THE TREND OF GRAVITY SURVEY

EINIGE SCHWEREVERHÄLTNISSE IN DÄNEMARK

By G. NÖRGAARD.

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The Geodetic Institute of Denmark, under the directorship of Professor N.E. NØRLUND, has become a pioneer in gravity measurement on land and sea. It owes much to the genius of Mr. G. NÖRGAARD who, after developing a static gravimeter for use at sea in surface craft, has now brought to a successful stage a new static quartz gravimeter for use on land.

The new instrument, described in "Ein statischer Quarzschweremesser und Schweremessungen" (Danish Geodetic Institute *Medd.* 10, 1939), was the subject of a brief note in this *Journal* for July 1939 (p. 92). It is a three-pronged fork of quartz with points upwards, the centre prong being rigid and vertical, while the outer prongs, very slender save for bulbous swellings near their top ends, are slightly inclined inwards. There are thus two symmetrically disposed astatic pendulums and the distance apart of their two pointed ends, read by a vertical micrometer microscope, is a sensitive measure of the force of gravity. The systematic response of each member of this force depends on accurate levelling of the base; the pointed and rigid centre column acting as a control. When the instrument is levelled the three prong points are equally spaced, but whereas the distance of either sensitive prong from the rigid one depends upon this levelling, the distance between the two sensitive ones is unaffected by a slight dislevelment. The instrument appears to have some advantages over the Holweck-Lejay gravity pendulum, with which it has much in common, the first being the static and the second the dynamic form of the same thing. The balance and symmetry of the NÖRGAARD arrangement and its construction in one piece of fused quartz are in its favour. As the new instrument is not highly dependent on levelling (it may be stood on a plate carried on three pegs driven into the ground and operated by the observer and one assistant) its reading is rapid; it demands no accessories; it is light enough to be carried in one hand; it is apparently robust enough to be unaffected by transport in an ordinary motor car over long distances; and even a road collision did not alter its performance.

The chief initial difficulties in the new technique were to provide adequate damping and to avoid electrostatic forces and temperature effects. All these have been more or less satisfactorily overcome by immersing the working parts in a fluid, at the first trials nothing more than water. The damping is said to be so good that observations can be made near traffic. Differences of temperature between the upper and lower thermometers rather than absolute temperature are said to necessitate a correcting term in the formula for gravity, but its significance is not quite clear, for we are told that the effect of small convection currents is not serious as the container is effectually lagged.

The Geodetic Institute has lost no time in getting full value out of the new instrument. In the second half of 1938 and the early part of 1939, no less than three hundred new gravity stations distributed over the whole Jutland peninsula were observed, and the results published within a few months.

Static gravimeters have, as is well known, been developed and used for a decade or more by oil and other prospecting companies, but instruments and results have, unfortunately though perhaps not unnaturally, been withheld from the public view, even of the scientific world. The precision of gravimeters approaches one 10-millionth part of the quantity measured, and they suffer from the disability common to all ultra-precise measuring apparatus that no reliance can be placed on the reading unless it be frequently checked for drift. In the present case drift rarely exceeded 1 milligal per day, but some wise precautions against systematic error were nevertheless taken. A network of nine well-scattered primary stations in Jutland was first, carefully and with considerable repetition, observed with the new gravimeter, being connected also with Copenhagen through two other stations. The network was adjusted and showed the mean error of a single gravity observation to be 0.25 milligal. Five comparisons with earlier pendulum observations showed a maximum difference of but 1.5 milligal and no systematic tendency with respect to the magnitude of g. Since even in the best of circumstances pendulum observations have a mean error approaching 2 milligal, these results are very satisfactory and are encouraging to any authorities thinking of extending their national gravity surveys economically.

Most of the secondary stations were observed in closed loops of 10-15, each loop taking a day or two, and each starting and closing with one of the primary stations. In the single month of July 1938 the Jutland peninsula was thus covered with a network of 150 stations at a mean spacing of about 15 km. Later a further 150 stations at some ten times the density were observed in a special area. This rapid campaign has produced a convincing gravity-anomaly map of Jutland full of interest and future usefulness. On the general map the lines are drawn at intervals of 5 milligal and on the special maps at 2 milligal. With the land observations are shown the values of gravity at sea around Denmark already obtained by Mr. NÖRGAARD, and the hitherto assumed precision of the latter 1-2 milligal, is confirmed. The most conspicuous features of the general map are a broad positive anomaly in the centre of Jutland and a very steep gravity gradient equal to 4 or 5 milligal per km. across the northern end of the Öresund, the narrow strait separating Denmark from Sweden. This, we are reminded, accords with the fact that the Palaeozoic floor has been found, both by geological and seismic research, to be 1500 metres lower on the Danish side of the sound than on the Swedish.

A gravity anomaly at any one place has some interest and value, but is in itself no more than an isolated clue. Fifty gravity stations scattered at random, one station for each 4000 or 5000 square kilometres, possess little more than a value proportional to that of the one. Increase the density of distribution of the stations by ten times and suddenly the whole assemblage springs to life as a picture and its value becomes immeasurably greater. Such is the present publication. Behind it is the realization that the complete and intensive gravimetric survey of a country is both scientifically and economically justified. New information becomes available for the geologist, the geodesist, and the geophysical prospector. In the present case the correlation of gravity gradients with anomalies of the vertical already found has both confirmed past work and suggested future work.

After discussing the broad features of his gravity anomaly map, the author says (the original is in German): "Finally the correlation between anomalies of the vertical already known and the gravity results which we have found is of the greatest geodetic interest. Unfortunately only north-south components of the deflection are known. One sees the beautiful agreement of the deflections both as regards direction and magnitude........ to the north and south of the Silkeborg gravity maximum;.............. One might say that the great deflection at Uranienborg (on the Swedish island of Ven in the Öresund) had already demonstrated the great gravity gradient there".

Minima flanking a maximum, and negative gravity-gradient in general, are often closely connected with valuable mineral beds; such irregularities in the gravity map direct attention. The author concludes: "One can therefore say that from the gravimeter standpoint Denmark appears to offer quite good possibilities of mineral beds".

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Mr. NÖRGAARD's instrument has something in common with that of Mr. ISING (see *Bull. géod. int.* 28 (1939) 556-76), in which a rigid pendulum is carried by a stretched horizontal quartz fibre that bears its whole weight; and this may have introduced complicated strains in the quartz fibre. The somewhat similar instrument constructed by Threlfall and Pollock in 1899 had the further disadvantage that large torsions were applied to the fibre. If an instrument depends upon the elasticity of quartz it seems indispensable that the strain shall be kept everywhere quite small. The NÖRGAARD instrument fulfils this condition admirably. A change of gravity makes only a minute alteration of shape in the quartz body and the small gravity strain is distributed smoothly though not evenly over the deformable parts. The proof of its practical value lies in the remarkable survey of Denmark already made with it. The same result could never have been achieved with the gravity pendulum, which requires at least ten times as long to operate and cannot produce a survey of gravity in which isogams at 2 milligal intervals can be drawn with confidence. Geodesists must give as much constructive thought to the modern gravimeter as they have in the past to the gravity pendulum. One may even now ask whether the gravity pendulum, with its complicated technique and none too great precision, will not soon be superseded in the fundamental gravity comparisons, though two pendulum stations are required to standardize the instrument. One thing at least is clear: an exhaustive test of all modern gravimeters should be made by one or more competent authorities, to compare the Lejay astatic pendulum, the new Nörgaard instrument, the gravimeters depending on the properties of helical springs and developed mostly in secret, and finally the Nörgaard and Halck patterns of hydrostatic gravimeter.

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