THE HIGHLY DIFFERENTIATED HOLTEBU GRANITE AND ITS RELATION TO THE HEREFOSS PLUTON

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Annis, M. P.: The highly differentiated Holtebu granite and its relation to the Herefoss pluton. *Norsk Geologisk Tidsskrift,* Vol. 54, pp. 169–176. Oslo 1974.

A small, discordant granite body crops out at Holtebu, just north of the Herefoss pluton. It contains muscovite and garnet, is fine-grained, and has a mean K/Rb ratio of only 74. Intrusion breccia associated with the Holtebu granite cuts the Herefoss pluton, indicating it intruded after the Herefoss pluton had been emplaced.

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The northeastern boundary of the Herefoss pluton has long been a key area for hypotheses bearing on the origin of the Herefoss pluton. Barth (1947) mentioned complex geologic field relations in this area in support of a petroblastic origin of the Herefoss pluton (then known as the Birkeland granite). Elders (1963) concluded that the granite was mobile at the time of emplacement and that fine-grained granites along the northeastern border and elsewhere might be offshoots of the main granite, possibly formed by reaction between later, more mobile portions of the magma and country rock gneisses. Heier & Taylor (1959) and Taylor & Heier (1960) included feldspars from the Herefoss granites in their study of chemical distributions in alkali feldspars from southern Norway. One sample from the northern offshoot showed a very low K/Rb ratio and increased Cs, Pb and Tl contents, indicating to the authors that it might be more differentiated than those from other parts of the Herefoss mass. Dickson & Ball (1965) found systematic chemical variations within the pluton which were difficult to explain solely by means of liquid crystallization processes. They noted that the Herefoss pluton typically has sharp, concordant contacts, but that gradational contacts occur in the northeastern area, and locally elsewhere.

For this investigation of the northeastern boundary area geologic mapping was carried out using 1:15,000 air photographs during field work in 1965 and 1966. Laboratory data were gathered in 1965–1966 at Mineralogisk-geologisk museum, Oslo and in 1972–1973 at Aarhus Universitet.

Rock units

The Holtebu granite is shown as a distinct unit on the geologic map (Fig. 1). A broad zone of intrusion breccia separates it from the Herefoss pluton to the

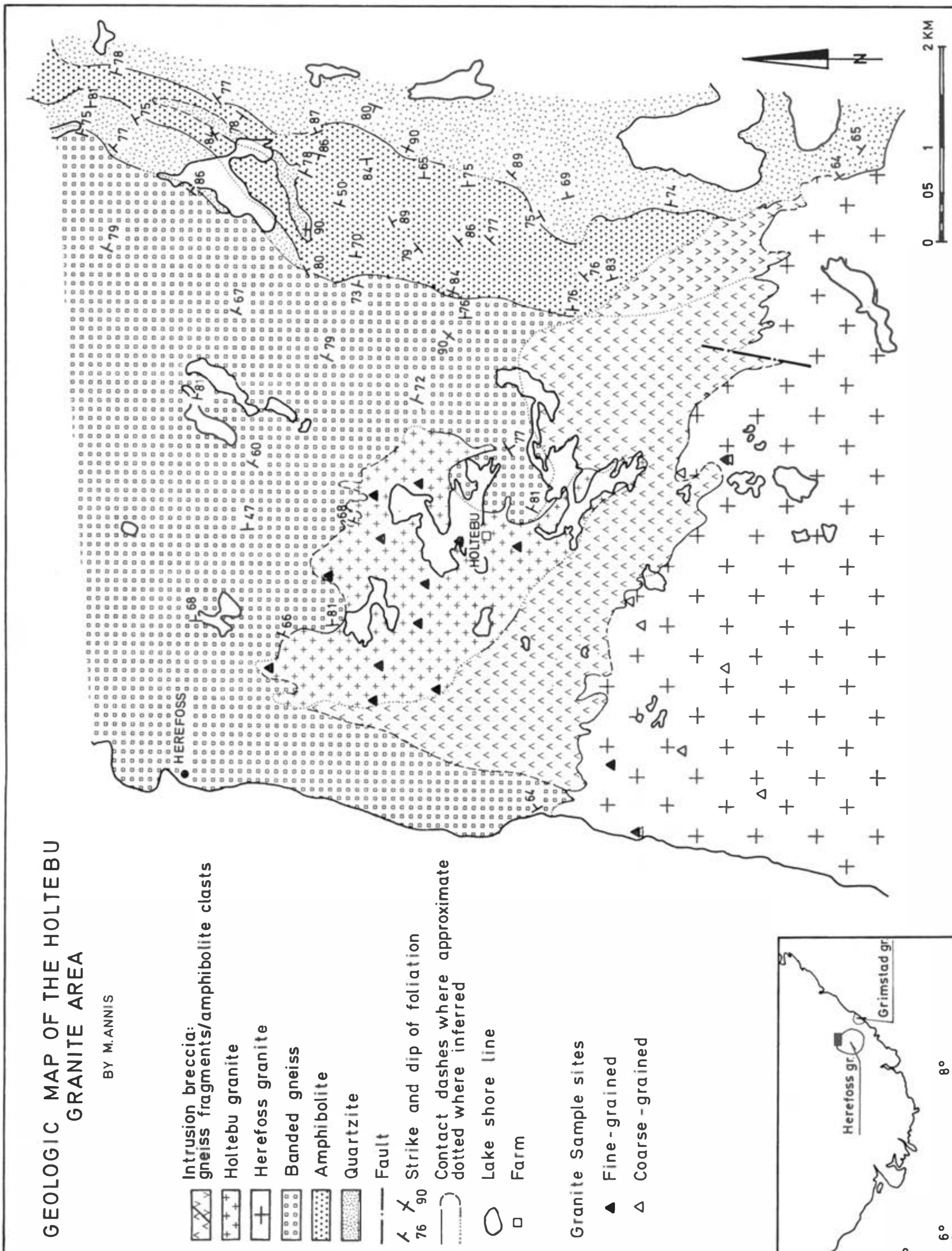

Fig. 1. Geological map of the Holtebu granite area.

south. Amphibolite, quartzite and banded gneiss form the country rocks for both granite bodies.

Country rocks

Banded gneiss, quartzite and amphibolites extend northward from the granitic rocks. Banded gneiss has characteristically alternating light and dark, fine-grained bands, a few mm to 15 cm thick. Dark bands are biotite rich and, less frequently, hornblende rich. Light bands are quartz rich, and generally contain up to 15% biotite. Feldspar is typically subordinate, but occasionally plagioclase is about as abundant as quartz. Biotite and hornblende parallel the banded structure which typically strikes about N2OE and dips 80 SE.

Quite pure quartzite and heterogeneous amphibolites occur east of the banded gneiss. The quartzite contains trace amounts of muscovite which reveal the foliation in outcrop. The amphibolites vary in both lithologic and structural features, with fine- to medium-grained dark green to black schistose varieties being most common. Structurally these units are more complex than the banded gneiss, but the general foliation trend again is about N2OE with near vertical dips.

Herefoss pluton

Only a small portion of the Herefoss pluton is shown in Fig. 1. It is typically a coarse-grained porphyritic granite composed of alkali feldspar megacrysts measuring about $1 \times 1 \times \frac{1}{2}$ cm enclosed in a granular groundmass of quartz, alkali feldspar, plagioclase and biotite. Elders (1963) observed hornblende in addition. Round patches of fine-grained granite from one to several meters across occur locally within the pluton. They have sharp contacts with the enclosing coarse-grained Herefoss granite.

Holtebu granite

This fine-grained homogeneous granite occupies an area of about 5 km^2 near Holtebu. It is typically equigranular, but locally develops a porphyritic texture with the presence of coarser alkali feldspar crystals. Quartz and alkali feldspars are the most abundant minerals and make up the bulk of the rock, together with minor amounts of oligoclase (An_{15}) and less than 5% biotite. Trace amounts of muscovite, garnet (in part interstitial) and opaque minerals are present.

Contact relations of the granite vary according to location. The northern boundary with banded gneiss follows an irregular course. It is generally well defined, even where fragments of gneiss have separated from the wall to form small zones of intrusion breccia. Occasionally the fine-grained granite coarsens and forms pegmatite dikes which cut the banded gneiss. The eastern contact more nearly parallels the strike of country rocks and tends to be well-defined where exposed. To the south the granite is bordered by intrusion breccia.

Intrusion breccia

Banded gneiss and amphibolite fragments up to 30 cm long make up about half of this unit. They are set in a variably textured granitic matrix. Most fragments are angular, have sharp contacts with the granitic matrix, and are disoriented. Banded gneiss fragments frequently remain identical to corresponding banded gneiss country rock and have the same mineralogy and texture in thin section. Others have begun to be assimilated, having quartz rich layers with additional feldspar and gradational contacts against the matrix. In contrast amphibolite fragments generally differ from their country rock counterpart in having poikilitic quartz and plagioclase within hornblende and biotite grains.

The breccia contains predominantly banded gneiss fragments over most of its exposed area but amphibolite fragments are most abundant in southeastern exposures. The resulting internal boundary between these (Fig. 1) suggests banded gneiss and amphibolite continued southwards as far as the Herefoss pluton, and were truncated by it prior to formation of the intrusion breccia.

The intrusion breccia has distinct although poorly exposed contacts in many areas. The contact with country rocks is marked by the presence of variably textured granitic matrix separating fragments of gneiss or amphibolite from continuous country rock. Individual dikes and veins of matrix granite may extend into country rock for a distance. Intrusion breccia is most easily distinguished from Herefoss granites by the presence of gneiss or amphibolite fragments. Well exposed rock surfaces reveal that there is a sharp textural contrast between the Herefoss granites and the highly variable granitic matrix of the breccia. The intrusion breccia cuts across fine-grained patches of Herefoss granite located along the contact. Rarely, a small dike of granitic matrix cuts into the pluton. The contact with fine-grained Holtebu granite is also most easily located by the limit of gneiss fragments. In addition the granitic matrix here grades into fine-grained granite in places and forms a sharp textural contact elsewhere.

These features, together with local development of intrusion breccia along the northern boundary, indicate that the intrusion breccia is associated with Holtebu granite and formed after at least the northern boundary of the Herefoss pluton had crystallized.

Grimstad granite

Also known as the Fevig granite, this coarse-grained post-kinematic pluton occurs about 10 km east of the mapped area. Its similarity with the Herefoss

Table 1. Mean values (m) and standard deviations (sd) of elements analysed and selected ratios.

	Holtebu (1)		Herefoss (1)				Grimstad (2)		USGS-G2		USGS-GSP-1	
			coarse grained		fine grained		normal type					
	m	sd	m	sd	m	sd	m	sd	(3)	(4)	(3)	(4)
n =	12		9		3		17					
K %	4.20	0.22	4.24	0.49	4.24	0.35	4.5	0.5	3.69	3.74	4.71	4.55
Ca %	0.67	0.12	1.34	0.73	1.38	0.78			1.37	1.42	1.40	1.45
Rb ppm	576	52	303	52	277	68	266	52	221	234	344	343
Sr ppm	68	15	319	119	344	138			507	463	248	247
Ba ppm	231	71	1195	196	1345	398			1898	1950	1442	1360
K/Rb	74	7	142	16	161	32	207	46				
Ba/Rb	0.41	0.18	4.13	1.28	5.65	3.26						
Sr/Ca	0.0103	0.0017	0.0260	0.0060	0.0308	0.0131						
K/Ba	194	41	37	9	35	13						

(1) S. Fregerslev analyst.
(2) from Christie et al. (1970)
(3) values for this study, S. Fregerslev analyst.
(4) values from Flanagan (1969).

pluton and their probable common origin have been discussed by Barth (1947), Elders (1963), and Barth & Reitan (1963). However, Heier & Taylor (1959) found quite different chemical distributions in their alkali feldspars. K/Ar age determinations produced 850 and 860–970 m.y. values for Grimstad and Herefoss granite respectively (Neumann 1960). The petrology of the Grimstad granite has recently been studied by Christie et al. (1965, 1970). They concluded it formed by emplacement of granitic melt together with varying degrees of granitization of country rocks.

Chemical data

K, Ca, Rb, Sr and Ba have been analysed (by means of X-ray fluorescence of pressed powders following the method of Leake et al. (1964)) for whole rock samples of Holtebu and nearby Herefoss granite. Sample localities are shown in Fig. 1. Table 1 summarizes the results of these analyses and compares them with K and Rb values reported by Christie et al. (1970) for normal Grimstad granite. Values obtained for analyses of USGS-G2 and USGS-GSP-1 standards in this study are also tabulated and compared with the values given by Flanagan (1969).

The Holtebu granite samples contain considerably more Rb and much less

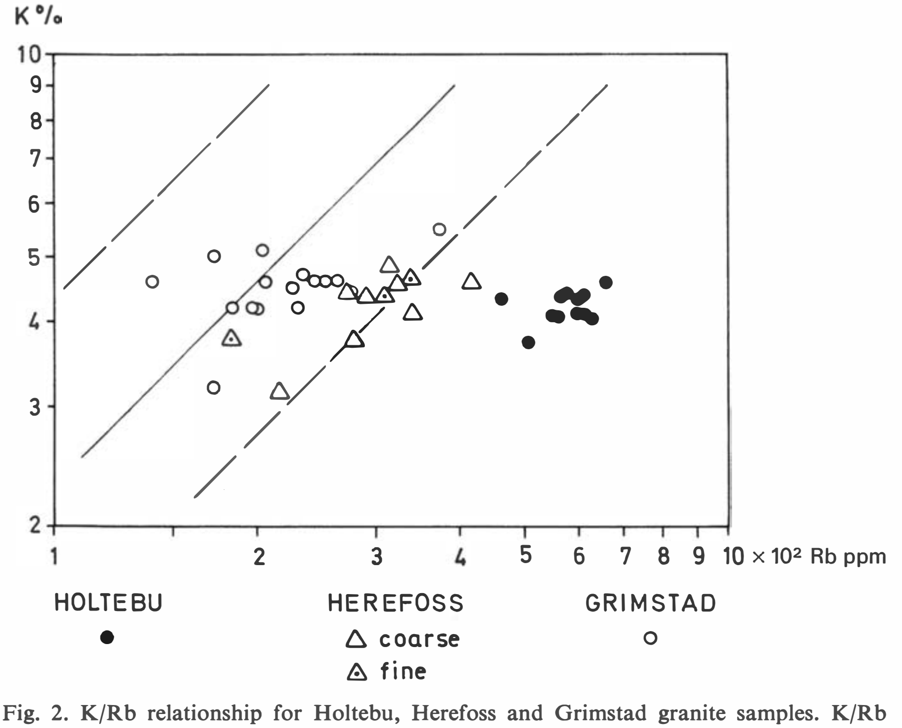

Fig. 2. K/Rb relationship for Holtebu, Herefoss and Grimstad granite samples. K/Rb curve (solid line) with limits of normal scatter (dashed lines) as shown in Heier & Taylor (1959).

Ca, Sr and Ba than the coarse-grained and fine-grained Herefoss samples. K is relatively constant. The comparatively small standard deviations for Holtebu samples reveal again the homogeneous character of this granite. The low Ba and high Rb contents of the Holtebu samples yield a mean Ba/Rb value which is only one tenth that of the coarse-grained Herefoss samples. Likewise the mean Sr/Ca value is distinctly less for Holtebu samples even though both Sr and Ca are less abundant. The mean K/Ba value is greater and the mean K/Rb value is less for Holtebu samples, as expected, and further distinguish Holtebu from Herefoss samples. These relations strongly support the conclusions that the Holtebu granite is distinctly different from the coarse-grained and fine-grained Herefoss granites and that it is more differentiated.

The K/Rb relationship is equally instructive because the mean K/Rb value for the Holtebu samples is extremely low, and because comparable K/Rb values are available for the Grimstad granite. Fig. 2 shows that all the Holtebu values plot outside the K/Rb range of normal granites presented by Heier & Taylor (1959). They compare favorably with K/Rb values reported by Taylor et al. (1956) for St. Austell granites, Mourne granites and Bank's Peninsula rhyolites. In contrast most Herefoss and all normal Grimstad granite values plot within the range of normal granites. On the basis of the low K/Rb values, together with low Ba, Sr and Zr, Taylor et al. (1956) postulated that the St. Austell granites, Mourne granites and Bank's Peninsula rhyolites crystallized from an extremely differentiated magma. Likewise the Holtebu granite is thought to have crystallized from a highly differentiated magma.

Acknowledgements. – Dr. F. W. Dickson introduced me to the geologic problems of this area and has encouraged this study on a number of occasions. In addition this report has benefitted greatly from discussions with Professor T. F. W. Barth and Mrs. B. Nilssen during its early stages, and with Dr. J. R. Wilson at Aarhus Universitet. The study was supported financially in 1965–1966 by the U.S. Fullbright Foundation in Norway.

June 1973

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