The Geological Interpretation of the Slidre Positive Gravity Anomaly.

By

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Abstract.

A positive gravity anomaly that occurs in Slidre has an amplitude of 53 mgal and can be separated into two parts. The top of the disturbing body causing the anomaly cannot be deeper than 4 km. Gabbros and mafic gneisses are exposed in windows of Precambrian rocks which are overlain by about 1000 m of Cambro-Ordovician sedimentary rocks. The cause of the anomaly is probably a body of mafic rocks lying at the upper surface of the Precambrian basement. The model calculated to satisfy the observed anomaly consists of a 2.5-km-thick slab underlain by a 10.5 km deep column. This model is interpreted to represent a sheet-or saucer-like mafic intrusion, a lopolith, that has a thick, deep feeder.

Introduction.

A gravity traverse of the Geographical Survery of Norway's (Norges geografiske oppmåling) regional gravity net revealed unusually high Bouguer anomalies along Slidre Fjord. Later gravity measurements in connection with a study of the Flå granite (Smithson, 1963 a) indicated a positive gravity anomaly of considerable extent. Additional measurements were, therefore, undertaken by the writer in order to define the anomaly more clearly. The area studied is located in Valdres, Oppland "Fylke" between 59° 30′ and 62° 00′ N. Lat. and 8° 15′ and 10° 00′ W. Long. about 150 km NW of Oslo (Fig. 1).

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Figure 1. Bouguer gravity anomaly map of southern Norway.
The area investigated is outlined by the heavy broken line (after Grønhaug, 1963).

Gravity Methods.

Field Work.

A pre-existing station net measured by the Geographical Survey of Norway, mostly on precision levelled elevations, consisted of 249 stations. This net was filled in by the writer along roads in areas of particular interest during the summers of 1961 and 1962. In 1963, additional measurements were carried out with helicopter transportation in the rugged terrain of the Jotunheimen at the north end of the map area. A total of 313 gravity stations were measured by the writer.

The writer's gravity measurements were carried out with a Worden Master model gravimeter that has a dial constant of 0.107 mgal/division. Instrument drift was controlled twice daily; the observed gravity values were tied into the first-order gravity station at the Geological Museum, Oslo.

The general procedure followed in making the gravity reductions has been described previously (Smithson, 1963 b). In this case, a density of 2.74 gm/cc was used for the Bouguer correction. Station elevations were determined from spot elevations on the topographic maps and by means of aneroid barometers. The error of the map elevations is ± 1 m; the maximum probable error of the barometric elevations is ± 5 m. Terrain corrections were applied using the method of Hammer (1939). The terrain corrections range from 6–8 mgal. for stations in the main valleys to 0 mgal for a large number of stations situated on the flat upland surface. The maximum error expected in the Bouguer anomalies is about 2 mgal which is relatively small compared with the size of the anomalies.

Bouguer Anomaly Map.

The Bouguer gravity map (Fig. 2) reveals one main feature, the large positive anomaly ~~marked by the closure that attains a maximum~~ value of –20 mgal in Slidre. The Bouguer gravity map of southern Norway (Fig. 1) shows that this hugh positive feature lies athwart a negative gravity trough that ranges from –80 to –100 mgal and extends parallel to the front of the Caledonides. The Slidre anomaly then must be a feature of high gravity relief.

Negative closures are indicated over the Flå granite south of the Slidre anomaly and southwest of Slidre. The negative anomalies, however, are overshadowed by the magnitude of the Slidre gravity "high".

The value of the gravity field begins to increase rather markedly at Bagn in Begnadalen and continues northward as a broad NNW–SSE-trending positive area. In the center of this positive area, increased gradients define an E–W-trending positive feature. It is in this E–W trending feature where the most positive value of –20 mgal is attained.

At the north edge of the map (Fig. 2), another positive anomaly is found in the Jotunheimen. Although the station density is low, the eastern part of the map seems to be characterized by low gravity relief.

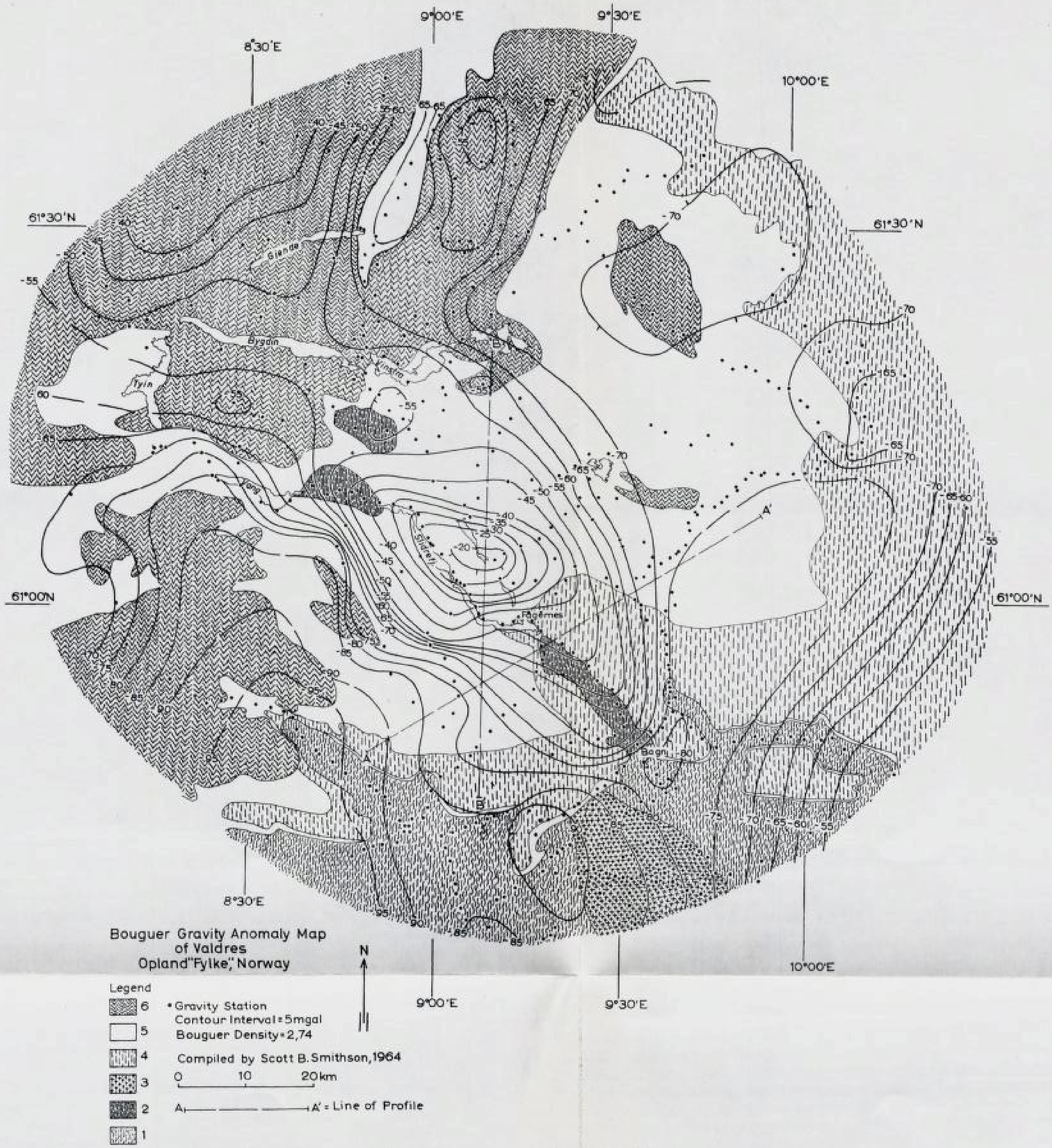

Figure 2. Bouguer anomaly map of Valdres.

Legend: 1–3 precambrian rocks

1. Banded granodioritic gneiss. 2. Quartz-dioritic gneiss and gabbro enclosing some quartzite. 3. Flå granite.

4–5 Eocambrian and Cambro-Silurian sedimentary rocks

4. Eocambrian quartz sandstone. 5. Cambro-Ordovician sandstones, slates, and the Valdres sparagmite.

6. *Crystalline rocks of the Caledonian overthrust massifs.*

Geology.

The rocks of the area are composed of the following divisions: 1) Precambrian rocks 2) Eocambrian sandstones, Cambro-Ordovician sedimentary rocks, and the Valdres sparagmite 3) The crystalline rocks of overthrust massifs.

Precambrian rocks are exposed in two windows in the center of the map area (Fig. 2) and along its southern border. Except for the extreme northern part of the map area, the elevation of the peneplaned Precambrian surface ranges from about 300 to 1000 m above sea level.

Banded granodioritic gneisses and the Flå granite, which cuts them, crop out from the Precambrian basement along the southern edge of the area (Strand, 1954; Smithson, 1963 a). Along Begnadalen north of Bagn, quartz-dioritic gneisses are exposed. These gneisses are separated from the granodioritic gneisses to the south by a northwestward-dipping shear zone marked by augen gneiss at Bagn. The quartz-dioritic gneiss is a banded rock containing numerous bands of amphibolite and a few anorthositic bands together with plagioclase-rich quartz-dioritic bands (Strand, 1943). Some of the amphibolite bands contain relics of hypersthene. Northward, these gneisses pass locally into massive quartz diorite that contains hypersthene and antiperthite; the mineral facies also increases to the north.

Northwestward to the east of Vang, the rocks of the southern Precambrian window consist of foliated gabbro, anorthosite, quartz diorite, and most commonly amphibolite. In the northern Precambrian window, quartz schists and quartzites of supracrustal origin are concordantly enclosed by gabbroic rocks. An actinolite schist here probably represents a metamorphosed ultramafic rock.

Strand (1943, p. 54–56) believes that these quartz-dioritic rocks from north of Bagn and the two windows are all related and form an igneous differentiation series. The gneisses and amphibolitic members of the complex are regarded as protoblastic having passed directly from a magmatic stage into the various metamorphic rocks. The mafic rock complex is construed to be a large concordant batholith, which has incorporated lenses of supracrustal rocks.

Overlying the Precambrian basement, Eocambrian quartz sandstone and a Cambro-Ordovician sequence of sedimentary rocks are found. The Cambrian consists of alternating shale, sandy slate, and sandstone. These are overlain by phyllites and then alternating slates and sandstones. The stratigraphic thickness of the Cambro-Ordovician deposits is probably between 500 and 1000 m. The Valdres sparagmite, which overlies the Ordovician rocks unconformably, is composed of arkoses and quartz conglomerates and represents a molasse-type deposit.

Massifs of crystalline rock belonging to the Bergen–Jotun kindred (Goldschmidt, 1916) have been thrust to their present tectonic position overlying the Cambro-Ordovician rocks or Valdres sparagmite. These rocks form small klippen in the middle of the map area and large masses along the northern edge. The massifs are separated from the underlying sedimentary rocks by mylonitized zones adjacent to thrust planes.

All the rocks younger than the Precambrian basement show strong effects of Caledonian deformation.

Interpretation.

The interpretation of the Bouguer anomalies requires the separation of these anomalies into two parts, the regional gravity field and the local field. The regional field is usually caused by deeper, larger-scale features; the local field is caused by smaller shallower geologic features. The Bouguer anomaly map (Fig. 2) and the map of southern Norway (Fig. 1) indicate that the gravity field decreases with a low gradient towards the south. The general background anomaly in the central map area from –70 to –80 mgal.

Superimposed on this background value is a gravity high that has a maximum value of –18 mgal. This indicates a maximum gravity relief of about 50 to 60 mgal, a huge anomaly; moreover, this gravity "high" seems to be composed of two components. The one is the broad north-northwest-trending feature whose upper value is outlined by the –55-mgal contour. *This anomaly begins abruptly at Bagn over the geological contact between the granodioritic gneiss to the south and the quartz-dioritic gneiss on the north.* The other component of the gravity "high" is the almost E-W trending closure characterized by high gradients and the –20-mgal contour.

The high gradients in the gravity field suggest that the cause of this anomaly lies at a relatively shallow depth. The cause of this anomaly must be a geologic feature with a positive density contrast and a large mass excess relative to the surrounding crustal rocks. A survey of the geologic map indicates that neither the early Paleozoic sedimentary rocks nor the klippen of dense gabbroic rocks of the overthrust massives can plausibly be the source of these anomalies.

The properties of a gravity field allow an estimation of the maximum depth at which a gravitating body causing the anomaly can lie (Smith, 1960). The most likely source of the positive anomaly is some sort of mafic rock body which may have a density of about 3.00 gm/cc. The Precambrian granodioritic gneiss on the south side of the map area has a mean density of about 2.74 gm/cc (Smithson, 1963 a). If a density contrast of 0.25 gm/cc is used and the base of disturbing body is placed at infinity, the inequalities of Smith (*op. cit.* p. 608) show that the depth to the top of this body is less than or equal to 4 km. This means that the source of the anomaly must be at or near the surface of the Precambrian basement.

The geology indicates that, in fact, the source of the anomaly lies at the surface in a few places and is only covered by a superficial veneer of sedimentary rocks in most places. The fact that the gravity gradient increases abruptly over the contact between the granodioritic and quartz-dioritic gneiss suggests that the source is shallow and actually lies in the density contrast between these two rock types. Strand, moreover, has interpreted the widely separated occurrences of mafic rock to be a single Precambrian mafic intrusion of batholithic dimensions.

Measurements of the vertical magnetic intensity were also undertaken in conjunction with the gravity survey. Although the measurements were too scattered and variable to delineate the contacts of the disturbing body, the measurements did indicate a maximum anomaly of slightly over 1000 gammas at Røn near the center of the gravity anomaly. This is comparable in amplitude to the magnetic anomalies found over the Cortlandt complex (Steenland and Wollard, 1952) and the Sudbury lopolith (Miller and Innes, 1955).

For analysis of the gravity anomalies, two profiles, A-A' and B-B', are drawn across the "high" (Figs. 2 and 3). The background anomaly is arbitrarily determined from the apparent average gradient over a larger area. A positive density contrast of 0.25 gm/cc is used for computations of the models.

Profile A-A' (Fig. 3 a) shows that a broad local anomaly of 25 mgal is found over the southern part of the broad flat gravity high. This anomaly can be simulated by the gravitative effect of a slab of dense material 2.5 km thick. The contacts dip in under the slab.

A maximum local anomaly of 53 mgal occurs along profile B-B' (Fig.

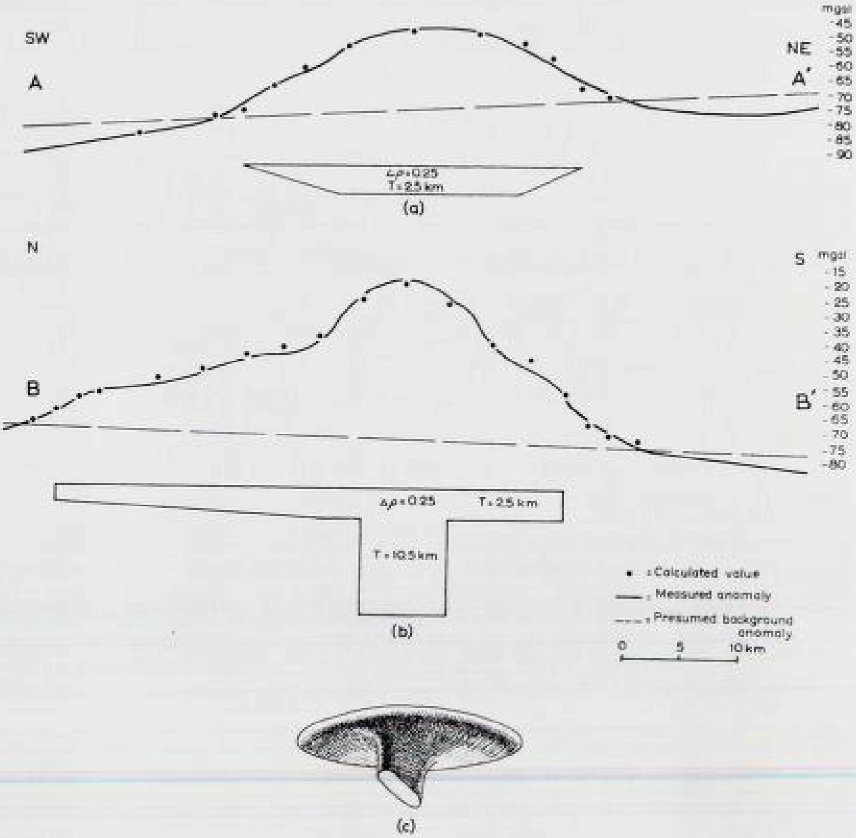

Figure 3. Profiles through the gravity anomaly and models calculated to approximate the anomaly. (a) Profile A–A'. (b) Profile B–B'. (c) Three-dimensional representation of the body calculated to simulate the gravity anomaly – viewed from the side and below.

3 b). Along this profile, the broad smaller anomaly and the abrupt larger anomaly are readily distinguished. The disturbing body in this profile is a 2.5-km-thick plate underlain by a deep, narrow block whose calculated base is 10.5 km deep.[1] Since the addition of more material at the base of this block has only a small effect, the actual figure for the depth of the base cannot be taken literally. The northern contact of the upper slab dips in gently; the southern one probably dips steeper because of the high gradient here.

The shape of the model that satisfies the observed gravity anomalies

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[1] Model computed by the method of Hubbert (1948) with end corrections applied where necessary (Nettleton, 1940, p. 117).

is an elongate north-south-trending slab underlain by a deep vertical stem whose oval cross section has an east-west-trending longer axis (Fig. 3 c). Because their exact position is unknown, the attitudes of contacts for the slab cannot be determined with certainty; however, the calculated model probably represents the gross overall shape of the geologic body. The east-west structural trends in the mafic gneisses of the Precambrian window east of Vang (Strand, 1951) exhibit an encouraging correspondence with the gravity contours in this area and, consequently, with the longer axis of the oval-shaped stem. The structural trends in the northern window show irregular structural trends that are not readily reconciled with the model.

Both scattered geologic observations and the gravity anomalies indicate that much of the Slidre area is underlain by a large mafic intrusion which lies at the surface of the Precambrian. That this mafic intrusion would be called a lopolith by geologists if it were fully exposed is suggested by the gravity model. The visible part of the intrusion would be a large plate-shaped body. Gravity interpretation demonstrates that this presumed lopolithic body is underlain by a column of dense material of considerable mass; this stem or column is construed to be a large feeder pipe.

Mafic intrusions may be highly variable in shape and composition. Steenland and Woollard (1952) used gravity interpretation to demonstrate that the Cortlandt igneous complex is a thin plate of mafic rock underlain by vertical feeder pipes, one of which is of relatively large diameter. In addition, the foliation in the intrusion generally coincides with the outline of the largest feeder pipe (*ibid.*, p. 1091). In the Great Dyke of Southern Rhodesia, gravity interpretation confirms the trough-like structure in places which is indicated by the attitude of mineralogical layering. Elsewhere, the higher broader gravity anomalies are interpreted in terms of a thick, deep funnel (Worst, 1960); *i. e.*, possible feeders. Wilson (1956) has postulated that because the layering in mafic intrusions generally dips more gently than the contacts, mafic bodies interpreted to be lopoliths may actually be funnel shaped.

Baker and Bott (1962) have used gravity interpretation to propose a broad funnel shape for a mafic intrusion in Sierra Leone. The gravity interpretation of the Sudbury mafic intrusive (Miller and Innes, 1955) confirms its lopolithic form; however, the presence of small feeders cannot be excluded (*ibid.*, p. 27). Mafic intrusions may vary from thin plates with large feeders to hugh funnel-shaped masses and more or less bracket the shape proposed for the body causing the Slidre anomaly.

Conclusions.

The Slidre positive gravity anomaly corresponds in position with rather mafic rocks occurring in Precambrian windows. Calculations show that the source of this anomaly must lie at shallow depth. In this area Precambrian rocks are covered by a thin sequence of Cambro-Ordovician sedimentary rocks. The source of the anomaly must be in the Precambrian basement and is most likely at the surface of the Precambrian.

The separate exposures of variable mafic rocks have been interpreted as differentiated members of a concordant mafic batholith (Strand, 1943). The positive gravity anomaly in Slidre is approximated by a model composed of a thin horizontal plate with a large deep feeder in the middle. Since sufficient geologic control is not available, the proposed model can hardly be regarded as unique; however, it is probably plausible in its gross features. On the other hand, not only the positions and attitudes of contacts could alter the picture, but also vertical variations in density so common in mafic intrusions (Wilson, 1956) would effect the calculations. The shape of the model is consistent with a flat or saucer-shaped intrusion underlain by a thick deep feeder.

The areal extent of this postulated mafic intrusion is about the same as Sudbury. The concordantly enclosed bodies of supracrustal rocks are explained by the lopolith hypothesis. Another possibility is, however, that the banded gneisses of the Aurdal rectangle represent metamorphosed equivalents of mafic volcanics and tuffs deposited in a basin and intruded by gabbro. The Slidre anomaly is, in any case, probably caused by a mafic intrusion which could contain mineral deposits. Detailed geophysical studies would be necessary to locate any possible economic occurrences.

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