Variation diagrams supporting the stratiform, magmatic origin of the Jotun Eruptive Nappes

BY

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With 6 text-figures

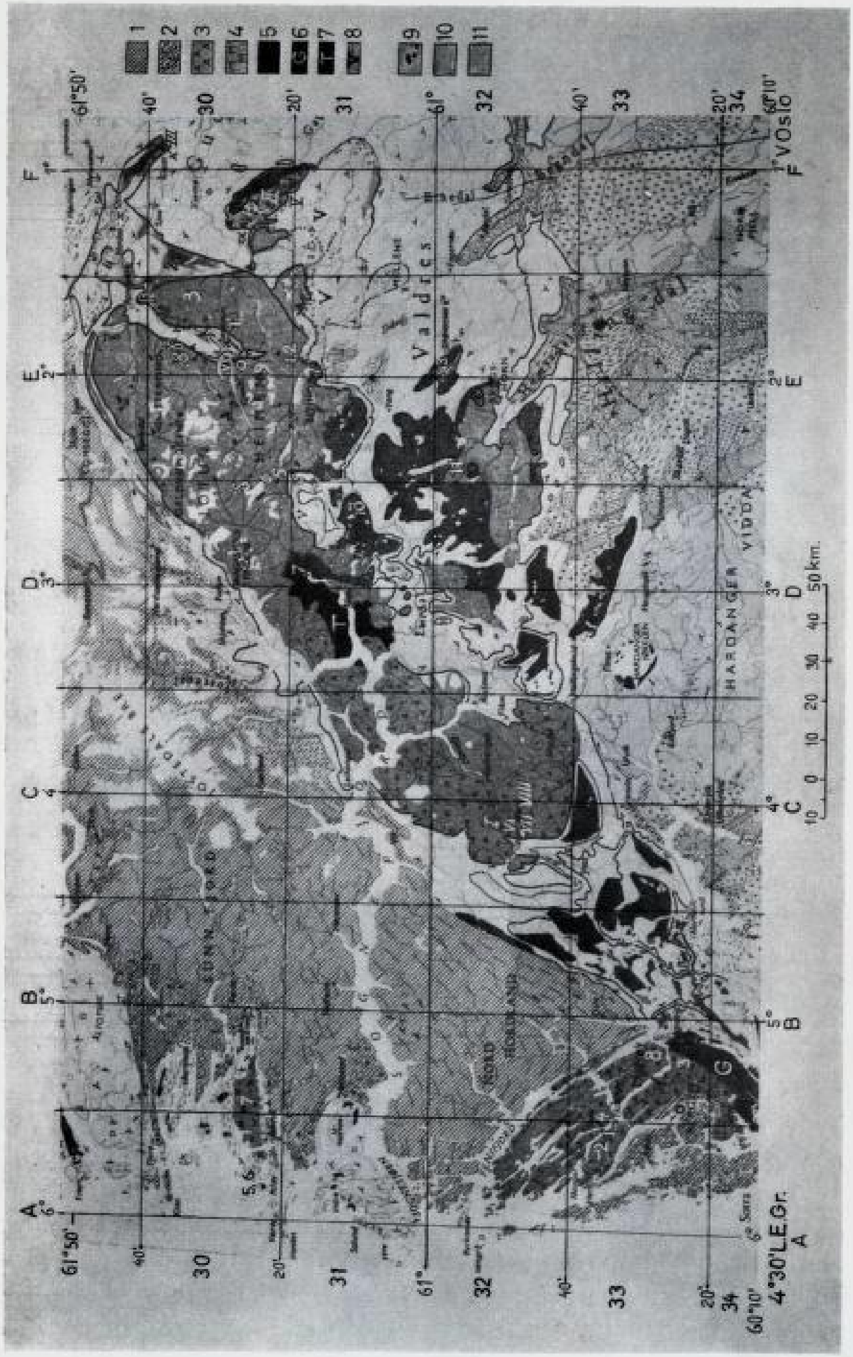
In the author's paper (1955, p. 30—55) the stratiform charakter of the Jotun eruptive nappes was suggested. It is admitted that additional evidence is desirable before making a definite statement in this case, which is supposed to be of great importance for solving the "High Mountain Problem of Norway", that is, an interpretation of the layering of the crystalline complexes which are gneissic and mylonitic at the base, with masses of eugranitic, plutonic rocks at higher levels.

In v. Bubnoffs "Geologie der Erde" (Bd. II—2—1930, edition in collaboration with V. M. Goldschmidt) a synopsis of about 70 pages is given of the Caledonides of Norway. Excerpt from p. 33:

"Das Problem dieser Lagerungsumkehr ist nicht nur auf das kaledonische Gebirge beschränkt; es besitzt grundlegende Bedeutung für die Geologie eines Faltengebirges überhaupt, und die hier erzielten Ergebnisse können für unsere gesamte tektonische Auffassung massgebend werden."

The interdependence of tectonics and petrology was emphasized by R. A. Daly (1925, p. 306): "Neither volcanism, nor plutonism can be understood until we understand the formation of mountain chains."

The statements of these late masters are a challenge to geologists of this country. The mountain chain extending for more than 1500 kms marks the topography of most of Norway. The earth-shells from 20—30 kms deep may be regarded as elevated, and are now as eruptive nappes exposed for investigation by erosion, and swept clear by glaciers.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A
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6°
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61°50'
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33
34
60°10'
4°30' L.E.Gr.
Oslo
Valdres
HARDANGER VIDDA
Sogn
Sunnfjord
Hordaland
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0
10
20
30
40

Fig. 1

Explanation of fig. 1. Index map of The Bergen—Jotunheim area.

1. Mainly gneissic rocks of various origin in NW and W ("basal gneiss": granitic and quartz-dioritic, further paragneiss). Structure wholly or in part Caledonian. (To the SE of Jostedal is foliation partly absent.)

Bergen—Jotun rocks of the lower Eruptive Nappes:

2. Areas in which eclogite occurs: Sunnfjord and the Bergen Arcs, sparsely in Sogn.
3. Areas in which anorthosite ("labradorfels") occurs: Sunnfjord and the Bergen Arcs, Sogn and the near foreland of East-Jotunheimen.
4. Mangerite in Sogn and the Western area. Mainly gneissic. ("Jotunite" in Sogn, "Mangerite-syenite" in Sunnfjord.)
5. Mainly acidic plutonic rocks, often gneissic. Hardangervidda and Hallingskarvet (D 33) Bergsdalen migmatic nappes: B 33 vest, C 33 øst.
6. Gabbro: B 34 vest and diverse smaller localities.
7. Trondhjemite: D 31 vest, F 30 vest, and diverse connected localities.
8. Valdres Sparagmite with cgl. Synorogenic Caledonian flysch.

Rocks of the upper Jotun Eruptive Nappe.

9. Dunite, ultrabasic rocks.
10. Troctolite, Olivine gabbro, Jotun Norite. (Medium grained, eugranitic on higher levels in High Jotunheimen.)
11. Leucocratic Mangerites, Monzonites, Hypersthen syenites, granites. (Gneissic and mylonitic in the foreland and at the base.)

Rocks of Devonian in NW, and of sedimentary Cambro-Ordovician and Precambrian Basement, mainly to the SE are not specified in this index map.

Indekskart over Bergen — Jotunheimområdet.

1. *Hovedsakelig gneissbergarter av forskjellig opprinnelse i NW og W («basalgneiss: granitisk og kvartsdioritisk, ennvidere paragneiss»). Strukturene fullstendig eller delvis Kaledonske (SE for Jostedal mangler delvis forskifring).*

Bergen — Jotunbergarter tilhørende de undre Jotuneruptivdekker.

2. *Områder med eklogit: Sunnfjord og Bergensbuene, sparsomt i Sogn.*
3. *Områder med anorthosit (labradorfels) Sunnfjord og Bergensbuene, Sogn og Øst-Jotunheimens forland.*
4. *Mangerit i Sogn og det vestlige område. Hovedsaklig forgneiset. («Jotunit» i Sogn, «Mangerit-syenit» i Sunnfjord.)*
5. *Hovedsaklig sure dypbergarter, ofte forgneisset. Hardangervidda og Hallingskarvet (D 33), Bergsdalens migmatiserte dekker (B 33 vest, C 33 øst).*
6. *Gabbro: B 34 vest og diverse mindre lokaliteter.*
7. *Trondhjemit: D 31 vest, F 30 vest, og diverse dermed forbundne lokaliteter.*
8. *Valdressparagmit med konglomerat, Synorogen kaledonsk flysch.*

Det øvre Jotuneruptivdekkes bergarter.

9. *Dunit, ultrabasit.*
10. *Troctolit, olivingabbro, jotun-norit.*
11. *Leukokrat mangerit, monzonit, hypersthensyenit, granit (forgneisset og mylonitisert i forlandet og i bunnlagene).*

Devonfeltene i NW og underlaget av sedimentær kambrosilur og av prekambrium, vesentlig i SE, er ikke spesifisert på dette indekskart.

The index map fig. 1 is a portion of "Berggrunnskart over Norge" (scale 1 : 1 mill.) by O. Holtedahl and J. Dons (1953), reprinted without colours at half scale. The circles of latitude and the meridians (Oslo = 0) limiting the topographic sheets of Norw. Geogr. Survey are drawn. Along the margin are noted the designations of the quadrangles in letters (vest and øst) and in figures (for lat.). White figures show the locations of the analyzed specimens. Not all the topographic maps marked are available, and so far only few corresponding geological maps at the scale 1 : 100.000 have been published.

In the original map the designation "A" stands for "anorthosite". It is, however, to be pointed out that "A" in fig. 1 stands for the characteristic leucocratic to white "labradorfels" in the older Norwegian terminology. In the Bergen—Jotunheim area this is a metamorphic rock, the original coarse grains being preserved as relics, Commonly containing over 85 % normative plagioclase with An 60—62.* In fig. 1 has the designation A on F 29 vest (analysis no. 4) therefore been removed. The rock on this locality is mainly "anorthositegabbro", chemically almost identical with analysis no. 3 in the vicinity and with many Jotun Norites of the High-Jotunheimen (East of 3° W Oslo) which have plagioclase up to An_{53} and medium-grained eugranitic texture. — These rocks might be termed "anorthosites" in modern sense (the term being inaccurate), but not "labradorfels".

Moreover the author has in an argumentative paper (1957 p. 8—41) reported the pseudo-conglomeratic character of a composite rock layer, which had been interpreted as a true conglomerate and claimed to prove the stratigraphical correspondence of the above "anorthosite-gabbro-complex" and the "labradorfels" of the lower Jotun eruptive nappe.

The presentation on the NE-part of fig. 1 has consequently been altered since the edition of the orignial map of 1953. In accordance with the author's geological survey map (l. c. 1957, fig. 1, p. 15) the extention of the Caledonian flysch, the Valdres Sparagmite on E 30 øst, is now considerably smaller than shown on the map of 1953. Previously unknown and very interesting outcrops of erosional remnants of labradorfels have also been marked "A" on this quadrangle of fig. 1. They underly the Valdres Sparagmite and doubtless belong to the lower eruptive nappe. "A" in fig. 1 is identical with symbol no. 5 hatched and designated "E" on the survey map of 1957, *while symbol*

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* A striking feature of these rocks is absence of P_2O_5 in chemical analyses.

no. 4, hatched and designated "H" on this map ("Mangerite, anorthosite-gabbro in Heidal. Mangerite gneiss in Kvam "F 29 øst, F 30 øst-" and in the Espedalen gneiss complex "F 30 vest-), *is now ranked with the upper Jotun Eruptive Nappe*, as the author's field investigations during the summer of 1957 on F 30 vest confirm the strong indications stated above.

The conclusion that the "anorthosite complex" (socalled by T. Gjelsvik, 1946) of Heidal, belongs to the upper Jotun eruptive nappe is important, because it leads to a satisfactory solution of the High Mountain Problem. It may be added that Gjelsvik (1. c. p. 4—5) pointed out that no real anorthosite occurs in the complex, which mainly contains "anorthosite-gabbro", but also ample acidic and mangeritic rocks. Gjelsvik admitted therefore that a designation "Mangerite Complex" might have been equally right. T. Strand (1951, p. 16) for this reason — and because of the predominating gneissic texture, altered the designation to "Rudihø Crystalline Complex".

In the same paper Strand advocated the theory which he had advanced in 1940 (1. c. p. 272). It involves the interpretation of the complex as an autochtonous basement of the Valdres Sparagmite as well as of the Cambro-ordovician sequence. Accordingly this Jotun eruptive nappe presumably rose and was exposed to denudation in Precambriam, and "had carried on its back" the sedimentary layers, the whole forming "a large and far-travelled nappe" (Strand 1. c. 1951, p. 26) during the Caledonian Orogeny.

The conceptions advanced in the authors paper of 1955, and in a unpublished lecture at the "Nordiske geologiske vintermøte 1956" (Abstract NGT bd. 36, p. 73) were in opposition to Strand's ideas as to the rise and the Caledonian movement of The Jotun eruptive nappes in the Heidal aera. So also was the author's paper, (1957).

The presentation of the variation diagrams in the present paper represents the next step along the path towards a solution of the High Mountain Problem of Norway in light of modern petrological results.

The attention is here particularly drawn to the recent investigations of the Stratified Lopoliths, i. e. the classical work of L. R. Wager and W. A. Deer (1939). T. Barth (1952, p. 196—197) mentions 3 hypotheses for the genesis of the layered structures, but concludes that none of them is satisfactory and writes: "It seems that a promising field of research is here open for exploration." F. J. Turner and J. Verhoogen (1951, p. 235) point out: "Since even not the most enthusiastic devotee of the hypothesis of plutonic emplacement by solid diffusion could doubt the strictly igneous (magmatic) origin of gabbro-peridotite lopoliths, the petrogenesis of such rocks has important broad implications. In them is seen a picture of the kind and degree of lithologic variation that tends to develop within large masses of basic magma under plutonic conditions in a relatively undisturbed tectonic environment."

Turner and Verhoogen (1951) distinguish between bytownite-anorthosite layers in stratified gabbro-lopoliths (i. e. Bushhveld, Stillwater, 1. c. p. 225 f. f.) and "large *independent* intrusions of andesine- and labradorite anorthosites in Precambrian terranes" (l. c. p. 254 f. f.). They take as examples for the latter the Adirondack massif and less extensively the Precambrian area of Southern Norway, referring to the account of T. Barth (1933) stating that the "intrusive body of anorthosite and congenetic rocks—(The Egersund-area in the WSW)—are the youngest" in this Precambrian area. More recent investigations i. e. by P. Michot,* which demonstrated the existence of primary layered and subsequently folded structures of the anorthosite bodies, confirm the comagmatic connection to acid complexes farther to the ENE inferred by C. F. Kolderup and T. Barth. These complexes possibly reach much farther than formerly suggested. The dating of the anorthosite bodies as the youngest, may then refer to their "mis en place", analogous to what here will be demonstrated for the Jotun eruptive nappes.

As to the Adirondack massif Bowen and Balk derive anorthosite and pyroxene-quartz syenite from the same parent magma.

V. M. Goldschmidt (1916, p. 58) pointed out the close petrographic similarity between the rocks of the Egersund-area and the Bergen-Jotun rocks. Based mainly on his classic studies of the latter (1912—1922) he recognized — as other Norwegian petrologists have done— a magmatic anorthosite- mangerite- charnockite-stem.

It is remarkable, that the term "Charnockite", like the term "Anorthosite", today is somewhat inaccurately applied, and thus not only used for rocks of strictly magmatic origin as was originally intended by Sir Thomas Holland, who introduced the term (1900). Moreover is interesting to recall that Sir Thomas in the 1900 paper

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* In *P. Michot:* "Phénomènes géologiques dans la catazone profonde." Geol. Rundschau Bd. 46, 1957 p. 147—173, is found in Chapt. III p. 158—173 descriptions from the Egersund-area ("Rogaland méridional, Norvège") based on Michots studies 1936 — 1956.

(p. 134) emphasized the similitary between his charnockite series and the rocks of the Egersund- area, which he knew from the petrological pioneer work of J. H. L. Vogt and from C. F. Kolderup's reports on the area.

The lower Jotun eruptive nappes.

A comparison of the variation diagram of the upper Jotun eruptive nappe, fig. 3, with those of the lower Jotun eruptive nappes, fig. 2, the latter also containing analyses from the Adirondack massif and the Egersund-area, reveals that the "real anorthosite"—the labradorfels of the lower Jotun eruptive nappes—comes close to similar rocks from distant massifs. By contrast the diagram of the upper Jotun eruptive nappe displays a cognate, but distinctly different trend.

While the "labradorfels"-analyses now available are so abundant that not all of them were used in the diagrams, the analyses of mangeritic and acidic rocks are scanty. This is probably due to the fact that the almost white, seemingly uniform monomineralic labradorfels is not an ordinary rock, and is thus easily recognizeable in the field, while the adjacent acidic rocks in most localities are difficult to determine, having varied mineral-associations and being of gneissic, often mylonitic appearance. Their remarkably higher content of alkali felspars accompanied by an H_2O-content attained by contact with the sedimentary cover during orogenic conditions, is probably responsible for a partially liquid state of these layers at a temperature (say 800° C) at which the "dry" anorthosite layers are almost completely crystalline. During the orogenic movements, squeezing, not only of the anorthosite layers in the sense of Bowen's hypothesis, but also of the acidic layers is highly probable. The behavior of the basic and acidic masses (of high alkali-content) in the temperature interval indicated must be different, the latter, due to their lower melting points, maintaining a much higher internal mobility, and a total mobility as well, facilitated by lubrication by molten alkali silicates along the zone of movement, where gneissification and mylonitization of the rocks are conspicuous.

The author's investigations of corresponding rocks from the upper Jotun eruptive nappe published (1953—55—57) and still going on, verify the conceptions advanced here as to the generation and importance of silicate melts along the zones of movement (thrust-zones).

Table I

Chemical Compositions of rocks of Lower Jotun Eruptive Nappe in Sogn and in the East-Jotunheimen (Variation diagram Fig. 2)

Constituent	I	II	III	III A Calc. $Ab_{36,2}$ $An_{62,4}$	IV	IV B Calc. Or_1 Ab_{37} An_{62}	V	VI	VII	VII B Calc. H_2O free	VIII
SiO_2	51.11	51.8	51.89	52.4	51.54	52.0	52.5	56.40	57.51	58.5	69.64
TiO_2	0.01	0.1	0.25	—	0.19	—	0.1	3.41	1.31	1.3	1.64
Al_2O_3	29.00	25.3	19.50	30.4	24.49	30.4	28.3	14.93	16.69	16.9	12.42
Fe_2O_3	0.67	0.5	1.01	—	2.48	—	0.4	2.46	1.05	1.0	0.55
FeO	0.64	3.6	7.60	—	1.17	—	1.4	4.41	2.10	2.1	2.28
MnO	—	0.07	—		0.03	—	—	—	0.01	—	—
MgO	1.46	4.0	8.25	—	1.09	—	0.6	3.88	5.34	5.4	2.88
CaO	12.73	11.2	8.15	12.9	10.73	13.1	11.9	6.22	6.01	6.1	1.95
Na_2O	3.82	3.1	2.76	4.1	3.51	4.2	4.3	3.71	3.95	4.1	2.25
K_2O	0.31	0.4	0.15	0.2	3.49	0.2	0.4	4.22	4.35	4.4	5.61
P_2O_5	0.00	0.0	0.00		0.08	—	—	0.06	0.23	0.2	0.25
$H_2O\div$	0.21	—	0.48		0.06	—	—	0.05	1.45	—	0.53
H_2O+		—			1.13	—	—	ZrO_2 0.25			
	100.00	100.0	100.04	100.0	99.99	99.9	99.9	100.00	100.00	100.0	100.00

Explanation of Table I.
(Solid, black circles, connected with full lines.)

I. Labradorfels (Anorthosite) Larsfonnfjell (1319 m. a.s.l.) C 32 vest.
Johanne Hødal collect: (1945) descr. p. 166 and volume analysis.
Analyst: Calculated from vol. anal. p. 188 l. c. Σ fem: 8,0.
Plagioclase: An_{63} = Σ sal: 92.0

II. Labradorfels. S-end Espedalsvann, ca. 750 m. a.s.l., F 30 V.
V. M. Goldschmidt collect. 1916 p. 32. Sp. g. 2.828.
Analyst: Olaf Røer, Norsk kemisk Bureau, Oslo (calculated H_2O-free for diagram).

III. Labrador-Norite (very coarse-grained). S of Sulseter (924 m. a.s.l.) N. Fron. F 30 Ø.
Chr. Oftedahl collect., 1944, pp. 193—201.
Analyst: B. Bruun (NGU chem. lab.).
CIPW norm and mode in good accordance. Pyroxene En_{61} Fs_{39} = 33,1
ol + ore 2,5 Σ fem: 35.6
Plagioclase $Or_{1\cdot4}$ $Ab_{36\cdot2}$ $An_{62\cdot4}$ = Σ sal: 64.4
which latter is plotted as IIIa in the diagram.

IV. *Labradorfels-mylonite*, Xenolithe in the Syenite sheet of the upper Jotun eruptive nappe, above Valdressparagmite and below the Jotun norite sheet. — 1350 m. a.s.l. on track 2 kms N of Gjendesheim, E 30 øst.

Author's collect 1954 Sp.g. 2,87.
Analyst NGU chem. lab. No. 980—1957.

CIPW-norm:	Ap 0.2, Il 0.2, Mt 2.5,	sum 2.9	
	Wo	4.6	
	Fo	2.2	Σ fem: 9.7
	Ne	4.2	
	Or 20.5, Ab 24.6, An 40.9	86.0	Σ sal: 90.2
			99.9

(20 % Or, 66 % Or_1, $Ab_{37}An_{62}$)

The determination of the alkalis was repeated by NGU chem. lab., and it is assumed that the labradorfels-mylonite were invaded by alkalisilicates from the embedding syenite sheet. When 20 % Or and 4 % Ne is subtracted, the remaining 60 % plagioclase of composition Or_1 $Ab_{37}An_{62}$ represents the labradorfels-composition noticeable common in the lower Jotun eruptive nappe of Sogn — Jotunheimen, and is plotted as IVB in the diagram.

V. Labradorfels-mylonite, schistose, near no. II (1.5 km SE Solåtjern) F 30 V.
V. M. Goldschmidt collect. 1916, p. 32.
Analyst: Olaf Røer, as no. II (calculated H_2O-free for diagram). Σ sal: 94,5 % Or_3 Ab_{39} An_{58}.

VI. Pyroxene-Mangerite, Tveite (S of Stalheim — NE of Uppheimsvatn, 330 m. a.s.l.) C 32 vest.
Johanne Hødal collect. (1945) Descr. p. 172 and volume analysis.
Analyst: Calculated from vol.anal. p. 186 l. c. Σ fem: 29.0
Σ sal: 71.0

VII. Mangerite ("Quartz-Jotunite") Tveite, (S of Stalheim — NE of Uppheimsvatn, 330 m a.s.l.) C 32 vest.
Johanne Hødal collect. (1945) Descr. and vol.anal. p. 170.
Analyst: Calculated from vol.anal. p. 187 l.c Σ fem: 26.3
Σ sal: 73.7

VIII. Granite ("Charnockite") Haugstøl, E of Uppheimsvatn, 330 m. a.s.l. C 32 vest.
Johanne Hødal collect. (1945) Descr. and vol.anal. p. 178.
Analyst: Calculated from vol.anal. p. 187 l.c. Σ fem: 11.8
Σ sal: 88.2

An independent occurence of the anorthosites (labradorfelses) in relation to their common association of mangerites-charnockites can not be argued for the lower Jotun eruptive nappe in Sogn. Johanne Hødal (1945, p. 129—274 C 32 vest) here verifies the comagmatic origin recognized for the Bergen-Jotun rocks by V. M. Goldschmidt. The puzzling structures of a large (some 20 km²) anorthosite-massif and its boundary, is excellently described by Mrs. Hødal (l. c. p. 142, fig. 4): "The anorthosite, then, lies in a bowl surrounded by intermediate and acid rocks, chiefly mangerites"—The "structures show that the anorthosite must have sunk in relation to the surrounding mangerites". The structural and petrological conditions in and around the massif may readely be explained by presuming an earlier "mis en place" of the (gneissic) mangerites, gliding down the slope into the Jotunheim syncline from a corresponding anticline to the NW. By continuous rising of the anticline the anorthosite nappe eventually followed, maintaining a considerable amount of heat in its large, not completely crystallized masses, capable of melting down and squeezing away the acidic rock masses of much lower melting points.

A discussion of possible generation of frictional heat along the zones of movements in this case, will be postponed until recently collected material from the East Jotunheimen has been studied in detail. Also in the latter the author has observed a reversed layering of a basic and an acidic division of the upper Jotun eruptive nappe.

The two Jotun eruptive nappes in the foreland of the East-Jotunheimen were distinguished in space and time by T. Strand in 1938. As a criterion he pointed out the deposition of the Caledonian flysch, the Valdres Sparagmite, during an interval of profound erosion.

The concept of *two* Jotun eruptive nappes was thus not taken into consideration by V. M. Goldschmidt, who (1916, l. c. p. 24) marked "labradorfels" as well as Jotun norite in a 3-phase diagram illustrating the congenetic origin of all Bergen-Jotun rocks.

As shown on the index map fig. 1 and emphasized above, the real anorthosites (labradorfelses) and the real Jotun Norites (eugranitic types) are restricted to the outcrops of the lower and the upper Jotun eruptive nappe respectively.

While the labradorfelses in Sogn, as demonstrated by J. Hødal (1945), doubtless are accompained in the field by their common association with mangerites-charnockites, the labradorfelses in the East-Jotunheimen, according to the author's investigations, apparently occur independently, resting directly on the sedimentary basement, the broad "thrust zone" being often developed as "greenchists" containing minor remnants of labradorfels (i. e. g. exposed in the Rauskar Water power tunnel F 30 vest). The author explains this fact by presuming that the rising layers of mangerite-charnockite by traversing the thick sedimentary cover to the NW partly were used up in the "granitization", while remaining masses filled up and bridged the Jotunheim syncline. The later advancing labradorfels-division of the lower nappe in the East-Jotunheimen also seems partly "arrested" in the syncline, while surplus, often heavily altered sheets of the labradorfels advanced into the foreland to the SE.

The distance along the direction of the mountain chain, NE—SW, of more than 100 kms between the outcrops of chemically identical labradorfelses of the large massifs in Sogn, and the less extensive occurences in the East Jotunheimen may be interpreted by inferring a connection buried below a cover of Valdres Sparagmite in turn overridden by the upper Jotun eruptive nappe.* The author's discovery of a labradorfels xenolith (Analysis IV, Tab. I) embedded in the syenitic sheet basing the upper Jotun Eruptive nappe at Gjendesheim, and presumably taken from "Klippen" overtopping the flysch, support this interpretation.

Connected to the conceptions deduced above, the author (merely as a preliminary communication) advances a hypothesis as to the generation of the synorogenic Trondhjemites and related rocks (The Opdalite-Trondhjemite-stem of Goldschmidt, 1916, p. 60 f. f.). This is based on the above assumption that intermediate to charnockitic masses from the lower Jotun eruptive nappe accumulated on the bottom of the Jotunheim syncline, and then yielded material for palingenesis of new magmas. Of petrological arguments is here mentioned only the invariable occurrence of often recurrently zoned oligoclase-crystals in the Trondhjemites, which might indicate an intermittent addition of Ca to the magma. This is consistent with the close lateral association of Trondhjemite outcrops with the anorthosite massifs, conspicuous on the maps and emphasized by several authors. The Trondhjemites of Sogn-Jotunheimen were intruded during the orogeny raising the upper Jotun Eruptive nappe. The advanced hypothesis may have a much wider importance in the NW-Caledonides, and may possibly have general application.

In fig. 2 the variation diagram for the *lower Jotun eruptive nappe of Sogn—East-Jotunheimen* is drawn with *full lines;* analyses are found in Tab. I with adjoining explanations.

When trying to combine the latter analyses with analyses from the Bergen Arcs, the author soon verified almost forgotten verbal statements of V. M. Goldschmidt, who recognized the anorthosite-kindred of the Bergen Arcs as " somewhat different" from the anorthosite

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* This interpretation is verified by I. Th. Rosenqvist's recent investigations N.G.T. b.d 37, 1957, p. 413.

Table II

Chemical Compositions of rocks of the bergen Arcs and the Western area
(Variation diagram in Fig. 2 — broken lines)

Constituent	1	2	3	4	5 Calcul. H_2O free	6	7 Calcul. H_2O free	8
SiO_2	46.97	52.80	56.31	57.34	57.4	64.80	66.2	68.69
TiO_2	1.48	0.	0.73	0.40	0.5	0.75	0.2	0.31
Al_2O_3	9.99	28.57	20.35	24.90	19.3	15.74	18.7	17.12
Fe_2O_3	0.97	0.19	2.78	1.10	2.6	1.53	0.8	0.88
FeO	10.54	0.43	3.49	0.94	3.1	2.65	1.0	0.41
MnO	0.00		Sp.	—	0.2	0.00	0.1	—
MgO	11.54	0.27	1.49	0.25	0.3	1.11	1.3	0.39
								BaO
								0.40
CaO	14.46	12.17	3.76	7.99	5.8	2.26	2.3	1.91
Na_2O	3.17	4.82	6.01	5.37	6.2	4.55	9.5	7.03
K_2O	0.28	0.56	4.12	1.23	4.3	5.24	0.2	3.82
P_2O_5	0.20		0.50	sp.	0.4	0.41	0.05	F sp.
$H_2O\div$			—	0.33	—	0.13	—	Glødetap
			—		—		—	0.56
H_2O+						0.67		
S.	0.71	0.24	0.54	0.40	0.03	0.22	0.02	
	100.31	100.05	100.08	100.25	100.1	100.06	100,3	101.52

Explanation of Table II.
(Open circles, connected with broken lines.)

1. Eklogit, Landsvik on Holsenøy, A 33 øst.
   C. F. Kolderup (1903) cit. V. M. Goldschmidt (1916, p. 25).
   Analyst: Lillejord.
2. Labradorfels, thin-schistose, Røsseland on Holsenøy, A 33 øst.
   C. F. Kolderup (1903) cit. V. M. Goldschmidt (1916, p. 32). N.-H. Kolderup (1921, p. 30).
   Analyst: Lillejord.
3. Mangerite-syenite ("Soda-syenite") Tunes, Sørfjord, Bergen area, B 33 vest.
   C. F. Kolderup (1903, p. 114) cit. N.-H. Kolderup (1921, p. 54).
   Analyst: Lillejord.
4. Andesinfels. Fosse. Alværstrømmen N of Bergen, B 33 vest.
   C. F. Kolderup (1903) cit. N.-H. Kolderup (1921, p. 30).
   Analyst: Lillejord.
5. Mangerite-syenite, Atle-øen, Sunnfjord, A 30 øst.
   N.-H. Kolderup, 1921, p. 40.
   Analyst: Alfred Vindenes, Bergens Museum chem. lab.
6. Mangerite-syenite, quartz-bearing. Grane, Atleøen, Sunnfjord, A 30 øst.
   N.-H. Kolderup, 1921, p. 35.
   Analyst: Alfr. Vindenes.

7. Albitfels, Langedalsnipen, Holmedal, Sunnfjord, A 30 øst.
   N.-H. Kolderup, 1921, p. 30.
   Analyst: Alfr. Vindenes.
8. Hypersthene granite, Prestunseter, Osterøy, B 33 vest.
   C. F. Kolderup (1903, p. 118) cit. V. M. Goldschmidt (1916, p. 48).
   Analyst: P. Schei.

series of Sogn. A conspicuous feature seems to be higher contents of Na_2O in the rocks of the Western area, as far as appears from the scanty material.

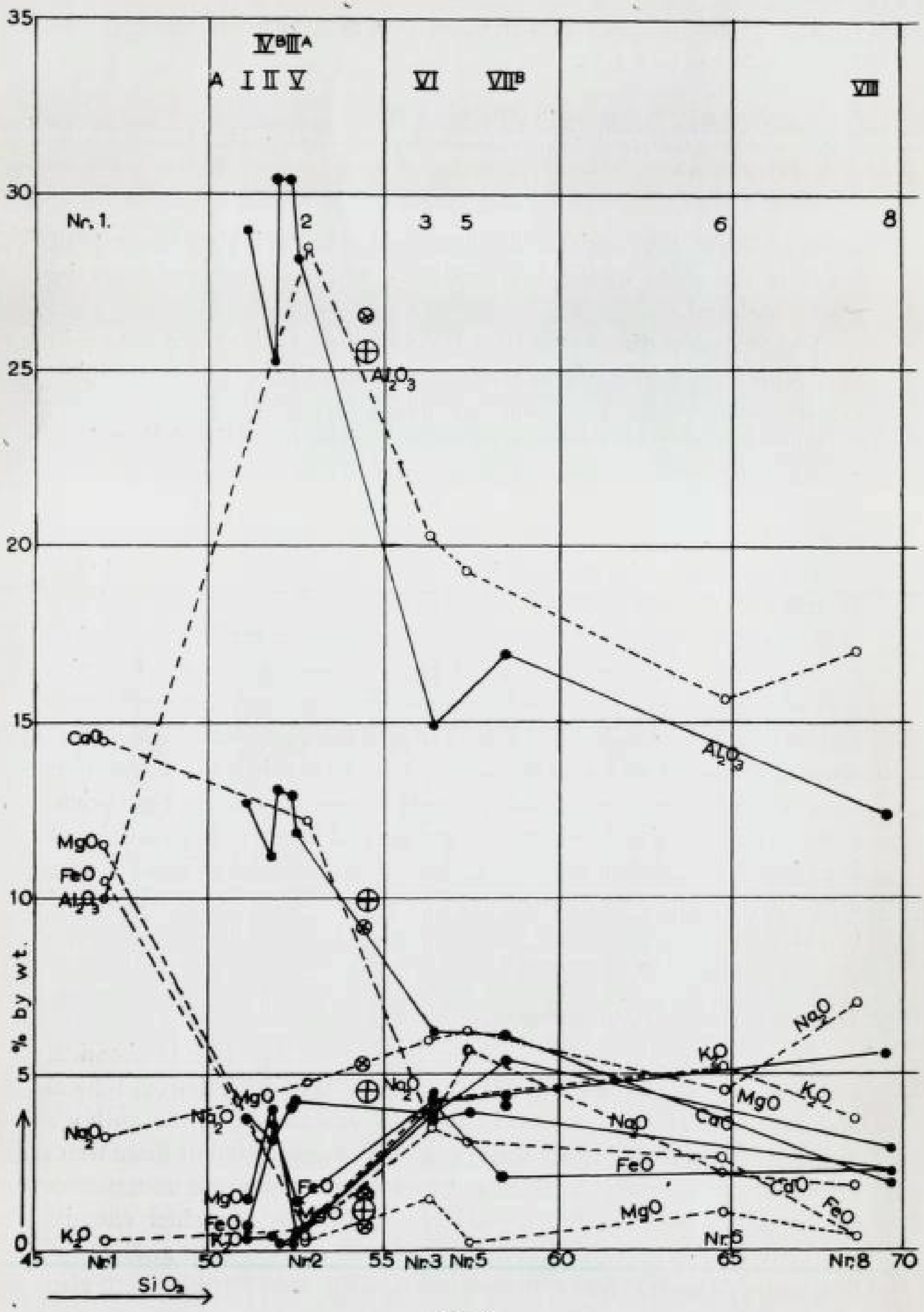
The variation diagram of the *Western area* is therefore drawn in fig. 2 with *broken lines;* the analyses are found in Tab. II with adjoining explanations.

Like the plotted analyses of anorthosites from the Adirondack massif and from the Egersund area in fig. 2, the variation diagram of the Western area is mainly drawn for comparison with the Sogn—Jotunheim rocks.

For this reason the Na_2O-rich analyses, no. 4 and no. 7, are included in table II though not appearing in the diagram. In the author's opinion there might be taken into consideration a possible generation of these albite-rich rocks by some kind of metamorphic differentiation during transportation and remelting from plutonic material. Analogues processes are indicated by the rocks represented by the analyses α, β, γ and δ of Table III below. Moreover it is pointed out, that the granite analysis, No. 8, of Table II is also noticeably Na_2O-rich, and the locality (Prestunseter) is the only one known where a dyke of a Bergen-Jotun-rock intersects schists of the Cambro-Silurian basement (jfr. V. M. Goldschmidt, 1916 p. 48—49, C. F. Kolderup, 1903 p. 117).

The upper Jotun Eruptive Nappe.

The construction of the variation diagrams is based on 14 chemical analyses of rocks, which on stratigraphical, tectonical, petrographical and petrological grounds briefly pointed out above, in the author's opinion belong to the upper Jotun eruptive nappe. Seven of these were, at the author's request, carried out at Norges geologiske undersøkelser kjemiske laboratorium (NGU chem. lab.) by the chief chemist Civil engineer Brynjolf Bruun and his able assistants. Four analyses of fine grained, noritic rocks, displaying neo-volcanic features were also



IV^B III^A
A I II V
VI
VII^B
VIII
Nr. 1.
2
3
5
6
8
35
30
25
20
15
10
5
0
45
50
55
60
65
70
Nr1
Nr2
Nr.3
Nr.5
Nr.6
Nr.8
% by wt.
SiO₂
Al₂O₃
Al₂O₃
CaO
MgO
FeO
Al₂O₃
Na₂O
Na₂O
MgO
Na₂O
MgO
FeO
K₂O
K₂O
FeO
MgO
Na₂O
K₂O
MgO
Na₂O
CaO
FeO
CaO
FeO
MgO
K₂O
Na₂O

Fig. 2

made at the NGU laboratory. They are taken from "sole injections" of the zones of movement, and presumably represent plutonic rocks remelted by frictional heating. The 6 constituents of the analyses taken into consideration in the diagram and plotted against SiO_2 are marked with solid circles for the "sole injections" and with open circles for the other rocks.

6 of the author's 11 analyses here applied have been published recently (l. c. in the explanation below) 5 analyses have not been published before, and in these cases the CIPW norm and some brief remarks have been added in the explanation. In the analysis of No. 2 and of No. 7, moreover, of the "sole injections" α and β, the content of $H_2O + 110°$ exceeds 1 %, and they therefore have been calculated as water free in the diagram. The other specimens on which analyses were performed have maintained the "dry" character of the primary Bergen-Jotun-rocks, the CIPW-norm for the latter being in fairly good accordance with the mode.

The localities of the analysed samples found may be on the index map, fig. 1, by the quadrangle designations (i. e. E 30 øst) and figures, white on dark background and black on light background.

Explanation of fig. 2. Variation diagrams of rocks of the lower Eruptive nappes:

(1) The lower Jotun Eruptive nappe of Sogn and the East Jotunheimen (based on analyses in Table I with adjoining explanation) marked with solid black circles connected by full lines.

(2) The nappe of the Bergen Arcs and the Western area *(*based on analyses in Table II with explanation*)* marked with open circles connected by broken lines.

In fig. 2 is plotted *(*with greek cross in circle*)* average of 4 analyses of anorthosite *(*Marcy type*)* from core of Adirondack massif after Turner and Verhoogen (1951, p. 255). The constituents FeO, MgO and K_2O in this average are near 1 % and represented by one lower circle. Also plotted (with St. Andrew's cross in circle) are the constituents of one analysis from Ånasira, Egersund area, Southern Norway. T. F. W. Barth has kindly permitted the use of this analyses. This is one of the two analyses represented by average in the Table of Turner and Verhoogen (1. c. p. 255).

Variasjonsdiagram for bergarter fra de undre eruptivdekker.

(1) Det undre Jotuneruptivdekke i Sogn og Øst-Jotunheimen (basert på analyser i tab. I med «explanation»), merket med sorte fylte sirkler og helt opptrukne linjer.

(2) Eruptivdekket i Bergensbuene og det vestre område (basert på analyser i Tab. II med «explanation») merket med åpne sirkler og stiplede forbindelseslinjer.

I fig. 2 er dessuten merket med kors i sirkel gjennomsnitt av 4 anortositanalyser fra Adirondack-massivet (FeO, MgO, og K_2O, alle, nær 1 %, er representert ved ett merke). Med kryss i sirkel er merket en analyse fra Egersundfeltet (Ånasira) — (stilt til disposisjon av professor T. Barth).

Table III

Chemical Compositions of rocks of the upper Jotun Eruptive Nappe
(Variation diagram Fig. 3)

Constituent	0	1	2	2 calc. H_2O free	3	4	5	6	7	7 calc. H_2O free
SiO_2	38.08	44.96	46.43	47.0	48.15	49.17	52.76	53.90	54.91	55.9
TiO_2	0.06	0.72	0.98	1.0	0.83	0.83	0.52	0.65	0.43	0.4
Al_2O_3	2.91	10.23	17.11	17.4	18.03	19.08	15.40	17.42	16.73	17.0
Fe_2O_3	1.27	5.18	2.72	2.8	3.77	2.46	4.55	2.89	3.96	4.0
FeO	15.75	8.95	6.65	6.8	7.61	7.20	6.59	5.72	5,13	5.2
MnO	0.20	0.24	0.10	0.1	0.14	0.11	0.14	0.12	0.13	0.1
MgO	40.07	15.07	10.07	10.3	6.34	6.21	6.10	4.92	4.76	4.8
CaO	0.90	12.17	11.70	11.9	10.95	10.76	7.69	8.36	6,78	6.8
Na_2O	0.09	1.35	2.34	2.4	3.17	2.60	3.36	3.83	2.97	3.0
K_2O	0.03	0.17	0.25	0.3	0.36	0.69	2.02	1.86	2.53	2.6
$H_2O\div$	0.07	0.14	0.08	—	0.11	0.26	0.18	0.07	0.15	—
H_2O+	0.30	0.69	1.48	—	0.41		0.28	0.20	1.39	—
P_2O_5	0.16	0.06	0 01	—	0 14	0 38	0 29	0 38	0 18	0 2
	99.89 + 0.30 Cr_2O_3 incl. in Al_2O_3	99.89	99.92	100.0	100.01	99.75	99.88 CO_2 0.38 100.26	100.32	100.05 (+CO_2 0.29 tr. Cr_2O_3	100.0
Sp.g:	3.40	3.18	3.06	< higher	3.04	n.d.	2.88	2.89	2.80	< higher

Explanation of Table III.

0. Dunite,Leirungsdalen, Raudhammer, 1400 m. a.s.l. E 30 øst.
Author's collect. No. 72, 1956. Sp.g. 3.40.
Analyst: NGU chem. lab. No. 1081, 1957.
CIPW norm: Mt 1.2, Ab 0.5, An 4.0, Ol 91.8 ($Fo_{82}Fa_{18}$).
Mode: *Ol* 92 ($Fo_{88}Fa_{12}$) (+ Plagioclase 4 % not visible) 96 % Wt. *Picotite*, black, non-magnetic 4 % determ. with integration-table. Usual content of 8 % Cr_2O_3 corresponds to 0.3 % Cr_2O_3 for the rock as determined by NGU chem. lab.

1. Olivine-gabbro (troctolite) Sikkilsdalshornet, 1544 m. a.s.l. E 30 øst.
Author's collect. No. 204, 1954. Sp. g. 3.18.
Analyst NGU chem. lab. No. 433, 1955.
CIPW norm: Ap 0.16, Il. 1.0, Mt 5.3 sum 6.5
Di: Wo 15.4, + hy 15.4 30.8
Hy (En = 4.3 Fs) 3.0
Ol ($Fo_{80}Fa_{20}$) 24.9 Σ fem: 65.2
Or 1.0, Ab 12.5, An 21.3 Σ sal: 34.8
$Or_3Ab_{36}An_{61}$ 100.00

8	9	10	11	12	13	Const.	α calc. H_2O free	β calc. H_2O free	γ	δ
55.84	58.43	61.93	69.33	72.80	73.22	SiO_2	46.5	51.2	53.66	53.98
0.96	1.00	0.78	0.38	tr.	0.27	TiO_2	3.2	1.4	1.29	0.40
16.93	17.17	17.41	14.34	14.55	13.02	Al_2O_3	16.4	16.0	14.38	19.78
3.08	5.22	1.16	1.56	0.18	1.85	Fe_2O_3	3.5	3.0	2.30	2.93
4.87	3.59	3.74	2.12	1.04	1.21	FeO	10.6	8.5	7.49	4.57
0.15	0.08	0.18	0.08	tr.	0.05	MnO	0.2	0.2	0.13	0.11
3.91	1.29	0.73	0.44	0.47	0.15	MgO	6.1	6.7	8.08	3.94
6.45	2.52	2.14	1.34	0.82	0.67	CaO	9.9	8.6	7.94	7.24
4.35	4.66	5.07	4.01	3.54	3.63	Na_2O	2.6	3.1	3.40	4.84
2.92	5.39	6.16	5.42	5.48	5.64	K_2O	0.7	1.2	0.81	1.20
0.07	0.07	0.08	0.04	0.20	0.02	$H_2O\div$	—	—	0.15	0.19
0.18	0.33	0.37	0.48	0.40	0.32	H_2O+	—	—	0.28	0.13
0.41	0.55	0.32	0.10	0.15	0.01	P_2O_5	0.5	0.2	0.26	0.44
100.12	100.30	100.07	99.64	99.63	100.06		100.2	100.1	100.17	99.75
		0.21	0.17		0.08	BaO				
		0.08	0.06	0.19		Co_2				
		0.02	0.01		0.01	S				
		0.31	99.88	99.82	100.15					
2.84	2.76	2.70	n.d.	2.636	n.d.		n.d.	3.00	2.97	2.69

Mode: Grain size 1—1,5 mm, makes mode determination uncertain.
Tabular plagioclase An_{65}—30 %.
Rhomb.pyroxene 15 %, Monocl.pyroxene 20 %, Olivine 25 %.
Sparsely: Pleonaste + Ore 7 %, Biotite 3 %.

2. Hornblende gneiss, Heidalsmuen 1743 m. a.s.l. F 30 vest.
Author's collect. No. 42, 1945. Sp. g. 3.06.
Analyst: NGU chem. lab. 1954.
CIPW norm: Il 1.4, Mt 2.9 sum 4.3
Di: Wo 8.8 + hy 8.8 17.6
Ol: $(Fo_{80}Fa_{20})$ 19.6 Σ fem: 41.5
Or 1.5, Ab 21.0, An 35.9 Σ sal: 58.4
$(Or_2Ab_{36}An_{62})$ 99.9
Mode: ca. 85 % green hornblende, 12 % plagioclase (oligoclase?) and zoisite. 3 % sphene (titanite).

The metamorphism seems to have been accomplished on the primary rock with normative composition only by excess of H_2O and high stress, presumably at deeper levels before the "mis en place". The neighbouring rocks, represented by analyses no. 3 and no. 4, of similar primary composition have maintained the "dry" character, with parageneses (autometamorphic?) containing garnets, especially abundant in no. 4.

Attention is drawn to the striking similarity between no. 2 and the average of 5 analyses from the Birtavarre District (1 "green beds", 4 amphibolites) recently published by F. M. Vokes (1957, p. 59). The similarity is conspicuous not only as to the normative composition, but also as to the metamorphism. The localities are near 1000 kms apart, but both are connected with the Jotunheim—Lyngen syncline, the most conspicuous of the first order synclines in the Caledonides of Norway according to the interpretation of Thorolf Vogt (1922—1946). The current investigations of the Lyngen sheeted igneous complex may be expected to unveil interesting analogies between this and the upper Jotun Eruptive nappe. A preliminary note by W. A. Elders (1957), also seems to support these prospects.

3. Jotun Norite, Langvasshø, 1350—1400 m a.s.l. E 30 øst.
   Author's collect. no 77, 1953. Sp.g. 3.04.
   Analyst: NGU chem. lab. 1954.

CIPW norm:	Ap 0.3, Il 1.2, Mt 3.9	sum 5.4	
	Di: Wo 8.0 + hy 8.0	16.0	
	Hy (En = 2 Fs)	1.6	
	Ol ($Fo_{67}Fa_{33}$)	12.3	Σ fem: 35.3
	Or 2.0, Ab 28.5, An 34.2		Σ sal: 64.7
	($Or_3Ab_{44}An_{53}$)		100.0

4. Jotun Norite ("Anorthosite gabbro") Rudihø, 1162 m. a.s.l. F 29 vest.
   Tore Gjelsvik collect. Published NGT bd. 26—1947, p. 11 Sp.g. n. d.

	Σ fem: 33.6
$Or_{6\cdot8}\ Ab_{35\cdot3}\ An_{57\cdot8}$ =	Σ sal: 66.4
	100.0

   Analyst: Tore Gjelsvik, Univ. min. Inst., Oslo.

5. Jotun Norite, West-slope Breikvamnåsi 1550 m. a.s.l., NW Tyin, E 30 vest.
   V. M. Goldschmidt collect. 1916, p. 38. Sp.g. 2.878.
   Analyst: Max Dittrich, Heidelberg.

6 Jotun Norite. Tunnel Koldedalen 1180 m. a.s.l., 5 kms NW of No. 5 E 30 vest.
   Author's collect. apr. 1957 Sp.g. 2.89.
   Analyst: NGU chem. lab. 1957.

CIPW norm:	Ap 0.5, Il 0.8, Mt 3.0	sum 4.3	
	Di: Wo 6.2 + hy 6.2	12.4	
	Hy (Mg = 2.2 Fe)	11.6	
	Ol $Fo_{70}Fa_{30}$	1.5	Σ fem 29.8
	Or 11.0, Ab 34.5, An 24.7		Σ sal 70.2
	($Or_{15\cdot6}\ Ab_{49\cdot3}\ An_{35\cdot1}$)		100.0

   Finegrained, stressed, but fresh, unmetamorphic rock. Contain Jotun perthite, transitionel type between "droplets" and "spindle" perthite, not "mesopertite".

7. Mangerite, transitionel to Jotun Norite, W of Bitihorn (1608 m) E 31 øst.
   V. M. Goldschmidt collect. Published 1916, p. 40. Sp. g. 2.804.
   Analyst: Max Dittrich, Heidelberg.

8. Mangerite, transitionel to Jotun norite, Nautgardstind, 2257 m, E 30 øst.
   Author's collect. Published 1955, p. 32 Sp.g. 2.84.
   Analyst: NGU chem. lab. 1954. Σ fem: 25.6
   Σ sal: 74.3

9. Hypersthene syenite. Valdresfly highway, 1040 m. a.s.l. E 30 øst.
   Author's collect. Published 1955, pp. 34—37 Sp.g. 2.76. Dense, having apparently been almost completely remelted.
   Σ fem 12.1, Σ sal 87,9.
   Analyst: NGU chem. lab. 1953.
10. Hypersthene syenite,Suletind (1781 m. a.s.l.) Filefjell D 31 øst.
   Th. Kjerulf collect. (Publ. from locality 1879, p. 207) Sp.g. 2.703.
   V. M. Goldsmchidt published the analysis 1916, p. 43.
   Analyst: O. Røer, Oslo, on request V.M.G. 1916.
   Suletind has Jotun norite in the summit and a sheet of hypersthene-syenite ca. 150 ms thick below 1500 m. a.s.l.
   (K. O. Bjørlykke, 1905 p. 514.)
   CIPW norm: B. Dietrichson 1955, p. 36, where also the mineral calculation by V. M. Goldschmidt is quoted — showing fairly good accordance with the norm.
   Σ fem: 10—11.3. Σ sal: 90—88.7.
11. Granite, Fossanseter ca. 1000 m. a.s.l. Hemsedal E 32 øst.
   C. Bugge collect. Published 1939, p. 62—63.
   Analyst: Klüver chem. lab., Oslo.
12. Biotite Granite, SE-side Synshorn (1453 m. a.s.l.) E 30 øst.
   V. M. Goldschmidt collect. publ. 1916, p. 52. Sp.g. 2.636.
   Analyst: M. Dittrich, Heidelberg, 1912.
13. Granite, Grønsennknipa (1368 m. a.s.l.) E 32 øst.
   C. Bugge collect. Published 1939, p. 62—63.

Analyses of 4 fine-grained or dense norite rocks from "sole injections" at the base of the moving zones of the gabbroic division, highest in the upper Jotun eruptive nappe.

α Diabase-porphyrite, Espedalen, 725 m. a.s.l. F 30 vest.
Authors collect. Publ. 1953, p. 54.
(Photo p. 48 and Photomicrographs. Pl. III fig. 1 and 2 show intact, finegrained high-temperature plagioclase An_{60}. Descr. (p. 52—54) and CIPW-norm Σ fem 40,5 Σ sal 59.5.)
Analyst: NGU chem. lab. B. Bruun 1953.
(Calculated H_2O-free for the diagram.)

β Norite, finegrained. Rindhovda 1150 m. a.s.l. E 29 øst.
W. Werenskiold collect. 1941. Sp.g. 3.00.
Author's publ., 1957 p. 32—33:
(Photomicrograph. CIPW-norm Σ fem 38.8 Σ sal 61.3.)
Analyst: NGU chem. lab. 1955.
(Calculated H_2O free for the diagram.)

γ Spessartite, Nautgardstind 2257 m. a.s.l. E 30 øst.
Author's collect. Publ. 1956, p. 40—41.
(Photo p. 33, photomicrograph p. 39) CIPW-norm Σ fem 42, Σ sal 57.9.
Analyst: NGU chem. lab. 1954.

δ Diabase, Uranos Glacier 1800 m. a.s.l. D 30 øst. (Foot of Mt.-Saga 2041 m.)
Author's collect. 1957. Dense, glassy rock. Sp.g. 2.69.

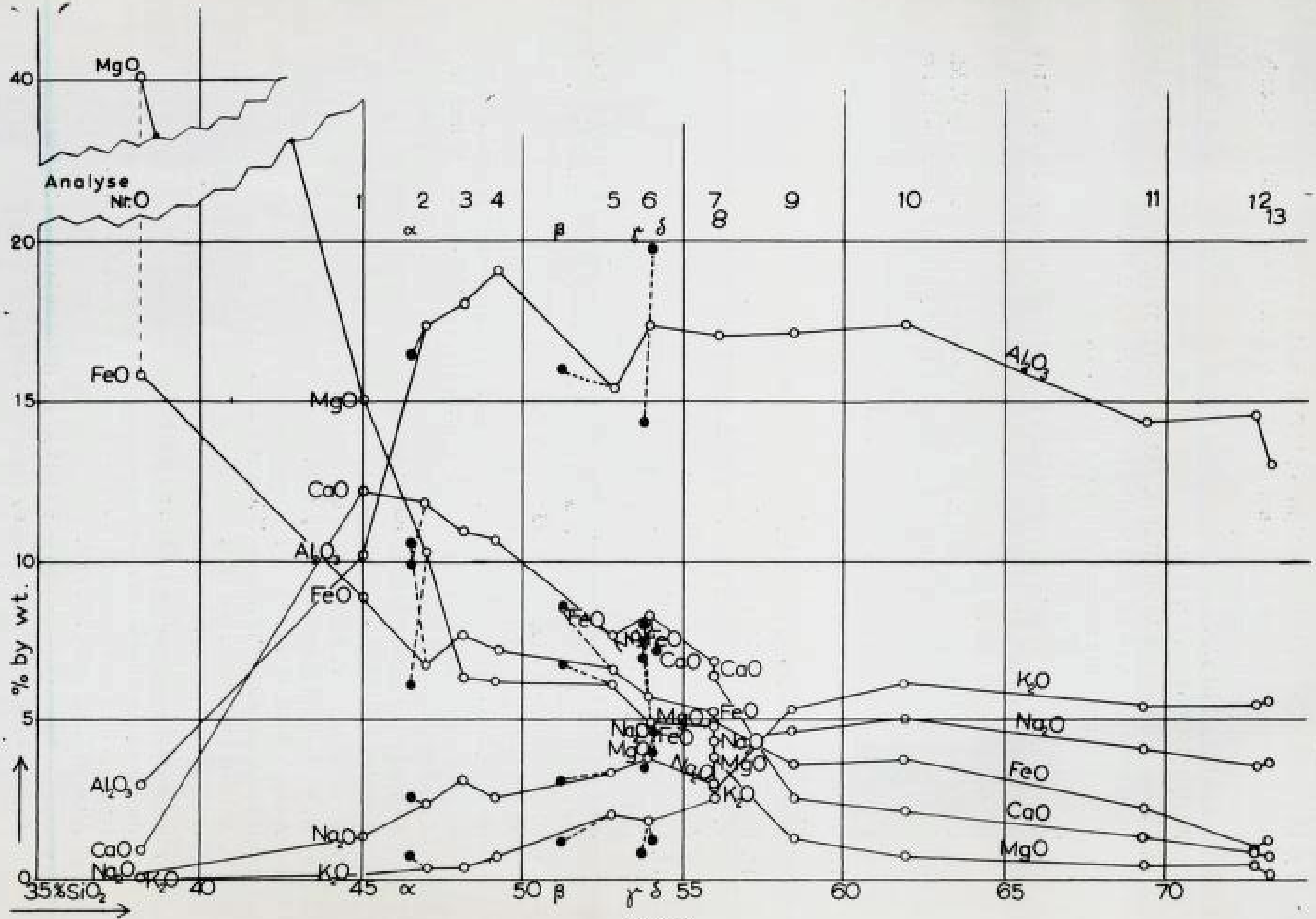

Analyse Nr.O
1 2 3 4 5 6 7 8 9 10 11 12 13
α β γ δ
MgO
FeO
CaO
Al$_2$O$_3$
Na$_2$O
K$_2$O
40
20
15
10
5
0
% by wt.
35%SiO$_2$
40
45
50
55
60
65
70

Fig. 3

CIPW-norm:	Ap 0.8, Il 0.6, Mt 3.0	sum	4.4
	Di: Wo 1.6 + hy 1.6		3.2
	Hy (Mg: Fe = 2)		12.6
	Ol $\mathrm{Fo}_{74}\mathrm{Fa}_{26}$		0.9
		Σ fem	21.1
	Or 7.0, Ab 43.0, An 28.9	Σ sal	78.9
	$(\mathrm{Or}_{8\cdot9}\mathrm{Ab}_{54\cdot8}\mathrm{An}_{36\cdot3})$		100.0

In fig. 4 is reproduced the variation diagram for 66 analyses of Tahitian lavas taken from Turner & Verhoogen (1951, p. 129 after H. Williams). To the right of this diagram are plotted the constituents of analysis no. 10, Table III, hypersthene-syenite from Suletind, the upper Jotun eruptive nappe (jfr. explanation p. 23). This (and adjacent analyses) fit remarkably well at the right hand side of the diagram for the Tahitian lavas.—The explanation obviously is the tendency to converge towards a composition characterized by "the low-temperature through" as shown by Bowen in the phase diagram for the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2. In fig. 5 this phase diagram is reproduced according to fig. 19 (p. 148) and fig. 37 (p. 275) in the textbook of Turner & Verhoogen (1951). Besides Dalys average compositions for granites (1), syenites (2) granodiorites and diorites (3), are plotted in fig. 5 the compositions of no. 9, no. 10, and no. 12 from Table III, falling well inside the border of the low temperature through ABCD. Similar converging tendency on the left, basic parts of the variation diagrams for the Tahitian lavas and the plutonic rocks of the upper Jotun eruptive nappe, are evident for all constituents except for CaO.

Explanation of fig. 3. Variation diagram of the rocks of the upper Jotun Eruptive nappe, High Jontunheimen with foreland (based on analyses in Table III with adjoining explanation). The 6 constituents of the analyses taken into consideration in the diagram, for 14 analyses are plotted with open circles and connected by full lines. 4 analyses are plotted with solid circles, and connected by broken lines to the neighbouring open circle representing the same constituent. The 4 analyses are from "sole injections" presumably remelted from corresponding plutonic rocks.

5 of the author's 11 analyses used in fig. 3, have not been published before.

Variasjonsdiagram for bergarter i det øvre Jotuneruptivdekke, høy-Jotunheimen med forland (basert på analyser i Tab. III med tilhørende «explanation»).

De 6 konstituenter som tas med for opptegning av variasjonsdiagrammet, er for 14 analyser merket med åpne sirkler og forbundet. 4 analyser er merket med sorte, fylte sirkler og tilknyttet diagrammets nærmeste merke for tilsvarende konstituent. De representerer «sole injections», antatte oppsmeltningsbergarter. 5 av forfatterens 11 analyser som er brukt i fig. 3, er ikke publisert tidligere.

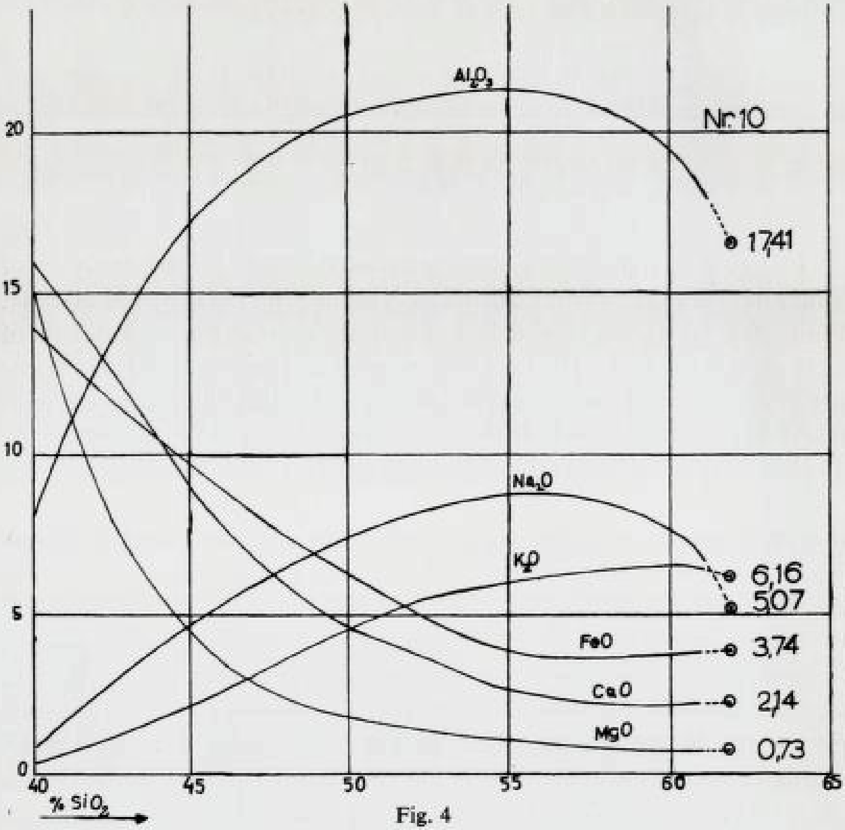


Fig. 4

Explanation of fig. 4. Variation diagram for 66 analyses of Thaitian lavas, reproduced from Turner and Verhoogen (1951, p. 129) after H. Williams.

At the right hand end of the diagram are adjoined the constituents af analysis No. 10 of Table III and fig. 3.

Variasjonsdiagram for 66 analyser av lavaer fra Tahiti. Til høyre i diagrammet er inntegnet verdien for de 6 tilsvarende konstituenter i analyse nr. 10 i tab. III og fig. 3.

While CaO in the lava diagram lies at 16 % plotted against 40 % SiO_2, the corresponding interpolated amount for the plutonic rock series is 5 % CaO (0,9 % CaO against 38.1 % SiO_2).

A still unexplained tendency of labradorfels composition to converge towards Or_1 $Ab_{37}An_{62}$ (with 53, 7 % SiO_2) is remarkable. Among diverse factors regulating the petrological equilibrium may be mentioned the composition and original temperature of the presumable continental-basaltic parent magma, the magma chambers dimensions,

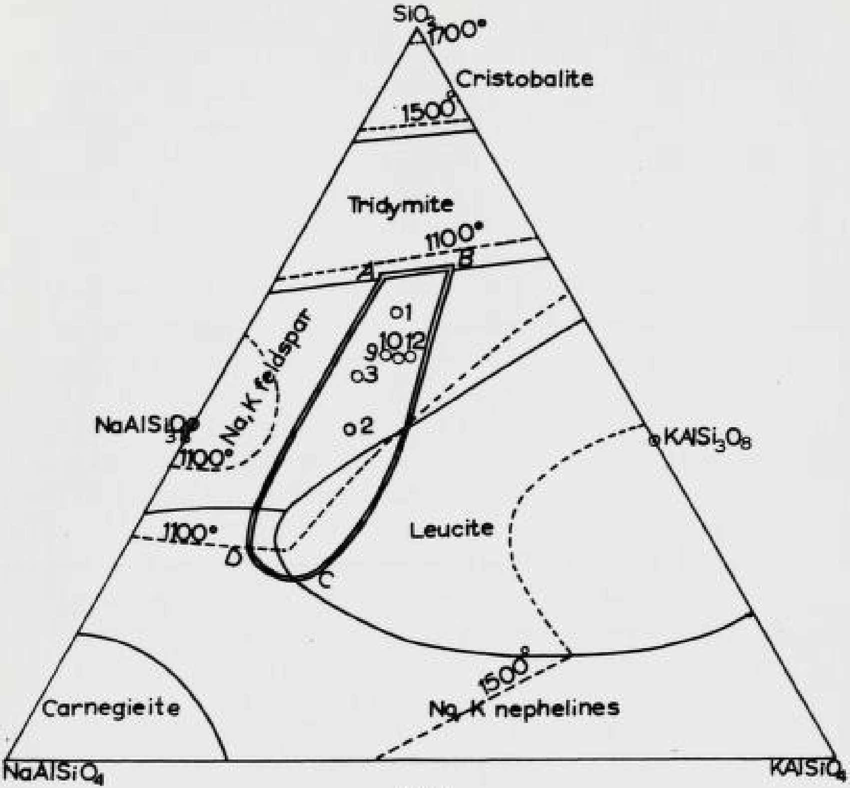


Fig. 5

Explanation of fig. 5. Bowen's phase diagram for the system $NaAlSiO_4$—$KAlSiO_4$ — SiO_2 with Daly's average compositions for (1) granites, (2) syenites, (3) granodiorites and diorites in relation to the low-temperature through ABCD. The corresponding compositions of the analyses No. 9, No. 10 and No. 12 of Table III and fig. 3 are calculated and plotted.

Fig. 5 is drawn after Turner and Verhoogen (1951) fig. 19 (p. 148) and fig. 37 (p. 275).

N. L. Bowens fasediagram for systemet $NaAlSiO_4$ — $KAlSiO_4$ — SiO_2 med inntegnet Daly's gjennomsnitts-sammensetning for (1) granit, 2 (syenit) og 3 granodiorit i forhold til "lavtemperatur trauet" ABCD. De tilsvarende verdier for analyse nr. 9, nr. 10 og nr. 12 i tab. III og fig. 3 er inntegnet.

Fig. 5 er tegnet etter Turner Verhoogen (1951) fig. 19 (p. 148) og fig. 37 (p. 275).

isolation and depths in the Earth-shell; and corresponding heat capacity and rate of cooling, and not least a period of undisturbed conditions sufficient for obtaining an optimal rate of differentiation. Regional evidence shows that most real anorthosites are of younger Precambrian age.

So wrote V. M. Goldschmidt (1916, p. 136):

"Ferner ist es sehr merkwürdig, dass die sicher bekannten Gebiete von Anorthosit-Charnockit-Gesteinen anscheinend stets ein sehr hohes geologisches Alter besitzen (Urgebirge oder Altpaläozoicum). — Man könnte, um einen bildlichen Ausdruck anzuwenden, fast sagen, die Gesteine dieser Art seien frühzeitig ausgestorben." This statement today must be restricted to the series containing real anorthosite (labradorfels).

As to the upper Jotun eruptive nappe it has been pointed out above, that its layers, corresponding to the real anorthosites of the lower Jotun eruptive nappe, are represented by the Jotun norites with plagioclase up to 53% An.[*] These rocks may often display a somewhat leucocratic appearance, though always containing considerable amounts of femic minerals. A characteristic feature never lacking in thin sections of these rocks, regionally repeated in analogues series from all parts of the world, is the rounded seemingly resorbed boundaries of the femic mineral aggregates and the apatite.—A clear impression of "arrested" rock constituents during sinking in "too early" chilled masses is remarkable. A dating of the differentiation of the rock series represented in the upper Jotun eruptive nappe (Tab. III)—possibly to old Paleozoic,—must be regarded as premature. A more exact dating on stratigraphical grounds of the "mis en place" is expected.

In the author's opinion the different series of Jotun Eruptive rocks, represented by the two eruptive nappes, may be regarded as an example which links the real anorthosite occurences to the typical gabbroic lopoliths.

Acknowledgement

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Professor dr. Ivar Oftedal, Mineralogical Institute of the University of Oslo, has—during several years—kindly given the author valuable advices,—now also as to the language, which finally was

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[*] The troctolites (No. 1 and No. 2, Tab. III) of the upper Jotun Eruptive nappe show however 30—50 % plagioclase with An_{60-62}.

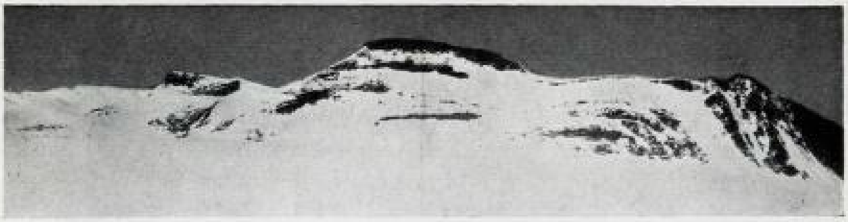

Fig. 6

Explanation of fig. 6. The mountain ridge Saga (the saw) 2041 m. a.s.l., overtopping the Melkedal- and Uranos-Glaciers, the West Jotunheimen (D 30 øst) seen from SSW. Shows layering in Jotun Norite. The analysis 8 (Tab. III, fig. 3) of specimen taken in outcrop at foot of Saga. Falketind (falcon peak) 2067 m. a.s.l. (D 30 øst), 7 kms. SSW of Saga, was — as the first peak in the Jotunheimen — climbed by Chr. Boeck and B. M. Keilhau in 1820, "the explorers of the Jotunheimen". The latter was professor in Geology at the University in Christiania (Oslo) 1834—1858). Author's photo 1957.

Fjellryggen Saga (Sagi) (2041 m o h.) sett fra Uranosbreen mot N. Prøve 8 (D30 øst). Tab. III fig. 3 er tatt i blotning ved foten (ca. 1800 m. o. h.) av Saga. Viser lagdeling i Jotunnorit, fot. forf. april 1957.

carefully corrected by Mr. P. H. Reitan, B. A. formerly of University of Chicago, p. t. at NGU.

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Sammendrag

Variasjonsdiagrammer av Jotuneruptivdekkenes bergartsserier bekrefter deres primært magmatiske lagdeling, fremkommet ved mere og mindre komplett, gravitativ differentiasjon.

De her publiserte diagrammer med tekst er ment som et skritt videre på vei mot løsningen av det norske høyfjellsproblem etter de linjer som indikeres i forfatterens refererte publikasjoner (1953, —55—57), samt i utrykt foredrag på det nordiske geologiske vintermøte i Oslo 1956.

Det gjennom mannsaldre uløste problem besto især i den «omvendte» lagning av eruptivmassene, særlig tydelig i Jotunheimen, men erkjent langs hele den Kaledonske fjellkjede i Norge fra Stavanger til Vestfinnmarken, ved forgneisede, mylonitiserte bunnlag, som tydelig hadde beveget seg fra NW mot SE utover i forlandet på underlag av

kambro-siluriske sedimenter; og høyereliggende eruptivpakker av samme serie med normalkorning eugranitisk tekstur.

Sitater fra vårt århundredes ledende geologer (s. 1) fremhever den vidtrekkende betydning løsningen av det norske høyfjellsproblem kan få for forståelse av fjellkjededannelse i sin alminnelighet med tilhørende eruptiv og vulkansk virksomhet. Disse uttalelser oppfattes som en utfordring til geologisk forskning i Norge, hvor naturforholdene vel ligger bedre til rette enn i noe annet noenlunde lett tilgjengelig land.

Den i videste forstand bevegende kraft ved fordelingen av bergartmassene og deres komponenter såvel i smeltet som i mere eller mindre konsolidert (krystallisert) tilstand, tilskrives den justerende virkning av gravitasjonen på jordskorpens stabilitetsforhold og kretsløp i stort som i smått. N. L. Bowens sats «Gravity never takes a holiday» innebærer således at tyngdekraften utpekes som «Deus ex machina» også i jordklodens periodisk gjentatte overmektige drama, fjellkjedefoldningen. Termen «overskyvning» erstattet den første brukte betegnelse «overskytning»* i overensstemmelse med svensk «överskjutning» anvendt av A. E. Törnebohn under hans banebrytende interpretasjon av de skandinaviske Kaledoniders berggrunn. Den siste betegnelse medførte ikke noen forestilling om at de enorme bergartsflaks laterale forflytning på ca. 100 km var foranlediget av «skyvning» bakfra. En enkel beregning basert på bergarters fasthetskonstanter og friksjon viser umuligheten av en slik antagelse. At hovedmassene har skjøvet unna relativt mindre flak som da ble breksiert er en i den grad iøynefallende sekundærvirkning at forestillingen om skyvning har festnet seg. Man så ikke skogen for bar trær.

Betydningen av et effektivt smøremiddel langs bevegelsessonene for de forflyttede hovedmasser er sterkt fremhevet av nærværende forfatter i overensstemmelse med R. A. Daly's (1925 — 295 ff) prinsipielle betraktning. En rekke nye lokaliteter av glassganger, pseodutachylit (karakterisert som «den mest gåtefulle bergart» av en av Storbritannias ledende, nålevende geologer) konstatertes i Jotuneruptivdekkenes bevegelsessoner. De interpreteres som raskt størknede silikat-masser som var smøremidlet, intrudert i relativt *kolde* breksierte deler av de fremglidende massers underlag. De bevegede masser holdt lenge en så høy temperatur, at de oppsmeltede silikater som dannet smøremidlet fikk tid til å danne finkrystallinske bergarter. Disse ble imidlertid i

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* Se H. Reusch, N.G.U. nr. 47, 1908, s. 17.

stor utstrekning atter oppknust under den fortsatte bevegelse, og ble ofte metamorfosert, særlig ved tilgangen på H_2O fra underlaget som de ble presset mot under veldig trykk fra de overliggende dekkmasser.

Glidning nedover en skrånende flate, selv med liten gradient, kunne holdes igang ved de enorme massers levende kraft og varmekapasitet, inntil den gradvise avkjøling førte til fullstendig størkning.

Den vesentlige forskjell i smeltepunkt og viskositet mellom de basiske (med $SiO_2 < 50\ \%$) og de surere bergarter (SiO_2 55—70 %) godtgjøres å ha spilt en vesentlig rolle for Jotuneruptivdekkenes bevegelse.

Ved deres hevning i en antiklinal av tilsvarende dimensjoner som den komplementære dype Jotunheim-synklinal, gled en avdeling av leukokrate sure lagpakker først ut fra antiklinalen, fylte synklinalen, hvoretter mulig overskytende masser gled utover forlandet. Dette forhold verifiseres ved kartlegningen. Smøremiddel av relativt lettsmeltelige alkalisilikater, må ha spilt en avgjørende rolle for adskillelsen fra underliggende basiske lagpakker som er fattige på alkalier. Under fortsatt hevning gled så de basiske masser ut.*

Forholdet med to-deling påvises for begge Jotuneruptivdekker. Variasjonsdiagrammene demonstrerer den beslektede, men uttalt noe forskjellige grad av differentiasjon mellom de respektive bergartsserier. For det undre dekke er virkelig anorthosit, «labradorfels», karakteristisk, inneholdende 60—62 % anortit (An_{60-62}) i plagioklasen; men ikke P_2O_5, mens den tilsvarende lagpakke i det øvre Jotuneruptivdekke representeres av Jotunnorit med opptil 53 % anortit (An_{53}), og mere av mørke mineraler og apatit, «arrestert» under nedsynkning i massene, som størknet på et relativt tidligere tidspunkt enn for labradorfelsserien.

Av særlig interesse er påvisningen av at den leukokrate, sure avdeling av det undre Jotuneruptivdekke i Øst-Jotunheimen i sin helhet ble tilbakeholdt i Jotunheimsynklinalen, etter først å ha foranlediget utstrakt granitisering av de mektige sedimentpakker NW for denne.

En del av labradorfelspakken ble også igjen. Tilsammen dannet massene bro over den dype synklinal, så overskytende labradorfelsmasser nådde SE-over i Øst-Jotunheimens forland. Den sydvestre del av det undre Jotuneruptivdekke er eksponert for undersøkelse i Sogn

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* På basaltisk underlag, med sammensetning etterhånden modifisert av overliggende gabbroide dekke til s. k. "sole injections", som mange steder har avgrenet større og mindre gabbroide ganger og apofyser i dekkene (f. eks. "doleritter").

på kartblad C 32 vest, Vossestrand, utmerket gjennomført av Johanne Hødal (1945). Av stor generel betydning er at de leukokrate masser i bunnen av synklinalen kan antas å ha gitt materiale for dannelse av Trondhjemitmagma og beslektede eruptiver som kom til intrusjon samtidig med at det øvre Jotuneruptivdekke ble hevet og rykket frem. I et langt mellomliggende tidsrom var da det undre Jotuneruptivdekke redusert ved erosjon og den kaledoniske flysch, Valdresparagmitten, avsatt. Den dannet i stor utstrekning (men ikke overalt) underlaget for det øvre Jotuneruptivdekke.* Nye undersøkelser viser at også Valdresparagmitten var utsatt for erosjon etter fremrykkingen av det øvre Jotuneruptivdekkes leukokrate avdeling, idet rullesteiner fra det sistnevnte er representert i Valdresparagmittens konglomerater.

Fig. 1 er nøkkelkart som viser på hvilke gradteiger de forskjellige analyseprøver er tatt. — De er merket med samme tall og bokstaver som i variasjonsdiagrammene fig. 2 og fig. 3. Til disse er forklaring for hver analyse i Tab. I, II og III.

Fig. 4 er variasjonsdiagram for 66 analyser av Tahiti-lavaer, og gir tydelig indikasjon om at differentiasjon av lavaer og dypbergarter foregår etter de samme lover, rimeligvis i begge tilfelle fra et basaltisk stammagma. — Fig. 5 er et 3-fase-diagram etter N. L. Bowen, som viste at de sure bergarters sammensetning konvergerer mot et begrenset område hvor temperaturen er relativt lav. Disse differentiasjonsprodukter holder seg lenger flytende under avkjøling.

Endelig er i fig. 6 vist feltfotografi fra Vest-Jotunheimen, hvor lagdelingen i det øvre Jotun-eruptivdekke er synlig på lang lei, sannsynligvis fordi lag av forskjellig sammensetning har beveget seg i forhold til hverandre under glidning mot SE.

Fig. 6 er av fjellryggen Saga, som stikker opp av Melkedalsbreen — Uranosbreen (D 30 øst). En av nabotoppene, Falketind, har form som sannsynligvis skyldes oppfoldning av harde motstandsdyktige eruptivlagpakker. Den er kjent som den først bestegne topp i Jotunheimen ved «Jotunheimens opdagere» Chr. Boeck og B. M. Keilhau i 1820. Begge ble senere professorer ved Universitetet i Christiania, Keilhau, «Geologiens rydningsmann i Norge», i geologi (1834—1959). Det er ikke utenkelig at Keilhau fant støtte for sin «transmutasjonsteori» ved å erindre utsikten til de lagdelte krystallinske masser

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* Ivan Th. Rosenquist: «Montmorillonit fra Fortun i Sogn», nettopp utkommet NGT Bd. 37, 1957, verifiserer p. 413 denne oppfatning av fjellbygningen.

som sees fra Falketind, Keilhau fastholdt til sin død denne teori, som forklarte alt hva vi nå kaller eruptivbergarter (også lavaer) som omdannede lagdelte sedimenter.

Som sitert (s. 9) finnes der fremdeles prominente geologer som holder en dør åpen for en lignende (transformistisk) teori til forklaring av lagdelte krystallinske masser i sin alminnelighet. For Jotunheimen og for sammenhengende deler av den norske fjellkjede kan denne oppfatning ikke opprettholdes.

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Abbreviations: NGU.: Norges geologiske undersøkelses skrifter.
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