Phys. Soc.*, vol. 35, p. 151 and p. 204.

[4] "The Acoustic Method of Depth Sounding for Navigational Purposes," by the Staff of the Director of Scientific Research, Admiralty, NATURE, Mar. 29, 1924, vol. 113, p. 463.

successful in practice, not because of the failure of the interface to reflect, the reflecting power being reasonably great, but because of the enormous damping of vibrations of audible frequency in the upper layers of the earth. Trials with an Admiralty echo-sounding machine have actually been made in Persia, but the sounds from the hammer proved much too feeble to be heard through the ground on the microphone at any useful distance. It is significant also of the poor transmitting power of the ground that the explosion of several hundred pounds of gelignite at half a mile distance was not audible through it as a medium, although it could be heard, of course, very loudly through the air.

We are thus faced with the position that great disturbances of the earth's surface, conveniently in the nature of explosions, are necessary effectively to penetrate to the depths at which oil-bearing structures are frequently found. Also that a seismograph, which will record vibrations of low inaudible frequency, is preferable to the microphone on account of the smaller damping of such vibrations. This at once rules out the direct determination of depth, previously suggested, for a sensitive seismograph obviously cannot be operated in the same position as a large explosion which excites the initial disturbance. The recording must be done at a ‘ safe ’ distance and the depths of the interface at points other than those immediately below the explosion become involved, thus complicating the problem by the change from one to two dimensions.

The necessity for using an explosion involves a new difficulty on account of the appreciable time the consequent disturbance of the earth lasts. In all cases the reflected disturbance reaches the seismograph *later* than that travelling direct near the surface, since its path is longer. Moreover, it is usually small in comparison with the direct waves, and the effects of the latter upon the seismograph at practicable distances last considerably longer than the difference of times of transmission. Consequently the reflected effect becomes so much obscured by the larger direct effect as to be unrecognisable. The solution to this difficulty lies in the existence in practice of another disturbance associated with the lower (higher velocity) medium, but distinct from the reflected disturbance, which may, at a sufficient distance from the explosion, reach the seismograph *first.* Although small, its time of arrival can be readily recognised, since it makes its record on the seismograph *before* the latter becomes violently disturbed by the direct waves. That is the essence of the success of the seismic method of revealing underground structure.

The phenomenon with which we are dealing is the same as that which has recently been recognised as operative in natural earthquakes. Even in near earthquakes, where the curvature of the earth plays no important part, the records of seismographs show preliminary displacements which apparently correspond to ‘ rays ’ from the earthquake source which pass from an upper stratum (of low propagation velocity) at the critical angle into a lower stratum (of higher propagation velocity), run parallel to the interface and eventually emerge again at the critical angle to reach the seismograph on the surface. This is, of course, an ‘ optical path ’ of an extreme character according to the ordinary laws of refraction, but since the initial incidence is at the critical angle, total reflection would occur according to the same laws, and no energy at all would be associated with the path in question. Dr. Jeffreys [5] has, however, shown that if the problem be treated as one of diffraction instead of simple refraction, the rather curious result emerges that a finite fraction of the initial energy may be expected to reach the seismograph (as is in fact found in practice) at a time which is the same as that obtained by considering the extreme optical path above described. This applies to longitudinal disturbances. There are in solids, of course, transverse disturbances as well, but these travel more slowly, and need not concern us here, since, as has been already stressed, the question is one of *first* arrivals.

Prof. Mintrop was the first to recognise the applicability of this phenomenon to the smaller scale problem of the relatively shallow formations in the earth, using artificial explosions instead of natural earthquakes. As a result he has initiated a practical system which has been widely and successfully used to determine the depths of such formations. To make the method clear, we may take the simple case of two superposed horizontal strata (Fig. 1) in which the velocities of compressional waves are V_1 and V_2, the latter corresponding to the lower medium and being (necessarily) greater than V_1. If an explosion is caused at O and a recording seismograph is located at A, three distinct disturbances reach the seismograph. One goes direct from O to A. (We are neglecting here the small curvatures which may arise from gradual variation of velocity with depth.) Another is reflected at D and arrives at A necessarily later than the former, its path being longer. The remaining disturbance arrives at A at a time corresponding to the equivalent path $OBCA$, OB and AC each making the critical angle $\theta_c = \sin^{-1} V_1/V_2$ with the normal. In the part BC the speed is the higher velocity V_2, and it is evident that if OA is great enough the total time occupied in transmission may be equal to or even less than that for the direct path OA, which is wholly in the lower velocity medium. If so, its small effect will be recognisable on the seismogram in spite of the large disturbance which follows afterwards.

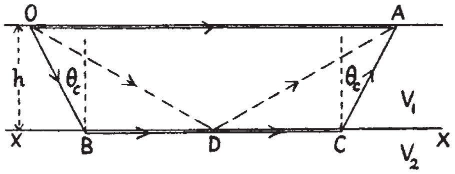

Fig. 1.—Explosion at O, seismograph at A, both on the earth's surface. XX is interface between two media of velocities V_1 and V_2, with $V_2 > V_1$.

(*To be continued.*)

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[5] “ On Compressional Waves in Two Superposed Layers.” By Dr. H. Jeffreys, *Proc. Camb. Phil. Soc.*, vol. 23, p. 472 ; 1926.