THE TEMPERATURE OF GRANITIZATION IN THE RENDALSVIK AREA, NORTHERN NORWAY

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Rendalsvik is a small village on the peninsula between Holandsfiord and Tjongsfiord south of Bodø and north of Mo i Rana in northern Norway. See map, fig. 1.

A graphite mine near Rendalsvik was worked before and during World War II but was closed down in 1945. It is now planned to re-open and develop the mine on a larger scale. The Geological Survey of Norway (Norges geologiske undersøkelse) has undertaken a thorough investigation of the area comprising field-mapping, geophysical measurements as well as petrological, mineralogical and geochemical studies.

The Holandsfiord—Tjongsfiord peninsula is situated in the central zone of the Caledonides, and in a major axial culmination where the strike of the rocks is locally E—W and thus nearly normal to the prevailing strike (NNE—SSW) of the Caledonides of this region.

The peninsula is made up[1] of granite, gneiss, and metamorphosed sediments in amphibolite facies, see map fig. 2. Because of the folding and subsequent granitization it is not altogether easy to reconstruct the stratigraphical succession, but it is probably, from the base upwards: mica-schists; lime-silicate-gneisses with layers of mica-schists, limestones, and amphibolites; graphite-schists; quartzite; and mica-

[1] A more detailed account (in English) of the geology of the region by S. SKJESETH and H. SØRENSEN will appear shortly among the publications of the Geological Survey of Norway. We have consulted their manuscript and made use of some of their factual data, maps and sections in the preparation of this paper.

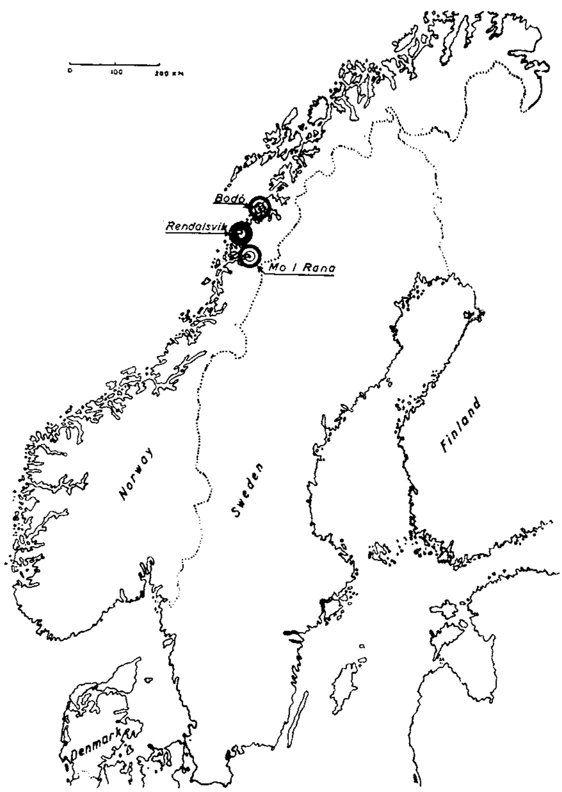

Fig. 1. Map showing situation of Rendalsvik.

schists; i.e. an original sequence of sediments mainly consisting of shales with layers of limestones, black shale and sandstone. The graphite-schist (black shale) is overlain by quartzite (sandstone) with a narrow zone of mica-schist (shale) in between.

The graphite-schist is folded into an anticline or anticlinorium with a steep and compressed southern limb and a more gently dipping and undulating northern limb (see section fig. 3). It is characteristically thickened in the crests of the anticlines.

The granite and granitic gneiss could be more correctly termed granodiorite and granodioritic gneiss. The junction between these rocks and the sediments may be a conformable or unconformable one. In several places there are gradual and continuous transitions from mica-schist via granitic gneiss to fairly homogeneous granite,

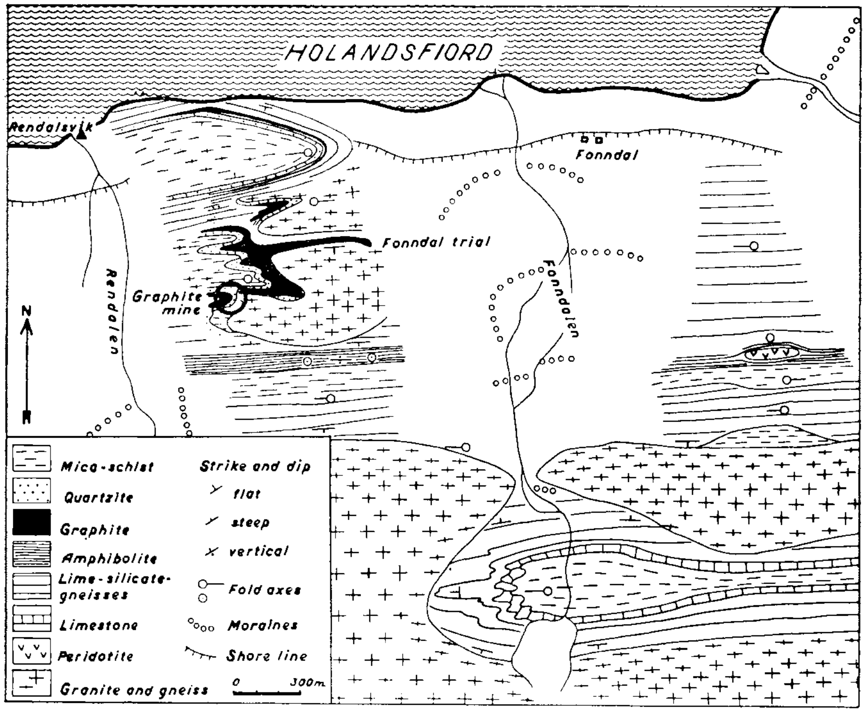

Fig. 2. Geological map of the Rendalsvik area (after S. SKJESETH). Centre of ring denotes place where analyzed sample was collected.

and from impure limestone via lime-silicate-gneiss to biotite-gneiss. The transitional changes can be especially well studied on the bare rock surfaces left uncovered on the withdrawal of the big glaciers Engenbreen and Fonndalsbreen during the last 30 or 40 years. It should also be mentioned that while the granitic rocks may transect the strike of the sediments, the foliation and lineation of the former are always parallel to the strike of the latter. The field evidence suggests a formation by replacement in situ of the pre-existing sediments. A beautiful illustration of this process is found a few metres south of the Fonndal trial (see fig. 2) where the graphite-schist and the overlying narrow band of mica-schist have been granitized: the typical zig-zag, smallscale folding of the mica-schist can be followed across the junction and for about 15 cm into the granite where a very clear "ghost structure" is discernible (see fig. 4).

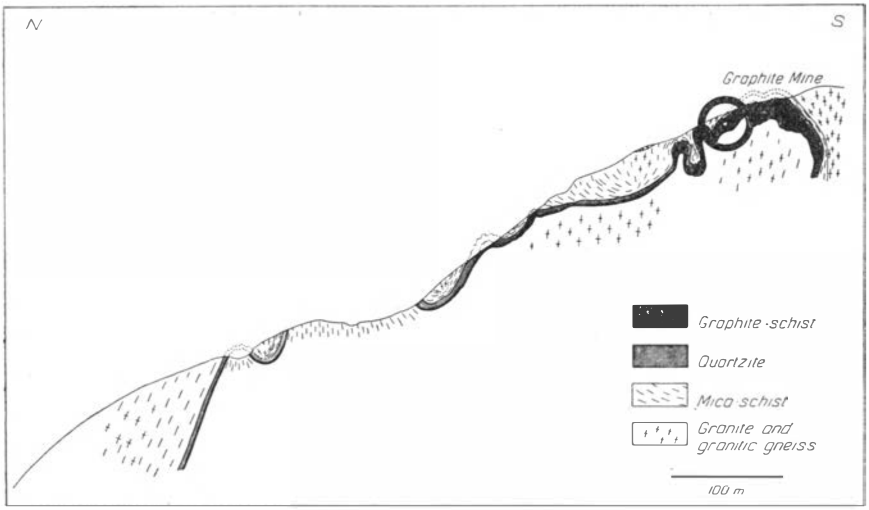

Fig. 3. North-south profile passing through the graphite mine (after S. SKJESETH). Centre of ring denotes place where analyzed sample was collected.

The three major events in the history of the Rendalsvik rocks were: 1) deposition of the sediments in the Caledonian geosyncline, 2) folding (and perhaps thrusting) which, apart from mere details, gave the rocks their present architecture, and 3) granitization, which affected all the sediments, though the graphite-schist least of all. In several places the sediments below and above the graphite-schist have been granitized and the schist itself is now totally enveloped by granite. The reason for the graphite-schist being more resistant to granitization will not be discussed in this paper.

Even if the sediments were mineralogically altered during the period of folding, there can hardly be any doubt that they acquired their present metamorphic state during the granitization period. The metamorphism and the granitization are in fact both manifestations of one and the same process, and the chemical equilibria which can be studied in the schists and gneisses are characteristic for the (P,T) conditions pertaining during the granitization.

The graphite-schist carries sulphides as accessory minerals. They do not originate from the granite, but are primary constituents of the original sediments, as they are evenly distributed in the schist

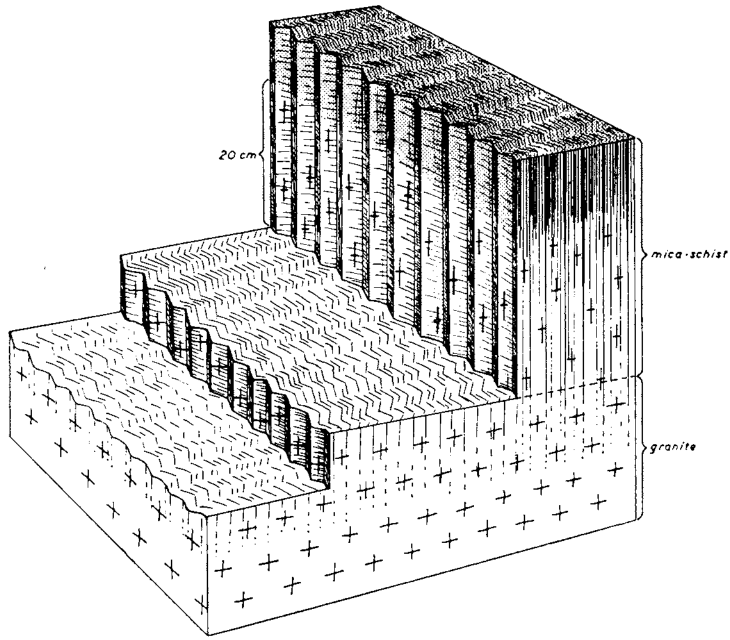

Fig. 4. Block-diagram illustrating the transition from granite to mica-schist south of the Fonndal trial (after S. SKJESETH).

and there are no indications of a metasomatic origin. Hydrothermal veins or veinlets are non-existent.

Pyrrhotite is by far the most abundant sulphide and represents 5—10 per cent of the rock while the cogenetic sphalerite is present in traces only.

When sphalerite crystallizes in the presence of Fe, some Fe will substitute for Zn forming a mixcrystal (Zn, Fe) S. If the amount of Fe be increased, a saturation point will be reached beyond which iron sulphide (as pyrrhotite or pyrite) will form as a separate phase in equilibrium with sphalerite. In the preceding paper of this journal one of us (G.K.) has studied the saturation point as a function of temperature and pressure and shown by experiments how the Fe content of sphalerite in the parageneses sphalerite-pyrrhotite and sphalerite-pyrite can be used as a geological thermometer (and manometer).

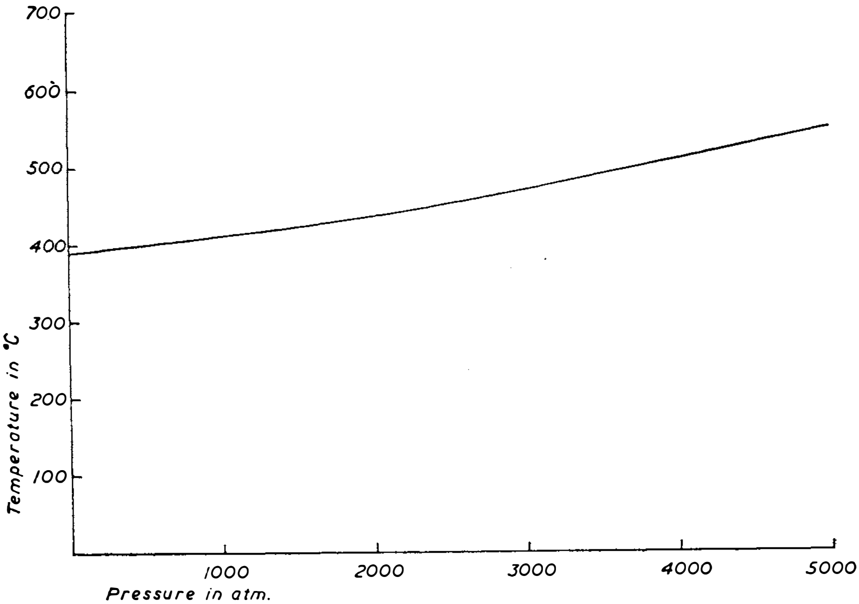

Fig. 5. Curve illustrating pressure-temperature relationship for the formation of the mix-crystals (Zn, Fe) S containing 12.5 mol.% FeS, when formed in equilibrium with pyrite or pyrrhotite.

A representative sample of the graphite-schist was ground to —70 mesh and a sphalerite (marmatite) concentrate obtained by application of heavy liquids. The concentrate was hand-picked under a binocular lens to remove composite grains and the pure sample (not containing more than 1—2 per cent foreign minerals) analyzed for iron and manganese by Miss Erna Christensen in the Chemical Laboratory of the Geological Survey of Norway. The (Zn, Fe) S mix-crystals were found to contain: 12.5 mol % FeS and 4.5 mol % MnS. Unfortunately no analysis was done on cadmium which ,in sulphides of this type is usually present to the extent of 0.1 to 1.0 per cent.

The unit cell length (a_0) of the mix-crystals was found from x-ray powder diagrams to correspond to 12.5 mol % FeS, 4.5 mol % MnS and about 0.8 mol % CdS, thus indicating that exsolution of FeS has not taken place to any measurable extent during the cooling process. The unit cell length versus composition relationship has been discussed in the preceding paper and will not be repeated here. It may only be mentioned that these investigations have shown that the presence of modest amounts of MnS and CdS with the FeS in the ZnS lattice does not influence the FeS solubility to any measurable extent.

When in equilibrium with pyrrhotite or pyrite the mix-crystals containing 12.5 mol % FeS are formed under atmospheric pressure at 390° C (see figure 1 in the preceding paper). The FeS solubility decreases with increasing pressure as shown in table X and figure 9 of the preceding paper.

Fig. 5 below shows the pressure-temperature relationship for mix-crystals containing 12.5 mol % FeS and the sphalerite of the graphite-schist must have been formed under (P,T) conditions corresponding to a point on this curve.

The metamorphism, of course, took place not at one specific temperature but within a temperature range. It is a matter of experience that Fe seems to dissolve more rapidly in the ZnS lattice than it exsolves. If this be the case, the measured temperature of formation will tend to represent a maximum rather than a minimum temperature.

As mentioned above, the schists and gneisses are found in amphibolite facies the temperature range of which has been somewhat differently estimated by various authors.

The sample used for these investigations was collected close to the schist-granite junction. The place is marked with a ring in figs. 2 and 3. Under the regional type of metamorphism which the area has suffered, the temperature of the graphite-schist at the time of equilibrium cannot have been much different from the contemporary temperature within the adjoining granite itself. Granitization must have taken place at the highest temperature which has existed at the schist-granite junction for any length of time and it is concluded that, within narrow limits, the temperature of formation of the sphalerite is identical with the temperature of granitization.

The fundamental data are lacking for an estimation of the average pressure pertaining during the granitization. It is highly improbable that the pressure would have been less than 1000 atm. (corresponding to the hydrostatic pressure at a depth of 3¾ km) and it has probably not been much above 3000 atm. (corresponding to a depth of about 11 km) as there are no signs of phenomena characteristic of the deep roots of mountain chains.

If the average pressure be estimated at 2000 atm. $\pm$ 1000 atm., the temperature of granitization in this area was

$$440° \text{ C} \pm 25° \text{ C}.$$

In view of the experimental evidence that no granitic magma can exist below 670° C and accepting the dictum by Read "no magma, no igneous rock", the granite of the Rendalsvik area, in full harmony with the field evidence, is non-igneous.

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