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GEOLOGICAL MAP OF THE WESTERN SØRLAND

BY

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With 1 geol. map, 2 plates, and 7 figures in the text.

The area covered by the map is limited to the north by 58° 40′ N latitude, in the east by longitude 8° 10′ E Greenwich. In south and west it is bounded by the North Sea. The area corresponds to the western part of the region which in Norway is known as the "Sørland".

The published data that have been incorporated in the present map have been taken from the following sources:

1) Th. Kjerulf og T. Dahll: Geologisk Kart over Det Søndenfjeldske Norge, 1858—1865. This is merely a reconnaissance map in the scale 1: 400 000 on which rather few details are shown. 2) C. F. Kolderup: Die Labradorfelse des westlichen Norwegens I —. Bergens Museums Aarbog 1896, No. *5*; 3): Fjeldbygningen inden rektangelkartet Egersunds omraade —. Norges Geol. Undersøk. No. *71*, 1914; 4): The anorthosites of Westen Norway —. Rep't. 16. Internat. Geol. Congress, Washington 1933, p. 289. In these papers Kolderup has published some field observations on the anorthosite-charnockite petrographic province in the west. But detailed mapping is given only in No. 3 dealing with the extreme western parts (country around Egersund). 5) Arne Bugge: Trekk av Sørlandets geomorfologi —. Norsk Geogr. Tidsskr. *7*, 98, 1939. This survey stops at the extreme eastern end of the present map; some features of the country around Kristiansand is shown.

Special geological and mineralogical details have been collected from the following papers:

6) Olaf Holtedahl: The submarine relief off the Norwegian coast —. Norske Vid.-Akad., Oslo 1940; 7) J. H. L. Vogt: Norske ertsforekomster V. Titanjernforekomstene i noritfeltet ved Ekersund—Soggendal —. Kristiania 1887; 8) Steinar Foslie: Syd-Norges gruber og malmforekomster —. Norges Geol. Undersøk. No. *126,* 1925; 9) Olaf Andersen: Feltspat II, forekomster i fylkene Buskerud og

Telemark, i flere herreder i Aust-Agder og i Hidra i Vest-Agder —. Norges Geol. Undersøk. No. *128 b,* 1931; 10) Olge J. Adamson: The granite pegmatites of Hitterø, Southwestern Norway —. Geol. För. Förh. Stockholm, *64,* 97, 1942.

Various cartographic data have previously been published by me in the following papers:

11) Tom. F. W. Barth: Zur Genese der Pegmatite im Urgebirge I, Die Geologie und Petrographie der granitischen Pegmatite im südlichsten Norwegen —. Neues Jahrb. f. Min. etc., B. Bd *58,* Abt. A, 385, 1928. 12): Zur Genesis der Pegmatite im Urgebirge II, Ein syntektischer Gesteinskomplex aus dem südlichsten Norwegen —. Chemie der Erde, *4,* 95, 1928; 13): Feltspat III, forekomster i Iveland og Vegusdal i Aust-Agder og i flere herreder i Vest-Agder —. Norges Geol. Undersøk. No. *128 b,* 1931; 14): The large pre-Cambrian intrusive bodies in the southern part of Norway —. Rep't. 16. Internat. Geol. Congress, Washington 1933, p. 297; 15): Geomorphology of Vest-Agder Fiord-Land —. Norsk Geogr. Tidsskr. *7,* 34, 1939; 16): Lamprofyrer av to forskjellige aldre i kystmigmatiten vest for Kristiansand —. Norsk Geol. Tidsskr. *23,* 175, 1943.

Furthermore I have made use of the field observations of Robert Major on the quartz-monzonite area W of Farsund (University exam paper 1940), and of Olge J. Adamson on the rock complex in the island of Hidra (University exam paper 1940).

I have spent several weeks in the field together with Dr. Robert Balk (professor at Mt. Holyoke College, Mass. U. S. A.) to whom I am particularly indepted for constructive discussions and for his teaching me the principles, problems, and methods of study of the structural patterns of igneous rocks. I also want to acknowlege my grateful remembrance of the pleasant and stimulating days in the field together with Dr. Arne Bugge (Norges Geologiske Undersøkelse), Dr. Harald Bjørlykke (Norges Tekniske Høgskole), cand. real. Anders Kvale (Bergens Museum), Dr. Otto Mellis (the University of Riga), and Dr. A. C. Waters (Stanford University, Calif. U. S. A.).

My own field investigations extend over several years: In 1930 and 1932, as a member of the Geophysical Laboratory of Washington, D. C., I stayed in the field for several months mainly studying the contact phenomena of the anorthosites and congenetic rocks. I want to express my thanks to Dr. A. L. Day for the positive interest he took in my activities, and I take great pleasure in acknowledging the financial support for the field work extended to me from the Geophysical Laboratory through its former director, Dr. A. L. Day.

For eight consecutive summers (1936—1943) I have for shorter or longer periods worked in the field under the auspices of Norges Geologiske Undersøkelse. During this period I have nearly completed the geological mapping of the following 10 "rectangle" map sheets in the scale 1 : 100 000: Evje, parts of Kristiansand, Oksø, Bjelland, Audnedal, Mandal, two still unnamed sheets between Bjelland and Egersund, Flekkefjord, Loshavn. I hope to be able to publish some of these maps as soon as the conditions in this country become more favorable and more normal. As a "summary" of these detailed field investigations I offer for publication the present map in the scale 1 : 300 000. For the pleasant co-operation with Norges Geologiske Undersøkelse and for defraying the full cost of the field work connected with the survey of these map sheets I want to express my hearty thanks to the director of the Survey, Dr. Carl Bugge.

The Rocks.

The map represents a part of the great pre-Cambrian shield of Southern Norway. Crystalline schists are dominating, but a rock province of anorthositic-charnockitic composition occurring in the western parts of the mapped area was generally believed to be truly igneous. All measurements pertaining to strike and dip have been stated in terms of degrees of the decimal system: $100^\circ =$ right angle.

Mixed Gneisses constitute the oldest rock formation representing a heterogeneous migmatic-anatectic rock complex in which the composition of the constituent rock types ranges from amphibolitic to granitic. The general trend of the strike of the gneisses is north—south with steep westerly dips. The amphibolites are present as bands, zones, and streaks in a granitic matrix, or else as larger bodies of irregular shape (nickeliferous "gabbro" at Evje-Iveland).

Some of the more characteristic gneiss types: Regular banded-gneisses with straight layers of amphibolite extending over long distances, Photos 3 and 7; in other parts the amphibolite may be pulled out to narrow sheets that have floated in the granitic migma and eventually congealed as phantastically twisted and folded "rheolites", Photo 8; again in other parts the amphibolite forms lenses or irregularly elongated bodies, Photo 5; true agmatites (= breccia-like structures) of amphibolite and granitic gneiss also occur (Photo 2) strikingly similar to the agmatites described by Sederholm from migmatites in Southern Finland.

Through potash metasomatism the amphibolites develop into biotite gneisses, Photo 4; under certain conditions they in turn change into augengneisses → granitic gneisses → gneiss granites → pegmatites, apparently in accordance with the scheme described by me in 1928 (reference No. 12).

The following summary statements represent my ideas on the genesis of the mixed gneisses: They developed at a deep level of the earth's crust during a pre-Cambrian orogenesis. Following Eskola and others I regard the granitic ichors or magmas as the "sweat" secreted by the crust during an orogeny. Thus is explained the dominant occurrence of rocks of granitic character.

At the contact of these granites a continuous transition into the adjacent gneisses is frequently encountered, see Fig. 1. In other places granite and gneiss are so intimately mixed that it requires a map on a very large scale to separate them. All the different types of gneisses have been formed through a metasomatic action of the granitic magma. Only anatectic processes, it seems to me, would be able to produce such gneisses and migmatites.

The granitic magma, which consequently was, at least partially, a palingenic magma, can thus be pictured as a pore liquid being formed in the interstices of the mineral grains of a pre-Cambrian rock complex as it was folded down deeply enough to suffer a differential re-fusion. Being lighter than the rock in whose pores it is first enclosed

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Fig. 1. Contact between granite and amphibolitic gneiss. Detail from the map of Fig. 2.

» 2. Map of the southern part of the Oddersjå granite, a granitic body surrounded by gneiss just N of Kristiansand.

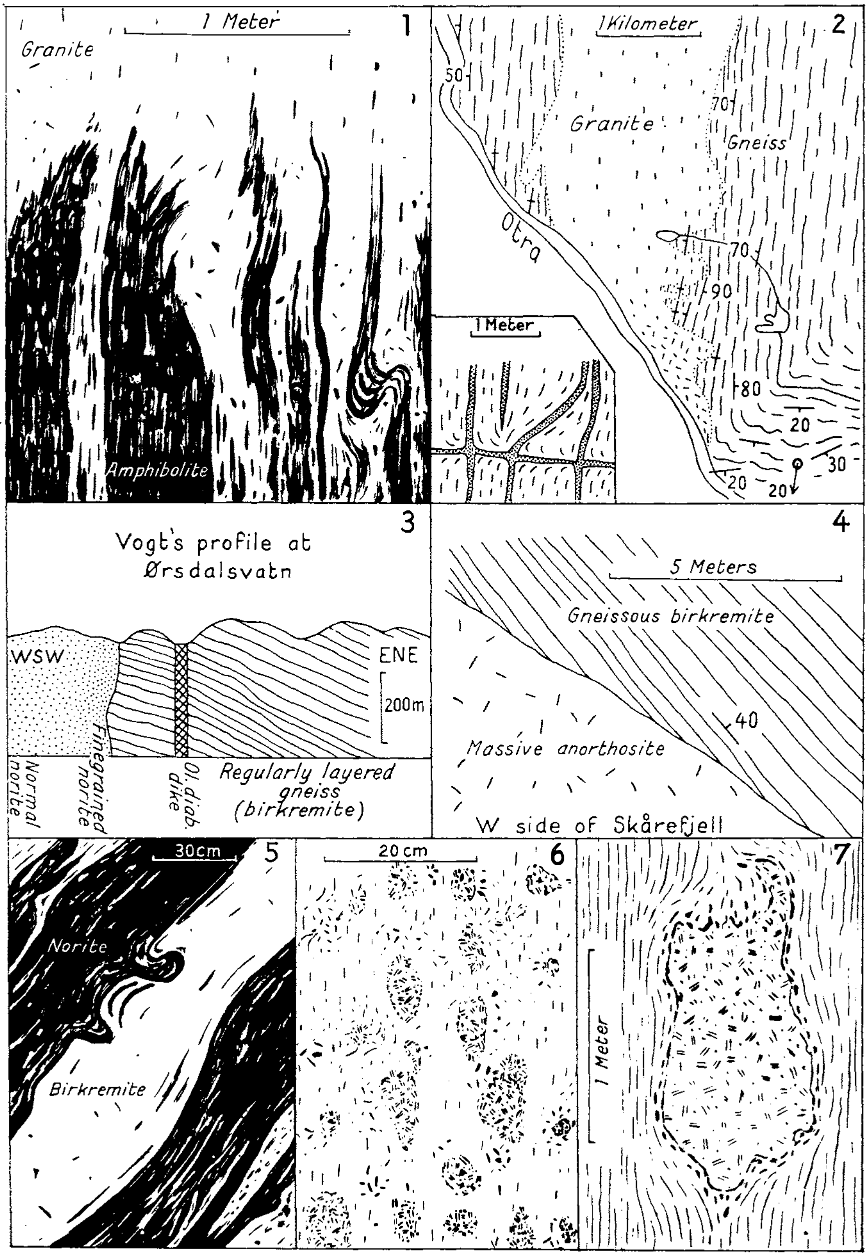
» 3. Contact between norite (anorthosite) and gneissic birkremite according to Vogt.

» 4. Contact between birkremite and anorthosite at Skårefjell.

» 5. Injection gneiss of norite and birkremite, Gyadal.

» 6. Pegmatoblastic gneiss. The pegmatitic blebs are massive and therefore younger than the pre-Cambrian orogeny and subsequent metamorphism. Sødal.

» 7. Pegmatitic "inclusion" in ampfibolite. Through potash metasomatism a selvage of biotite has formed around the pegmatite. Søm.


1
1 Meter
Granite
Amphibolite
2
1 Kilometer
Granite
Gneiss
Otra
1 Meter
50
70
70
90
80
20
30
20
20
3
Vogt's profile at Ørsdalsvatn
WSW
ENE
200m
Normal norite
Finegrained norite
Ol. diab. dike
Regularly layered gneiss (birkremite)
4
5 Meters
Gneissous birkremite
40
Massive anorthosite
W side of Skårefjell
5
30cm
Norite
Birkremite
6
20 cm
7
1 Meter

Figs. 1—7.

this melt tends to rise, and at first it soaks through the overlying rock masses, and in accordance with the law of mass action alters them metasomatically. As can be shown from chemical, mineralogical, and geological analyses, every volume unit of the adjacent gneiss has been influenced, indeed, severely altered by the granitic magma. Although the magma itself was passive it can thus be set in motion by orogenetic or gravitative forces. It may be squeezed out in some places, and will seek its way along shearing planes or other planes of small resistance. It may move shorter or longer distances. There may be formed veined gneisses or other kinds of migmatite (Photos 4 and 8). Or the magma may concentrate into large basins giving rise to bodies of pure granite. An example of these large bodies is shown in the map of the Oddersjå granite, Fig. 2. It is composed of pure granite, and displays a more or less pronounced linear parallelism which looks similar to what have been termed flow lines by H. Cloos and his school. But if they were common flow lines they should show a marked increase towards the selvages, where also platy parallelism, or foliation, should appear; and obstacles in the direction of the flow, like bends in the border, or inclusions, should cause the flow lines to wind around in back eddies. But no such phenomena can be observed. Quite the contrary, as seen from Fig. 2, it is a striking fact that the "flow lines" continue in their normal direction (almost due north) straight out to the border of the granite, even if the border obliquely cuts the direction of the "flow lines". This contact is shown in great detail on Fig. 1. These facts make it definitely impossible to account for the linear parallelism by magmatic flowage.

That, however, these lines indicate directions in which the magma was deformed prior to its complete solidification is seen from the lower left hand sketch of Fig. 2 proving the pre-pegmatitic age of the texture. This indicates, therefore, that there has not been any metamorphism after the solidification of the granite, and that the linear parallelism was caused during the crystallization of the granite by the same orogenetic forces that deformed the gneisses.

My contention regarding the mode of emplacement of these granites is thus that the granitic magma, which started as a palingenic pore liquid in the deeply down-folded pre-Cambrian rocks, partly soaking through the adjacent rocks, partly following planes of small resistance, would slowly concentrate in larger basins, crystallize *in situ,* and simultaneously develop a linear texture. Where the pore liquid was unable to concentrate in larger basins it congealed in "puddles", "blebs" or "drops" that had soaked through the surrounding gneisses — these are the innumerable small pegmatite bodies which have such a wide distribution in the mixed gneisses. See Figs. 6 and 7. It is impossible to mark the pegmatites on the map, but all feldspar quarries are shown.

At the conclusion of the pre-Cambrian orogeny the complex of mixed gneisses had received its present character.

Anorthosite (Andesinic) — Farsundite (Hornblende-Bearing Quartz-Monzonite) — Birkremite (Hypersthene Granite-Gneiss).

These rocks are probably younger than the mixed gneisses and exhibit a more "igneous" texture; but certain facies types of them may be just as "gneissic" as the mixed gneisses. By Kolderup 2), 3), 4) they were regarded as derivatives of a common magma. However, I have not been able to produce any clear evidence in favour of this view. The contact phenomena between these members among themselves and between them and the adjacent mixed gneisses are interesting but have so far failed to give a clue to the problem of interrelation or genesis.

The contact anorthosite — birkremite is usually conformable; foliated anorthosite of the border zones (including noritic facies) is in contact with birkremite exhibiting parallel foliation. See Fig. 5. In many places the transition is gradual giving rise to migmatite-like border zones composed of foliated, alternating layers of various rock types, such as: anorthosite, norite, mangerite, birkremite, amphibolite, and even other types of gneisses. Vogt 7) found a contact supposed to prove the younger age of the anorthosite. See Fig. 3. A similar border phenomenon has been observed by me on the west side of Skårefjell. See Fig. 4. However, in my opinion we have in these places no primary contacts: At Skårefjell the anorthosite exhibits a typical block structure, and "blocks" of anorthosite occur alongside with "blocks" of gneissic birkremite. The anorthosite is partly massive, partly intensely crushed. Just west of the crushed rocks an anorthosite crops out showing distinct foliation pointing directly into the gneissic birkremite which, therefore, must be separated from the anorthosite by a thrust plane. My conclusion is that the primary contact between anorthosite and birkremite is always conformable.

The contact between birkremite and farsundite is always very elusive, being effected over longer distances by a gradual increase in hornblende on the cost of hypersthene.

The contact birkremite — mixed gneiss is, as far as I have seen, always transitional and undeterminable.

The contact farsundite — mixed gneiss may take on two different aspects: It is typical for farsundite to become strongly foliated towards the borders, and the foliation is always parallel to the border walls. Also the foliation of the adjacent gneisses are usually swung into the plane of the border walls. The contact is in such places quite sharp. In other places the transition farsundite-mixed gneisses is similar to the transition between granite and gneiss shown in Fig. 1. This type of transition is found, as indicated by the map, at the end of the long offshoots which extend, two northwards, and one southward, from the main body of farsundite.

In my opinion farsundite and birkremite represent closely related derivatives of deepseated magma that some time after the conclusion of the pre-Cambrian orogeny rose from a deep center in the neighborhood of Farsund—Lista, and by metasomtic alteration, brecciation, disintegration, and assimilation invaded the country gneisses; thus forming with them "injection gneisses" and migmatites.

The relations of anorthosite are still uncertain. Even the magmatic mode of origin may be questioned. The following observations are hard to accept for an igneous rock: 1) Giant crystals of andesine that in places attain a length of 110 cm (3½ feet). 2) Homogeneous and undeformed crystals of "porphyric" andesine in a foliated or quite gneissouse groundmass. 3) Folds in anorthosite that is entirely surrounded by massive anorthosite. See Photo 6.

Faults, Thrust Zones, Friction Breccias.

Arne Bugge has demonstrated the existence of a mighty friction breccia extending for 350 kilometers from the Oslo region in NE to Kristiansand in SW. The trace of the southwestern part of this breccia zone is indicated on the present map. Sub-parallel thrust zones have been shown to exist farther north and west. The alleged "volcano" in Greipstad (K. O. Bjørlykke: "Remnants of a Volcano in Southwestern Norway", Norsk Geol. Tidsskr. 7, pp. 271—279, 1924) is merely a part of one of these zones. Thus this part of the pre-Cambrian shield has cracked up in long segments which again are cut crosswise by a system of faults running athwart. There is no striking difference in the rock types encountered on opposite sides of the thrust zones; this indicates that the thrusts, although representing first order dislocations, do not separate geological formations of very different character.

According to Holtedahl 6) the land masses are bounded by a system of submarine fault lines testifying to the epeirogenic rise of the country in Cainozoic time.

Mineralogisk Institutt, Oslo,
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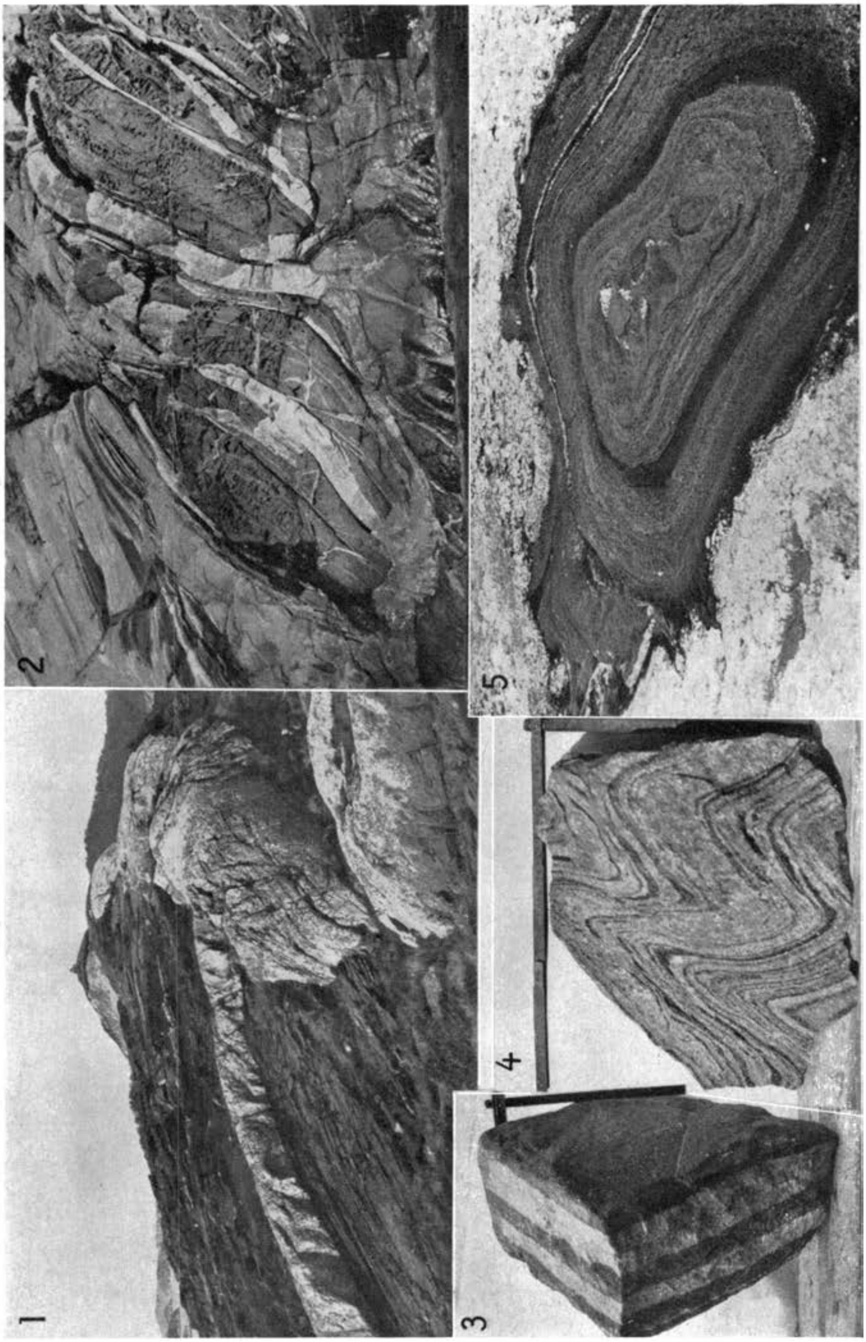
Trykt juni 1945.

Plate I.

Photo 1. Pegmatite dikes intrusive into amphibolitic gneiss, Herø, Søgne.
» 2. Agmatite. Nodeviksholmen, Søgne.
» 3. Banded gneiss, Brennåsen, Greipstad.
» 4. Striped biotite gneiss. Brennåsen, Greipstad.
» 5. An "egg" of amphibolite embedded in granitic gneiss 1 × 2 meters across. Herø, Søgne.

Plate II.

Photo 6. Fold in anorthosite. Bottenvann, Åna Sira.
» 7. Banded gneiss. Udvår, Try.
» 8. Rheolitic gneiss. Selskjær, Try.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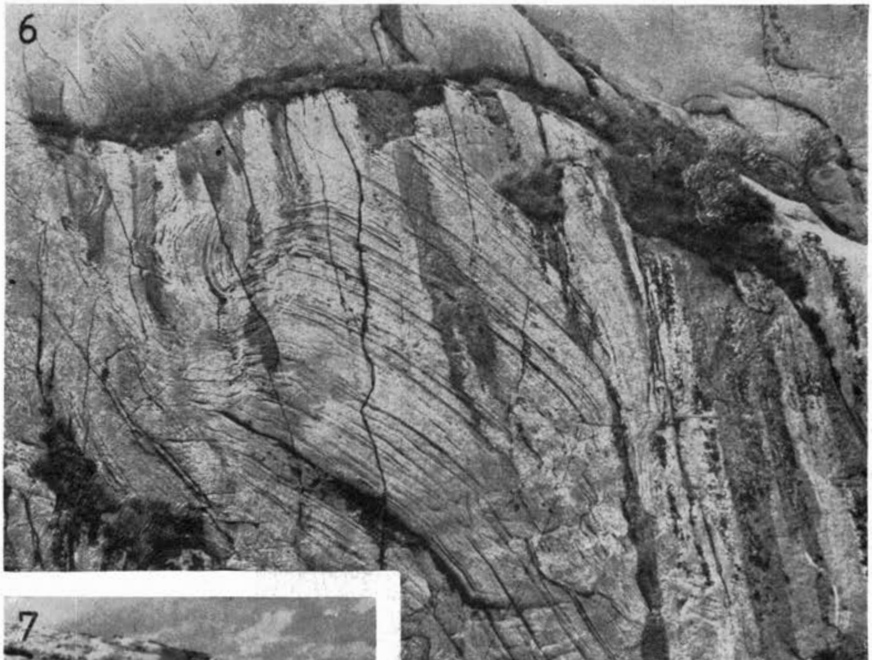
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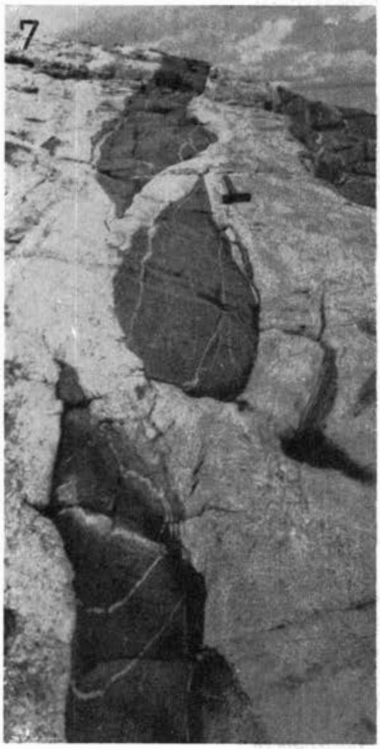
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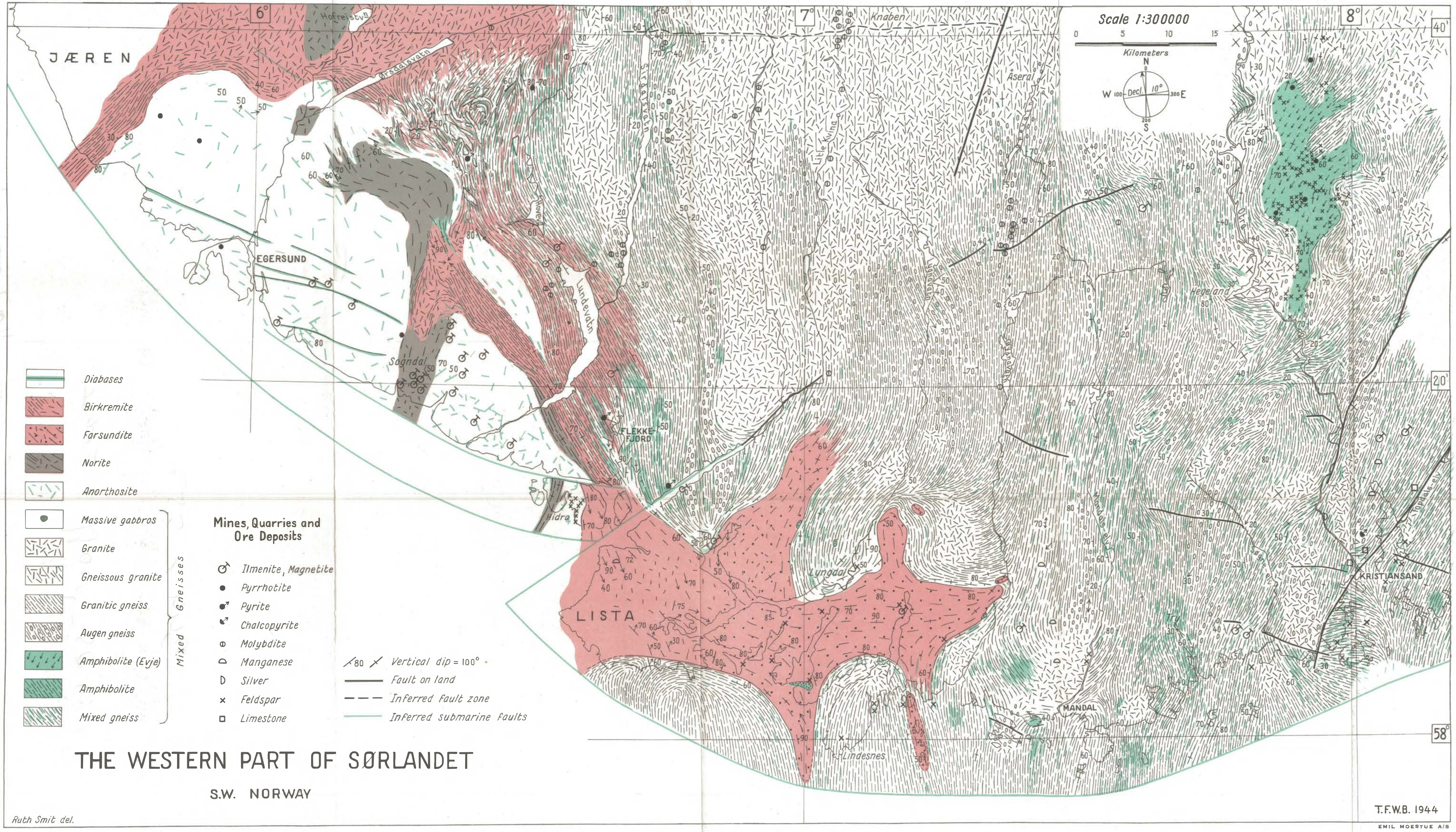

THE WESTERN PART OF SØRLANDET

S.W. NORWAY