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The geology of the northwestern sector of the Fen mining district: A progress report

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Malm/metall	Nb, RE, mt

Sammendrag / innholdsfortegnelse

Summering av kjent geologi, inndeling i 15 litologiske enheter. De 4 viktigste i økonomisk sammenheng: Basic Silicate Rocks med 0,01-0,03%, Søvitt med pyrokloritt og apatitt, Rauhaugitt med 1-3% P og Nb2O5 opptil 0,9 % og Rødbergitt, med opptil 2 % RE (Bastnasitt er bekreftet)
Hydrogangen inneholder minst 3 mill tonn reserver 0,1 - 0,4 % Nb2O5

Rapporten foreslår et borprogram på Hydro sonen, geologisk kartlegging i Tofte-området kombinert med geokjemisk prøving og ytterligere geologisk kartlegging mot syd.
Det bør også forsøkes en korrelering av geofysikk og geologi i dette området og mineralogien i Tuftestollen bør gjennomgås for RE

R. Jensen

THE GEOLOGY OF THE NORTHWESTERN SECTOR OF THE FEN MINING DISTRICT: A PROGRESS REPORT

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S.D. OLMORE
Union Minerals Norge A/S

March, 1981

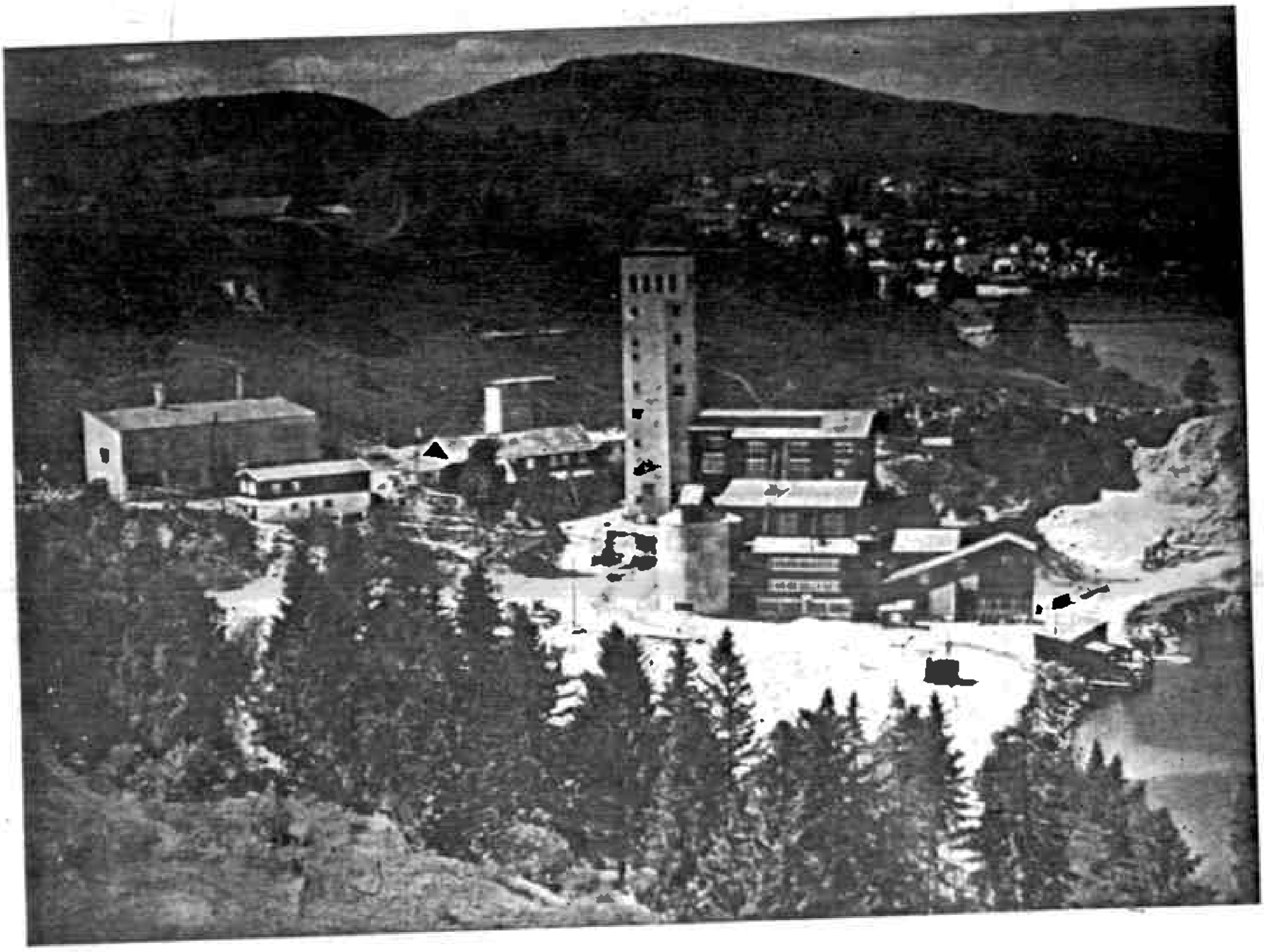

FIGURE 1. 1950'S PHOTO OF NORSK BERGVERK'S MINE FACILITIES WITH HEADFRAME FOR 270M SHAFT. ALSO SHOWN ARE MILLING AND ORE DRESSING PLANTS FOR PROCESSING PYROCHLORE MINERALIZATION.

ABSTRACT

Fifteen lithologic units that range in age from Precambrian to Permian are mapped in the northwest sector of the Fen district. A comagmatic sequence of Basic Silicate and Carbonatite units was emplaced into the Precambrian crust in mid-Cambrian time. The emplacement of these units was guided by a northeast-striking set of extensional fractures contemporaneous with extension in the adjacent Oslo Graben. The Oslo Graben is demonstrated to have a Cambrian ancestry.

The four most important lithologic units for economic evaluation purposes are: Basic Silicate Rocks, Søvite, Rauhaugite and Rødbergite.

Basic Silicate Rocks represent the early immiscible silicate-rich phase separated from a carbonate-rich, alkaline, parent magma. Fenitization of the granitic gneiss is regarded to have taken place largely during emplacement of Basic Silicate magma. Basic Silicate Rocks contain from 0.01 to 0.03 percent vanadium on the average.

Søvite is a magmatic segregation phase that has gradational boundaries with Basic Silicate Rocks. Søvite is enriched with variable segregations of pyrochlore, magnetite, apatite and biotite. The pyrochlore contains uranium and tantalum in addition to niobium (Mariano, 1980). Magmatic segregations of apatite bearing on the average 1 to 2 percent phosphorous are also approximately coincident with the pyrochlore mineralized zones. The zone of mineralization associated with the Hydro dike contains minimum reserves of about 3 million metric tons with an average grade between 0.1 to 0.4 percent Nb_2O_5. A drill program to test this mineralization is recommended in the summer of 1981.

Rauhaugite intrudes Søvite and Basic Silicate Rocks. This carbonate unit appears genetically tied to the Damtjernite Basic Silicate phase. Registered grades of Nb_2O_5 in this unit are as high as 0.9 percent. Phosphorous grades vary from 1 to 3 percent, vanadium geochemical values of about 0.02 percent are common. The Tufte mineralized zone,previously mined for niobium, may contain remaining economic reserves. Additional work is recommended at Tufte with an aim towards a drilling program in 1982.

Rødbergite is an alteration rock which formed from either Søvite, Rauhaugite or Damtjernite. Iron/rare earth mineralization is prevalent in this unit. Total rare earth grades on the order of 2 percent are indicated. Anomalous iron/rare earth mineralization that may be related to Rødbergite development is registered along a 2-meter wide fault zone in the Tuftestollen. Here total rare earth velues of 6 percent are indicated and the presence of Bastnasite is confirmed.

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INTRODUCTION

This report summarizes the present state of the author's knowledge of the geology of the northwest portion of the Fen mining district. The information presented has been collected, beginning in April of 1980, and no attempt at a synthesis of the geologic data available for the entire area has been attempted. The correlation of the results presented with the works of Sæther (1957), and Bjørlykke and Svinndal (1960) must be reserved for the future.

The primary purpose of the report is to help establish a detailed geologic framework of the Fen district, so that economic evaluation can proceed in controlled fashion. Another purpose is to begin to develop a detailed geologic picture of the entire carbonatite complex.

The principal exhibits of the report are the geologic map and cross section (Plates 1 and 2) and a set of geochemical data (Appendix). Emphasis is placed on presenting the more descriptive, megascopic aspects of the deposits, so that a firm data base can be established. Geologic mapping, one-hundred-and-fifteen chemical analyses for twenty elements, and petrographic discussion are presented.

The area of detailed investigation includes slightly in excess of 1km^2 which would easily contain a large porphyry molybdenum deposit (Figure 2), but this is only about one-fifth the area of the entire complex.

The multifaceted Fen carbonatite complex is a large mineralized district that has been prospected and mined for the past 300 years. Iron mining in the Gruveåsen portion of the complex proceeded from 1652 to 1927. Prospecting activity for niobium proceeded in the Søve area during the German occupation of World War II. Norsk Hydro prospected for apatite in the late 1940's and early 1950's, and Norsk Bergverk prospected and mined niobium ores from 1952 to 1965 (Figure 1).

The geographic expression of the Fen carbonatite complex is characterized by the development of fertile soil in a slight topographic depression surrounded by ridges underlain by silicate-rich Precambrian basement rocks. Because of the rich soil, agriculture has flourished, as evidenced by the location of the Søve agricultural college on the Søvite portion of the complex (Figure 3). The balance achieved by the works of man in his environment are of the utmost consideration with regards to the possible resumption of exploration development activities in this mining district.

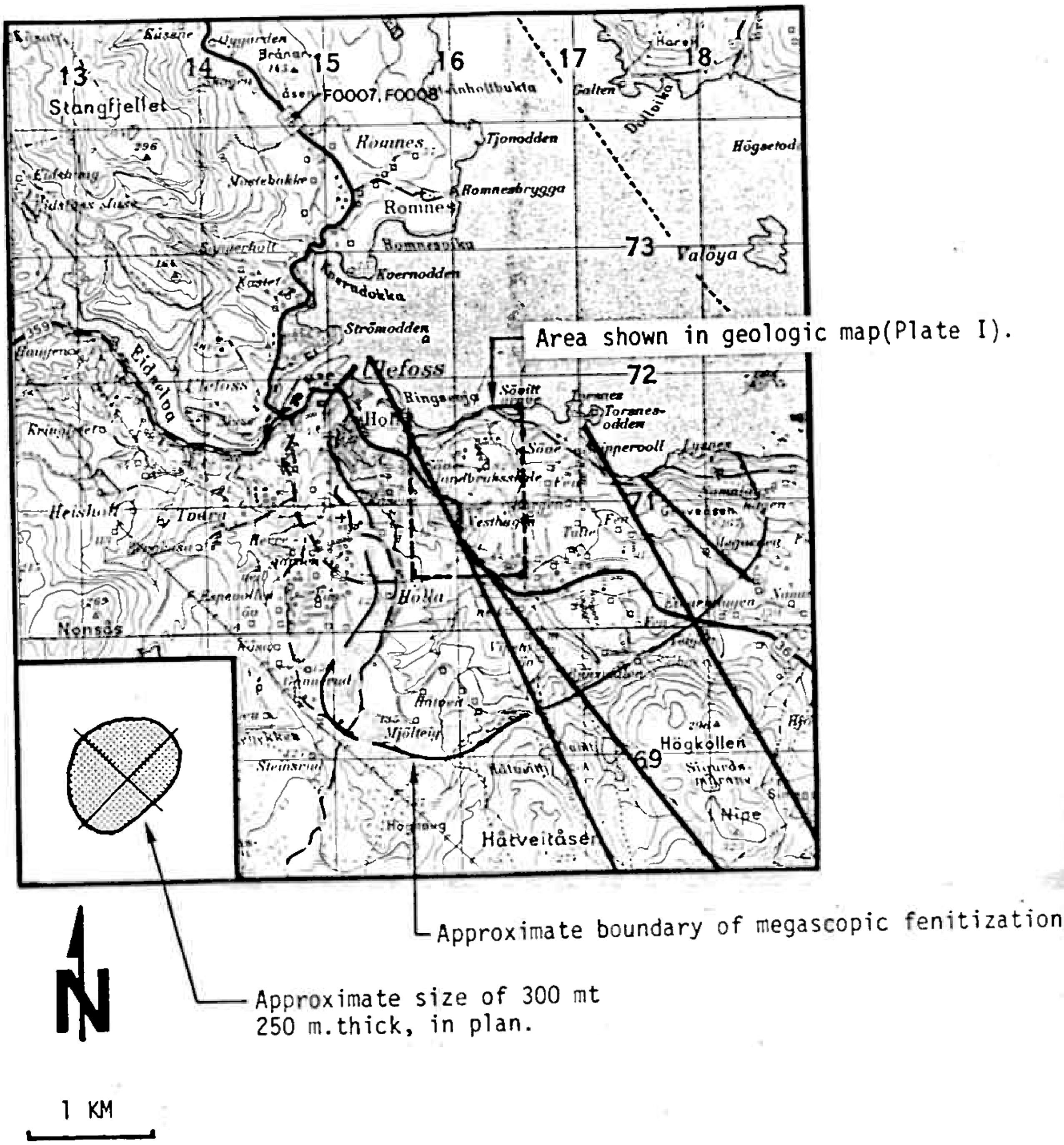


FIGURE 2. INDEX TO DETAILED GEOLOGIC MAPPING OF THIS REPORT. HEAVY LINES DEFINE ZONES OF PRONOUNCED EROSION, PROBABLY ALONG FAULTS. FOR COMPARITIVE PURPOSES, THE SHADED ELLIPTICAL AREA SHOWN AS AN INSET REPRESENTS PLAN SHAPE OF THE HENDERSON PORPHYRY MOLYBDENUM ORE BODY, ABOUT 300 MT. OF MINERALIZED ROCK. THE THICKNESS IS ABOUT 250 M. (AFTER WALLACE AND OTHERS, 1978).

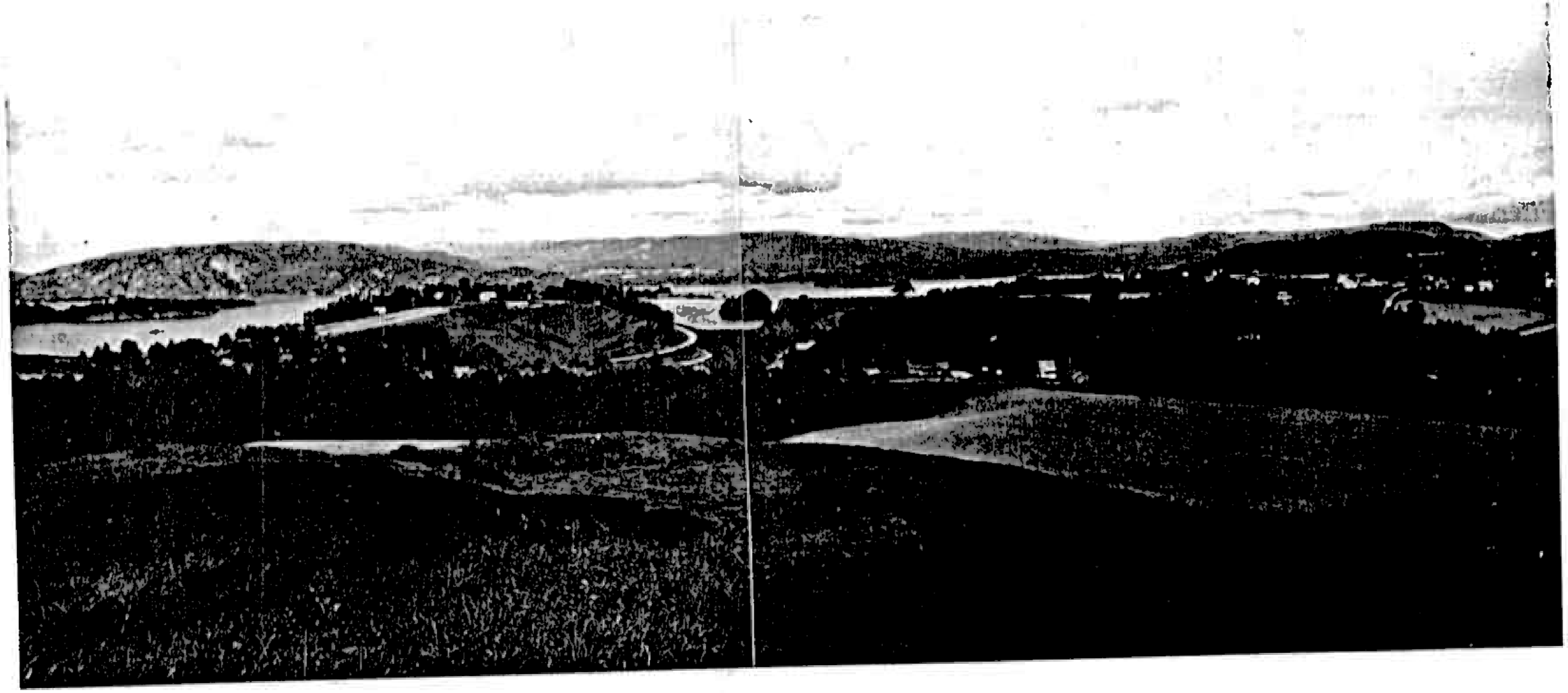


FIGURE 3. A PANORAMIC VIEW SHOWING THE TOPOGRAPHY AND CULTURE DEVELOPED ON THE FEN COMPLEX. PHOTOS WERE TAKEN FROM THE HOLLA CHURCH RUINS LOOKING NORTH-NORTHEAST. LAKE NORSJØ IS IN THE BACKGROUND. THE RED BRICK BUILDINGS ON THE TOP OF THE PROMINENT KNOB AT LEFT CENTER ARE THE ADMINISTRATION BUILDINGS OF THE SØVE LANDBRUKSSKOLE. THE FORESTED RIDGE ON THE FAR RIGHT IS THE GRUVEÅSEN. THE TUFTE AREA COMPRISES MUCH OF THE DENSELY FORESTED AREA IN THE RIGHT-CENTER FOREGROUND. THE FAINT RIDGES AT RIGHT CENTER IN THE BACKGROUND ARE UNDERLAIN BY PALEOZOIC SEDIMENTS OF THE OSLO GRABEN. (PHOTO NUMBERS ARE 0014 - 21 AND 0014 - 22; TAKEN 8. AUGUST 1980.)

REGIONAL GEOLOGY

The regional geology of the Fen district is strongly influenced by its close proximity (about 15kms) to the southwest margin of the Oslo Graben (Figure 4). The alkaline carbonatite system is completely surrounded by Precambrian basement complex between 1100 and 1000 m.y. old of amphibolite grade metamorphism.

Age determinations on the Fen system average about 560 m.y. which places alkaline intrusive development in earliest Cambrian time. Fortuitously, or perhaps not, this is almost precisely the age of the basal conglomerate of the initial sedimentary sequence exposed on the margin of the Oslo Graben, about 15kms to the east (Figure 3).

Whether the basal conglomerate once lay upon the gneissic complex above the Fen is presently a moot point. And because of the apparent lack of marker units, it is difficult to ascertain the depth the carbonatite system formed within the Precambrian basement or how much basement has been stripped off by erosion since Cambrian time. It is possible that the Paleozoic sequence never did lie above the Fen area and that the region was positive since carbonatite emplacement and the beginnings of sedimentation in the Oslo Graben.

Two dominant fracture systems are evident from visual inspection of LANDSAT data supplied by Ramberg and Gabrielson (1978). The dominant system is about N40°W and is sub-parallel to the southwest margin of the Oslo Graben. (This direction is also well defined within the Fen complex as shown in Figure 2.) The averages of strikes comprising the other dominant fracture system appears to be about N55°E and is sub-parallel to the northwest boundary of the Oslo Graben. Ramberg (1973) also makes note of these two prominent fracture directions in the Fen region and regards this pattern as characteristic of alkaline complexes of the Precambrian Baltic Shield.

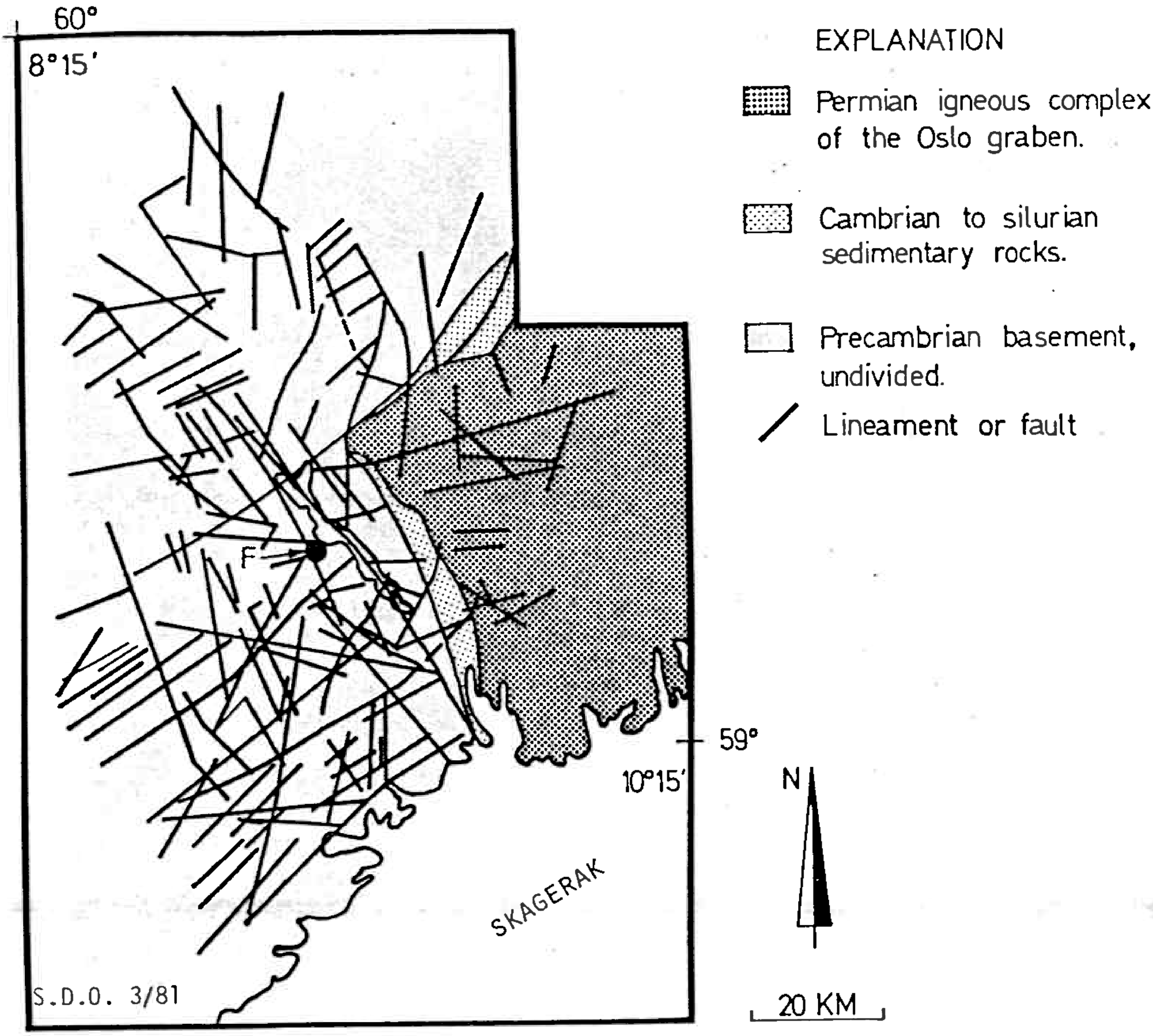


FIGURE 4. TECTONIC INDEX MAP SHOWING THE POSITION OF THE FEN COMPLEX WITH RESPECT TO THE SOUTHWESTERN PORTION OF THE OSLO GRABEN. DATA COMPILED FROM HOLTEDAHL AND DONS (1960), DONS AND JORDE (1978), RAMBERG AND GABRIELSON (1978).

LITHOLOGIC UNITS

Criteria for Definition

Lithologic units are defined here in the broad sense to include all megascopically mappable field units that can be shown on the geologic map (Plate 1). Text discussion follows in the sequence defined by cross-cutting relationships among units. Figure 5 shows the complexity that is typical of most outcrops and gives an indication of the challenges encountered in unravelling the sequence of events presented.

At this point it is appropriate to stress that the present designation of units A through L is a provisional, interim step used as a means of organizing the rock units that have been defined. The present sequence is by no means complete and new units, especially of intrusive origin, undoubtedly will be defined in future investigations. Notwithstanding this uncertainty, it is believed that the main, essential units are intact insofar as classification purposes are concerned, and the point has been reached where economic purposes can be served.

Gneissic Basement-Undifferentiated - Unit A

Definition and Field Relationships

Gneissic basement rocks have not been mapped in the area of the present investigation because rocks fresh enough to be included in this category simply do not crop out. What is presented here is based on casual examination of outcrops lying outside the mapped area.

Gneissic rocks are defined here as megascopically unfenitized granitic gneiss, amphibolite, pegmatite and aplite dikes. Pegmatite and aplite are injected sub-parallel to foliation. The entire sequence has undergone amphibolite grade metamorphism at approximately 1100 to 1000 m.y. during the Sveco-Norwegian orogeny, according to S. Dahlgren.

Petrography

One specimen of apparently fresh granitic gneiss exhibiting well-developed augen structure was sampled, so that the mineralogy and texture of fresh rock could be typified. The specimen (F0007) was collected about 2 kilometers north of the Fen complex along the main highway (see Figure 2). The specimen is medium-grained

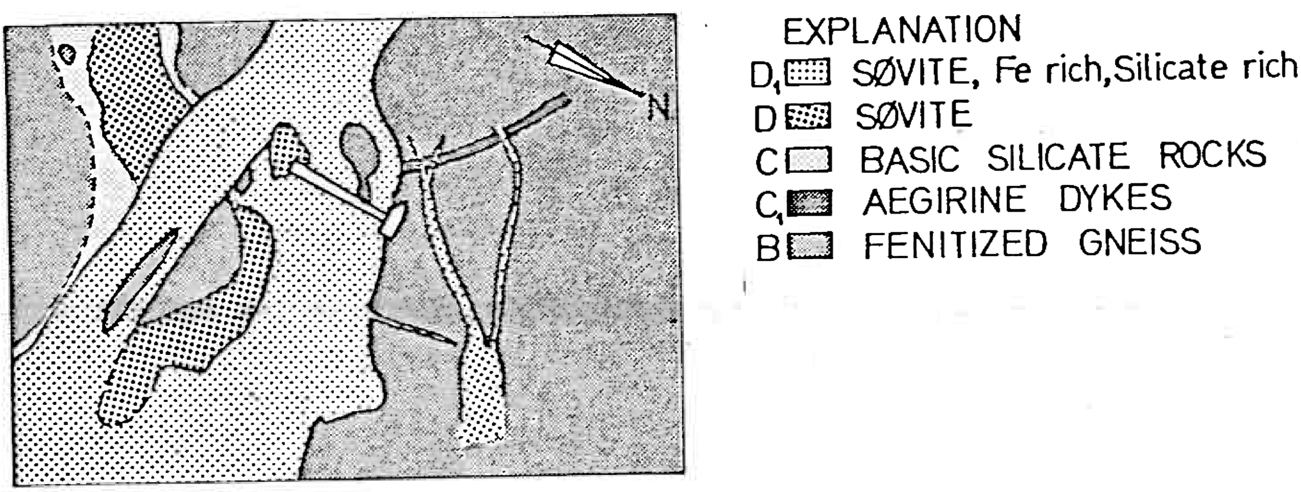


FIGURE 5. EXCELLENT, FLAT, NEARLY HORIZONTAL EXPOSURE ALONG ULEFOSSVEIEN EXHIBITING CROSS-CUTTING RELATIONSHIPS AMONG A FEW LITHOLOGIC UNITS. TWO PHASES OF SØVITE (UNIT D) ARE INDICATED; THE LATER PHASE CONTAINS MORE Fe AND Si . PHOTO NO. 0014 - 27; NEAREST GRID INTERSECTION 142.600 - 50.700. NOTE THAT UNIT D1 HAS NOT BEEN SHOWN ON THE GEOLOGIC MAP (PLATE 1).

gneissic granite; the average grain size is about 0.8mm. Essential minerals are quartz, plagioclase, microline and perthitic K-feldspar. Accessory minerals are apatite and biotite with patchy replacement by chlorite. Calcite is disseminated throughout the rock as very small circa 10 micron sized blebs, as observed under cathodoluminescence (CL). Also by CL it is evident Fe^{+3} activation of plagioclase and K-feldspar has occurred. Even though megascopic and conventional microscopic analyses suggest the rock is fresh and sparsely altered, except for weathering effects, it is clear from CL methods the rock has been fenitized (Mariano 1976).

A geochemical analysis of one specimen of slightly fenitized granitic gneiss is listed in Table 1.

Aplite - Unit A1

Aplite crops out as thin, 2 to 10cm dikes consisting dominantly of very fine-grained alkali feldspar. The dikes are commonly found as injections subparallel to granitic gneiss foliation. Observation of the dikes is best where fenitization of granitic gneiss is not intense (Figure 6). For example, in outcrops along Ulefossveien at its junction with the road to Febakke and just within the Tuftestollen at its portal. Without care it is easy to confuse aplite dikes with later quartz-bearing dolomite dikes associated with the Rauhaugite unit. The absolute age of the aplite is unknown, but assumed to be of the same age as the granitic gneiss.

The mineralogy and texture of one representative specimen (F0003) is typically aplitic. Essential minerals are quartz, K-feldspar, and plagioclase. Calcite specks are present as a secondary introduced mineral. Most of the grains average about 0.1mm in diameter, but there are sparse, scattered phenocrysts of K-feldspar as large as 0.25mm.

One geochemical analysis of a slightly fenitized specimen is presented in Table 1.

Fenitized Precambrian Gneiss - Unit B

Definition and Field Relations

Fenitized Precambrian gneiss is defined megascopically as well foliated to non foliated, aegirine veined, greenish-gray to pink, granite-textured rock. It forms an erosional rim on the northern margin of the complex and the rim can be traced around the complex, except, of course, where the shore of Lake Norsjø is intersected. Fresh fenitized gneiss typically is greenish gray and its weathered equivalent is yellowish brown (Figures 7 and 8).

	F0007	F0003
Fe	1.5	0.28
Si	32.3	29.1
Mg	0.26	0.27
Al	6.5	9.6
P	0.040	0.039
Na	2.8	2.6
Ti	0.13	0.007
K	3.1	9.3
Ca	1.8	0.26
Mn	0.026	0.017
Ba	0.096	0.29
Sr	0.015	0.013
V	<0.005	<0.005
Nb	0.005	0.042
Y	0.006	<0.005
Th	0.005	<0.005
S	0.03	0.04
La	0.01	0.01
Ce	0.01	<0.01
Nd	0.01	<0.01

TABLE 1. GEOCHEMICAL ANALYSIS OF A SPECIMEN OF WEAKLY FENITIZED GRANITIC GNEISS (F0007) AND A WEAKLY FENITIZED APLITE DIKE (F0003).

FIGURE 6. TYPICAL APLITE (UNIT A) DIKE; VIEWED LOOKING EAST AT A WET EXPOSURE ALONG ULEFOSSVEIEN. NOTE THAT FENITIZATION AFFECTS APLITE MUCH LESS THAN THE ADJACENT MODERATELY FENITIZED AND AEGIRINE VEINED GRANITIC GNEISS. PHOTO NO. 0014-28; NEAREST MAIN GRID INTERSECTION IS 142.700 - 50.600.

FIGURE 7. FRESH, FENITIZED PRECAMBRIAN GRANITIC GNEISS (UNIT B). HERE THE UNIT IS SHOWN TRANSECTED BY SØVITE VEINS WITH BASIC SILICATE MARGINS. NOTE THAT COMPOSITE CARBONATE-AEGIRINE VEINLETS DIE AWAY GRADUALLY INTO AEGIRINE VEINLETS. PHOTO NO. 0013-33; NEAREST MAIN GRID INTERSECTION IS 142.500-50.800.

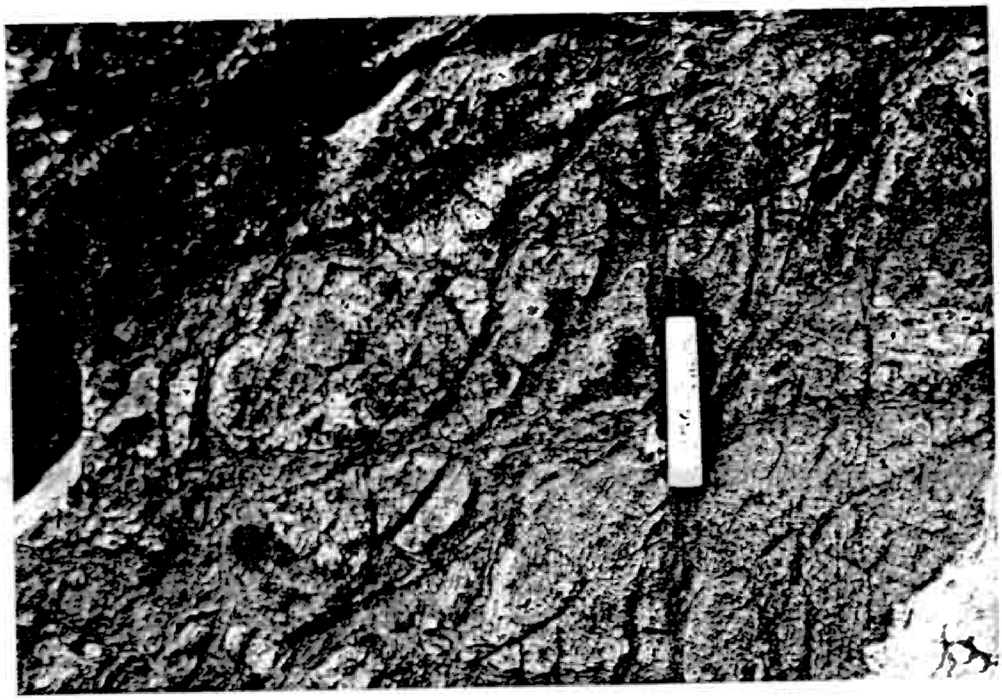


FIGURE 8. TYPICAL OUTCROP OF WEATHERED FENITE TRANSECTED BY SØVITE VEINS WITH BASIC SILICATE MARGINS. PHOTO NO. 0014-24; NEAREST MAIN GRID INTERSECTION 142.600 - 50.700.

The best exposures of the unit are along Ulefossveien near its junction with the road to Febakke and underground 20 - 40 meters from the portal of the Tuftestollen.

The fenitizing process appears to be roughly coincident with the filling of fractures with aegirine and crocidolite. Alteration as a result of fenitization is remarkably minimal.

Petrography

The petrographic aspect of fenitized gneiss is a complex subject of discussion: see for example Sæther (1957). Five fenite types are described here, each having unique textural and mineralogical characteristics. It should be pointed out that none of these types is as yet separated out on the geologic map or defined as a formal unit. They are merely examples of the mineralogic and textural diversity of the unit.

Type 1 is defined as possessing no visible megascopic or conventional microscopic effects of fenitization other than the development of Fe^{+3} ion in the alkali feldspars concomitant with introduction of trace amounts of carbonate. These effects are visible only in CL with criteria for recognition described by Mariano (1976). Practical purposes require that fenitization of this type be included with Unit A - Gneissic Basement, undifferentiated, until regional mapping and accompanying CL petrography is done systematically outside the complex.

Type 2 is defined as exhibiting only slight alteration of the primary meta-igneous texture with the addition of secondary K-feldspar overgrowths on primary grains of perthitic K-feldspar. Primary biotite is replaced by secondary ilmenite, which is locally abundant and is the characteristic feature of this alteration type. This fenite type is well developed north of the Hydro dike along Lake Norsjø.

Type 3 is defined as possessing moderate petrographic indication of fenitization using conventional practices with vestiges of meta-granitic texture remaining (Figure 9). Secondary calcite, aegirine in veinlets and as disseminated grains, and secondary overgrowths on K-feldspar grains are the most obvious indications of fenitic alteration. Under CL the intensity of fenitization is made apparent by the deep-red luminescence of the alkali feldspars. Despite these obvious petrographic changes, there is little megascopic change other than the blurring

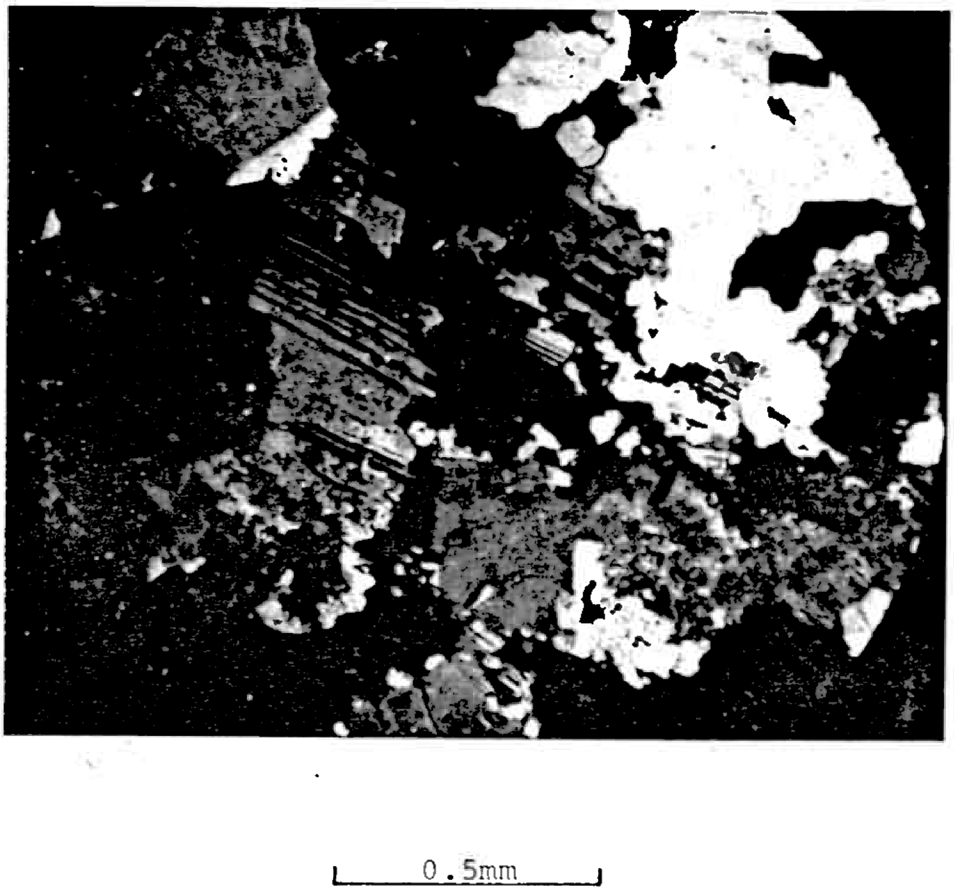


FIGURE 9. PHOTOMICROGRAPH OF TYPE 3 FENITIZATION UNDER CROSSED NICOLS. AEGIRINE IN VEINLETS, AND AS DESSIMINATIONS, IS COMMON. CARBONATE IS ALSO COMMON. THE PRIMARY GRANITIC TEXTURE IS LARGELY UNCHANGED AS EXHITITED ABOVE WITH LARGE PATCHES OF UNDULOSE QUARTZ, PERTHITE, AND PLAGIOCLASE FELDSPAR. SAMPLE F0073, TAKEN FROM PORTAL OF THE TUFTESTOLLEN.

of foliation.

Type 4 is typified by gneiss that has lost its foliation. Primary magmatic perthites have well-developed overgrowths of plagioclase feldspar (albite?) and many grains have a bladed appearance (Figure 10). Traces of primary magmatic minerals are left in the form of microcline and microcline perthite, each possessing blue Ti^{+4}-activated CL (Mariano, 1976). Quartz is absent; primary biotite is absent; aegirine is abundant. The rock is roughly 40 percent recrystallized.

Type 5 fenitization is defined as a metasomatic rock about 70 percent recrystallized, exhibiting almost total replacement of primary K-feldspar with secondary plagioclase. There can be local pervasive development of aegirine with sub-parallel blades 2 - 3mm long and an abundance of secondary veinlets. Secondary plagioclase blebs and blades are also pervasive (Figure 11). There is a total absence of quartz, only a few patches of primary K-feldspar remain. Type 5 fenitization grades to fine-grained alkali-feldspar-flooded gneiss - Unit E, which appears largely to be a mass of secondary albite and carbonate.

Geochemistry

The geochemical data for selected samples of fenitized granitic gneiss are listed in Table 2. Trends in geochemical dispersion patterns for selected elements correspond well with fenitization strength established by petrographic criteria. Silicon content exhibits an inverse correlation with fenitization strength and varies from 32.7 percent in type 3 to 25.2 percent in type 5. Titanium content increases directly with an increase in fenitization strength from 0.17 percent in type 3 to 0.27 percent in type 5. Calcium content increases directly in proportion to an increase in fenitization strength from 3.2 percent in 3 to 4.9 percent in type 5. Total Fe increases with fenitization strength from 2.7 percent in type 3 to 3.6 percent in type 5. Lanthanum, cerium, and neodymium definitely increase from less than 0.01 percent in type 3 to greater than 0.03 percent in type 5.

The reduction in Silica is demonstrated petrographically by reduction in modal quartz in the granitic gneiss. The analyses available indicate little likelihood that economic mineralization will be discovered in the fenite.

0.5mm

FIGURE 10. SECONDARY ALBITE REPLACEMENT OF PERTHITIC, PRIMARY MAGMATIC K-FELDSPAR AND MICROCLINE. (UNDER CROSSED NICOLS.) THIS IS TYPICAL OF TYPE 4 DEVELOPMENT IN GRANITIC GNEISS. SAMPLE NO. F0033.

0.5mm

FIGURE 11. AEGIRINE-PLAGIOCLASE-FLOODED FENITE WITH NEAR COMPLETE RECRYSTALLIZATION AND DEVELOPMENT OF METASOMATIC TEXTURE (UNDER CROSSED NICOLS). SUB-PARALLEL ORIENTATION OF PLAGIOCLASE AND AEGIRINE GRAINS IS COMMON. SAMPLE NO. F0075 TAKEN NEAR PORTAL OF TUFTESTOLLEN.

	F0092	75	74	59	69	62	73
Fe	3.6	3.4	3.1	4.6	2.8	1.9	2.7
Si	25.2	26.2	26.6	27.3	28.6	30.5	32.7
Mg	1.4	1.1	1.8	1.2	1.1	0.32	0.64
Al	6.0	6.3	6.1	6.4	7.4	7.5	6.2
P	0.21	0.28	0.29	0.41	0.35	0.13	0.21
Na	4.1	5.1	4.3	6.0	5.8	3.0	3.5
Ti	0.27	0.37	0.20	0.30	0.12	0.091	0.17
K	2.8	2.3	2.9	2.4	3.5	4.2	3.1
Ca	4.9	6.1	4.5	6.9	1.9	3.1	3.2
Mn	0.19	0.15	0.14	0.20	0.082	0.095	0.16
Ba	0.090	0.083	0.19	0.14	0.099	0.24	0.13
Sr	0.082	0.15	0.091	0.14	0.048	0.067	0.059
V	0.008	0.013	0.009	0.014	0.010	<0.005	0.007
Nb	0.007	0.018	0.044	0.006	0.011	0.021	0.011
Y	0.005	<0.005	<0.005	0.008	<0.005	<0.005	<0.005
Th	0.008	<0.005	<0.005	<0.005	<0.005	<0.005	0.009
S	0.09	0.14	0.18	0.07	0.12	0.05	0.12
La	<0.01	0.01	0.011	0.012	<0.01	<0.01	<0.01
Ce	0.014	0.015	0.023	0.021	<0.01	<0.01	<0.01
Nd	<0.01	<0.01	0.01	0.010	<0.01	<0.01	<0.01

TABLE 2. GEOCHEMISTRY OF SELECTED SAMPLES OF FENITIZED GRANITIC GNEISS. DATA ARRANGED WITH INCREASING SiO_2 FROM LEFT TO RIGHT.

Basic Silicate Rocks - Unit C

Definition and Field Relations

The modifier - basic silicate describes an heterogeneous, dark-gray, dense, massive appearing, medium to coarse grained, rock unit that is rich in dark mica, mainly biotite(?), and calcite. There are a few scattered outcrops in the northern portion of the area mapped between the Hydro and Cappelen open cuts, and there are numerous suboutcrops in the Tuftestollen. At the southernmost portion of the Tuftestollen, Basic Silicate Rocks appear to consist exclusively of coarse-grained, black biotite(?) mica and might best be labeled biotitite, a term used by Boetcher (1966). Basic Silicate Rocks were termed Hollaite by Bergstöl and Svinndal (1960), and by C. Oftedahl in Norsk Bergverk private reports.

Basic Silicate Rocks almost always occur in direct association with Søvite. Mafic borders on Søvite dikes range from a few millimeters (Figure 7) to twenty or thirty meters, for example on the margin of the Hydro dike (Plate 2). The symmetrical mafic borders of the Hydro Søvite dike are especially well defined underground in the Tuftestollen and in numerous drill holes, for example in H-27. Field relationships leave little doubt that the mafic borders on Søvite formed prior to the crystallization of the Søvitic magma. A typical exposure of Basic Silicate Rock is shown in Figure 12, where countless, randomly oriented, calcite veins (Søvite) stand out in sharp contrast to the dark-gray, biotite-rich host rock. A layered or zebra effect is also common where alternating biotite and calcite bands occur. Patches of Basic Silicate Rock also occur as boudins, or streaks in Søvite, where as a result of intrusive force, Søvitic magma has engulfed earlier-formed mafic margins and transported them along with the magma stream.

Basic Silicate Rocks also may be expressed as aegirine dikes and veins Unit C without the Søvite phase. Veritable swarms of aegirine veins have been observed in diamond drill hole H-27; are well exposed at the portal of the Tuftestollen and are exposed in roadcut at the intersection of Ulefossveien and the road to Febakke.

One sample of Basic Silicate Rock (F0129) yielded a potassium-argon radiometric age of plus or minus 21 m.y. Because this sample was collected adjacent the Rauhaugite intrusive mass at the south end of the Tuftestollen, the age obtained may, in reality, reflect heating during emplacement of Rauhaugite rather than the age of the mass itself.

FIGURE 12. UNDERGROUND EXPOSURE OF MICA-RICH BASIC SILICATE ROCK (UNIT C). THE IRREGULAR NETWORK OF WHITE CALCITE SEGREGATIONS AND VEINS OF SØVITE TYPIFY THIS ROCK UNIT. A RECTANGULAR PORTION OF A DIKE OF RAUHAUGITE (UNIT G) IS SHOWN ON THE LEFT. PHOTO NO. 0020-3; NEAREST GRID INTERSECTION IS 142.020 - 51.280.

Petrography

The petrography of Basic Silicate Rocks, an extensive subject, barely is penetrated in this investigation. The mineralogy of these rocks appears quite varied and easily is the most complex of the rock units defined.

One, anomalous, near-fresh sample (F0077) was collected underground immediately adjacent the Hydro dike. Anhedral interlocking grains, perhaps a consequence of eutectic crystallization, vary from 2 - 4mm. Zoned euhedral aegirine augite phenocrysts, averaging about 3mm long, are the most striking mineral phase present. Other essential and accessory minerals identified are melanite, biotite, calcite, albite, sphene, magnetite, pyrite and rutile. Niobium mineralization is known to be present, but the mineral phase bearing it is, as yet, unidentified.

Mica-rich Basic Silicate Rocks are much the ordinary case than the pyroxene melanite bearing variety. Essential biotite, riebeckite, magnetite, apatite, calcite and pyrite are invariably present. Chlorite often partly replaces biotite. Primary aegirine augite is not usually present in the mica-rich variety and this is a result of late magmatic or deuteric replacement by mica. Exceptionally coarse-grained, massive-appearing Basic Silicate Rock with 1 - 3mm books of mica form suboutcrops at the south end of the Tuftestollen. Some of this coarse-grained mica may be "vermiculite" resulting from late hydrothermal alteration adjacent the later emplaced Rauhaugite mass.

The presence of zoned pyroxene phenocrysts leads one to conclude that this rock unit is of undoubted magmatic origin. (Under an earlier interpretation Olmore (1980), it was considered to result from extreme hydrothermal biotitization of fenitized Precambrian granitic gneiss adjacent Søvite intrusions.)

Geochemical Analyses and Discussion

Partial geochemical analyses for five samples of Basic Silicate Rocks are listed in Table 4.

This unit is incredibly depleted in Si and enriched in Ca. Niobium and rare-earth elements are clearly anomalous. Locally niobium values reach sub-economic grades in the Tufte area. Vanadium is anomalous and may be contained in magnetite; phosphorous is anomalous and is in apatite. It is conceivable that vanadium could reach sub-economic grades and this especially could be the case in less differentiated portions of the unit.

	F0071	F0077	F0117	F0129	F0134
Fe	6.0	4.3	10.1	6.6	9.0
Si	14.8	21.5	11.4	11.6	11.9
Mg	5.2	2.7	6.5	5.2	6.0
Al	4.2	6.1	4.2	3.7	3.6
P	1.4	0.65	2.1	1.2	1.9
Na	1.2	3.6	0.53	0.49	1.2
Ti	0.78	0.45	1.4	0.91	1.9
K	2.1	2.1	0.9	<0.5	2.1
Ca	13.1	7.8	12.8	12.8	15.3
Mn	0.20	0.15	0.13	0.21	0.26
Ba	0.43	0.23	0.16	0.19	0.42
Sr	0.20	0.23	0.095	0.18	0.20
V	0.020	0.012	0.020	0.018	0.018
Nb	0.050	0.037	0.018	0.015	0.038
Y	0.006	0.005	0.009	0.005	0.007
Th	0.008	<0.005	0.007	<0.005	0.006
S	0.54	0.56	0.55	0.36	0.29
La	0.016	0.017	0.022	0.015	0.026
Ce	0.030	0.031	0.052	0.035	0.065
Nd	0.018	0.016	0.030	0.020	0.035

TABLE 3. GEOCHEMICAL ANALYSES OF SELECTED SAMPLES OF BASIC SILICATE ROCKS.

Søvite - Unit D

Definition and Field Relations

Søvite, named appropriately after the Søve landbruks-skole, is defined as the earliest emplaced, large-volume intrusive igneous carbonatite phase of the Fen complex. It is typified by variable content of silicate, phosphate and oxide phases; is both pink and light gray; and is medium to coarse grained.

Søvite occurs as gradations with Basic Silicate Rocks and as separate, clean strands and veins within Basic Silicate Rocks. It also occurs as dikes without Basic Silicate Rocks. As evidenced by intrusive relationships, it is comagmatic with the later crystalized phase of Basic Silicate Rock. Inclusions of Basic Silicate Rock are locally common in Søvite as viewed in underground exposures. Basic Silicate Rocks are intricately veined as well as banded with strands of Søvite.

Søvite is transected by several intrusive phases. It is cut by what is believed to be a late Søvite phase (Unit D1) which is presently unmapped and defined only in one outcrop (Figure 7). It is also cut by Fe-rich carbonate veins, and most importantly, Rauhaugite.

The best-exposed outcrops of Søvite are along the walls of the Hydro open cut and in the Cappelen open cuts. There are also a few excellent exposures along Ulefossveien. Continuous exposures are found underground in the Tuftestollen, and undoubtedly the best subsurface exposure was available underground in the Cappelen mine workings prior to their use as a waste-disposal receptacle.

Søvite occurs as numerous dikes transecting fenitized gneiss, and it is usually bounded in these instances by Basic Silicate Margins, as is the case for the Hydro dike. The Hydro dike is continuously traceable using both subsurface and surface information for about 600 meters. A large body of Søvite lies beneath the dike with its lower contact dipping about 80° to the south.

The Hydro dike describes the flared northwestern boundary of a carbonatite complex that has a northeast strike and dips inwards towards its core area to the south. (See also the block diagram of Bjørlykke and Svinndal, 1960).

The megascopic aspects of the Søvite are diverse. It is typically flow-banded (Figures 13 and 14). One type of Søvite varies from white to dark gray, depending on Silicate and oxide content. Another type is pink with patchy, irregular distribution of silicates and oxides. The pink variety (Figure 14) appears to be predominant

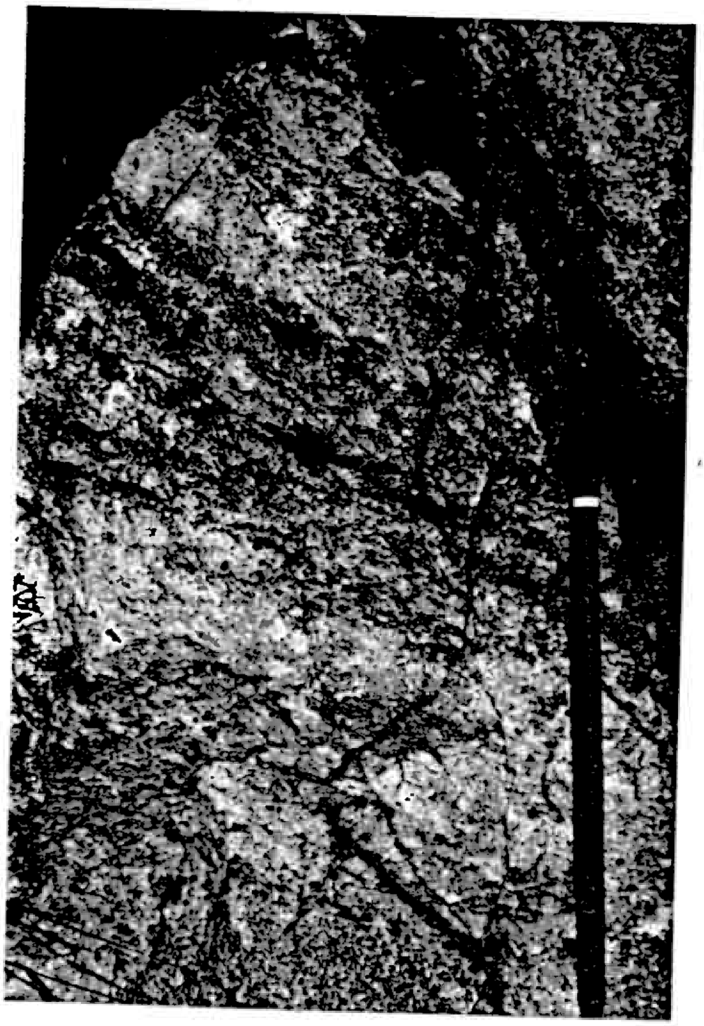


FIGURE 13. SLIGHTLY WEATHERED EXPOSURE OF SØVITE (UNIT D) IN OUTCROP ALONG ULEFOSSVEIEN. LARGE, DARK MINERALS ARE BIOTITE AND MAGNETITE, SMALL DARK SPECKS ARE FINE-GRAINED MICA. DARK MINERALS DEFINE FOLIATION, HERE CUT BY IRON-BEARING VEINS AND VEINLETS. PHOTO NO. 0015.5; NEAREST MAIN GRID INTERSECTION IS 142.400 - 50.900.

FIGURE 14. UNDERGROUND EXPOSURE OF SØVITE, PINK VARIETY, FLOW BANDED WITH NEAR VERTICAL DARK BANDS OF MAGNETITE AND BIOTITE. NOTE SUBTLE IRREGULAR PINK SILICATE-FREE PATCHES. ALSO NOTE LATE CROSS-CUTTING PINK DIKELETS. HORIZONTAL HAMMER HANDLE IN EXTREME LEFT-HAND CORNER OF PHOTO IS FOR SCALE. PHOTO NO. 0020-8; NEAREST MAIN GRID INTERSECTION IS 142.200 - 151.300.

in the southern portion of the Tuftestollen, where it has been invaded, and perhaps discolored, by Rauhaugite. The light-gray variety comprises the border region of the complex in the vicinity of the Cappelen and Hydro open cuts. The deeper plutonic facies of the Søvite is exposed in the Cappelen open cut: here the average grain size is circa 4mm. The hypabyssal facies of the Søvite unit is confined to dikes such as the Hydro where the grain size averages circa 0.5mm.

Megascopic minerals are magnetite, phlogopite, pyrochlore, and apatite. Also present in trace amounts is graphite(?) on the walls of the Hydro open cut, and molybdenite (discovered by T. Sverdrup). The Søvite can contain aegirine, where it grades to the Basic Silicate Rock series.

Petrography

Petrographic examination of Søvite indicates the approximate abundances of the following minerals: calcite - 50 to 70 percent, apatite - 5 to 20 percent, dolomite - 1 to 5 percent, pyrite - 1 percent, pyrochlore - 1 percent, and trace amounts of wollastonite(?). The texture is variable and depends upon the nature of the body sampled: fine grained hypabyssal bodies contain calcite grains averaging about 0.5mm, and averaging about 0.2mm grains of apatite. Phlogopite and magnetite phenocrysts can be as large as 4mm. Pyrochlore grains are nicely zoned (Bjørlykke and Svinndal, 1960) (Mariano, 1980). See Figure 15. Plutonic bodies are coarser grained as in the Cappelen area, and here anhedral calcite grains average 3 - 5mm in largest dimension. Steller aggregates of apatite grains are common. Phlogopite phenocrysts are occasionally euhedral and zoned.

Indications are that the Søvite magma was fairly well enriched in H_2O (as indicated by the early crystallization of OH^--bearing mineral phases such biotite, apatite and pyrochlore) during its early stages of crystallization. Calcite grains crystallized to form an anhedral, equigranular mosaic of interlocking grains. It is interesting to speculate whether the magma boiled incident to the crystallization of the calcite groundmass. If so, alteration zones peripheral to the Søvite mass may be easier to explain.

Geochemistry

It is quite obvious that the Søvite is enriched in niobium and locally contains pyrochlore mineralization of ore-grade proportions. Some of the higher-grade mineralization is from the Cappelen open cut area. It is also evident from the work of Bjørlykke and Svinndal (1960) and Mariano (1980) that uranium, thorium and tantalum occur with niobium in significant

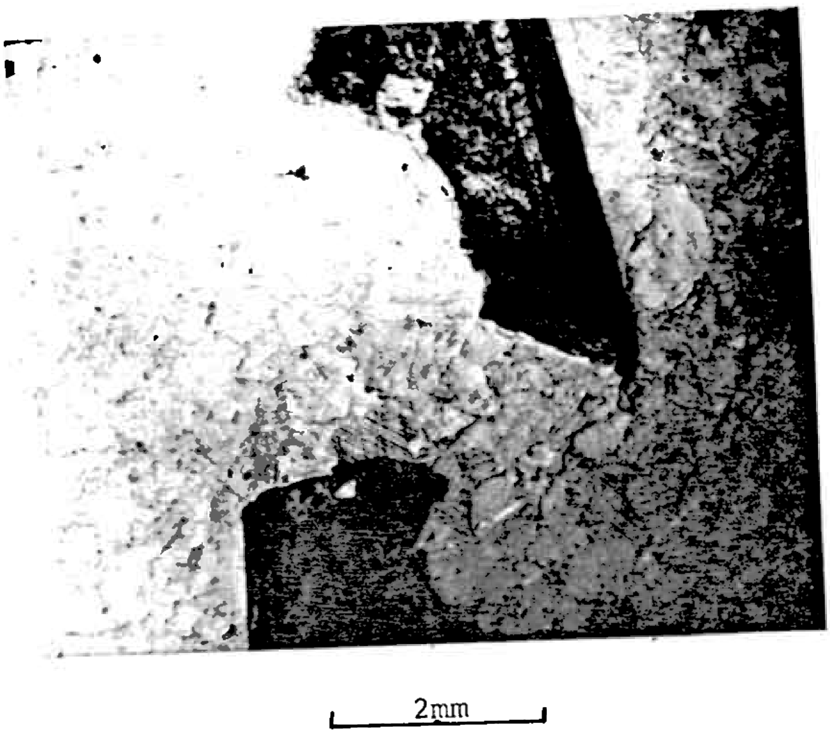


FIGURE 15. PHOTOMICROGRAPH IN PLANE LIGHT SHOWING LARGE, 2 - 4MM ZONED PHENOCRYSTS OF PYROCHLORE IN EQUIGRANULAR GROUNDMASS OF ANHEDRAL CALCITE. SAMPLE IS OF SØVITE FROM HYDRO DIKE (F0070).

quantities in the pyrochlores. Ratios for Nb_2O_5/Ta_2O_5 in Søvite pyrochlores average about 9 according to Mariano's (1980) calculation based on twenty-eight electron microprobe analyses. Ratios for ThO_2/UO_2 were established in the same study at 0.3. Using these ratios an estimate of the contained Nb on U present in the analyzed Søvite samples is made. (See Table 4 accompanying this section.)

Phosphorous is also anomalous in the Søvite: analyses range between about 1 and 2 percent, which require the presence of between 6 to 11 percent apatite, which is confirmed by petrography.

To summarize, Søvite clearly contains subeconomic grades of niobium, with possible byproduct tantalum, uranium, thorium and phosphorous.

Alkali Feldspar Flooded Gneiss - Unit E

Definition and Field Relations

Alkali feldspar-flooded rocks define a typical alteration assemblage developed in rocks largely of gneissic parentage, but the assemblage also is found in Basic Silicate Rocks (Figure 16). Previously fenitized gneiss appears in most localities to have been pervaded by solutions bearing carbonate and alkali feldspar, with patches of fenite left as relicts. Two substantial zones are intersected by the Tuftestollen and one occurs along Ullefossveien. The unit occurs adjacent the edge of the Søvite mass as shown in cross section and is traced out in an approximate N55°E zone.

Pink veins, thought to be comprised largely of K-feldspar and calcite may bear a relationship to the alkali-feldspar-flooding event, but for the present are classified as Unit G_1 on the geologic map.

In the final analysis the feldspar-flooded rock (Unit E) may be categorized as the latest stage of the early event of fenitization.

Petrography

Petrographically this unit is mixed. Essential minerals are albite, microcline, aegirine and K-feldspar. These have been introduced as secondary alteration assemblage minerals, having an average grain size between approximately 0.3 to 0.5mm. The microcline is perthitic. Relict quartz grains with undulose extinction as large as 3mm are unevenly distributed. The fine grain size of the unit along with the abundance of secondary microcline perthite

	F0012	17	20	32	34A	34B	36	52	53	67	70	72	78	79	80	82	84	107	123	138
Fe	1.5	1.7	0.14	3.6	2.5	8.2	3.4	3.4	3.7	1.3	1.1	2.1	0.89	1.5	1.9	1.0	1.0	3.5	1.5	1.3
Si	2.1	2.6	1.3	3.7	3.0	3.2	1.4	1.1	4.2	3.0	1.3	3.7	1.6	3.3	1.7	3.5	3.1	1.5	1.3	0.7
Mg	10.1	2.6	0.16	2.4	1.2	1.5	1.1	1.4	3.1	3.1	1.7	2.1	1.2	2.4	1.9	0.80	2.3	1.8	1.2	1.2
Al	0.15	0.29	8.2	0.58	0.46	0.23	0.15	0.15	0.99	0.78	0.22	0.28	0.18	0.77	0.20	0.28	0.37	0.24	0.38	0.20
P	1.2	2.9	0.033	1.5	2.2	1.6	0.97	1.7	1.3	0.85	0.43	1.9	0.34	1.3	1.3	1.1	1.1	3.7	2.1	1.0
Na	0.42	0.30	0.8	0.21	0.26	0.27	0.12	0.22	0.31	0.29	0.30	1.0	0.32	0.53	0.31	1.1	0.89	0.21	0.23	0.20
Ti	0.030	0.047	2.3	0.091	0.077	0.31	0.078	0.099	0.30	0.054	0.005	0.024	0.018	0.015	0.015	0.020	0.019	0.62	0.039	0.034
K	0.1	0.32	0.1	0.56	0.33	0.12	0.010	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ca	21.8	32.0	1.2	31.2	35.1	30.8	33.6	33.8	28.9	31.9	34.8	36.6	35.7	32.6	35.9	40.7	35.8	34.1	34.0	37.1
Mn	0.43	0.23	0.07	0.24	0.16	0.22	0.18	0.13	0.19	0.27	0.32	0.31	0.28	0.22	0.26	0.23	0.27	0.20	0.13	0.19
Ba	0.79	0.068	1.2	0.32	0.11	0.27	0.047	0.054	0.099	0.098	0.073	0.22	0.087	0.084	0.11	0.28	0.17	0.083	0.062	0.076
Sr	0.32	0.56	0.022	0.43	0.53	0.51	0.53	0.38	0.38	0.56	0.61	0.49	0.70	0.56	0.59	0.43	0.62	0.25	0.33	0.42
V	<0.005	<0.005	0.020	0.016	0.007	0.057	0.020	0.008	0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nb	0.80	0.38	1.5	0.20	0.51	0.45	0.39	0.009	0.016	0.20	0.028	0.19	0.24	0.14	0.14	0.032	0.12	0.012	0.011	0.014
Y	0.006	0.010	0.041	0.017	0.009	0.008	0.006	0.008	0.013	0.008	0.009	0.010	0.008	0.009	0.008	0.009	0.009	0.009	0.011	0.008
Th	0.046	0.045	0.90	0.031	0.030	0.041	0.011	<0.005	0.010	0.019	<0.005	0.028	<0.005	0.015	0.017	0.007	0.015	<0.005	<0.005	<0.005
S	0.07	0.34	0.04	0.34	0.43	0.35	0.28	0.17	0.25	0.18	0.33	0.82	0.30	0.41	0.40	0.25	0.18	0.30	0.17	0.14
La	0.020	0.033	0.13	0.030	0.019	0.017	0.018	0.030	0.027	0.028	0.032	0.032	0.033	0.028	0.028	0.028	0.032	0.024	0.024	0.021
Ce	0.045	0.075	0.53	0.070	0.045	0.045	0.050	0.065	0.060	0.065	0.068	0.070	0.070	0.062	0.060	0.059	0.072	0.052	0.056	0.048
Nd	0.028	0.038	0.19	0.033	0.021	0.023	0.020	0.030	0.032	0.03	0.031	0.034	0.031	0.033	0.031	0.028	0.036	0.026	0.016	0.025
U* est.	(0.15)	(0.15)	(2.9)	(0.10)	(0.10)	(0.13)	(0.04)			(0.06)		(0.09)		(0.06)	(0.05)		(0.06)			
Ta* est.	(0.11)	(0.05)	(0.199)	(0.03)	(0.07)	(0.06)	(0.05)			(0.03)		(0.03)	(0.03)	(0.02)	(0.02)		(0.02)			

TABLE 4. GEOCHEMICAL ANALYSES FOR 19 SELECTED SAMPLES OF SØVITE; NOTE SAMPLE NO. 20 IS OF SLAG.

*ESTIMATES ARE MADE ASSUMING ALL U AND Ta ARE FROM A PYROCHLORE SOURCE, USING RATIOS ESTABLISHED BY MARIANO (1980).

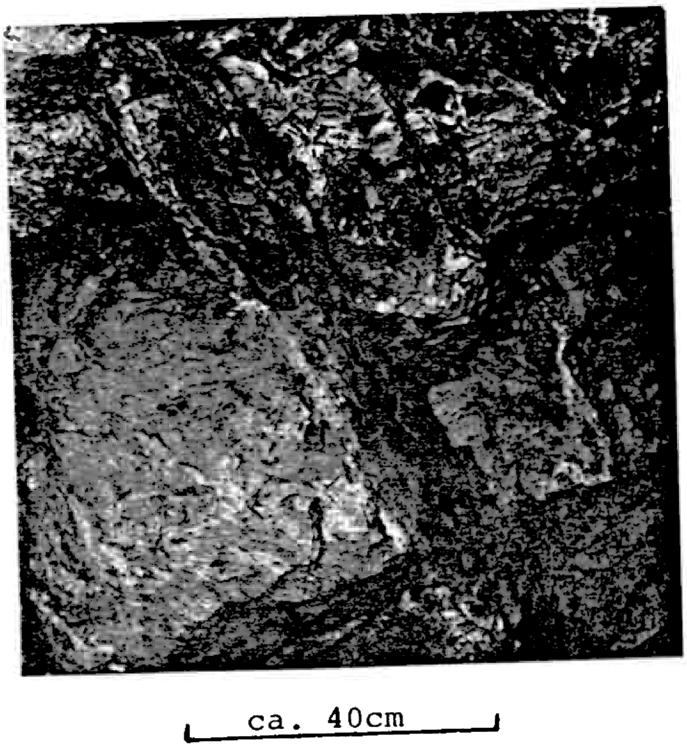


FIGURE 16. ALKALI-FELDSPAR-FLOODED AND REPLACED MAFIC SILICATE ROCKS IN THE TUFTESTOLLEN. THE ORIGIN OF THE RED-PINK ALKALI-FELDSPAR FLOODING IS UNCERTAIN, BUT IT BEARS A SPATIAL RELATIONSHIP TO THE MARGIN OF THE SØVITE INTRUSIVE MASS. PHOTO NO. 0019-9; NEAREST MAIN GRID INTERSECTION 142.800 - 51.000.

suggest that this unit may have had a magmatic history. Feldspar-flooded rocks seem to form where previously fenitized rocks are in juxtaposition with the main mass of carbonate magma. Perhaps these are the so-called rheomorphic fenites described in published investigations of carbonatite complexes.

Geochemistry

The geochemistry of alkali-feldspar-flooded rocks reflects their initial granitic gneiss parentage (Table 5). Relatively high values of silicon correlate with the presence of relict quartz grains. The slightly high values for potassium and sodium correlate with the increase in secondary alkali feldspar. The anomalously high calcium values correlate with the substantial introduction of calcite from adjacent Søvitic magma.

Iron Rich Carbonate Veins - Unit F

Iron-rich carbonate veins are locally abundant. Two of the best areas of exposure are in fresh outcrops along the walls of the Hydro open cut and the Cappelen open cut. The veins invariably are thin, ranging in thickness from several millimeters to 5 or 6 centimeters. When weathered the iron content of the carbonate is made evident by the presence of oxides.

Under the microscope in CL the dolomitic (or ankeritic) content of the carbonate is confirmed. Also indicated is that the carbonate comprising the veins is of metasomatic origin with calcite relics. It appears that iron-rich carbonate-bearing hydrothermal fluids may have altered the walls of fractures along which they were introduced.

The iron-rich carbonate veinlets formed dominantly along a northwest-striking fracture system, and are known only to transect Søvite. Perhaps these represent early fluids released along fractures that developed incident to emplacement of Rauhaugite magma.

Rauhaugite - Unit G

Definition and Field Relationships

Rauhaugite, the carbonatite phase with apparently the largest volume, occupies much of the interior portion of the Fen complex. In the area covered by this report the best exposure of Rauhaugite is in the Tufte area; here cross-cutting relationships with the older Søvite are subtle but definite (Figure 17).

The pure form of Rauhaugite is light-gray to white, occurs in dikes and is usually barren of silicates and oxides (Figure 18). Outer extensions of Rauhaugite dikes are reddish-pink veins which commonly transect Søvite

FIGURE 17. GRAY-BROWN RAUHAUGITE WITH LATE REDDISH-PINK VEINS CUTTING BANDED PINK AND DARK-GRAY MIXED SØVITE AND BASIC SILICATE ROCKS. NOTE VERMICULAR SEGREGATIONS OF SØVITE IN BASIC SILICATE ROCKS. PHOTO NO. 0020.12, NEAREST MAIN GRID INTERSECTION IS 142.000 - 51.200; PENCIL FOR SCALE IS ABOUT VERTICAL.

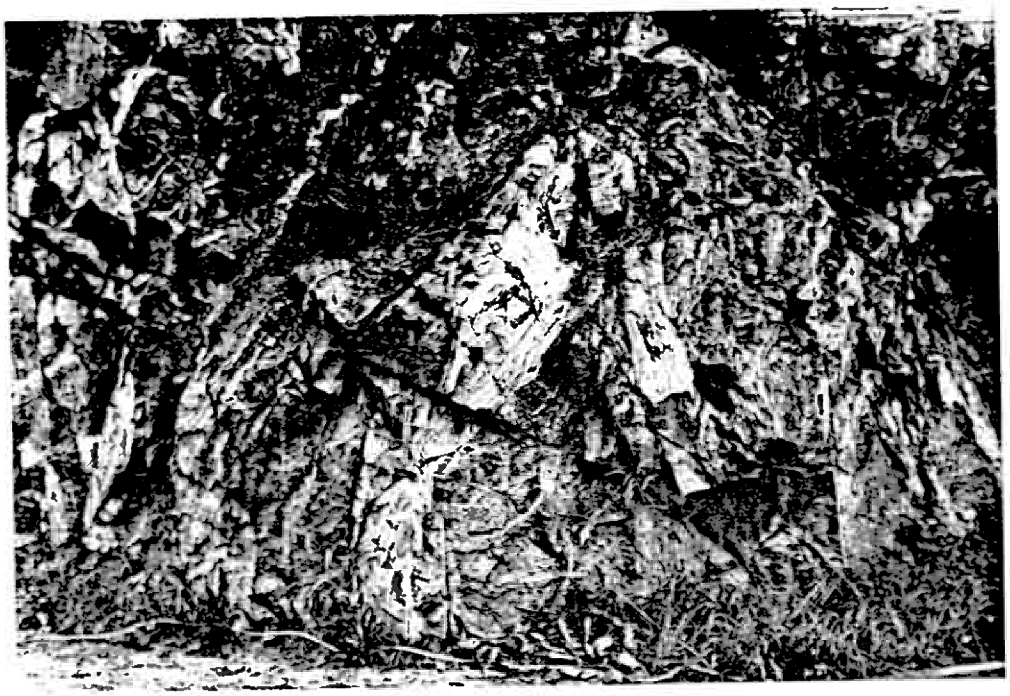


FIGURE 18. SLIGHTLY WEATHERED OUTCROP ALONG ULEFOSSVEIEN THAT SHOWS LIGHT-GRAY RAUHAUGITE DIKES TRANSECTING AN EARLIER-FORMED MIXTURE OF FENITE AND SILICATE-RICH SØVITE. PORTION OF PHOTO BELOW HAMMER AND TO THE RIGHT IS SHOWN IN DETAIL IN FIGURE 7. PHOTO NO. IS 0013-34; NEAREST MAIN GRID INTERSECTION IS 142.000 - 50.800.

	F0089	95	98	99	100	119
Fe	1.7	4.0	2.9	6.2	2.5	4.1
Si	25.2	28.1	27.8	25.1	27.3	21.0
Mg	0.47	1.6	0.72	2.2	1.2	2.7
Al	7.5	6.1	8.3	6.6	8.5	6.6
P	0.37	0.16	0.12	0.27	0.14	0.20
Na	3.3	4.2	6.1	3.3	4.2	3.9
Ti	0.18	0.26	0.15	0.30	0.10	0.033
K	4.0	2.8	2.8	2.8	3.7	0.8
Ca	6.7	3.1	3.9	4.6	3.1	6.5
Mn	0.11	0.14	0.12	0.16	0.11	0.28
Ba	0.37	0.089	0.16	0.19	0.40	0.20
Sr	0.13	0.064	0.082	0.080	0.065	0.088
V	0.01	0.008	<0.005	0.017	0.007	<0.005
Nb	0.069	<0.005	0.012	0.014	0.011	0.030
Y	0.007	<0.005	<0.005	<0.005	<0.005	<0.005
Th	0.008	<0.005	0.005	0.013	0.005	0.006
S	0.21	0.07	0.08	0.16	0.13	0.31
La	<0.01	≤0.01	<0.01	0.021	<0.01	0.014
Ce	0.01	0.014	≤0.01	0.036	≤0.01	0.024
Nd	<0.01	<0.01	<0.01	0.019	<0.01	0.018

TABLE 5. GEOCHEMICAL ANALYSES OF SIX SAMPLES OF ALKALI-FELDSPAR-FLOODED GRANITIC GNEISS.

	F0044A	F0118	F0121	F0122	F0125	F0127	F0128	F0133	F0136	F0137
Fe	2.9	2.8	6.2	3.0	2.8	4.1	2.6	2.8	8.2	11.7
Si	2.1	0.9	0.5	0.7	1.0	0.6	0.7	1.0	1.2	1.6
Mg	0.70	4.0	6.8	8.7	8.2	2.4	8.6	9.8	7.8	7.4
Al	0.11	0.21	0.05	0.05	0.03	0.05	0.07	0.12	0.046	0.11
P	0.71	2.8	1.8	1.8	0.93	2.3	1.3	1.1	3.1	2.0
Na	0.16	0.23	0.14	0.17	0.14	0.16	0.13	0.18	0.16	0.30
Ti	0.007	0.014	0.041	0.011	0.008	0.060	0.024	0.042	0.15	0.25
K	<0.05	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ca	21.1	28.3	20.9	21.7	22.0	27.7	20.3	20.8	23.1	23.4
Mn	0.70	0.34	0.64	0.62	0.62	0.36	0.59	0.49	0.43	0.43
Ba	0.038	0.16	0.26	0.042	0.032	0.025	0.010	0.017	0.011	0.046
Sr	0.40	0.18	0.20	0.31	0.31	0.30	0.34	0.35	0.39	0.31
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.020	0.034
Nb	0.010	0.061	0.40	0.23	0.060	0.44	0.094	0.16	0.56	0.41
Y	<0.005	0.008	0.010	0.007	<0.005	0.010	<0.005	<0.005	0.005	<0.005
Th	<0.005	0.012	0.022	0.007	0.005	0.017	<0.005	0.007	0.018	0.011
S	0.05	0.20	0.48	0.22	0.30	0.53	0.08	0.28	1.3	0.55
La	0.013	0.025	0.033	0.43	0.017	0.028	0.017	0.01	(0.03)	(0.02)
Ce	0.025	0.057	0.070	0.076	0.050	0.063	0.036	0.016	0.055	0.037
Nd	0.020	0.035	0.037	0.033	0.030	0.026	0.020	0.01	0.030	0.020

TABLE 6. GEOCHEMICAL ANALYSES OF TEN SELECTED SAMPLES OF RAUHAUGITE.

inclusions (Figure 17) and are included loosely in the map Unit G1, along with alkali feldspar veins. Contamination of Rauhaugite by the mechanical mixing and the dissolution of Søvite and Basic Silicate Rocks is a common phenomena (Figure 19), and where this has occurred it contains a relatively high percentage of silicates and oxides. The Tufte area is one such area where foliation of the unit is extremely well defined by the relative abundance of magnetite and columbite(?) and biotite. Figure 20 is a typical photo of Rauhaugite from this area.

Petrography

Petrographically Rauhaugite is extremely variable, especially with regard to the relative proportions of the various carbonate mineral phases. Essential primary minerals are calcite, dolomite or ankerite, and apatite. Accessory minerals are columbite, magnetite, pyrite and rutile. The average grain size of the essential minerals varies between 0.2 and 0.4mm. The accessory minerals have a greater spread in size distribution and vary from about 0.1 to 3mm. Fine-grained columbite(?) specks are scattered along lines of foliation and may comprise as much as 1 percent of the rock in the previously-mined mineralized zones (Figure 21). Magnetite grains are as large as several millimeters.

Under CL calcite and dolomite (or ankerite) are readily separated and the percentage of calcite is quite variable. In white to light-gray Rauhaugite dikes, the carbonate fraction comprises nearly 100 percent dolomite (or ankerite). In those masses mixed with pink Søvite and Basic Silicate Rocks there is approximately 25 percent dolomite (or ankerite) versus about 75 percent calcite. A definite positive correlation exists between the content of calcite and the abundance of columbite(?); those rocks with a high percentage of columbite(?) contain about 75 percent calcite.

The presence of rutile is indicated by yellow-green specks under CL, and it will be important to determine if the rutile contains appreciable niobium.

Geochemistry and Discussion

The geochemical analyses of 10 selected samples of Rauhaugite are listed in Table 6. The unit clearly is lower in calcium than Søvite and these values range from about 21 percent to 28 percent, versus calcium values in Søvite that range from about 28 percent to 40 percent. Correspondingly, iron and magnesium values are higher in Rauhaugite than in Søvite. Thus the geochemistry explains the dominance of dolomite (or ankerite) versus the dominance of calcite in the Søvite.

FIGURE 19. RAUHAUGITE (TUFTESTOLLEN) WITH STREAKS AND PODS (BOUDIN) OF PLASTICALLY DEFORMED BASIC SILICATE ROCKS. RED DOT AT EDGE OF PHOTO IS ABOUT 15CM WIDE. PHOTO NO. 0020-2; NEAREST MAIN GRID INTERSECTION IS 142.000 - 51.300.

FIGURE 20. RAUHAUGITE (TUFTESTOLLEN) LIGHT-GRAY WITH DARK STREAKS, FLOW BANDED, GEOLOGY PICK HANDLE IS HORIZONTAL. NOTE LATE, LOW-ANGLE FRACTURE WITH CARBONATE FLOODING ON EITHER SIDE. PHOTO NO. 0020-6; NEAREST MAIN GRID INTERSECTION IS 142.000 - 51.300.

0.25mm

FIGURE 21. PHOTOMICROGRAPH OF MINERALIZED RAUHAUGITE IN MIXED REFLECTED AND REFRACTED LIGHT WITH CROSSED POLARS (SAMPLE F0127 FROM THE TUFTE MINERALIZED ZONE). COLUMBITE(?) (GRAY) AND PYRITE (YELLOW) GRAINS ARE SHOWN DISSEMINATED IN AN EQUIGRANULAR MATRIX CONSISTING OF CALCITE AND ANKERITE(?).

Niobium geochemical values are of sub-economic proportions from the Tufte area and these correlate with higher than normal values of calcium for Rauhaugite. It is an empirical observation that where Rauhaugite magma has assimilated earlier Søvite, the niobium grades are highest.

Vanadium geochemical values of 200ppm and 340ppm (Table 6) are definitely anomalous and these values are thought to result from assimilation of vanadium-rich Basic Silicate Rocks by Rauhaugitic magma.

Thorium is over 100ppm in several samples; thus the presence of uranium is suspected, but not confirmed.

Søvite - Unit H

Søvite - Unit H is the youngest Søvite phase in the area mapped, and perhaps this observation may be correct for the entire complex. It apparently does not correlate with any of the units mapped by Sæther (1957). The unit definitely transected and partially assimilated Rauhaugite at one locality mapped in the Tuftestollen (Plate II). In hand specimen the rock appears fine-grained and has a specked appearance.

Petrographic examination of one sample (F0111) has been accomplished. In CL the unit appears to be greater than 90 percent calcite. The grain size averages about 0.3mm. Accessory minerals are pyrite and questionable barite.

One geochemical analysis (Table 7) confirms the high calcite content as observed petrographically. The unit is also anomalous in barium and rare earths with about 1 percent combined La, Ce, and Nd. Note also the low niobium value.

Damtjernite Intrusive Breccia - Unit I

Damtjernite occurs as late carbonate-rich Basic Silicate dikes that are associated with or grade into intrusive breccia. The largest patch of this unit crops out at about 51.550 - 142.550; and here the body appears to have a northwest strike. Two other small patches are mapped , one on the edge of the Hydro open cut, and the other south of the abandoned Cappelen mine workings.

In outcrop the unit clearly transects Søvite and it may be roughly contemporaneous with iron-rich carbonate veins. Often the texture of the unit is that of a dark-gray breccia with fragments of dolomite and large 2 - 5cm

Fe	2.9
Si	1.2
Mg	2.7
Al	0.20
P	0.37
Na	0.21
Ti	0.014
K	<0.5
Ca	31.6
Mn	0.69
Ba	0.93
Sr	0.12
V	<0.005
Nb	0.061
Y	0.006
Th	0.040
S	0.59
La	0.29
Ce	0.53
Nd	0.20

TABLE 7. GEOCHEMICAL ANALYSIS OF ONE SAMPLE OF LATE SØVITE.

biotite flakes. One specimen is depicted under the microscope (Figure 22) that clearly defines the brecciated nature of the rock.

Damtjernite may be younger than Rauhaugite as evidenced by inclusion of dolomite (or ankerite) fragments, but it also could be related to the Rauhaugite, genetically. A genetic tie between these two rock units would place Damtjernite as the less differentiated, Basic Silicate parent magma to the Rauhaugitic magma. This is apparently a concept espoused by Sæther (1957) as well.

The geochemistry of one specimen is depicted in Table 8. As most mafic Silicate Rocks in the complex, it is anomalous in vanadium. One K/Ar age determination on coarse biotite (F0056) yielded a result of 561 plus or minus 56 m.y.

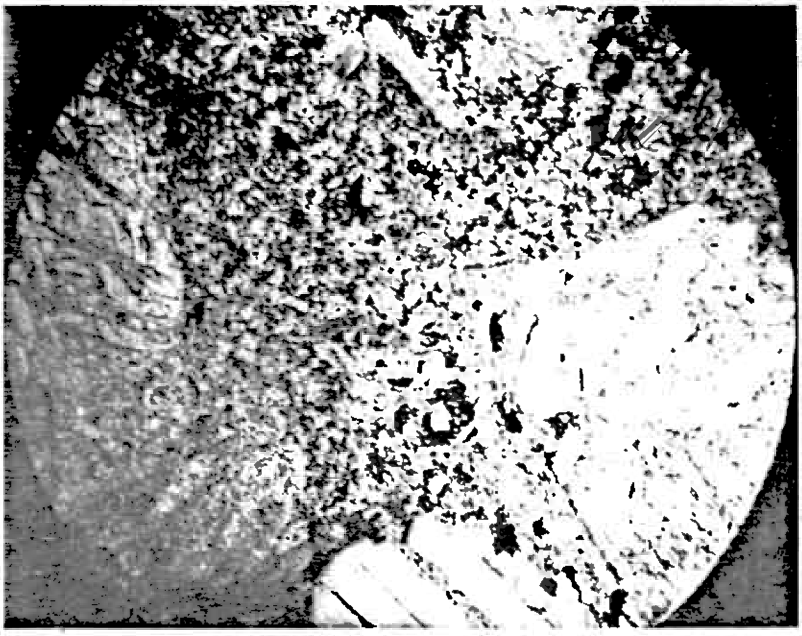
Rødbergite - Unit J

Definition and Field Relations

Rodbergite, a rock type discussed at length by Sæther (1957), contains hematite as its principal mineral characteristic. Locally pervasive occurrences of hematite, having the same origin as the Rødbergite, constituted the ore of the Fen iron mines on the east side of the complex. In the area mapped, Rødbergite crops out only as a few small patches. One very small outcrop is at 142.420 - 50.850; another group of outcrops is in the vicinity of 142.500 - 52.500 (Plate I). Underground in the Tuftestollen one 60-meter wide zone and a number of small zones are exposed.

Underground and surface exposures in the area mapped indicate that Rødbergite has formed from the alteration of pre-existing carbonatite, or damtjernite. Damtjernite is locally altered to Rødbergite at 142.540 - 51.540; this observation also has been made by Sæther (1957) and Viik (personal communication). Underground, both Søvite and Rauhaugite are altered to Rødbergite. Relict patches of near fresh, foliated, Søvite and Rauhaugite grade to pervasive Rødbergite with faint sub-parallel foliation preserved (Plate II). The border zone separating Søvite from Rauhaugite appears to be a preferred zone of Rødbergization.

Cross cutting relations indicate that the event of Rødbergite formation transected virtually all carbonatite units, perhaps except for late Søvite - Unit H. Diabase dikes definitely transect Rødbergite. It seems probable that the formation of Rødbergite is the last principal event that can be related directly to the carbonatite complex.



0.2mm

FIGURE 22. PHOTOMICROGRAPH OF DAMTJERNITE INTRUSIVE BRECCIA FROM HYDRO STEINBRUDD (F0056). CONTAINS LARGE BIOTITE BOOKS AND LARGE SUBANGULAR DOLOMITE FRAGMENTS SET IN A GROUNDMASS COMPRISED DOMINANTLY OF CALCITE AND MAGNETITE. THERE ARE A FEW QUARTZ FRAGMENTS IN THE GROUNDMASS.

Petrography

The petrographic characteristics of Rødbergite have been briefly scanned in four thin sections: F0103, F0104, F0105, and F0109. Since Rødbergite is an alteration phase, its characteristics differ considerably, depending on the composition of the host rock. In sample F0103, which was Søvite - Unit D, apatite is fresh and unaltered, magnetite has been 90 percent replaced by hematite, and calcite is dusted with very fine-grained hematite. In sample F0104 partial Rødbergization has occurred with metastable pyrite and magnetite unaffected. In F0105 hematite occurs as small patches in Søvite and is irregularly disseminated. Here also, primary magnetite is metastable and is partially altered to hematite. In F0109 the hematite content is of the highest percentage.

Petrographic criteria definitely establish the fact that secondary alteration of primary carbonatite by Fe^{+3} rich solutions has taken place (Sæther, 1957). Thus what is mapped is an alteration zone of Fe^{+3} development, i.e: fenitization, not a primary intrusive phase of carbonatite.

Geochemistry

Four geochemical analyses of Rødbergite in various stages of host-rock replacement are listed in Table 8. Rødbergized carbonatite units are anomalous in rare earths, and these are presumed to have been introduced during Rødbergization. Anomalous niobium is probably inherited from pyrochlore or columbite mineralization in the parent rock.

Diabase Dikes - Unit K

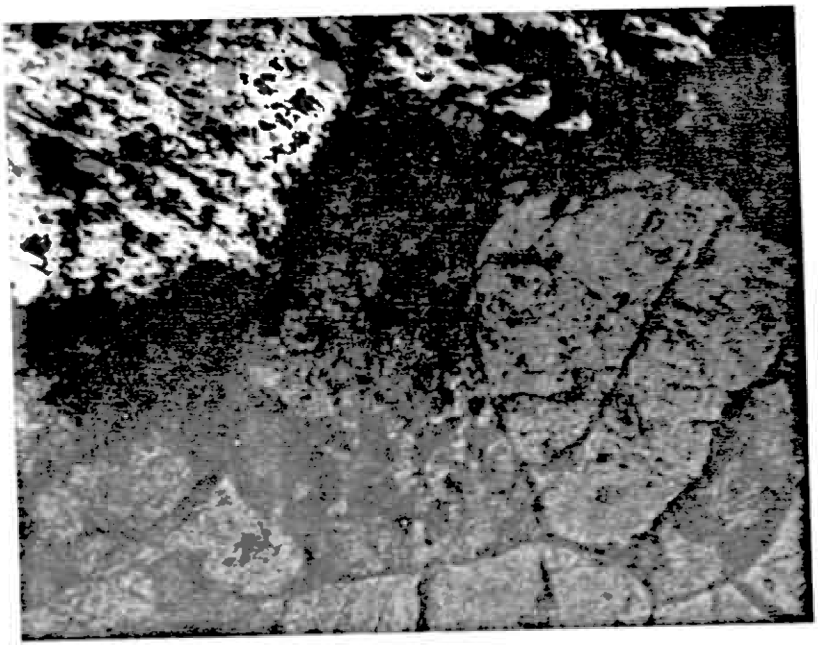
Definition and Field Relations

The injection of diabase dikes was the latest igneous event at Fen, thought to be Permian in age and to correlate in time with the early development of basalt magmatism in the Oslo Graben (S. Dahlgren (1981), personal communication).

The dikes that crop out in the Fen area are thin, never more than a few meters thick, and are exposed underground in the Tuftestollen as well as in the Hydro and Cappelen open cuts. The dikes are often rich with carbonate inclusions, and locally appear to grade into late carbonate breccia. Where the dikes cut the Hydro Søvite dike they form a braided pattern in cross section.

Petrography

The petrographic characteristics of the diabase are varied. Essential primary minerals are plagioclase, pigeonite and magnetite. The texture is thought to be dominantly intergranular as exhibited in sample F0065.



ca.0.1mm

FIGURE 23. PHOTOMICROGRAPH OF PARTIALLY RØDBERGIZED SØVITE, (SAMPLE F0103) SHOWN HERE IN MIXED REFLECTED AND REFRACTED LIGHT. LARGE OPAQUE GRAIN IN UPPER LEFT HAND CORNER IS A PSEUDOMORPH OF MAGNETITE ALTERED TO HEMATITE. HEMATITE (WHITE TO LIGHT GRAY) MOSTLY REPLACES MAGNETITE (LIGHT BROWN). LARGE PRIMARY MAGMATIC APATITE GRAINS ARE UNALTERED. DARK SPECKS ARE FINELY DISSEMINATED HEMATITE GRAINS IN CARBONATE MINERAL AND AROUND THE EDGES OF THE LARGE HEMATITE GRAIN.

	F0103	F0104	F0105	F0109	F0056
Fe	5.6	7.6	7.6	5.3	7.0
Si	2.2	5.0	1.2	1.3	9.9
Mg	6.4	2.6	5.5	6.3	10.1
Al	0.49	0.80	0.15	0.26	2.3
P	2.3	3.5	3.2	1.3	0.97
Na	0.20	0.19	0.19	0.17	0.20
Ti	0.25	0.21	0.016	0.016	0.77
K	<0.5	<0.5	<0.5	<0.5	0.7
Ca	24.6	25.5	23.7	24.2	14.7
Mn	0.49	0.40	0.81	0.80	0.43
Ba	0.86	0.18	1.8	0.26	0.44
Sr	0.17	0.30	0.19	0.11	0.25
V	<0.005	0.014	<0.005	<0.005	0.014
Nb	0.040	0.105	0.040	0.17	0.030
Y	0.020	0.009	0.016	0.009	0.010
Th	0.032	0.011	0.030	0.013	0.014
S	0.40	0.46	0.83	0.17	0.12
La	0.020	0.029	0.28	0.11	0.055
Ce	0.050	0.067	0.55	0.19	0.11
Nd	0.036	0.030	0.14	0.060	0.039

TABLE 8. GEOCHEMISTRY OF FOUR SELECTED SAMPLES OF RØDBERGITE AND ONE SAMPLE OF DAMTJERNITE INTRUSIVE BRECCIA.

However, sample F0124 is definitely porphyrytic with large 3mm euhedral phenocrysts of pigeonite. Alteration products are chlorite, hornblende, white mica, and calcite. In F0124 calcite replaces many large phenocrysts of pigeonite.

Petrographically it can be seen that the dikes are not fenitized, as indicated by the presence of magnetite and pigeonite, and that the contained calcite has been derived from the carbonatite units that have been intruded.

Geochemistry

Two chemical analyses are listed in Table 9. Neither of these samples is particularly fresh and includes as much as 15 percent calcite, presumably derived from carbonate wall rocks. Nevertheless, rare earths, thorium, and niobium are below detection limit.

Calcite Veins - Unit L

Calcite veins are the youngest geologic unit mapped; they are best exposed underground and are typically about one-half-meter wide, vertically dipping and west-northwest to east-west striking. One unusually large 10 - 15m wide mass of coarse 4 - 6cm pink calcite is found underground in the Tufte area, and this, as are the thinner calcite veins, is thought to occur along late faults. One geochemical analysis of coarse, pink calcite is presented in Table 10. Another similar coarse-grained calcite zone, marked by a small prospect, occurs along the southeast wall of the Hydro open cut.

Calcite veins post-date the complex as demonstrated by the fact that they cut diabase.

	F0065	F0124
Fe	8.8	8.2
Si	21.6	20.1
Mg	3.5	7.9
Al	8.5	2.5
P	0.29	0.13
Na	2.9	1.1
Ti	1.8	1.4
K	0.5	0.5
Ca	5.4	9.6
Mn	0.13	0.14
Ba	0.093	0.10
Sr	0.12	0.050
V	0.029	0.034
Nb	<0.005	<0.005
Y	<0.005	<0.005
Th	<0.005	<0.005
S	0.19	0.09
La	<0.01	<0.01
Ce	<0.01	<0.01
Nd	<0.01	<0.01

TABLE 9. GEOCHEMICAL ANALYSIS OF TWO SAMPLES OF TYPICAL DIABASE.

	F0139
Fe	1.4
Si	0.8
Mg	2.0
Al	0.09
P	0.74
Na	0.26
Ti	0.052
K	<0.05
Ca	37.6
Mn	0.39
Ba	0.069
Sr	0.15
V	<0.005
Nb	0.15
Y	0.007
Th	<0.005
S	0.12
La	<0.01
Ce	0.020
Nd	0.015

TABLE 10. GEOCHEMICAL ANALYSIS OF A TYPICAL LATE CALCITE VEIN FROM THE TUFTESTOLLEN AREA.

STRUCTURE

Geologic Map

Structures relating to the development of the carbonatite complex are depicted on the geologic map and composited in a contoured stereonet plot depicted on Plate 1. Poles to 350 planar structures are plotted including, in apparent sequence of development: Precambrian foliation planes (10), aegirine veins (13), Søvite dikes (51), Søvite foliation planes (32), alkali feldspar veins (21), late, iron-rich carbonate veins (53), Rauhaugite foliation planes (29), faults (75), joints (45), diabase dikes (12), and late calcite veins (9).

Precambrian Structures

First-hand knowledge of Precambrian structure is restricted to the fenitized granitic gneiss in the northern portion of the mapped area, and therefore it was necessary to include data presented on Sæther's (1957) geologic map. The geometry of the Precambrian basement is important, because it may have had a bearing on the emplacement of the carbonatite and related Basic Silicate Rock units.

Structural features in the area of Plate 1 are difficult to define in the field owing to blurring by fenitization. Ten Precambrian foliation directions are shown on the geologic map. Poles to these foliation planes plotted and analyzed on a Schmidt net indicate a conformity with an axis of folding that strikes northeast. The northeast-striking, hinge surface of a northeast-plunging fold in the Precambrian is indicated by the pattern of foliation planes between the Hydro open cut and the portal of the Tuftestollen.

Thirty-two strikes of foliation, taken from Sæther (1957), have an average strike of about N30°E. These are depicted with respect to later, carbonatite-related structures in Figure 24.

The average for the foliation strikes and the indicated fold axis are nearly the same.

Carbonatite Structures

A brief description of the structures related to carbonatite emplacement is outlined in this section.

The earliest formed carbonatite-related planar features are aegirine dikes - Unit C_1 (Figure 5). The average attitude of the veins measured is about N58°E, 45°SE. These indicate the presence of an early, pre-Søvite-age fracture system of the above attitude in the northwest sector of the Fen complex.

Søvite (Unit D) was clearly injected into Precambrian basement along an approximate N55°E fracture system that

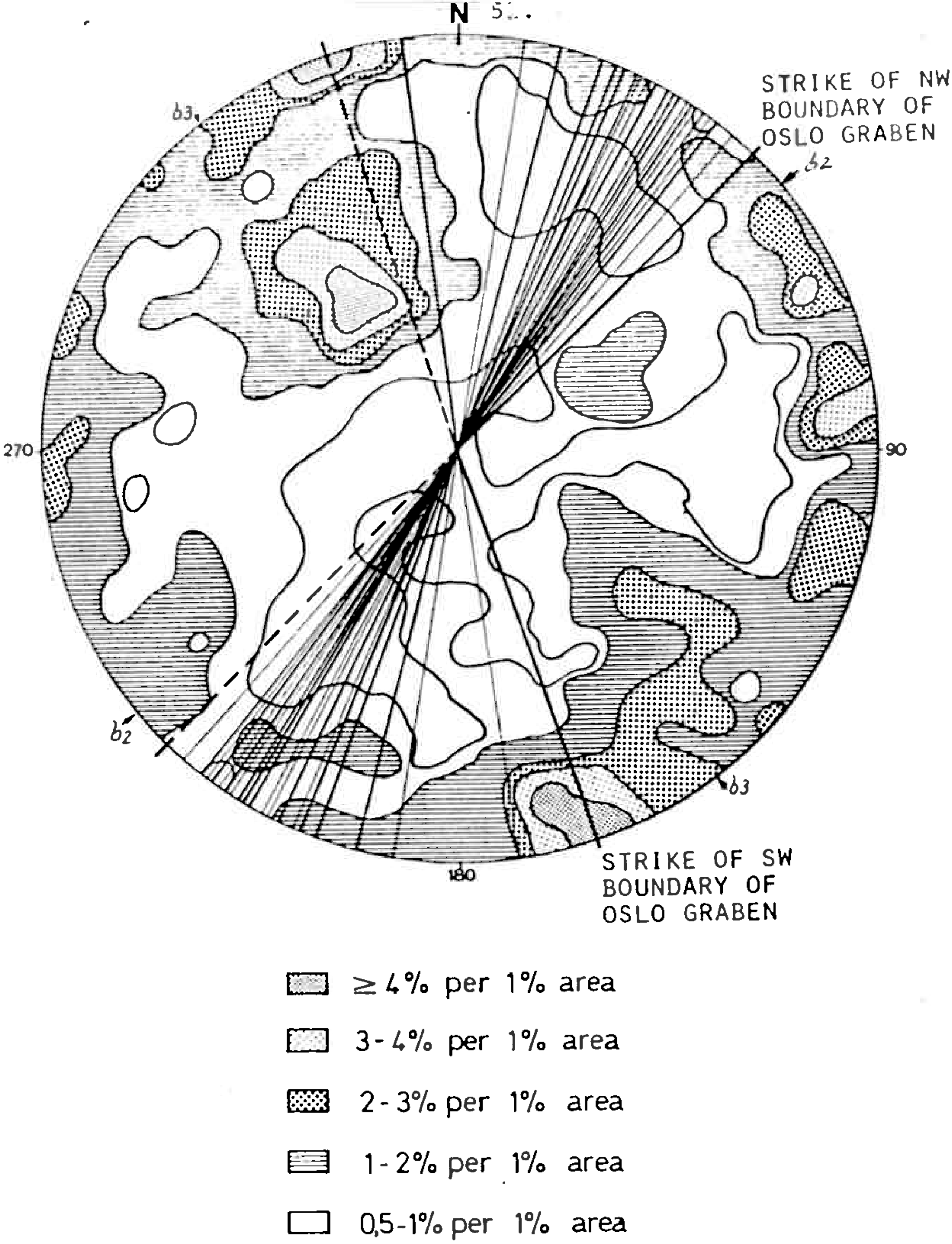


FIGURE 24. CONTOURED PLOT OF 350 POLES TO ALL STRUCTURES SHOWN ON THE GEOLOGIC MAP (PLATE 1). POLES ARE SHOWN WITH RESPECT TO FAMILY OF LINES REPRESENTING 36 FOLIATION STRIKES MEASURED IN THE PRECAMBRIAN GRANITIC GNEISS SURRONDING THE FEN COMPLEX (AFTER SÆTHER, 1957). ALSO SHOWN ARE APPROXIMATE STRIKES FOR THE BOUNDARY OF THE OSLO GRABEN, AND THE INFERRED POSITIONS OF SIGMA 1, 2 AND 3.

dipped both to the northwest and to the southeast (Figure 25). The fact that Søvite was emplaced along this fault system also is demonstrated in the Tuftestollen adjacent the Hydro dike, where a small dike of Søvite, a subsidiary of the Hydro dike, with a Basic Silicate margin has intruded the gouge zone of a northeast-striking, southeast-dipping fault. Moreover, Søvite foliation planes, as one would suspect, are sub-parallel to the strike and dip of the dikes (Figure 25), and are clearly intrusive phenomena.

Late, iron-rich carbonate veins (Unit F) form a definite pattern, striking about N30°W and dipping steeply to the northeast and southwest. These carbonate-filled fractures demonstrate clearly that the carbonate complex had deformed in a brittle manner outward from large pulses of carbonate magma intrusion.

Rauhaugite (Unit G) foliation planes were measured underground in the Tuftestollen and these cluster about two orientations. The best defined orientation strikes about N75°E and dips about 80°NW. Foliations of this trend are dominant in the area of the Tufte glory hole (Plate 2). There is also a group of attitudes that clusters about an approximate north-south direction with a dip of about 70° to the east. The east-northeast direction of foliation is important in the Tufte area because it may define the overall geometry of the niobium mineralization in this sector. It is important to point out that Sæther (1957), Figure 26, shows that C axes of ankerite from Rauhaugite in the Tufte area tend to be oriented perpendicular to foliation planes. The above observations of Sæther add support to the concept that the Rauhaugite is of magmatic origin.

Post Carbonatite Structures

Post carbonatite structures include faults, joints, late diabase dikes and late coarse-grained calcite veins.

Most measured faults, but certainly not all, are thought to be post-carbonatite in age; if they were not, they would have been filled with a carbonatite intrusive phase or vein-filling mineral. Fault orientations are somewhat random, but two definite patterns of attitudes are prominent: one is about N60°E, 55°SE, the other forms a band of poles on the stereonet from about N-S to N30°W, 80°SW.

Several large fault zones require separate mention. One large fault is measured on the southeast side of the Cappelen open pit. Here a N40°E striking near-vertical fault has down-dropped the Cappelen orebody on the order of 50 meters. A large north-striking, near-vertical fault cuts through the Tuftestollen (Plate 2). This is believed to have downdropped the east side, and it may bend to the northeast to connect with the late Cappelen fault (Plate 1).

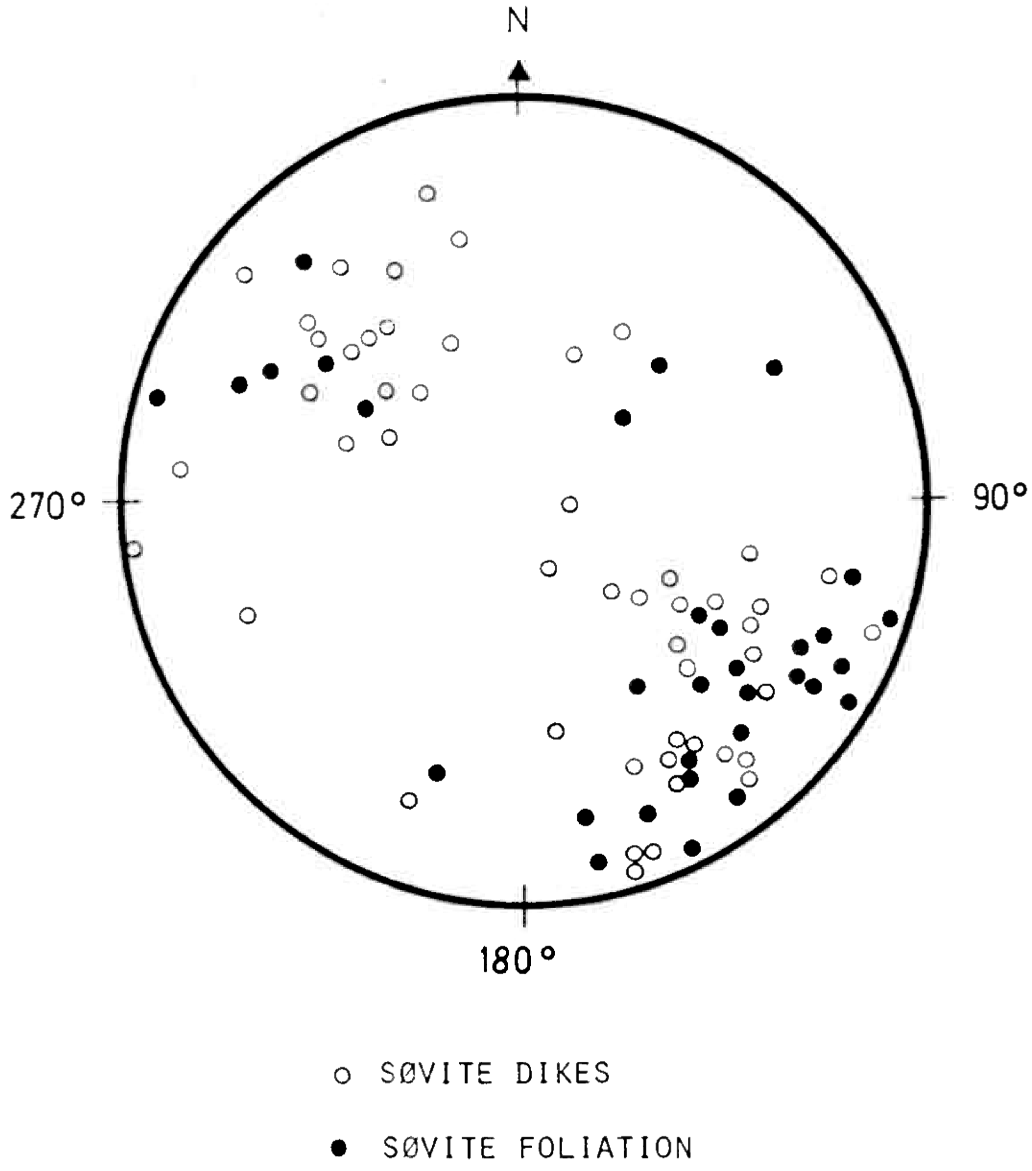


FIGURE 25. STEREONET PLOT SHOWING DISTRIBUTION OF POLES TO 51 SØVITE DIKES AND POLES TO 32 PLANES OF FOLIATION IN SØVITE.

A large northwest-striking fault is intersected in about the center of the Tuftestollen and this is regarded as, perhaps, earlier than the two faults mentioned above, as it contains massive sulfide mineralization as well as rare earth mineralization and may control the intrusion of late carbonatite phases. This fault zone may be akin to faults with similar strikes that contain mineralization in the Gruveåsen area as defined by K. Mørk. A large northwest-striking fault along the trace of Ulefossveien offsets the westward extension of the Hydro dike. This fault zone may trace into the Tufte mineralized area.

Joint attitudes are random in appearance but, as with the faults, they tend to be dominantly northeast striking and southeast dipping.

Diabase dikes have two principal orientations; one is east-northeast and near vertical, the other is northeast and near vertical.

Calcite veins have an east-west to west-northwest strike and dip steeply north.

Structural Analysis

A structural analysis of the fracture patterns mapped is attempted with the full realization by the author that just the northwest portion of the complex is considered.

A genetic relationship of the fractures in the northwest portion of the Fen complex to regional fractures probably exists. Figure 24 shows the strike of the boundaries of the nearby Oslo Graben (Figures 2, 4) with respect to all of the structures mapped at Fen. The Oslo Graben is a well-defined rift zone related to extensional tectonics, and as discussed earlier it may have had its inception in Cambrian time. Thus, regional extension (sigma3) in a northwest-southeast direction applies to the fractures of the Oslo Graben as well as the Fen region. Approximately N40°W extension on a small scale is demonstrated in the Fen area in one unique sub-outcrop (Figure 26), as well as the overall fracture pattern. Sigma one is assumed vertical in this scheme. Thus, most of the faulting may be explained by the action of gravity, as sigma one, in an extensional regime.

The orientation of the carbonatite body as a whole appears to be sub-parallel to sigma two, about N50°E. For example, the orientation of the Hydro dike is about N40°E; the orientation of foliation in Søvite of the main body where it comes in contact with the Precambrian country rocks varies between N50°E and N70°E. It was noted in an earlier report (Olmore, 1980) that the overall strike of the central magnetic anomaly of the Fen area has an axis

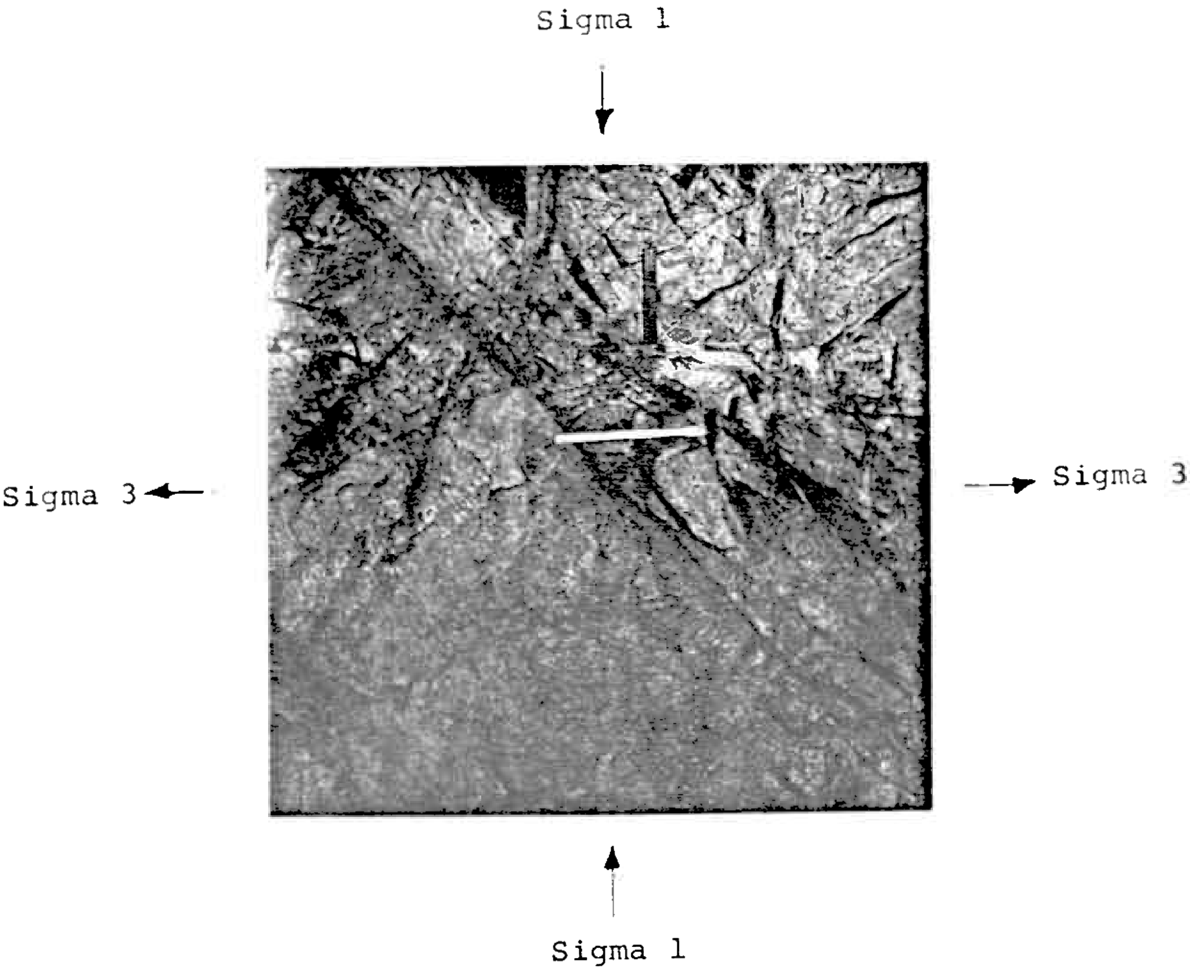


FIGURE 26. CONJUGATE FRACTURE SET DEVELOPED IN FENITIZED GRANITIC GNEISS NEAR PORTAL OF TUFTESTOLLEN. HAMMER HANDLE IS HORIZONTAL. PINK DIKES ARE APLITE OF PRECAMBRIAN AGE INJECTED SUB-PARALLEL TO FOLIATION IN GRANITIC GNEISS. THE PRINCIPAL FRACTURE SET DIPPING FROM LEFT TO RIGHT IN THE PHOTO HAS AN ATTITUDE OF N65°E, 45°SE. THE ANTITHETIC SET HAS AN ATTITUDE OF ABOUT N65E, 40NW. NOTE THE VERITIBLE SWARM OF EARLY, THIN, AEGIRINE VEINLETS SUB-PARALLEL TO THE LARGE FAULT. (THE PHOTO NUMBER IS 0019-7; THE NEAREST GRID INTERSECTION IS 142.880 - 50.930.)

that strikes approximately N45^{o}E. It is probably not a coincidence that the gravity anomaly over the Fen complex measured by Ramberg (1973) has an approximate N40^{o}E axis of symmetry.

Northwest-striking fractures and faults in the Fen area are more obviously related to regional structure than are the northeast-striking ones, as several large northwest lineaments can be traced into the area from the outside (Figure 2). The northwest strikes in the Fen area are sub-parallel to the northwest-striking, southwestern boundary of the Oslo Graben (Figure 2).

It is suggested by the above data that extensional tectonics on the scale of the Oslo Graben have influenced the emplacement of carbonatite and comagmatic basic magma, on the scale of the Fen district. Thus, extensional tectonism in the Oslo Graben is indicated to have a Cambrian ancestry. It is further suggested that at the intersection of northwest and northeast striking fractures lies the Fen district, this accords with observations made by Ramberg (1973).

MINERALIZATION

Hydro Zone

The Hydro zone of niobium mineralization projects along the entire length of the Hydro dike (Søvite) from the Cappelen open cut southwest to Ulefossveien. The zone has been penetrated to a depth of 50 to 150 meters on the average by about 25 diamond drill holes during previous prospecting activities. The zone is depicted in cross section along the Tuftestollen where two deep holes have penetrated the extension of the zone to a depth of at least 300 meters.

Pyrochlore mineralization occurs as a narrow magmatic segregation band at the lower contact separating Søvite and Basic Silitate Rocks. Grades in this zone range anywhere from 0.1 to 0.4 percent Nb_2O_5 according to assay records from Norsk Bergverk's drill core (drill cores from these drilling operations have not been preserved).

A rough estimate of possible mineralization beneath the Hydro dike to depths of about 300 meters are a minimum of 3 million metric tons with grades ranging from 0.1 to 0.4 percent Nb_2O_5. Also possible for this zone are substantial, but yet unquantified amounts of uranium and tantalum in the pyrochlore mineralization (Mariano, 1980). The addition of these two elements as byproducts in a mining operation could substantially change the equivalent grades of Nb_2O_5.

Other interesting elements for consideration as possible byproducts are phosphorous and vanadium. Apatite varies from approximately 5 to 10 percent, and P_2O_5 grades of 3.5 percent to 5 percent are indicated by geochemical analysis. Vanadium geochemical values can be as high as 0.05 percent but are generally low for the Søvite. The anomalous vanadium values are generally in the adjacent Basic Silicate Rocks, and grades of 0.02 to 0.03 percent are common.

Tufte Zone

The Tufte zone of mineralization, situated at the south end of the Tuftestollen, is in Rauhaugite, rather than Søvite. Underground mapping (Plate 1) suggests the Rauhaugite body has an east-northeast strike sub-parallel to foliation in the body. The foliation is defined by the alignment of columbite(?) grains, magnetite and pyrite. This observation is, however, incongruent with the observations of Bjørlykke and Svinndal (1960) who indicate that the niobium mineralization is related to N-S trending, partly brecciated zones.

Niobium mineralization in the Tufte zone grades anywhere from 0.05 to 0.9 percent Nb_2O_5 with grades between 0.1 to 0.4 percent Nb_2O_5 the most common. Presumably the bulk of the niobium mineralization is in columbite(?) (Figure 21) but pyrochlore is also present (Bjørlykke and Svinndal, 1960); some bearing as much as 15 to 20 percent U_3O_8. In this investigation pyrochlore has been observed to occur in Søvite inclusions in Rauhaugite. It is also possible that rutile could also contain niobium, but this is presently unconfirmed.

Apatite is evenly distributed and varies from about 5 percent to 15 percent of the Rauhaugite. Corresponding phosphate geochemical values from the samples taken for this examination indicate values ranging from 2 to 7 percent P_2O_5.

Vanadium mineralization is indicated by anomalous geochemical values ranging from 0.02 to 0.03 percent. It appears to occur in both Basic Silicate Rocks and Rauhaugite and the mineral phase that it occurs in is yet to be identified.

Rare Earth Mineralization

Anomalous rare earth mineralization occurs in the central portion of the Tuftestollen at about 142.450 - 51.270. Here two principal forms are registered.

Rødbergite is indicated to contain dispersed low-grade rare-earth mineralization ranging from about 0.1 to 1.0 percent lanthanum, cerium, and neodymium, and a maximum of 2 percent total rare earths is indicated, according to K. Mørk. The rare earth-bearing mineral phases have not been identified, but carbonates are suspected.

One sample of near-massive sulfide and magnetite mineralization (Table 11) mixed with iron oxides and bastnasite (identified by microprobe) yielded the highest rare-earth concentration registered in the complex, according to K. Mørk. This sample contains 3 percent combined lanthanum, cerium, and neodymium and a total rare-earth content of 6 percent is indicated. The sample was collected from a mineralized fault zone about 2 meters wide. This is a northwest-striking fault zone and it may be typical of the fault zones mined for iron in the Gruveåsen, as its southeast extension appears to connect with a large patch of iron mineralization shown on Sæther's (1957) geologic map, and would crop out at about 142.100 - 51.500 on Plate 1.

Fe	22.0
Si	0.8
Mg	0.25
Al	0.16
P	0.15
Na	0.06
Ti	0.011
K	<0.5
Ca	1.2
Mn	0.020
Ba	0.020
Sr	0.014
V	0.007
Nb	0.01
Y	<0.005
Th	0.020
S	14.00
La	1.1
Ce	1.6
Nd	0.30

TABLE 11. GEOCHEMICAL ANALYSIS OF SAMPLE F0113 - BEARING HIGH RARE EARTH GEOCHEMICAL VALUES.

CONCLUSIONS

The area mapped represents the northwest portion of a magmatically-zoned carbonatite complex. A comagmatic suite of intrusive igneous phases developed in the following sequence: 1 - Basic Silicate Rocks, 2 - Søvite, 3 - Rauhaugite and 4 - Damtjèrnite. Basic Silicate Rocks grade to Søvite and are regarded as the early immiscible silicate that separated from a carbonate-rich, silicate magma. Rauhaugite apparently is gradational with its associated silicate phase, which is Damtjernite. Rauhaugite intruded and dissolved large volumes of Søvite and Basic Silicate Rocks.

The emplacement of Basic Silicate Rocks and Søvite in the mapped area was structurally controlled by a northeast-striking conjugate fracture system. This fracture system exerted fundamental controls on the geometry of both the carbonatite phases and their contained mineralization.

Well-defined zones of alteration formed incident to pulses of igneous injection. Fenitization of Precambrian wall rocks correlates with the emplacement of an early Basic Silicate magma. Alkali-feldspar flooding of fenitized Precambrian rocks correlates with the emplacement of Søvite magma. Rødbergization bears a spatial relationship to the edge of the Rauhaugite body and may be its alteration (fenitization) zone.

The types of mineralization indicated thus far are: primary magmatic segrations of pyrochlore, apatite, and magnetite (along with Nb, Ta, U, P, and V) in Søvite and Rauhaugite; and hydrothermal introduction of rare-earth/iron mineralization to form Rødbergite.

The pyrochlore of the Hydro zone contains uranium and tantalum in addition to niobium. Reserves on the order of a minimum of 3 million metric tons with Nb_2O_5 grading between 0.1 and 0.4 percent are indicated. The possibility of increasing this tonnage by as much as several times is substantial.

The Tufte zone consists of Rauhaugite mineralized with columbite(?) and apatite; tonnage and grade of mineralization are unknown at present.

Dispersed rare earth mineralization is related to the development of Rødbergite. Higher grade rare earth/iron mineralization appears related to late, northwest-striking fault zones that may be akin to similar mineralized faults in the area of the Gruveåsen.

RECOMMENDATIONS

1) A drill program should be designed to test niobium mineralization and associated uranium, tantalum, phosphorous, and vanadium mineralization in the Hydro zone. Chemical and microprobe analyses of pyrochlores should be done on a systematic basis to determine their niobium, uranium, and tantalum content.

2) Surface geologic mapping and geochemical sampling should be accomplished in the Tufte area. Microprobe examination of the niobium-bearing mineral phases should be checked. The possibility of uranium and tantalum mineralization should be checked here as well. The aim should be to gain enough geologic information to test the Tufte zone by drilling in 1982.

3) The field work of V. Viik (Summer, 1980) in the Vipeto area should be compiled with the results of this examination. Geologic mapping coverage should be extended to the south margin of the complex, thus completing a north-to-south cross section of geologic information.

4) An effort should be made to correlate the ground magnetic map with the geology of this area. Magnetic susceptibility measurements must be made in the Tuftestollen using the underground mapping and geology as a guide.

5) The mineralogy and geologic controls on anomalous rare earth mineralization encountered in the Tuftestollen should be checked thoroughly.

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APPENDIX - GEOCHEMICAL ANALYSES

ultater (%):

ove	Nb	Y	Th	S	La	Ce	Nd
2	0,006	0,006	<0,005	0,08	0,017	0,020	0,011
3	0.042	<0,005	<0.005	0,04	0.01	<0.01	<0.01
4	<0.005	<0,005	<0,005	<0,03	<0,01	<0.01	<0,01
5	<0.005	<0,005	<0.005	0.04	<0,01	<0.01	<0,01
6	0.009	<0,005	<0,005	0,06	<0,01	<0,01	<0,01
7	<0.005	0.006	<0.005	<0,03	<0,01	0,01	<0,01
8	0.019	<0,005	0,010	<0,03	0,020	0,020	<0,01
9	0.095	<0,005	<0,005	0,08	<0,01	0,019	0,015
10	0,11	<0,005	<0.005	<0,03	0,010	0.020	0,012
12	0,80	0,006	0.046	0,07	0,020	0,045	0,028
13	<0,005	<0,005	<0,005	0,05	<0,01	<0,01	<0,01
16	0,19	0,009	0,024	0,30	0,029	0,070	0,033
17	0,38	0,010	0,045	0,34	0,033	0,075	0,038
18	0,049	<0,005	<0,005	1,5	0,022	0,045	0,025
19	0,024	<0,005	<0,005	0,04	<0,01	<0,01	<0,01
20	1,5	0,041	0,90	0,04	0,13	0,53	0,19
23	0,048	<0,005	0,005	2,7	<0,01	0,020	<0,01
24	0,10	0,010	0,015	0,12	0,032	0,075	0,040
25	0,045	0,011	0,012	0,27	0,034	0,075	0,033
26	0,14	0.005	0,014	0,16	0,028	0,050	0,025
27	0,33	0,006	0,006	0,11	0,020	0,055	0,025
28	0,022	<0,005	<0,005	0,12	0,014	0,020	0,012
29	0,077	0,009	0,015	0,11	0,040	0,070	0,025
30	0.015	<0.005	<0.005	0,21	<0,01	<0.01	<0.01
31	0.012	<0,005	<0,005	0,08	<0,01	<0.01	<0.01
32	0.20	0,017	0,031	0,34	0,030	0,070	0,033
33	0.008	<0,005	<0,005	0,07	<0,01	<0,01	<0,01
34 A	0,51	0,009	0,030	0,43	0,019	0,045	0,021
34 B	0,45	0,008	0,041	0,35	0,017	0,045	0,023
35	0,25	0,006	<0,005	1,0	0,019	0,045	0,023
36	0,39	0,006	0,011	0,28	0,018	0,050	0,020
37	0,022	<0,005	0,005	0,95	0,014	0,023	0,012
44 A	0,010	<0,005	<0,005	0,05	0.013	0,025	0,020
49	0,083	0,015	0,032	0,62	0,11	0,17	0,050
50	0,22	0,006	0,019	0,32	0,028	0,057	0,028
51	0,006	<0,005	<0,005	0,18	<0,01	<0,01	<0,01
52	0,009	0,008	<0,005	0,17	0,030	0,065	0,030
53	0,016	0,013	0,010	0,25	0,027	0,060	0,032
56	0,030	0,010	0,014	0,12	0,055	0,11	0,039
59	0,006	0,008	<0,005	0,07	0,012	0,021	0,010
60	0,026	0,006	<0,005	0,38	0,010	0,015	0,010
61	0,026	<0,005	<0,005	0,18	<0,01	<0,01	<0,01
62	0,021	<0,005	<0,005	0,05	<0,01	<0,01	<0,01
64	0,009	<0,005	<0,005	0,08	<0,01	<0,01	<0,0
65	<0,005	<0,005	<0,005	0,19	<0,01	<0,01	<0,0
66	0,010	<0,005	<0,005	0,06	<0,01	<0,01	<0,0
67	0,20	0,008	0,019	0,18	0,028	0,065	0,03
68	0,030	<0,005	<0,005	0,10	<0,01	<0,01	<0,0
69	0,011	<0,005	<0,005	0,12	<0,01	<0,01	<0,0

Resultater (%):

Prøve	Nb	Y	Th	S	La	Ce	Nd
F-70	0,028	0,009	<0,005	0,33	0,032	0,068	0,031
71	0,050	0,006	0,008	0,54	0,016	0,030	0,018
71A	0,10	0,011	0,015	0,46	0,035	0,050	0,028
72	0,19	0,010	0,028	0,82	0,032	0,070	0,03[illegible]
73	0,011	<0,005	0,009	0,12	<0,01	<0,01	<0,0[illegible]
74	0,044	<0,005	<0,005	0,18	0,011	0,023	[illegible]
75	0,018	<0,005	<0,005	0,14	0,01	0,015	<0,0[illegible]
76	0,023	0,008	0,005	0,40	0,023	0,039	0,01[illegible]
77	0,037	0,005	<0,005	0,56	0,017	0,031	0,01[illegible]
78	0,24	0,008	<0,005	0,30	0,033	0,070	0,03[illegible]
79	0,14	0,009	0,015	0,41	0,028	0,062	0,03[illegible]
80	0,14	0,008	0,017	0,40	0,028	0,060	0,03[illegible]
82	0,032	0,009	0,007	0,25	0,028	0,059	0,02[illegible]
83	0,050	0,005	0,013	0,53	0,011	0,030	0,01[illegible]
84	0,12	0,009	0,015	0,18	0,032	0,072	0,03[illegible]
85	0,074	0,016	0,014	0,79	0,029	0,067	0,03[illegible]
86	0,031	<0,005	<0,005	0,41	<0,01	0,01	<0,0[illegible]
87	0,024	0,007	0,011	0,57	<0,01	<0,01	<0,0[illegible]
88	0,009	<0,005	0,16	1,6	0,39	0,80	0,3[illegible]
89	0,069	0,007	0,008	0,21	<0,01	0,01	<0,01
90	0,075	0,006	<0,005	0,48	0,013	0,023	0,01
91	0,20	0,013	0,015	0,41	0,024	0,048	0,03
92	0,007	0,005	0,008	0,09	<0,01	0,014	<0,0[illegible]
93	0,20	0,012	0,012	0,58	0,032	0,080	0,04
94	0,055	0,009	0,010	0,30	0,024	0,055	0,02
95	<0,005	<0,005	<0,005	0,07	≤0,01	0,014	<0,0[illegible]
96	0,015	<0,005	0,008	2,6	0,01	0,017	0,01
97	0,080	0,009	0,009	0,46	0,023	0,060	0,02
98	0,012	<0,005	0,005	0,08	<0,01	≤0,01	<0,0[illegible]
99	0,014	<0,005	0,013	0,16	0,021	0,036	0,0[illegible]
100	0,011	<0,005	0,005	0,13	<0,01	≤0,01	<0,01
101	0,020	0,015	0,011	0,38	0,030	0,070	0,0[illegible]
102	0,11	0,005	0,007	0,18	0,010	0,017	0,01
103	0,040	0,020	0,032	0,40	0,020	0,050	0,0[illegible]
104	0,105	0,009	0,011	0,46	0,029	0,067	0,03
105	0,040	0,016	0,030	0,83	0,28	0,55	0,14
106	0,038	0,024	0,050	0,49	0,060	0,18	0,1[illegible]
107	0,012	0,009	<0,005	0,30	0,024	0,052	[illegible]
108	0,085	0,007	0,006	0,46	0,050	0,090	0,03
109	0,17	0,009	0,013	0,17	0,11	0,19	0,0[illegible]
110	0,008	<0,005	0,031	0,83	0,27	0,50	0,14
111	0,061	0,006	0,040	0,59	0,29	0,53	0,2[illegible]
112	0,008	<0,005	0,019	0,48	0,19	0,35	0,10
113	0,01	<0,005	0,020	14.	1,1	1,6	0,3[illegible]
114	0,040	0,006	0,016	6,24	0,40	0,70	[illegible]
115	0,060	0,006	0,023	0,12	0,23	0,50	[illegible]
116	<0,005	0,009	<0,005	0,65	0,025	0,052	0,0[illegible]
117	0,018	0,009	0,007	0,55	0,022	0,052	0,0[illegible]
118	0,061	0,008	0,012	0,20	0,025	0,057	0,0[illegible]
[illegible]	[illegible]	<0,005	0,006	[illegible]	[illegible]	[illegible]	[illegible]

Prøve	Nb	Y	Th	S	La	Ce	Nd
120	0.020	0.015	0.016	0,15	0,035	0.080	0.04[illegible]
121	0,40	0.010	0,022	0,48	0.033	0.070	0.03[illegible]
122	0.23	0.007	0.007	0.22	0.043	0.076	0.03[illegible]
123	0,011	0.011	<0.005	0,17	0.024	0.056	0.01[illegible]
124	<0.005	<0.005	<0.005	0,09	<0.01	<0.01	<0.01
125	0.060	<0.005	0,005	0,30	0,017	0.050	0.02[illegible]
127	0,44	0.010	0,017	0,53	0,028	0.063	0.02[illegible]
128	0.094	<0.005	<0,005	0,08	0,017	0.036	0.02[illegible]
129	0.015	0.005	<0.005	0.36	0.015	0.035	0.02[illegible]
131	0.053	0.009	0,012	0,35	0.029	0.065	0.03[illegible]
133	0.16	<0.005	0,007	0,28	0.01	0.016	0.01
134	0.038	0.007	0,006	0.29	0,026	0.065	0.03[illegible]
136	0.56	0.005	0.018	1,3	(0,03)	0,055	0.03[illegible]
137	0.41	<0.005	0.011	0,55	(0.02)	0.037	0.02[illegible]
138	0.014	0.008	<0,005	0,14	0.021	0.048	0.0[illegible]
139	0.15	0.007	<0.005	0,12	<0.01	0.020	0.01

* not completely dissolved

	Fe	Si	Mg	Al	P	Na	Ti	K	Ca	Mn	Ba	Sr	V
F0002	4.1	26.2	0.94	7.0	0.15	4.5	0.21	2.3	2.8	0.10	0.29	0.048	0.006
3	0.28	29.1	0.27	9.6	0.039	2.6	0.007	9.3	0.26	0.017	0.29	0.013	<0.005
4	2.1	32.0	0.35	5.9	0.051	3.7	0.14	3.5	0.39	0.041	0.030	0.010	0.005
5	2.7	29.6	0.77	6.4	0.037	3.3	0.22	4.3	1.6	0.11	0.099	0.021	0.006
6	2.6	28.3	1.3	6.3	0.14	3.5	0.15	3.7	2.4	0.10	0.11	0.039	0.011
7	1.5	32.3	0.26	6.5	0.040	2.8	0.13	3.1	1.0	0.026	0.096	0.015	<0.005
8	2.4	23.5	0.83	10.5	0.026	0.25	0.17	9.6	2.4	0.13	0.24	0.026	"
9	1.2	1.7	10.5	0.23	0.80	0.35	0.008	0.2	21.0	0.39	0.051	0.33	"
10	4.0	13.4	9.6	3.2	1.5	0.08	0.080	4.4	11.5	0.19	0.019	0.13	"
12	1.5	2.1	10.1	0.15	1.2	0.42	0.030	0.1	21.8	0.43	0.079	0.32	"
13	4.2	26.9	0.84	7.2	0.21	4.8	0.17	4.0	3.5	0.087	0.073	0.051	0.011
16	1.0	1.3	2.0	0.22	1.2	0.15	0.010	0.15	34.0	0.26	0.072	0.58	<0.005
17	1.7	2.6	2.6	0.29	2.9	0.30	0.047	0.32	32.0	0.23	0.062	0.56	"
18	3.1	17.0	1.2	5.1	1.0	3.9	0.085	0.72	15.8	0.14	0.049	0.32	"
19	3.7	21.9	2.7	5.2	0.15	3.1	0.17	2.8	9.9	0.11	0.036	0.039	0.010
20 *	(0.14)	(1.3)	(0.16)	(2.2)	(0.033)	(0.2)	(2.3)	(0.1)	(1.2)	(0.07)	(1.2)	(0.022)	(0.020)
23	7.7	13.6	4.4	2.4	0.48	0.090	0.057	0.17	16.5	0.34	0.017	0.053	<0.005
24	0.65	1.6	1.7	0.24	2.4	0.22	0.009	<0.05	35.8	0.23	0.16	0.50	"
25	1.4	1.6	1.5	0.11	0.75	0.11	0.010	<0.05	35.7	0.28	0.051	0.38	"

	Fe	Si	Mg	Al	P	Na	Ti	K	Ca	Mn	Ba	Sr	V
26	2,9	14,3	8,5	3,8	1,2	1,1	0.16	4.6	14.3	0,24	0,29	0,23	<0,005
27	6,7	1,5	1,2	0.23	2,1	0,10	0.14	1,8	32,1	0.28	0.055	0,52	0.045
28	8,2	16,8	7.8	4.3	0.47	0,44	1.9	3.7	9.6	0,18	0.52	0,13	0,025
29	3,9	8.8	4,7	0.42	1.3	0.81	0,11	0.40	22,6	0.50	0,11	0.26	0.006
30	7.3	24,5	3,6	6,0	0,32	4.0	0.32	1.9	4.8	0,14	0,022	0.070	0.036
31	5.9	30.5	0,75	7,3	0,14	6.1	0.23	3,4	2,7	0,12	0,17	0.031	0,026
32	3,6	3,7	2,4	0,58	1,5	0.21	0.091	0.56	31.2	0.24	0.32	0.43	0.016
33	2,1	31.7	0,41	9,0	0,040	6.3	0.097	4.4	1,5	0.051	0.24	0,030	0.008
34A	2,5	3,0	1,2	0,46	2.2	0.26	0,077	0.33	35,1	0.16	0,11	0.53	0.007
34B	8,2	3,2	1,5	0.23	1,6	0,27	0,31	0,12	30,8	0.22	0,27	0.51	0,057
35	4.8	1.3	0.75	0,11	1.5	0,13	0,088	0,05	33,0	0.25	0,045	0.55	0.031
36	3,4	1,4	1,1	0,15	0.97	0,12	0,078	0,10	33,6	0,18	0.047	0,53	0.020
37	5.8	16.3	2,2	3.4	0,64	2,5	0.11	3.4	15.0	0,14	0,18	0.32	0.052
44A	2,9	2.1	0,70	0,11	0,71	0,16	0,007	<0.05	21,1	0,70	0,038	0,40	<0.005
49	5,1	6.8	6,8	0,89	0,29	0,14	0,081	0,75	19.8	0,42	0.90	0,21	0,009
50	7.9	22,1	3,2	8,6	0.39	3,3	1.3	1,4	5,1	0,14	0,12	0.12	0,022
51	4,6	5,5	3,7	0,42	1,6	1,5	0,052	0,20	30.1	0.32	0,29	0.57	0,014

	Fe	Si	Mg	Al	P	Na	Ti	K	Ca	Mn	Ba	Sr	V
52	3,4	1,1	1,4	0,15	1,7	0.22	0,099	<0,5	33,8	0,13	0.054	0.38	0,008
53	3,7	4,2	3,1	0,99	1,3	0.31	0,30	<0,5	28.9	0,19	0.099	0.38	0.010
56	7.0	9,9	10,1	2,3	0.97	0.20	0.77	0,7	14.7	0.43	0.44	0.25	0.014
59	4.6	27,3	1,2	6.4	0.41	6.0	0.30	2.4	6.9	0,20	0,14	0.14	0.014
60	3,8	25,8	1,1	6.4	0.34	4.7	0.49	1,8	5.1	0,18	0,12	0.089	0.010
61	1.7	30,1	0,42	6.6	0.11	3.3	0,092	3,0	3.9	0.10	0,19	0.068	<0.005
62	1.9	30,5	0,32	7,5	0.13	3,0	0.091	4.2	3.1	0.095	0.24	0.067	<0.005
64	3.1	31.3	0.75	6,9	0.12	4.2	0.33	2,7	2.3	0.10	0.18	0.061	0.009
65	8.8	21.6	3,5	8,5	0.29	2.9	1,8	0,5	5.4	0.13	0,093	0,12	0,029
66	3,1	32,3	1,5	6.7	0,17	5.9	0.21	2.5	1,2	0,10	0,16	0.025	0.008
67	1.3	3,0	3,1	0,78	0.85	0.29	0.054	<0,5	31,9	0.27	0,098	0.56	<0.005
68	4,5	28,0	1.3	6,6	0.31	6.2	0.21	2,0	2,6	0,12	0.068	0,063	0.014
69	2,8	28,6	1,1	7,4	0.35	5,8	0,12	3,5	1,9	0,082	0,099	0,048	0.010
70	1,1	1,3	1,7	0,22	0,43	0.30	0,005	<0.5	34,8	0.32	0.073	0,61	<0,005
71	6,0	14,8	5.2	4,2	1,4	1,2	0,78	2,1	13,1	0.20	0,43	0.20	0,020
71 A	3,9	6,7	3,1	1,8	1,9	0,23	0,19	<0.5	26,5	0,19	0,051	0.37	<0,005
72	2,1	3,7	2,1	0,28	1,9	1,0	0,024	<0,5	36,6	0,31	0.22	0,49	<0,005
73	2,7	32,7	0,64	6,2	0,21	3,5	0,17	3,1	3,2	0,16	0,13	0.059	0.007
74	3,1	26,6	1,8	6,1	0,29	4,3	0.20	2,9	4,5	0,14	0,19	0,091	0,009

	Fe	Si	Mg	Al	P	Na	Ti	K	Ca	Mn	Ba	Sr	V
75	3.4	26.2	1.1	6.3	0.28	5.1	0.37	2.3	6.1	0.15	0.083	0.15	0.013
76	6.9	22.7	2.4	5.6	0.53	4.0	1.3	1.7	10.6	0.24	0.40	0.30	0.026
77	4.3	21.5	2.7	6.1	0.65	3.6	0.45	2.1	7.8	0.15	0.23	0.23	0.012
78	0.89	1.6	1.2	0.18	0.34	0.32	0.018	<0.5	35.7	0.28	0.087	0.70	<0.005
79	1.5	3.3	2.4	0.77	1.3	0.53	0.015	<0.5	32.6	0.22	0.084	0.56	<0.005
80	1.9	1.7	1.9	0.20	1.3	0.31	0.015	<0.5	35.9	0.26	0.11	0.59	<0.005
82	1.0	3.5	0.80	0.28	1.1	1.1	0.020	<0.5	40.7	0.23	0.28	0.43	<0.005
83	5.4	19.1	3.2	6.3	0.82	1.7	0.23	2.8	9.9	0.17	0.46	0.12	0.007
84	1.0	3.1	2.3	0.37	1.1	0.89	0.019	<0.5	35.8	0.27	0.17	0.62	<0.005
85	2.2	2.2	2.2	0.37	1.4	0.27	0.020	<0.5	34.1	0.27	0.19	0.48	<0.005
86	3.3	24.7	2.4	6.7	0.26	3.9	0.24	3.0	6.5	0.14	0.36	0.10	0.007
87	6.5	20.9	3.0	3.1	0.24	0.23	0.25	0.5	11.6	0.34	0.26	0.050	0.012
88	11.1	7.5	4.8	0.40	0.15	0.20	0.017	<0.5	14.7	1.1	2.4	0.20	0.016
89	1.7	25.2	0.47	7.5	0.37	3.3	0.18	4.0	6.7	0.11	0.37	0.13	0.010
90	3.9	15.8	2.6	5.0	0.55	2.1	0.44	2.2	14.1	0.23	0.097	0.26	0.010
91	3.1	5.8	2.6	1.3	2.2	0.62	0.19	0.6	27.3	0.27	0.21	0.57	0.005
92	3.6	25.2	1.4	6.0	0.21	4.1	0.27	2.8	4.9	0.19	0.090	0.082	0.008
93	2.0	7.2	3.0	1.0	3.8	1.5	0.14	0.6	30.3	0.22	0.24	0.51	<0.005
94	1.1	1.2	0.60	0.052	0.50	0.30	0.024	<0.5	36.8	0.29	0.17	0.63	<0.005

	Fe	Si	Mg	Al	P	Na	Ti	K	Ca	Mn	Ba	Sr	V
95	4.0	28.1	1.6	6.1	0.16	4.2	0.26	2.8	3.1	0.14	0.089	0.064	0.008
96	7.4	20.7	2.6	4.6	0.040	0.21	0.11	<0.5	8.5	0.27	0.021	0.072	0.011
97	3.[illegible]	2.1	1.0	0.17	1.5	0.48	0.13	<0.5	36.8	0.24	0.11	0.67	0.011
98	2.9	27.8	0.72	8.3	0.12	6.1	0.15	2.8	3.9	0.12	0.16	0.082	<0.005
99	6.2	25.1	2.2	6.6	0.27	3.3	0.30	2.8	4.6	0.16	0.19	0.080	0.017
100	2.5	27.3	1.2	8.5	0.14	4.2	0.10	3.7	3.1	0.11	0.40	0.065	0.007
101	2.9	3.3	1.6	0.62	1.5	0.42	0.053	<0.5	32.5	0.24	0.12	0.48	<0.005
102	5.4	19.6	2.6	6.6	0.67	0.67	0.29	5.0	8.5	0.18	0.45	0.096	0.009
103	5.6	2.2	6.4	0.49	2.3	0.20	0.25	<0.5	24.6	0.49	0.86	0.17	<0.005
104	7.6	5.0	2.6	0.80	3.5	0.19	0.21	<0.5	25.5	0.40	0.18	0.30	0.014
105	7.6	1.2	5.5	0.15	3.2	0.19	0.016	<0.5	23.7	0.81	1.8	0.19	<0.005
106	4.0	9.4	2.0	0.43	7.4	0.21	0.027	<0.5	24.7	0.39	0.20	0.36	<0.005
107	3.5	1.5	1.8	0.24	3.7	0.21	0.062	<0.5	34.1	0.20	0.083	0.25	<0.005
108	4.8	3.3	7.9	0.33	2.7	0.85	0.012	<0.5	23.3	0.78	0.35	0.42	<0.005
109	5.3	1.3	6.3	0.26	1.3	0.17	0.016	<0.5	24.2	0.80	0.26	0.11	<0.005
110	6.0	0.8	7.9	0.[illegible]	0.31	0.19	0.031	<0.5	20.[illegible]	1.04	0.75	0.48	<0.005
111	2.9	1.2	2.7	0.20	0.22	0.21	0.014	<0.5	[illegible]	0.19	0.93	[illegible]	[illegible]

	Fe	Si	Mg	Al	P	Na	Ti	K	Ca	Mn	Ba	Sr	V
112	5.8	1.5	7.1	0.20	0.20	0.28	0.005	<0.5	23.3	1.0	0.67	0.36	<0.005
113	22.0	0.8	0.25	0.16	0.15	0.06	0.011	<0.5	1.2	0.020	0.020	0.014	0.007
114	4.2	1.1	5.7	0.16	1.5	0.20	0.014	<0.5	27.4	0.91	0.20	0.28	<0.005
115	2.3	1.4	0.93	0.75	0.97	0.16	0.075	<0.5	32.7	0.21	0.040	0.074	<0.005
116	3.2	2.4	2.1	0.47	1.9	0.21	0.15	<0.5	30.0	0.15	0.10	0.28	<0.005
117	10.1	11.4	6.5	4.2	2.1	0.53	1.4	0.9	12.8	0.13	0.16	0.095	0.020
118	2.8	0.9	4.0	0.21	2.8	0.23	0.014	<0.5	28.3	0.34	0.16	0.18	<0.005
119	4.1	21.0	2.7	6.6	0.20	3.9	0.033	0.8	6.5	0.28	0.20	0.088	<0.005
120	5.3	5.5	2.7	1.5	4.7	0.18	0.32	<0.5	25.0	0.20	0.14	0.26	0.015
121	6.2	0.5	6.8	0.05	1.8	0.14	0.041	<0.5	20.9	0.64	0.26	0.20	<0.005
122	3.0	0.7	8.7	0.05	1.8	0.17	0.011	<0.5	21.7	0.62	0.042	0.31	<0.005
123	1.5	1.3	1.2	0.38	2.1	0.23	0.039	<0.5	34.0	0.13	0.062	0.33	<0.005
124	8.2	20.1	7.9	2.5	0.13	1.1	1.4	0.5	9.6	0.14	0.10	0.050	0.034
125	2.8	1.0	8.2	0.03	0.93	0.14	0.008	<0.5	22.0	0.62	0.032	0.31	<0.005
126													
127	4.1	0.6	2.4	0.05	2.3	0.16	0.060	<0.5	27.7	0.36	0.025	0.30	<0.005
128	2.6	0.7	8.6	0.07	1.3	0.13	0.024	<0.5	20.3	0.59	0.010	0.34	<0.005
129	6.6	11.6	5.2	3.7	1.2	0.49	0.91	<0.5	12.[illegible]	0.21	0.19	0.18	0.018

	Fe	Si	Mg	Al	P	Na	Ti	K	Ca	Mn	Ba	Sr	V
131	1.6	0.7	2.1	0.14	2.4	0.18	0.012	<0.5	31.9	0.26	0.054	0.20	<0.005
133	2.8	1.0	9.8	0.12	1.1	0.18	0.042	<0.5	20.8	0.49	0.017	0.35	<0.005
134	9.0	11.9	6.0	3.6	1.9	1.2	1.9	2.1	15.3	0.26	0.42	0.20	0.018
136	8.2	1.2	7.8	0.046	3.1	0.16	0.15	<0.5	23.1	0.43	0.011	0.39	0.020
137	11.7	1.6	7.4	0.11	2.0	0.30	0.25	<0.5	23.4	0.43	0.046	0.31	0.034
138	1.3	0.7	1.2	0.20	1.0	0.20	0.034	<0.5	37.1	0.19	0.076	0.42	<0.005
139	1.4	0.8	2.0	0.09	0.74	0.26	0.052	<0.5	37.6	0.39	0.069	0.15	<0.005