SVERIGES GEOLOGISKA UNDERSÖKNING

SER. Ca AVHANDLINGAR OCH UPPSATSER I A4 NR 65

BJÖRN ÖHLANDER

PROTEROZOIC MINERALIZATIONS ASSOCIATED WITH GRANITOIDS IN NORTHERN SWEDEN

7th IAGOD SYMPOSIUM
AND NORDKALOTT PROJECT MEETING

EXCURSION GUIDE NO 7

UPPSALA 1986

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With a contribution by P. Weihed

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TO THE MEMORY OF MICHAEL R. WILSON

2/9 1943 – 14/6 1985

The present excursion guide concerns granitoid-related mineralizations in the Proterozoic of northern Sweden. As originally planned, the senior leader would have been Mike Wilson. It was Mike who took the initiative in February 1985 to organize the excursion and write this guide book in cooperation with Björn Öhlander. A few months later, Mike and his wife Carol were killed in Managua, Nicaragua, on a geological mission for SAREC (Swedish Agency for Research Cooperation with Developing Countries).

Mike Wilson's first contact with Scandinavian geology was as a Manchester University PhD student in the late 1960 ies, working with metamorphism, stratigraphy and structures in the Sulitjelma area, Norway. After a few years in the isotope laboratory at the Free University in Amsterdam, Mike and Carol moved to Sweden and were both employed by the Geological Survey (SGU) in 1973. Mike was primarily concerned with uranium prospecting and led the SGU activities in this field for several years. His interest in isotope geology led him in more recent years to focus upon granite petrology and petrogenesis as well as on mineralizations associated with granitoids. He became Sweden's leading expert on the application of modern techniques to the study of Proterozoic granitoids.

Due to Mike Wilson's tragic death, the responsibility for this excursion has fallen on the shoulders of Björn Öhlander. Björn's efforts to fulfill the original plans for this excursion are most appreciated. We have decided to dedicate this guide book to Mike, whose competence and enthusiasm are missed in many sectors of geology in Sweden today.

Krister Sundblad

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Falu copper mine has been continuously mined for more than 900 years. Copper plate engraving from 1687 in Dahlberg's *Svecia Antiqua et Hodierna*.

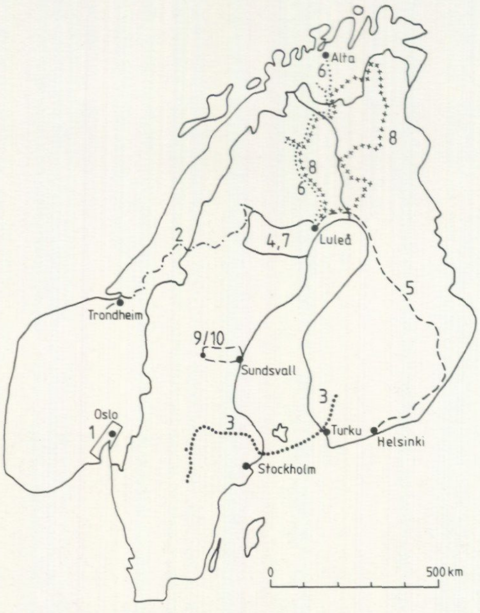
FOREWORD

Mining has ancient traditions in Scandinavia and Finland. In Bergslagen, Sweden, numerous mines produced Cu, Fe and Ag already during the medieval period. Some of them, e.g. Falun and Dannemora, are still active and are thus among the oldest operating mines in the world. Minerals like scheelite, gahnite and långbanite were first recognized in this region and the word skarn (originally having a pejorative connotation in Swedish meaning crap and whore) was used as a name for a certain mineral association for the first time by the old miners in Bergslagen. The most famous mining districts in Norway are Kongsberg, where silver was produced 1623–1957, and Røros, where copper was mined from 1644 until recently. The first mine in Finland was the Ojamo iron ore deposit, which was opened in 1540.

In addition to these ancient workings, ore bodies in several new mining districts have been exploited during the last century. Some of the most important of these occur in northern Sweden such as the Kiruna iron ores, the sulphide ores in the Skellefte district, the Laisvall Pb-mine and the Aitik Cu-Au mine. The sulphide ores in the Outokumpu district and in the Vihanti-Pyhäsalmi area are the most well-known Finnish deposits discovered during this century. In Norway, numerous deposits of pyrite and base metals were discovered round the turn of the century in the Sulitjelma and Grong districts and have been of major importance for the Norwegian mining industry. The discovery of extensive Mo-mineralization in the Oslo area, Norway and Pt-mineralization in the Kemi area, Finland have not led to any significant mining but have revealed new aspects of the metallogeny in the Nordic countries.

As a result of this long tradition in mining, the question of how ores are formed has been debated longer than any other geological problem in Scandinavia and Finland. It is therefore of special interest for the Nordic countries that the International Association on the Genesis of Ore Deposits (IAGOD) this year will arrange its 7th symposium in Scandinavia. The symposium, which is held in Luleå, Sweden, is arranged by the Geological Surveys of Sweden, Finland and Norway and the Luleå University of Technology. As an important part of the symposium programme, nine pre- and post-symposium excursions covering most of the important mining districts in Norway, Sweden and Finland are arranged (see overleaf). For these excursions, guide books have been written and are now available amongst the publications of the Geological Survey of Sweden (SGU Ca 59–67). The Swedish part of excursion no 6 was prepared in 1980 and was published by the Geological Survey of Finland. To all who have been involved in planning and organizing the excursions as well as writing the guide books I would like to express my sincere thanks.

Krister Sundblad, Geological Survey of Sweden
coordinater of the IAGOD-excursions 1986



1. Metallogeny associated with the Oslo Paleorift
Guide book: SGU Ca 59.
Excursion leader: S. Olerud.
Topic: Porphyry molybdenum mineralizations (Nordli, Hurdal and Bordvika, Drammen). Native silver-bearing veins at Kongsberg. Mineralizations associated with the Drammen granite; contact metasomatic Zn-Pb deposits (Konnerudkollen), intramagmatic Mo deposits.

2. Stratabound sulphide mineralizations in the central Scandinavian Caledonides
Guide book: SGU Ca 60.
Excursion leaders: M.B. Stephens and A. Reinsbakken.
Topic: Early Palaeozoic, massive Cu-Zn sulphide mineralizations in both volcanic (Gjersvik, Joma, Løkken and Stekenjokk) and sedimentary (Ankarvattnet) environments. The Laisvall sandstone-hosted, disseminated Pb-Zn deposit.

3. Mineral deposits of southwestern Finland and the Bergslagen province, Sweden
Guide book: SGU Ca 61.
Excursion leaders: H. Papunen and I. Lundström.
Topic: Proterozoic Zn-Cu-Pb deposits in volcanosedimentary environments including the mined-out Orijärvi and Aijala deposits in Finland, and the Garpenberg and Åmmeberg deposits in Sweden; the iron ore deposit of Dannemora in Sweden. Deposits associated with intrusive rocks include the Vammala Ni-Cu mine in Finland and the Wigström W deposit in Sweden.

4. Massive sulphide deposits in the Skellefte district
Guide book: SGU Ca 62.
Excursion leader: D. Rickard.
Topic: Proterozoic Cu-Zn-(Pb-As-Au) mineralizations in volcanosedimentary environments, including the Boliden, Långsele, Näsliden and Kristineberg deposits.

5. Proterozoic mineral deposits in central Finland
Guide book: SGU Ca 63.
Excursion leader: G. Gaál.
Topic: Early Proterozoic mineralizations including the Kemi Cr mine, PGE mineralization in the Penikat layered intrusion, Pyhäsalmi Cu-Zn deposit, Outukumpu Cu-Co-Zn mine and the Enonkoski Ni-Cu deposit.

6. Precambrian mineral deposits in northernmost Scandinavia
Guide books: SGU Ca 64 (Norwegian part)
Geol. Surv. Finland (1980), Guide 078 A+C, part 1 (Swedish part)
Excursion leaders: J.S. Sandstad and H. Lindroos.
Topic: Precambrian copper and iron ore deposits including visits to two of the largest mines in northern Europe: Kiirunavaara underground mine (Fe) and Aitik open pit operation (Cu, Au). In addition, the Raipas, Repparfjord, Bidjovagge and Viscaria Cu deposits and Au prospects in the Gällivare area will be shown.

7. Proterozoic mineralizations associated with granitoids
Guide book: SGU Ca 65.
Excursion leader: B. Öhlander.
Topic: Mineralizations associated with Proterozoic granitoid intrusions including the Pleutajokk, Rävaberget and Björklund U deposits, the Allebouda and Kåtaberget Mo deposits, the Storuman W mineralization and Tallberget Cu-Mo deposit.

8. Archaean and Proterozoic geology in northern Finland, Norway and Sweden
Guide book: SGU Ca 66
Excursion leaders: T. Sjöstrand, M. Often and V. Perttunen.
Topic: Archaean and Proterozoic geological environments in the ore-bearing Nordkalott area, including greenstone belts and granulites.

9/10. Enåsen Au deposit and Alnö alkaline complex
Guide book: SGU Ca 67.
Excursion leaders: T. Lundqvist, S. Sundberg and P. Kresten.
Topic: Geology at and around the Proterozoic Enåsen Au deposit and the Alnö alkaline complex.

IAGOD-excursions 1986

PROTEROZOIC MINERALIZATIONS ASSOCIATED WITH GRANITOIDS IN NORTHERN SWEDEN

CONTENTS

INTRODUCTION

Extensive exploration programmes conducted in northern Sweden during the late sixties, seventies and the early eighties by the Geological Survey of Sweden (SGU), the Swedish Geological Company (SGAB), LKAB Prospektering AB (LKAB) and Boliden Mineral AB led to the discovery of a number of U-, Mo-, W-, Sn- and Cu-occurrences associated with Proterozoic granitoids. None of the deposits associated with granitic rocks in northern Sweden are mined, since in general, they are too small and/or are of too low a grade.

The mineral deposits mentioned above are closely associated with various episodes of granitoid development in the Svecokarelian orogeny (duration of plutonic activity approximately 1.89–1.75 Ga, Wilson *et al.* 1985, Skiöld, in press). The Skellefte sulphide ore district, a suggested volcanic arc system, subdivides the Svecokarelian of northern Sweden into two structural provinces; a continental domain in the north (the Karelian continent) and a marine one in the south (the Bothnian basin). The development of Svecokarelian granitoids (1.89–1.75 Ga) in northern Sweden can be divided into two dominant stages which are as follows:

(1) The early stage (1.89–1.84 Ga) comprises essentially mantle-derived magmas composed of granitoid suites which, in general, have a relatively wide compositional range. Calcic, calc-alkalic and alkaline suites are recognized. The latter are found in association with tensional or transverse faulting environments just north of the Skellefte district.

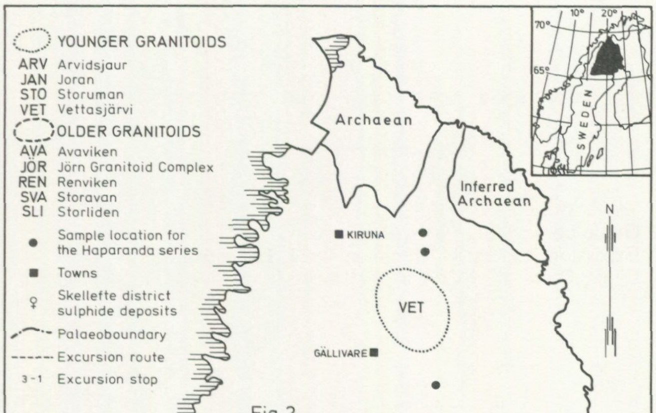


Fig. 1. Precambrian bedrock of northern Sweden showing main crustal provinces and location of granitoid suites discussed in the text. Also indicated is the excursion route.

(2) The late stage (1.80–1.75 Ga) comprises granitoids with a more restricted compositional range. They are derived dominantly from crustal sources of local provenance including Archaean sources in the far north, and Proterozoic sedimentary sources in the Bothnian basin.

Mo-occurrences are confined to the continental domain and are, at least in the southern and southwestern part of the Karelian continent, associated with granites of the older group. The largest Mo-enrichments are of aplitic association.

Porphyry type Cu-occurrences are associated with the oldest intrusions in the northern part of the Skellefte district.

The major U-mineralizations in northern Sweden are located in the continental domain and have been dated to c. 1.75 Ga. In economic terms, the most important U-occurrences are epigenetic veins and impregnations. The host-rocks are, in general, U-enriched rhyolites or granites of the older group. It is speculated that the granites belonging to the younger group, which is approximately coeval with the U-mineralization, provided the driving mechanism to generate the hydrothermal mineralizing fluids.

W- and Sn-enrichments occur both on the continental and on the marine side of the Skellefte district. The former are associated with intrusions that probably belong to the older group. The latter are associated with highly differentiated, U- and Th-rich intrusions, belonging to the younger group, that have been generated from the marine supracrustal rocks.

The excursion will concentrate on granitoids and related mineralizations in the southern parts of the Karelian continent, the Skellefte district and the northern part of the Bothnian basin. Granitic intrusions and supracrustal rocks of all three domains will be visited, and U-, Mo-, Cu- and W-occurrences will be examined. The excursion route is indicated in Fig. 1. Fig. 2 shows a simplified geological map of the excursion area.

REGIONAL SETTING AND METALLOGENY

The Precambrian of northern Sweden is completely dominated by the Proterozoic Svecokarelian rocks (age range c. 1.9–1.75 Ga, Skiöld, in press, Wilson *et al.* 1985). In the far north a gneiss area has yielded Archaean U-Pb zircon ages (Welin *et al.* 1971, Skiöld 1979a). The Archaean is represented by a monotonous series of gneisses, predominantly of acid to intermediate composition (Witschard 1984).

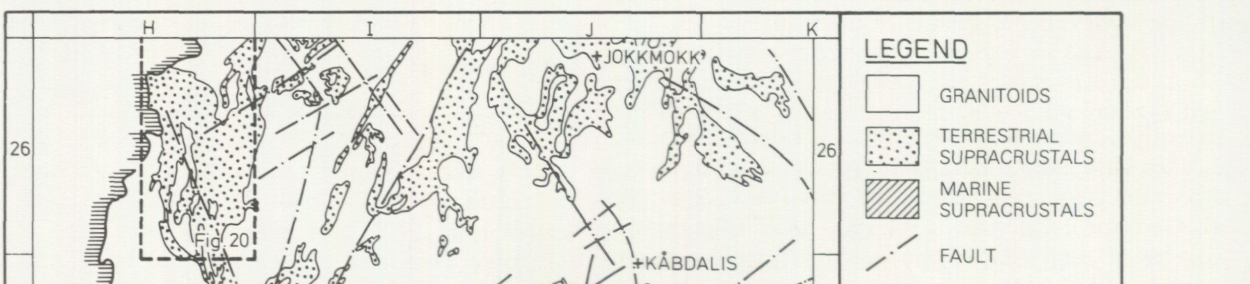


Fig. 2. Simplified geological map of the excursion area. Modified after R. Quesada and P. Ihre (unpublished material, SGAB, Luleå).

Svecokarelian supracrustal provinces

Although the Svecokarelian of northern Sweden is dominated by granitoids, there are sufficient supracrustal suites preserved to allow a subdivision of the region of the basis of palaeoenvironments. The northern part of the area shown in Fig. 1 is dominated by terrestrial supracrustal rocks. It is interpreted as a continental domain, and is termed the Karelian continent (Adamek & Wilson 1979). It is bounded to the south by a narrow volcanic belt, the Skellefte district. To the south of the Skellefte district lies a major province dominated by marine metasediments and basic metavolcanics, termed the Bothnian basin. U-Pb zircon ages of volcanics from the Karelian continent and the Skellefte district lie in the range 1.87–1.91 Ga (Skiöld & Cliff 1984, Skiöld in press, Welin 1985). Greenstone belts surrounding the Archaean and the inferred Archaean areas (Fig. 1) may be slightly older. A Sm-Nd mineral isochron from basaltic metavolcanics from the Kiruna area indicates an age of 1.93±0.05 Ga (Skiöld & Cliff 1984).

The regional fabric of north Sweden is illustrated in Fig. 3, an interpretation of a high-resolution airborne survey. The Karelian continent is subdivided into a number of large domains with low and homogeneous magnetic susceptibility, representing either Archaean basement (in the far north) or homogeneous granite or migmatite.

These domains are separated by wide zones with banded magnetic anomalies and distinct circular structures interpreted as granitoid diapirs, representing mobile zones between the domains. These mobile zones contain metamorphosed greenstone belts, sediments, volcanics, gabbros and intermediate to acid plutonic suites. They also contain most of the ore deposits and mineralizations to be found in this region (Fe, Cu, Au, Mo, W, U), see e.g. Öhlander & Nisca 1985.

Metamorphic grade and the degree of deformation vary considerably throughout the Karelian continent. For example, in the Arvidsjaur district, the supracrustal rocks are of low metamorphic grade. Also, penetrative deformation of the rocks found here is uncommon. In contrast, the supracrustal rocks of the Arjeplog area are strongly deformed and recrystallized in amphibolite facies.

The southern part of the Karelian continent is composed of a wide zone of granitoids and continental supracrustals (dominated by acid metavolcanics often referred to as the "Arvidsjaur porphyries"), metamorphosed to varying degrees. A series of subalkaline to alkaline monzonites and granites in the Arvidsjaur-Storavan district, some 50 km north of the palaeogeographic continental margin, forms together with an extensive peralkaline rhyolitic ignimbrite an alkali magmatic subprovince which is closely related to a major NNE–SSW trending fault zone and associated with Mo- and U-mineralizations (Adamek & Wilson 1979, Walser & Einarsson 1982). The province is characterized by a regional negative gravity anomaly.

The similarity between the stratabound complex sulphide ores of the Skellefte district and those developed in Phanerozoic destructive arcs was first noted by Mitchell & Bell (1973) and developed in detail by Rickard and Zweifel (1975), who proposed a model with a northward-dipping subduction of oceanic crust. Hietanen (1975) and Adamek and Wilson (1977) subsequently proposed similar models. These were based on the chemistry of plutonic associations and on the palaeogeography of the southern margin of the Karelian continent. Further contributions were made by Adamek and Wilson (1979), Rickard (1979), Lundberg (1980), Wilson (1980), Walser and Einarsson (1982), Claesson (1982, 1985), and Pharoah and Pearce (1984).

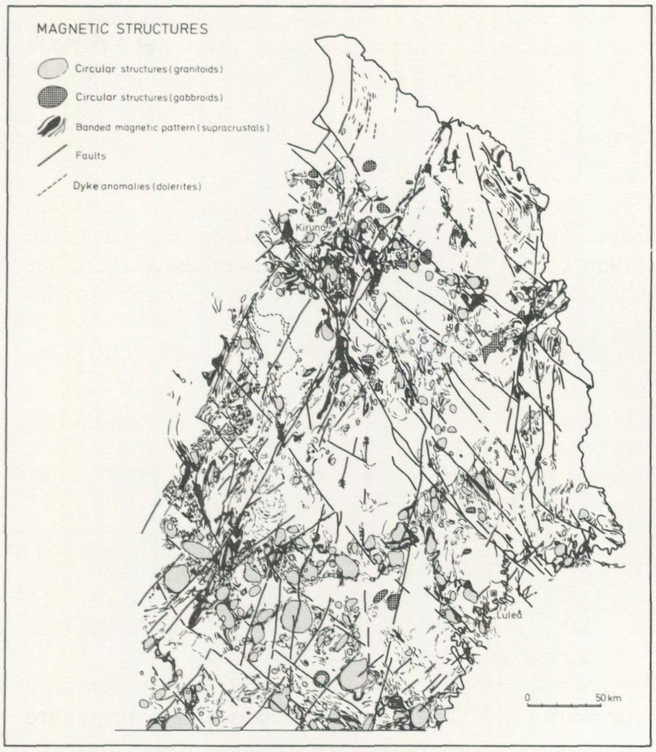


Fig. 3. Interpretation of aeromagnetic measurements. Within the measured areas, white represents low magnetic field (generally granites). After Nisca in Öhlander & Nisca (1985).

The supracrustal rocks of the Skellefte district include a variety of metasediments and metavolcanics which can be divided into two major units, the Skellefte Group and the Vargfors Group (Table 1). The stratabound ores in the Skellefte district are associated with the submarine Skellefte volcanics, belonging to the Skellefte Group. The Jörn granitoid complex is approximately coeval with the Skellefte volcanics (Wilson *et al.*, in press). It intrudes the volcanic rocks, but may be their subvolcanic equivalent. On the northern flank of the district, the Skellefte Group is overlain by the continental volcanites of the Karelian continent. The latter are, however, close in time to the Skellefte Group (Welin 1985, Skiöld, in press), but considerably older than the Vargfors group. Pebbles of the terrestrial volcanics are a major component of the Dödmanberg conglomerate (Vargfors Group).

The metamorphic grade and the degree of deformation of the Skellefte district appears to be relatively low in the north. However, it increases rapidly southwards.

TABLE 1. Stratigraphy of the central part of the Skellefte District. Compiled by L. Widenfalk.

	REVSUND GRANITE (1.77 Ga)	
	VARGFORS GROUP	
DÖDMANBERG FORMATION: – CONGLOMERATES & SANDSTONES		*GALLEJAUR FORMATION:* – GRANITOIDS & VOLCANITES
DÖDMANBERG FACIES – pebbles of reddish volcanics		MONZONITE
	ABBORTJÄRN FORMATION:	
TREHOLMFORS FACIES – pebbles of quartz-porphyry	ABBORRTJÄRN CONGLOMERATE	GABBRO
GALLEJAUR VOLCANOCLASTICS	– granitic pebbles	DACITE
– dacitic matrix – andesitic matrix	litharenite & mudstone at Vargfors canal	ANDESITE
		BASALT
	JÖRN GRANITOIDS (1.89 Ga)	
	SKELLEFTE GROUP	
PHYLLITE SERIES: – Metasediments & mafic volcanites		*MAURLIDEN FORMATION:* – metasediments
interlayered slates, greywackes and mafic volcanites		greywackes and slates with bigger, rounded and more abundant clasts as compared to the Phyllite Series
SKELLEFTE VOLCANICS: – bimodal, but dominantly felsic series of pyroclastics and lavas – stratabound, massive sulphide ores, generally hosted in the upper parts of the series. – occasional strata of fine-grained clastic sediments		

The Bothnian basin is composed of high-grade metasedimentary gneisses, migmatites and late, cross-cutting granites. Some older foliated granitoids also occur. Supracrustal rocks include greywackes, pelites, pillow lavas and an ultramafic breccia. The Bothnian basin may represent slices of flysch and ocean floor in an outer arc accretionary wedge south of the Skellefte district volcanic belt (Wilson *et al.*, in press). The contrast in metamorphism and in the degree of deformation between the southern parts of the Karelian continent, the Skellefte district and the Bothnian basin indicates that the Bothnian basin was depressed to a considerable depth. It was later uplifted to its present relative elevation. Much of the strain accommodating the latter movement is seen in the southern part of the Skellefte district.

Svecokarelian granitoids

The following description of the evolution of Svecokarelian granites in northern Sweden is based mainly on the work of Wilson *et al.* (1985), Wilson *et al.* (in press) and Öhlander *et al.* (in press).

Early Proterozoic granitoid suites in northern Sweden fall into two main groups, an older phase 1.89–1.84 Ga, and a younger phase 1.80–1.75 Ga (Skiöld 1979b, 1981a, 1981b). The earliest intrusions are thus approximately coeval with the volcanic rocks. Various representative granitoid suites have been studied by geochemical and isotope geological methods (Fig. 1).

Older group. In the older group, the Jörn granitoid complex intruded at 1.89 Ga into the base of Skellefte district volcanic arc succession and is associated with porphyry type copper occurrences (see pp. 34–37). It contrasts with four granitoids from the Arvidsjaur district some 50 km further north. The Avaviken and Storavan granites have irregular forms (Fig. 18), while the Storliden granite has a diapiric form. All three are associated with U-, Mo- or W-mineralizations. The Renviken granitoid suite is irregular in shape. These intrusions are also compared with analyses of separate intrusions of the Haparanda suite further to the northeast (Öhlander 1984a). Typical analyses of the various granitoids are shown in Table 2.

The older granitoids can be subdivided geochemically (Fig. 5) into the calcic Jörn complex within the Skellefte district, the calc-alkalic Haparanda suites, and the alkali-calcic to alkalic intrusions of the Arvidsjaur alkaline province (Avaviken, Storavan, Storliden and Renviken). Both the Jörn complex and the Haparanda suite have very low Nb- and Y-contents (Jörn also has low Yb and Ta) and low

TABLE 2. Analyses of representative samples from granitoids.

Granitoid Sample	JOR 1–8	JOR III–15	AVA 124	AVA 177	AVA 602	REN 290	REN 180	SVA 189	SLI 122
SiO_2	71.2	72.0	57.0	72.7	73.3	74.3	76.2	76.7	73.3
TiO_2	0.25	0.26	1.20	0.31	0.31	0.21	0.25	0.10	0.22
Al_2O_3	15.6	14.1	16.5	12.7	13.3	13.3	10.7	11.9	14.0
Fe_2O_3	1.7	0.9	1.6	1.1	0.7	2.2*	1.6	0.6	0.7
FeO	1.7	0.8	6.1	2.0	2.2	–	1.3	0.7	1.3
MnO	0.07	0.05	0.18	0.09	0.08	0.05	0.04	0.02	0.05
MgO	1.02	0.66	3.6	0.26	0.3	0.25	0.04	0.05	0.44
CaO	3.5	1.7	6.3	1.2	1.2	0.63	0.3	0.4	1.3
Na_2O	4.1	4.2	3.9	4.4	4.4	4.0	3.6	4.0	3.2
K_2O	2.1	3.4	2.5	4.0	4.0	4.9	4.6	4.6	5.5
H_2O	–	0.1	1.1	0.8	0.5	0.5	0.7	0.7	0.9
SUM	100.90	98.85	100.05	99.70	100.30	100.38	99.27	99.88	100.90
Ba	–	662 n	1070	–	800	–	–	268	620
Ga	18	–	19	–	23	20	–	22	19
Rb	50	88	61	–	127	135	–	161	213
Sr	297	384	397	–	122	41	–	23	115
Y	11	9 n	35	62	73	55	61 i	74	46
Zr	94	–	161	474	251	254	885 i	206	219
Nb	6	–	9	–	21	17.9	–	21.2	20.1
Pb	16	–	14	–	20	17	–	13	35
Th	15	15 s	5	–	15	16	–	15	36
U	2.3 s	8.1 s	2.7 s	6.5 s	7.0 s	–	6.8 s	12 s	11.5 s
Ta	1.2 i	–	–	1.26 i	–	–	1.83 i	1.82 i	–
Yb	0.94 i	0.83 n	–	5.48 i	–	–	6.63 i	5.92 i	–
Nd	–	22.6 e	29.1	64 i	–	–	112 i	49 i	–
Sm	–	3.5 e	6.3	–	–	–	–	–	–

Granitoid Sample	HAP 013	VET 007	VET 014	ARV 023	ARV 190	JAN 016	STO 005	STO 006
SiO_2	66.0 L	71.9 L	75.6 L	76.2	75.3 g	73.3 n	74.1 n	73.9 n
TiO_2	0.53	0.15	0.19	0.2	0.17	0.26	0.01	0.19
Al_2O_3	14.8	15.5	13.9	13.0	12.3	13.6	14.0	13.5
Fe_2O_3	5.0*	0.71	1.0	1.0	1.1	2.4*	1.0*	1.7*
FeO	–	0.76	1.04	1.10	0.67	–	–	–
MnO	20.08	0.02	0.02	0.08	0.03	0.03	0.03	0.3
MgO	2.34	0.22	0.25	0.28	0.12	0.2	0.26	0.26
CaO	3.6	1.49	0.95	0.5	0.49	1.03	0.83	0.79
Na_2O	4.17	3.73	3.41	4.1	3.36	3.16	3.87	3.21
K_2O	2.6	5.59	5.3	4.8	5.0	5.72	4.36	5.25
H_2O	–	0.3	0.3	0.5	0.87	0.45	0.72	0.96
SUM	99.70	100.10	101.69	101.77	99.49	100.13	99.16	99.80
Ba	941 L	1230 L	520 L	–	–	493 n	331 n	369 n
Ga	–	21	21	21	–	24	17	20
Rb	81 L	186	213	112	–	367	181	327
Sr	533 L	243	95	41	–	106	88	110
Y	13 L	8	19	55	–	68	14	31
Zr	113 L	110	179	295	300 i	272	70	170
Nb	<10 m	3.5	11.7	23.3	–	20.2	8.3	17.8
Pb	–	13	15	16	–	39	26	33
Th	–	22	56	14	–	34	11	32
U	–	–	–	4.2 s	–	7.5 oi	11.5 oi	20.6 oi
Ta	–	–	–	–	3.2 i	1.78 oi	0.82 oi	2.33 oi
Yb	–	0.44 L	1.28 L	–	4.22 i	5.52 oi	1.15 oi	2.46 oi
Nd	–	31.5 e	45.4 e	–	56 i	68 e	13.1 e	37 e
Sm	–	3.4 e	5.9 e	–	–	12.3 e	2.5 e	6.2 e

Major elements: XRF/wet at SGAB Luleå except for REN-290 (XRF Open Univ. UK), HAP/VET (plasma, Lulea Univ.), JAN/STO (plasma, CRPG Nancy) and ARV-190 (XRF, Univ. Geneva) Fe203* total Fe.
Trace elements: XRF Open University except as follows:
oi = INAA, Open Univ., S = DNA Studsvik, Sweden, i = INAA ICI, UK, e = isotope dilution SURRC, UK, n = plasma CRPG, France, L = plasma Luleå Univ., m = opt. emm. LKAB.

Rb-contents. They are similar to Phanerozoic volcanic arc granites (Fig. 7).

The intrusions of the Arvidsjaur region have significantly higher Nb-, Y-, Ta- and Yb-contents and also slightly higher Rb-contents. This suggests a significant "within-plate" contribution (Fig. 7). However, they do not show the marked Ba depletion of modern mature alkali provinces, such as Nigeria (Bowden & Turner 1974). It is therefore suggested that the Skellefte district Jörn complex represents a granitoid in a rather immature volcanic arc environment. The Haparanda suite represents a more mature volcanic arc environment, while the Arvidsjaur province is similar to the type of sub-alkalic to alkali province developed in the Andes, inland of the main calk-alkaline belt and possibly related to ensialic spreading.

Sm-Nd isotopic studies show (Fig. 4) that the older granitoids are derived from sources with relatively short average crustal residence times. This suggests rapid evolution from mantle-derived material.

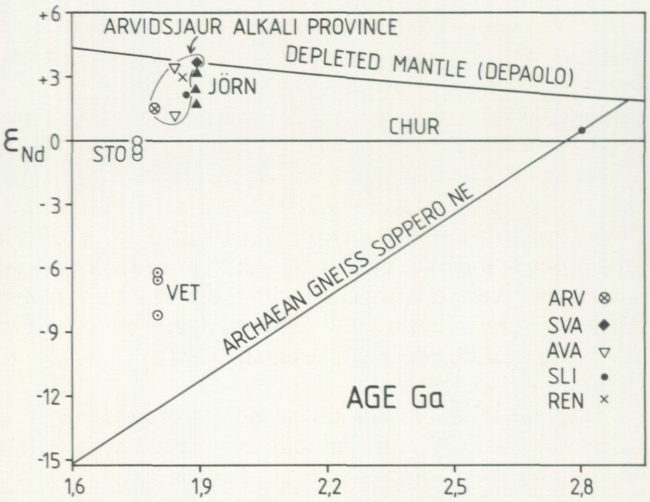


Fig. 4. Epsilon Nd values at T-zircon for selected granitoid suites, northern Sweden (Wilson *et al.*, in press). LREE-depleted mantle evolution line after DePaolo (1981). Archaean evolution line based on unpublished data from map-sheet 30K Soppero NE, on Archaean gneiss U-Pb zircon dated by Skiöld (1979a).

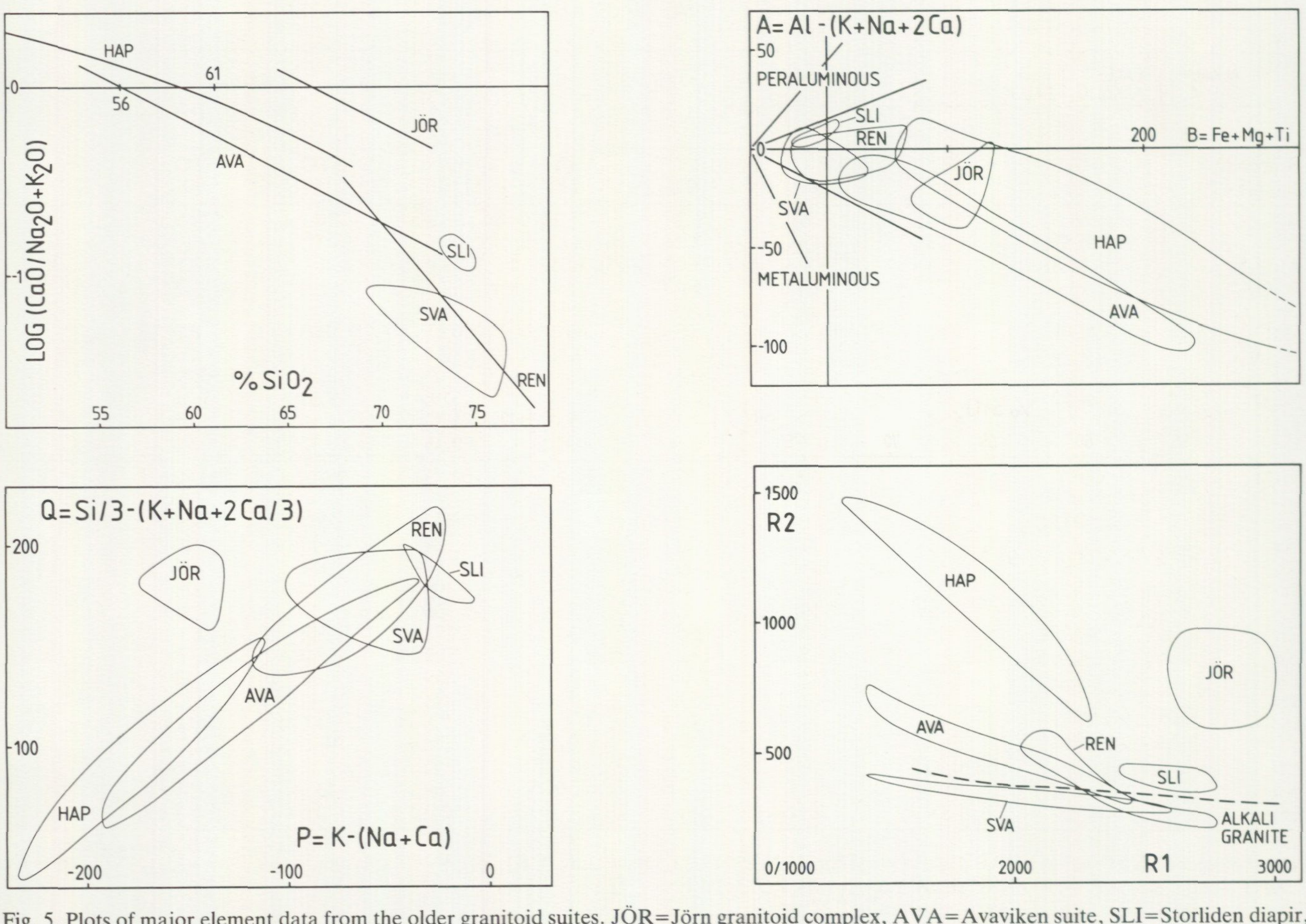


Fig. 5. Plots of major element data from the older granitoid suites. JÖR=Jörn granitoid complex, AVA=Avaviken suite, SLI=Storliden diapir, SVA=Storavan granite, REN=Renviken suite.
(a) Alkali lime index (Peacock 1931).
(b) Q-P diagram (Debon & Le Fort 1982). The positions of the main rock-forming minerals are indicated on the inset (see Fig. 6b).
(c) A-B diagram (Debon & Le Fort). See Fig. 6c.
(d) R1-R2 diagram (De la Roche 1980). R1 = 4Si-11(Na+K)-2(Fe+Ti).
R2 = 6Ca+2Mg+Al. Boundary between alkali granites and granites s.s. marked. After Wilson *et al.* (in press).

Younger group. In order to illustrate the younger group of granites, three granite intrusion types have been examined. These include the barren Vettasjärvi granite (c. 1.8 Ga, Skiöld 1981a) occurring in a large low-magnetic area northeast of Gällivare, the barren diapiric Arvidsjaur granite (1.79 Ga) and the late tectonic granites (c. 1.75 Ga) occurring in the Storuman area of the Bothnian basin. The Storuman granites vary considerably in character. They are relatively rich in the trace elements U and Th, and some W- and Sn-occurrences are associated with them. A highly evolved diapir at Joran, southeast of Storuman, and a less evolved two-mica granite north of Storuman have been investigated chemically, see Table 2.

The younger granitoids have a more restricted major element chemistry (Fig. 6) but still vary significantly both in major and trace elements, depending on their geological environment. For example, the Vettasjärvi granite is near the minimum melting composition for granites. The Arvidsjaur granite has a more alkaline character. Intrusions in the metasedimentary environment of the Storuman area have higher oxygen isotope ratios than the other granitoids. These intrusions can be relatively peraluminous, although intrusions with highly restricted compositional ranges (e.g. Joran) are less peraluminous.

All the younger granitoids show the high Rb- and low Sr-contents typical of evolved granites with a major crustal component. However, they vary considerably in the content of Nb and Y (and to some extent also Ta and Yb), see Fig. 7. The Vettasjärvi granite is similar to Phanerozoic syn-collision granites. The Arvidsjaur and Joran granites appear to inherit "within-plate" characteristics. These may be compared to Phanerozoic "post-collision" granites.

Sm-Nd isotopic results show (Fig. 4) that, in contrast to the older group, the younger granites are derived from sources with long average crustal residence time – i.e. dominantly crustal sources. An obvious example is the Vettasjärvi granite which has been generated with a major Archaean component as source material.

In conclusion, it is suggested that the magmatic evolution of northern Sweden between 1.90 and 1.75 Ga may be divided into the following two dominant stages:

(1) An early stage essentially consisting of mantle-derived magmas leading to granitoid suites with a generally wide

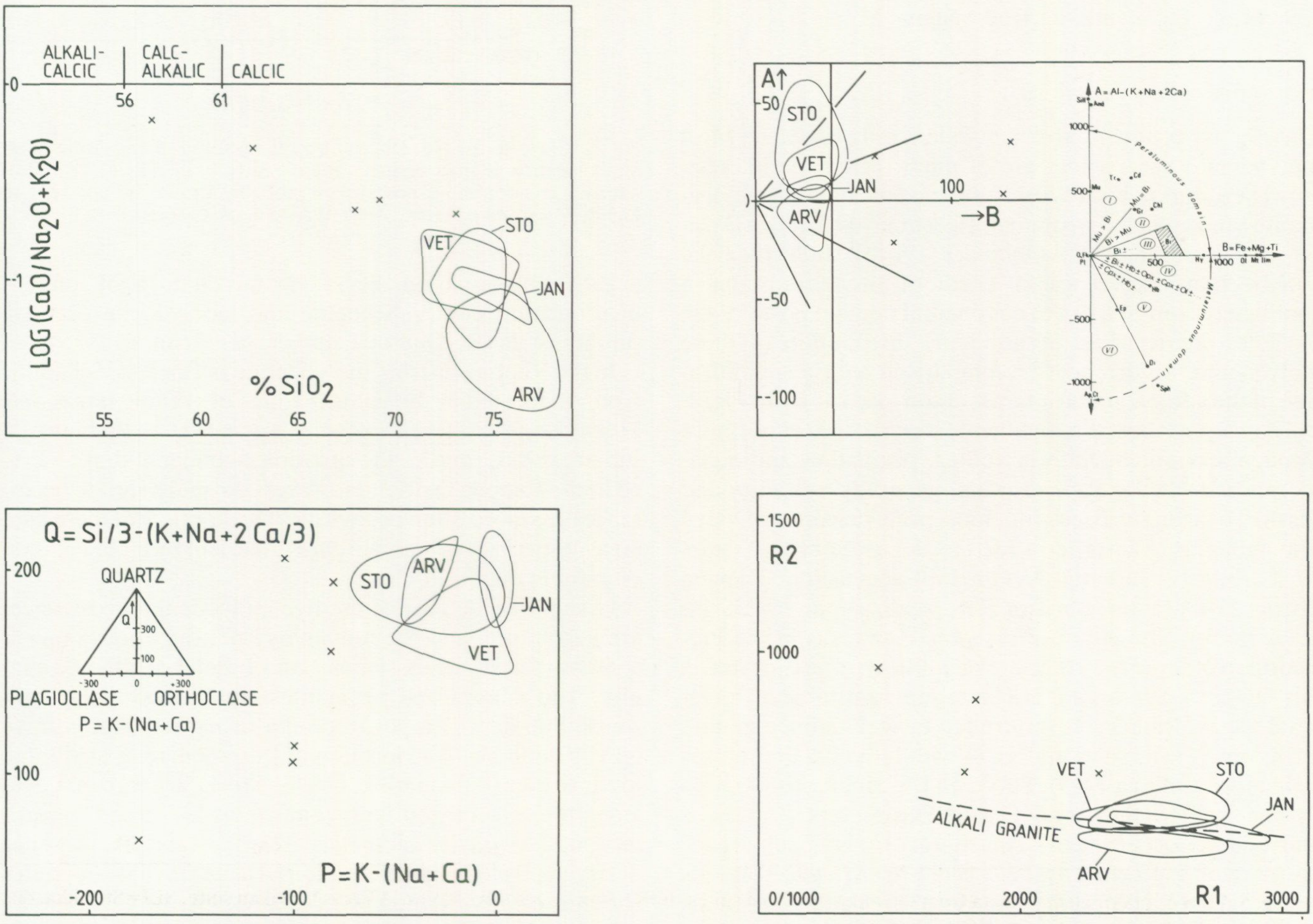


Fig. 6. Plots of major element data from younger granitoid suites. ARV=Arvidsjaur diapir, STO=2-mica granite, Storuman, JAN=Joran dome, Storuman, VET=Vettasjärvi granite.
(a) Alkali-lime index, (b) Q-P, (c) A-B. The positions of the characteristic minerals are indicated on the inset. (d) R1–R2. See Fig. 5d. Samples from the Storuman 2-mica granite which do not fall within the indicated area are marked with a cross. After Wilson *et al.* (in press).

compositional range, which are subdivided into three magma series: (a) calcic magmas which could be directly related to subduction, (b) calc-alkalic magmas also similar to those of mature volcanic-arc environments, and (c) subalkaline to alkaline magmas similar to those found in tensional or transverse faulting environments behind a destructive plate margin.

(2) A late stage consisting of magmas of a more restricted compositional range. They are derived dominantly from crustal sources of possibly local provenance and including (a) Archaean sources in the far north, (b) Proterozoic sedimentary sources in the Bothnian basin.

It is therefore suggested that at least part of northern Sweden, including the Skellefte district and its surroundings may have been formed through a typical "Wilson cycle". This would involve subduction of ocean crust under a continental margin, giving a volcanic belt with sulphide deposits south of which occurs an accretionary wedge with greywackes and slices of ocean floor. Continental collision at around 1.80–1.75 Ga resulted in imbrication of the sedimentary prism, and the depression and metamorphism of deeper parts, resulting in extensive anatexis with a minimum involvement of new mantle-derived magma.

Molybdenite occurrences

There is no production of molybdenum in Sweden. Most molybdenite occurrences are of minor economic interest. However, during both World Wars, a few mineralized pegmatites and aplites were mined. Recent investigations (Walser & Einarsson 1982, Öhlander 1984b) show that the molybdenum occurrences of northern Sweden are almost completely confined to the continental domain north of the Skellefte district. Fig. 8 shows the distribution of these molybdenite occurrences in comparison with a simplification of the aeromagnetic interpretation map shown in Fig. 3.

The major types of molybdenite occurrences in northern Sweden are molybdenite in aplites, pegmatites and metamorphosed altered supracrustals, generally volcanics and skarn. To facilitate discussion, most occurrences are divided into subareas. The criteria for the delineations are somewhat arbitrary. Sub-area A is the well-documented Rappen district (Walser & Einarsson 1982, see also pp. 22–25, this guide book). The largest molybdenite deposits in the Precambrian of Sweden, which are of aplitic type, are located in this sub-area. Sub-area B is a large supracrustal area (terrestrial metavolcanics). It is intruded by well-defined granite intrusions (Fig. 3) and underlain with large granite masses (Öhlander & Nisca 1985). Sub-area C is similar to sub-area B, but smaller. Sub-areas D and E represent clusters of molybdenite occurrences. The supracrustals in sub-area F are part of a greenstone belt. Sub-area G, the Tjåmotis structure, is of a different type. Here, the banded magnetic pattern of supracrustal rocks is deformed by a rounded structure, about 20 km in diameter, which coincides with a positive gravity anomaly. However, the principal circular structure contains smaller dome structures with shallow

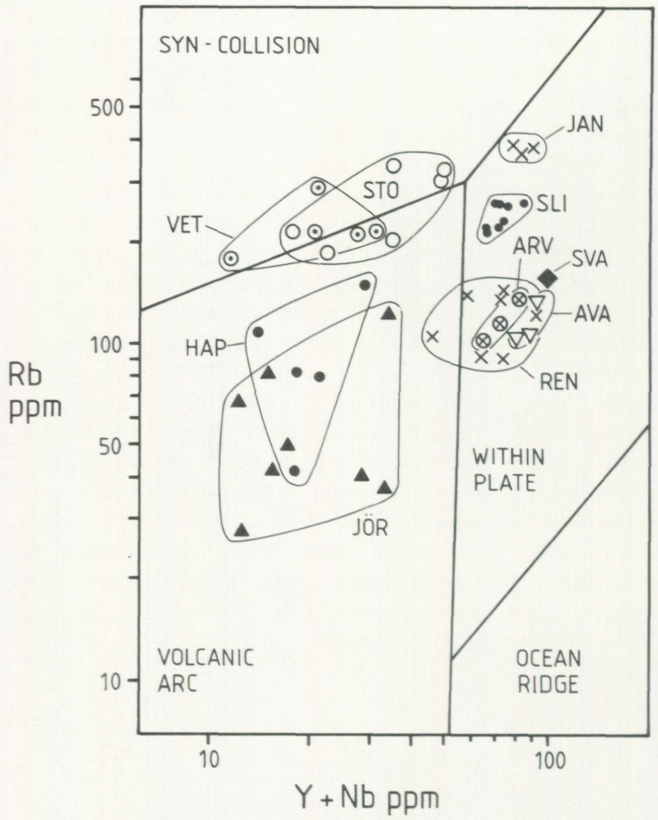


Fig. 7. Rb *versus* Y+Nb. Discriminant fields for granitoids from different Phanerozoic environments after Pearce *et al.* (1984). For Proterozoic granitoids the boundaries probably should be adjusted to slightly lower abundances. After Wilson *et al.* (in press).

negative gravity anomalies. Near the contacts of some of these smaller domes, scheelite and moblydenite occur in supracrustals (R. Quesada, Luleå, pers. comm. 1985).

In the Rappen district, molybdenite occurrences of aplitic type are located at the contact zones of granitic intrusions. Molybdenite in altered volcanics is associated with faults. In sub-areas B, C, and E, the situation is similar to that observed in the Rappen district. However, the molybdenite occurrences are more often pegmatitic than aplitic. All these subareas, especially sub-area B, are underlain by large volumes of granitic material.

In sub-area D, four of the five molybdenite occurrences are pegmatitic, and the remaining one, the northernmost, consists of a minor dissemination of molybdenite in a granite. The mineralized pegmatites are located along fault zones. Sub-area D is situated on a strong regional positive gravity anomaly. The location of this anomaly is attributed to a basement culmination. Granitic rocks are common, and along the mineralized fault zones there is a trend towards less positive gravity anomalies. This indicates the presence of large volumes of granitic material at depth. However, this is not as clearly defined as in subareas A, B, C, E and F.

It is obvious that the molybdenite occurrences in northern Sweden are associated with granitic intrusions located at the supracrustal belts. The large granite areas such as the Vettasjärvi granite are mostly barren, and have low contents of

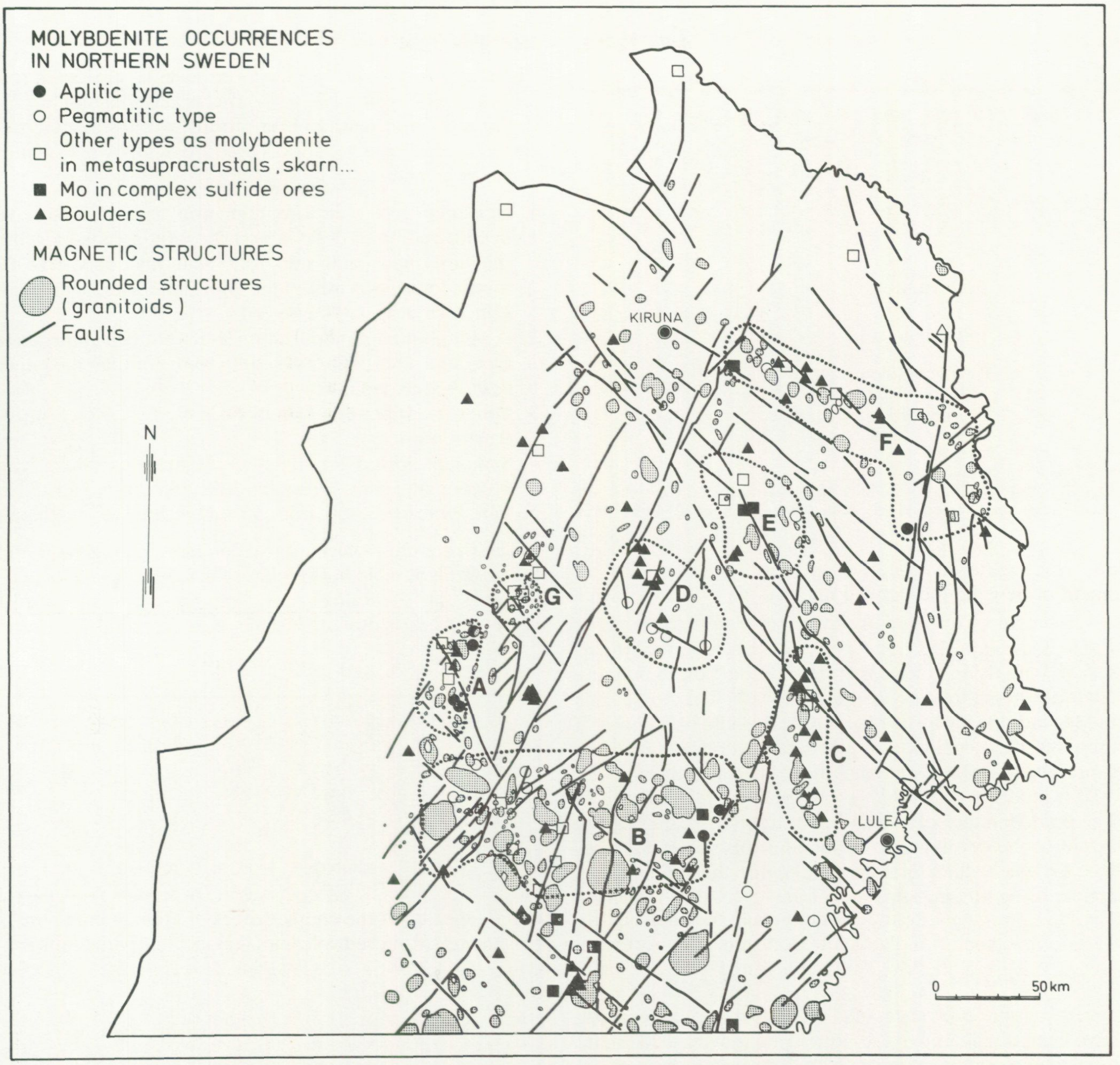


Fig. 8. Simplified interpretation map of aeromagnetic measurements. Areas covered by Caledonian rocks are not included (Fig. 1). Only rounded granitoid structures and faults are included, and compared with the distribution of molybdenite occurrences in northern Sweden. After Öhlander & Nisca (1985).

elements such as Sn, Mo, F, Cl, S, Be, and Y (Öhlander 1985a, Öhlander *et al.*, in press). At least in the southern and southwestern parts of the Karelian continent, where the largest molybdenite deposits are located, the granites associated with mineralization show increased radioactivity and are distinctly uraniferous (Wilson & Åkerblom 1982). These granites probably belong to the older (1.89–1.84 Ga) group of granitoids.

Considering that the average content of Mo in granitic rocks is probably less than the Mo-content in the parent magmas (Shatkov *et al.* 1970, Haffty & Noble 1972), a simplified genetic model for most molybdenite occurrences in northern Sweden can be proposed (Fig. 9), which is as follows:

In the upper part of a rising granite batholith, incompatible elements such as Mo were enriched (Mutschler *et al.* 1981, Westra & Keith 1981). The enrichment was most efficient in the apical parts of cupolas rising from the upper surface of the batholith. The Mo that could not be incorporated in the silicates of the rocks was precipitated as molybdenite in aplites or pegmatites. The aplites probably crystallized from the magmatic rest liquid without the

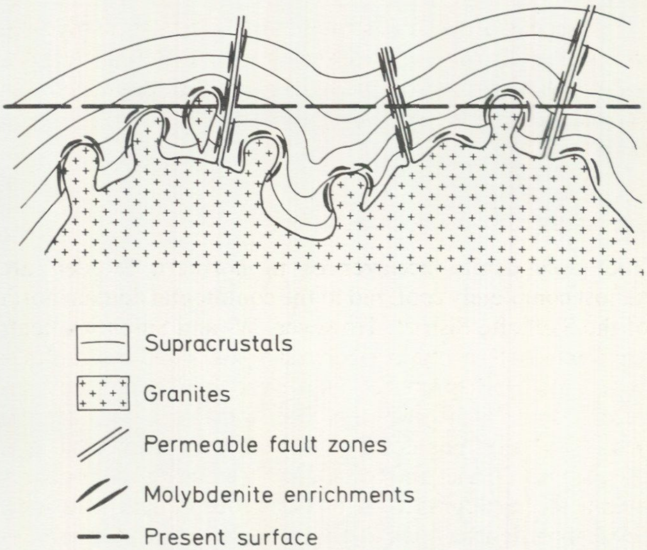


Fig. 9. Vertical section of a model of the generation of the molybdenite occurrences, see discussion in the text. After Öhlander & Nisca (1985).

development of an aqueous phase (cf. Jahns & Burnham 1969, Krauskopf 1979, p. 359–361). Locally deep faults reached the rising granite surface. A reduction of pressure led to the generation of an aqueous phase. This phase, rich in Mo, escaped partly through the permeable fault zones. It crystallized as pegmatites or precipitated molybdenite in the supracrustals, which simultaneously became altered.

This model is applicable to sub-areas A, B, C, E and F. The predominance of pegmatites or aplites depends on the extent of the development of the aqueous phase. For sub-area D, where thick granites underlying the supracrustals appear to be missing, this model may to be less relevant.

Copper occurrences

Several minor occurrences of possible porphyry copper type have been discovered in the northern parts of the Skellefte district (Walser & Einarsson 1982). The most important ore mineral is chalcopyrite. Molybdenite is common, but the content is generally low. Enrichments of gold occur. These porphyry type occurrences are associated with intrusions belonging to the older (1.89–1.84 Ga) group of granitoids.

There are, however, differences between Phanerozoic porphyry type deposits and the Proterozoic ones dealt with here. For example, the largest known porphyry type mineralization in the northern parts of the Skellefte district (Tallberg), located in the border zone of the Jörn granitoid complex which has a compositional range from tonalite to granite, has lower grade than the Phanerozoic deposits and lacks obvious alteration zoning (Weihed, in prep.) The other occurrences are much smaller than the Phanerozoic deposits. These discrepancies may partly be explained by the deeper erosion level of the Proterozoic intrusions.

Uranium occurrences

The major U-province in northern Sweden is the Arvidsjaur-Arjeplog region (Fig. 10). It contains a number of U-occurrences belonging to four groups with distinctly different ages and characteristics. These are as follows (Hålenius *et al.*, in press):

1. Epigenetic veins and impregnation types. These have been dated to c. 1.75 Ga and constitute, economically, the most important group. The Pleutajokk deposit (6000 metric tons U) as well as the Björklund and Rävaberget U-occurrences will be visited.
2. A stratabound mineralization in rhyolitic ignimbrites at Dobblon. This deposit is slightly younger than the group described above.
3. Peneconcordant disseminations in old (c. 1.9 Ga) supracrustal rocks.
4. Sediment-hosted uranium concentrations along the Caledonian Front. These exogenic deposits are hosted in Late Proterozoic to Cambrian autochthonous sediments.

The first group, which is most common, is epigenetic and the most favourable host rocks are acid igneous rocks (e.g. rhyolites at Pleutajokk) or granites from the oldest (1.89–1.84 Ga) group of plutonic rocks (e.g. Björklund and

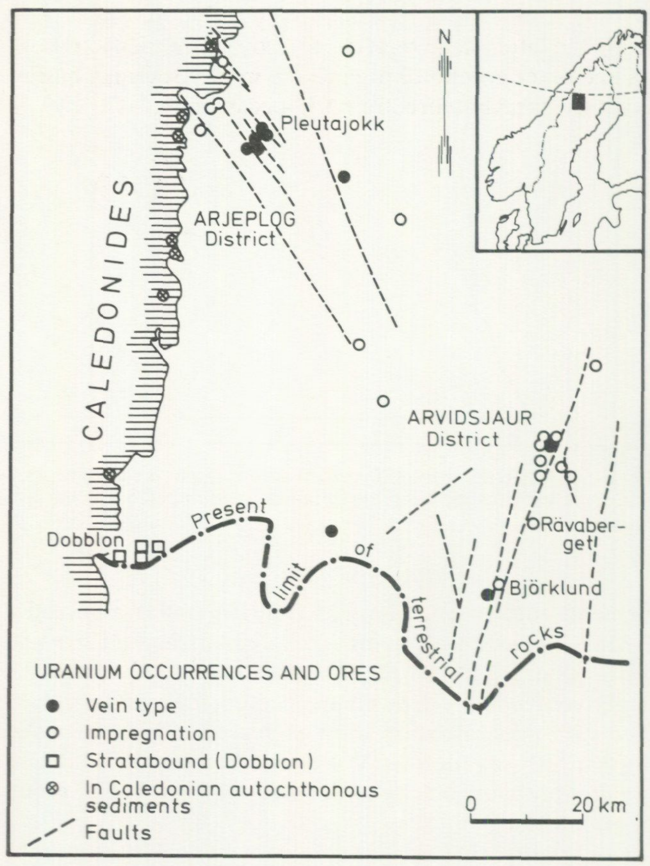


Fig. 10. The Arvidsjaur-Arjeplog uranium province. Modified after Adamek & Wilson 1979.

Rävaberget). The host rocks are affected by Ca- and Na-rich hydrothermal fluids slightly older than the U-bearing mineralizing fluids. Regional zones of structural weakness and bedrock lithology have played a major role in the transport of both types of fluids. This has resulted in the precipitation of uranium along fractures and joints (vein-type), and has marginally dispersed concentrations (impregnation-type).

The U-mineralization (c. 1.75 Ga) is approximately coeval with the emplacement of the latest intrusions of the younger (1.80–1.75 Ga) granite group. It can be speculated that these granites provided the driving mechanism to generate hydrothermal fluids. During the passage of these fluids through U-enriched volcanic and granitic (older group) country rocks, elements such as U, Na and Ca were mobilized, concentrated and transported. Eventually, under favourable physico-chemical conditions, the precipitation of certain elements and the removal of others resulted in the formation of alkali-metasomatites and later U-mineralization.

Although U-enriched granites (belonging to the 1.8–1.75 Ga group) occur in the Bothnian basin, the area is characterized by its lack of real U-occurrences (Wilson & Åkerblom 1982). U-mineralization is almost completely confined to the continental domain. A probable explanation is that at least two major stages are needed to create rich U-occurrences. First uranium is remobilized from U-enriched rhyolites and 1.89–1.84 Ga granitoids, and then concentrated during the latter stage referred to above. U-enriched rhyolites and older granitoids are lacking in the Bothnian basin, and consequently there are no U-occurrences.

The second group, i.e. stratabound U-deposit in rhyolitic ignimbrites, is only represented by the Dobblon deposit, which will be visited on the fourth day. For details on this deposit, see pp. 28–30.

Tungsten and tin occurrences

The molybdenite occurrences in northern Sweden are almost completely confined to the continental domain north of the Skellefte district. However, W- and Sn-enrichments are found both in the continental domain and in the Bothnian basin. It is probable, however, that the W- and Sn-occurrences in the two separate domains have different ages. The granitoids associated with Mo-enrichments in e.g. the Rappen district and the Tjåmotis area (Fig. 8) probably belong to the older (1.89–1.84 Ga) group of acid intrusions. Some intrusions in these districts are also associated with W- and/or Sn-enrichments, which are thus thought to be approximately of the same age.

The excursion will, however, concentrate on W-occurrences in the Bothnian basin. The most common granitoid types in the Bothnian basin are the coarse grey porphyritic granites which belong to the younger (1.8–1.75 Ga) group. These granites are generally referred to as Revsund granites. The W-enrichments in the Storuman area of the Bothnian basin are associated with "specialized" intrusions of the Revsund type, e.g. the Joran granite dome and the Storuman two-mica granite mentioned above. The latter two granites are highly evolved. They have high contents of elements such as Rb and U.

EXCURSION PROGRAMME

INTRODUCTION

The major purpose of the excursion is to study mineralizations associated with granitoids. However, other important subjects include the development of Proterozoic granitoids in northern Sweden in general, as well as typical examples of the supracrustal rocks in the Karelian continent, the Skellefte district and the Bothnian basin. The excursion route is indicated in Fig. 1.

The first day of the excursion includes an examination of a Mo-occurrence, well preserved terrestrial volcanics and a barren granite intrusion belonging to the younger (1.8–1.75 Ga) group. The granites and the U-occurrences in the Arvidsjaur-Storavan alkali province are the subjects of the second day. On the third day, the excursion will head northwestwards to the Rappen district where the largest known Mo- and U-occurrences in the Precambrian of Sweden will be visited (Allebuoda and Pleutajokk). The fourth day will be devoted to the stratabound U-mineralization at Dobblon, close to the palaeoboundary between the continental and the marine domains. On the fifth day, two wolframite occurrences and one of scheelite in the Bothnian basin will be visited. The subject of the last day will be the Tallberg porphyry type copper mineralization in the Skellefte district.

DAY 1. THE KÅTABERGET MO-OCCURRENCE, THE RAKKUR TERRESTRIAL VOLCANICS AND THE ARVIDSJAUR GRANITE

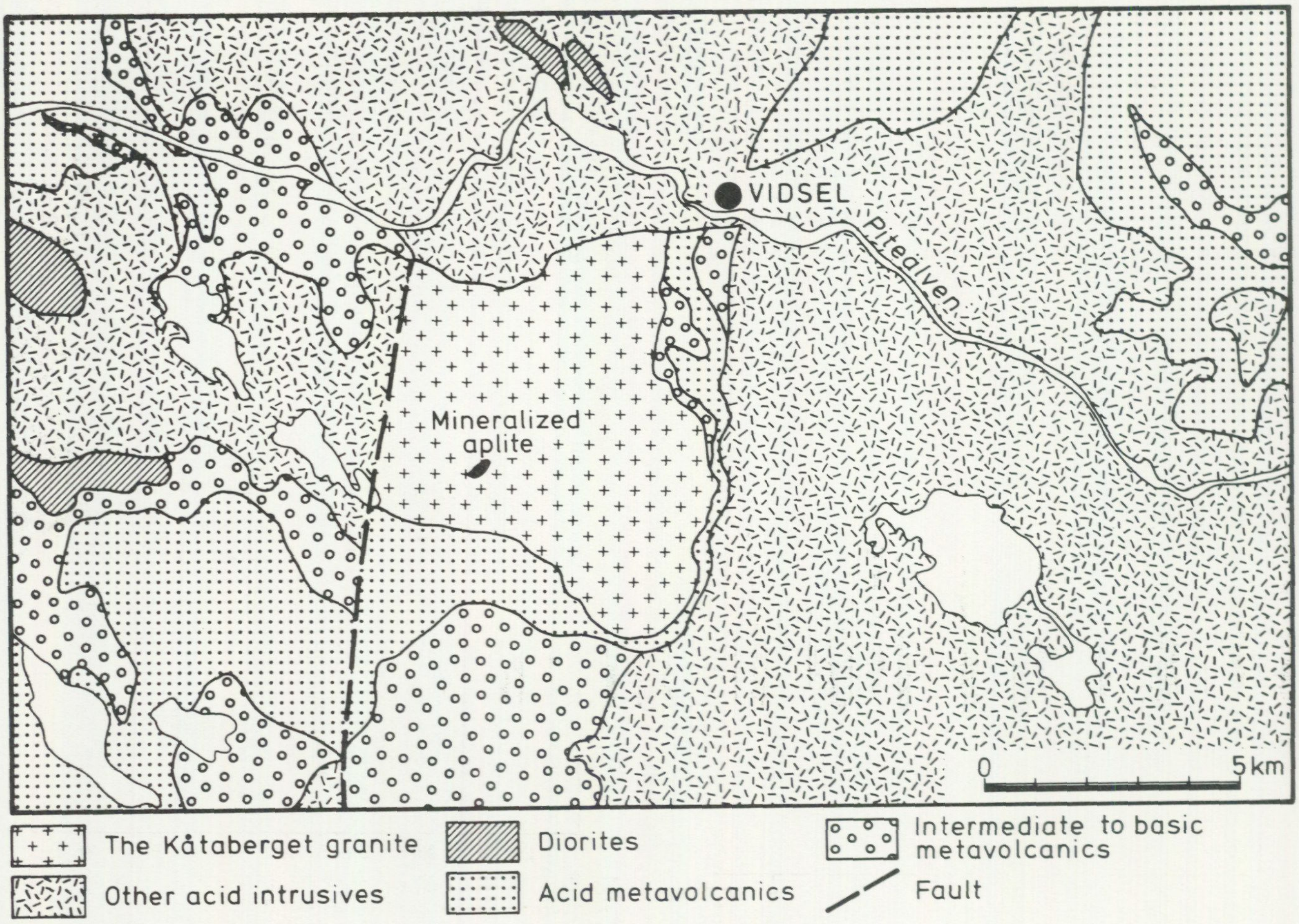


Fig. 11. Geological map of the area surrounding the Kåtaberget Mo-occurrence. Modified after an unpublished map compiled by Tomas Sjöstrand, SGAB. Published with the permission of The State Mining Property Commission (NSG).

At Kåtaberget near Vidsel (Fig. 11), a molybdenite mineralized aplite is situated in the central part of a granitic intrusion, which probably belongs to the older (1.89–1.84 Ga) group of granitoids. The intrusion is surrounded by terrestrial volcanics.

Exceptionally well preserved Proterozoic ignimbrites and basic lavas occur in the area around the lake Rakkur (Fig. 15). The acid volcanic rocks in the Rakkur area and the volcanics surrounding the Kåtaberget granite belong to the Svecokarelian group of terrestrial volcanics called the "Arvidsjaur porphyries".

The Arvidsjaur granite forms a massif which is 25 km in diameter (Fig. 16); it intruded during the later phase of the Svecokarelian orogeny. The granite is U-Pb zircon dated to 1.79±0.01 Ga (Wilson *et al.* 1985). No significant enrichments of e.g. U, Mo, W or Sn have been found in association with the Arvidsjaur granite.

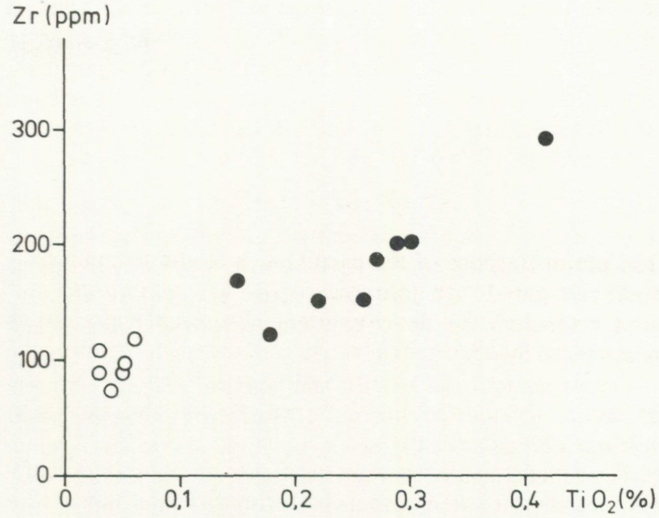


Fig. 13. Zr (ppm) *versus* TiO_2 (wt.%) for Kåtaberget samples. Symbols as in Fig. 12.

STOP DESCRIPTIONS

Stop 1–1. – The Kåtaberget Mo-occurrence. The mineralized aplite at Kåtaberget is relatively coarse-grained, and grades without sharp contacts into a coarse grey granite (Öhlander 1985b). Molybdenite occurs over an area of more than 17 000 m^2, but the average grade is probably less than 0.05 % Mo (Isaksson 1982). In several small areas, having a total area of 700 m^2, the grade may be as high as 0.1 %. The molybdenite generally occurs as irregularly distributed coarse aggregates. Fluorite is common. Small quantities of pyrite and chalcopyrite are also present.

In the aplite, the microcline shows a perthitic texture. The plagioclase (albite-oligoclase) is sericitized to varying extent and large quartz grains have often been replaced by many small grains. The biotite is usually chloritized and rich in radioactive haloes. Zircon and sphene occur as tiny disseminated crystals. Apatite and allanite have been observed. The aplite is enriched in uranium (Isaksson 1982). It has higher contents of SiO_2, K_2O, Rb and Y than the associated granite. Clear differentiation trends are illustrated in Figs. 12 and 13.

Chondrite normalized REE patterns are presented in Fig. 14. The aplites are enriched in heavy REE and depleted in light REE, compared with the granites. All samples have significant negative Eu anomalies, but the aplites have the largest. A depletion of light REE relative to their host granites is a common feature for aplites (Noyes *et al.* 1983). Residual hydrothermal fluids can also result in enrichment of the heavy REE by autometasomatizing processes, but

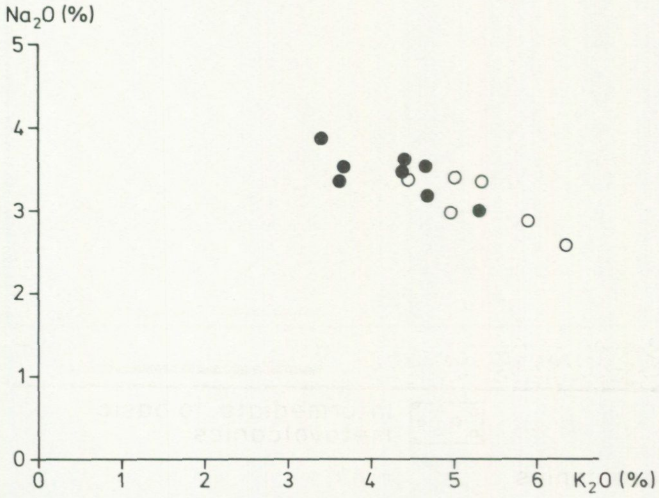


Fig. 12. Na_2O *versus* K_2O for Kåtaberget samples. All values in wt.%. Dots = granites, Open circles = aplites.

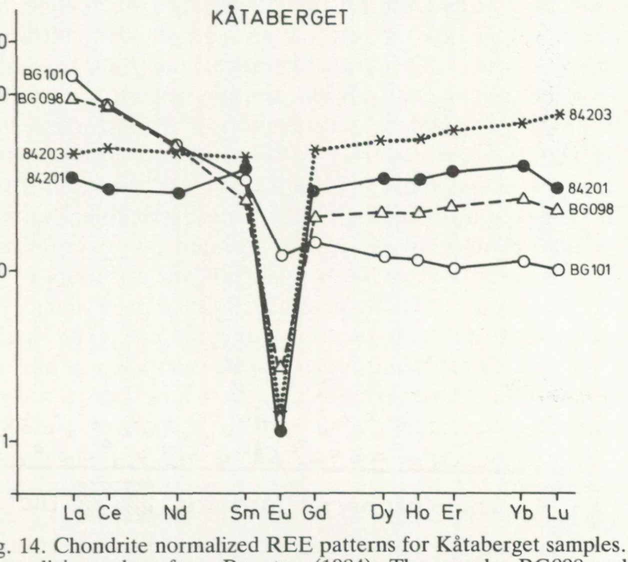


Fig. 14. Chondrite normalized REE patterns for Kåtaberget samples. Normalizing values from Boynton (1984). The samples BG098 and BG101 represent granites while 84201 and 84203 represent mineralized aplites.

tend to obliterate the Eu anomalies (Bowden & Whitney 1974). It is probable that the aplite at Kåtaberget, and its Mo-enrichment, have resulted from magmatic differentiation from the granite without the development of a hydrothermal solution (cf. e.g. Jahns & Burnham 1969; Krauskopf 1979, pp. 359–361).

Stop 1–2. – The Rakkur ignimbrites. The following description of the Rakkur area is based on the work of Lilljequist and Svensson (1974). The acid volcanic rocks of the Rakkur area belong to the Svecokarelian terrestrial "Arvidsjaur porphyries".

The volcanic rocks around lake Rakkur (Fig. 15) consist of basic lavas and ignimbrites. It is probable that the basic volcanics have a stratigraphic position above the ignimbrites. The majority of the acid volcanics in the Rakkur area have been grouped as ignimbrites but Lilljequist and Svensson (1974) have classified them as follows (Fig. 15): tufflavas, agglomerates and lapilli tuff, dacitic tuff, rhyolitic tuff, welded tuff and unspecified ignimbrites.

The term "tufflava" is used to describe rocks with distinct flow structures represented by a fine lamination. The tufflavas are often rich in lithophysae. All varieties are found from sequences without lithophysae to sections almost completely composed of them.

The welded tuffs are normally dense, porphyritic rocks, with a medium to dark grey, brownish grey or greyish purple colour. Abundant lithophysal cavities, up to 5 cm in size, are characteristic. Welded tuffs with pisoliths have been observed, indicative of a subaerial origin (Rittman 1962).

The appearance of the agglomerates and lapilli tuffs within the area is rather uniform. The fragments consist of aphanitic and fine-grained tuffs, welded tuffs and tuff lavas.

Stop 1–3. – The Arvidsjaur granite. The Arvidsjaur granite (Fig. 16) is a reddish medium-grained leucocratic granite with riebeckite (Muller 1980). Perthitic microcline and quartz are the main minerals, with subordinate quantities of albite, biotite, riebeckite, magnetite and fluorite. Other accessory minerals are zircon, apatite, sphene, epidote and rutile. Major element geochemistry is characterized by a high SiO_2-content (average 76 %) and a high differentiation index (0.93 and above). Table 2 and Figs. 6 and 7 illustrate the geochemical characteristics of the Arvidsjaur granite.

The texture of the Arvidsjaur granite varies over the area of an outcrop, but presents no significant variations in the intrusion as a whole. No phenocrysts have been found. The typical texture is hypidiomorphic-granular. The quartz grains are often round, whereas the microcline grains are idiomorphic. Crystallization of quartz and microcline with granophyric or hieroglyphic textures is common.

The northwestern contact zone of the Arvidsjaur intrusion is complex. It consists of successive slabs of granite and volcanics across a zone of about 2 km width (Muller 1980). At the eastern contact with acid tuffs, a small chilled margin effect appears, and the granite is finer grained 20 to 30 cm from its contact with the volcanics. The western contact with

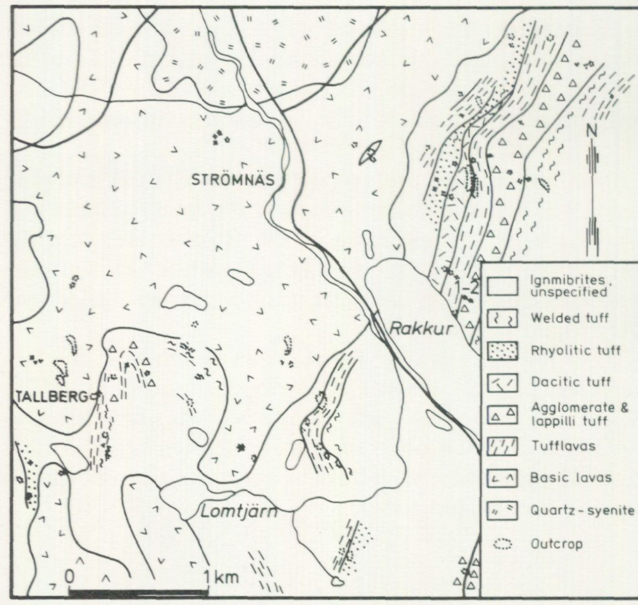


Fig. 15. Geological map of the area around Lake Rakkur. After Lilljeqvist & Svensson 1974. 1–2 is the excursion stop.

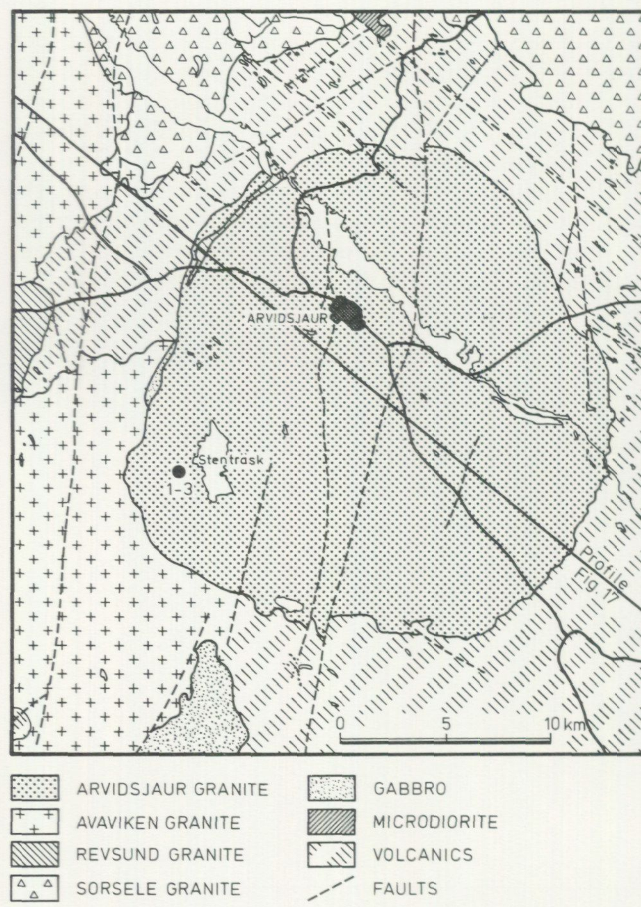


Fig. 16. Geological map of the Arvidsjaur granite and its surroundings. After Muller (1980). 1–3 is the excursion stop.

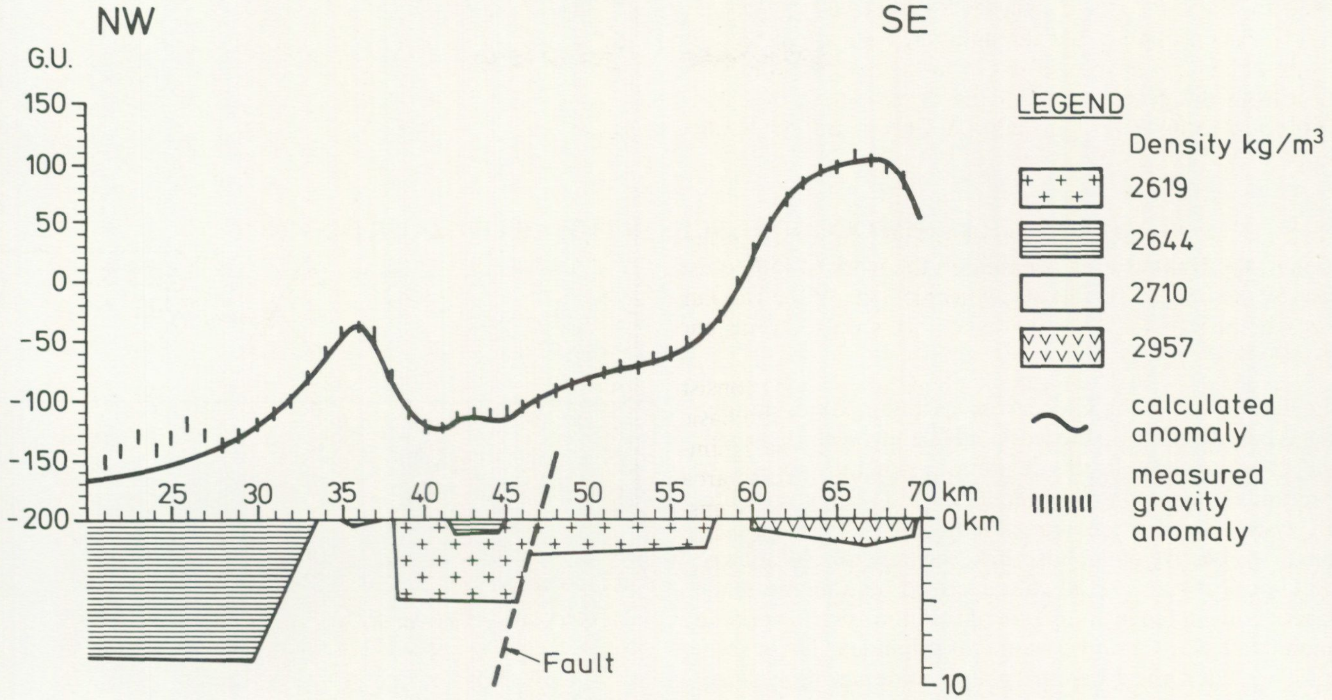


Fig. 17. NW-SE profile with a model of the Arvidsjaur granite intrusion. Calculated from gravity data. After Enmark (1982).

the Avaviken granite is smooth and gradual.

Barren aplitic dykes occur throughout the intrusion. Their mineralogical composition is similar to that of the granite. However, ore minerals are either scarce or absent in the aplite.

Gravity measurements indicate (Enmark 1982) that the Arvidsjaur granite has a discoid shape with an actual thickness of 2–5 km (Fig. 17); it probably represents the basal part of a diapiric intrusion of which the upper part has been removed by erosion.

DAY 2. URANIUM OCCURRENCES IN THE ARVIDSJAUR DISTRICT

The description of the U-occurrences in the Arvidsjaur district is based mainly on the work of Hålenius *et al.* (in press). The U-occurrences in this region are generally located in granitoids belonging to the older (1.89–1.84 Ga) group (Fig. 18). U-enrichments are aligned along a N–S trending fault zone. Irrespective of the host rock, the mineral evolution of the U-occurrences are all characterized by a metasomatic stage involving the introduction of solutions rich in variable amounts of Na, Ca and base metal sulphides. These solutions preceded the hydrothermal U-mineralization stage. The Björklund U-occurrence, located in the leucocratic Storavan granite, and the Rävaberget U-occurrence which is confined to the Avaviken granite, will be visited.

STOP DESCRIPTIONS

Stop 2–1. – The Storavan granite. A non-mineralized variety of the leucocratic alkalic Storavan granite will be visited. It has an enhanced U-content and is of a hypersolvus type, with microcline perthite as the sole feldspar. Mafic minerals appear in minor amounts, Na-rich hornblende, riebeckite and biotite being most characteristic (Adamek & Wilson 1979). Fluorite, magnetite, crocidolite and zircon are characteristic accessories. The Storavan granite is mostly porphyritic, in large areas quartz-porphyritic. Micrographic texture is typical. The geochemical characteristics of the granite are shown in Table 2 and Figs. 5 and 7. A correlation between U and some other trace elements indicates that the concentration of U increases proportionally with increasing differentiation. In spite of the obvious spatial relation between this granite and epigenetic U-occurrences, no other evidence, which supports a direct genetic relationship has been found. The Storavan granite was emplaced along the large fault zones in the Arvidsjaur district (Fig. 18), and has been U-Pb zircon dated to 1.89±0.4 Ga (Wilson *et al.* 1985).

Stop 2–2. – The Björklund U-occurrence. The U-enrichment at Björklund occurs within the leucocratic Storavan granite as uraninite disseminations together with fracture and fissure infillings. The uranium stage was preceded by an episyenitization phase of local extent. The mineralized zone of the Björklund deposit has been U-Pb dated to 1.75±0.01 Ga (Hålenius *et al.*, in press). A summary of the main mineralogical characteristics at Björklund is as follows:

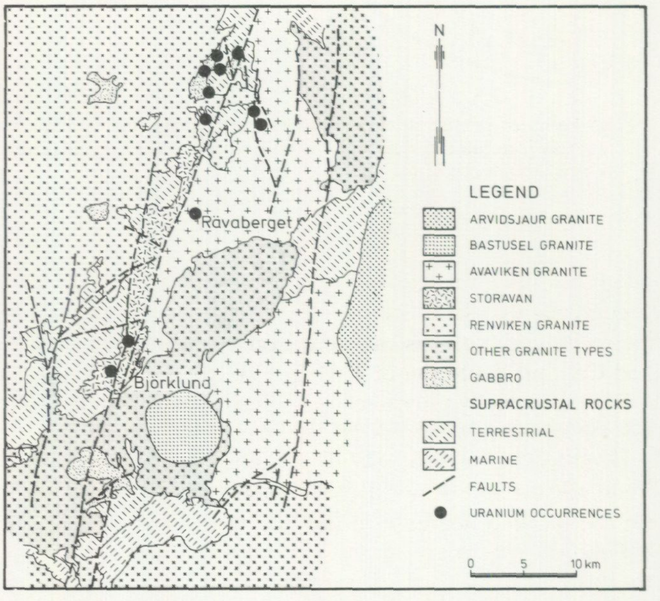


Fig. 18. Geological map of the Arvidsjaur uranium district showing the relationships between uranium mineralization and regional fault controlled structures. Modified after Hålenius *et al.* (in press).

Metamorphic stage:	1) Albitization. 2) Garnet + biotite. 3) Amphibole + sphene + epidote + magnetite + calcite. 4) Sulphides + calcite.
Hydrothermal uranium mineralization stage:	1) Uraninite + calcite + fluorite + hematite±FeOOH. Oxidation and alteration of mafic minerals. 2) Uranotitanates. (Different types of fracture infillings. Garnet association).
Late-stage, low temperature hydrothermal stage:	Remobilized radiogenic galena, chlorite, hematite and FeOOH. Alteration of uraninite to complex uranotitanates and secondary U-silicates. Pyrite.

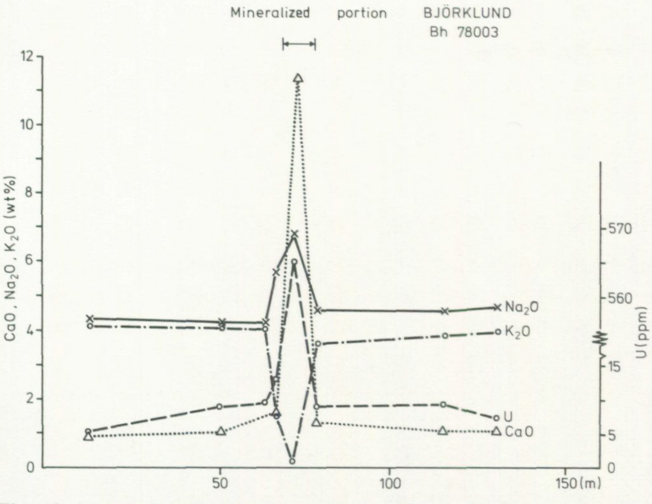


Fig. 19. Sampled profile along a drillcore showing the chemical variations across the mineralized zone of the Björklund U-occurrence. After Hålenius *et al.* (in press).

The initial pervasive metasomatic phase, the extent of which is controlled by local structural weaknesses and rock permeability variations, is characterized by enrichments of Na and Ca, and depletion of K (Fig. 19).

Mineralogically, increases in Ca have resulted in the formation of Ca-amphiboles and Ca-rich garnet, sphene and epidote. An increase in Na has resulted in the albitization. Texturally, these mineral assemblages partly compensate for the marked decrease in the quartz content.

Following the metasomatism, oxidizing uraniferous hydrothermal solutions have penetrated along the zones of weakness previously opened by the Ca- and Na-rich fluids. Not all metasomatized zones are mineralized with respect to U. When possible, the precipitation of U has resulted in uraninite formation which occurs as vein/fracture infillings up to 2 mm in width. The uraninite grains have usually rounded to subhedral shape.

Stop 2–3. – The Avaviken granite. A non-mineralized part of the Avaviken granitoid suite will be visited. This is a metaluminous alkali-calcic series (Fig. 5) ranging from monzonite to alkali granite. The results of typical geochemical analyses are shown in Table 2. The Avaviken massif has, together with the Storavan granite described above, the high contents of Nb and Y which is typical of rift-related granitoids (Fig. 7). The Avaviken granite has been U-Pb zircon dated to 1.84±0.1 Ga (Wilson *et al.* 1985).

Stop 2–4. – The Rävaberget U-occurrence. The Rävaberget U-occurrence is impregnation in type. It occurs within a leucocratic variety of the Avaviken granite. The mineralization is confined to irregular zones of episyenitized granite, the extent of which is governed by the regional joint and fracture patterns. The mineralized zone of the Rävaberget deposit has been U-Pb dated to 1.77±0.1 Ga. A summary of the main mineralogical characteristics is as follows:

Metamorphic stage:	1) Albite episyenitization. 2) Biotite + calcite + Ti-oxides + sulphides.
Hydrothermal uranium mineralization stage:	1) Uraninite + calcite + fluorite + hematite ± FeOOH. Oxidation and alteration of mafic minerals. 2) Uranotitanates. (Dissemination type, latter stage accompanied by sphene + pyrite + epidote + magnetite).
Late-stage low temperature hydrothermal stage:	Remobilized radiogenic galena, chlorite, hematite and FeOOH. Alteration of uraninite to complex uranotitanates and secondary U-silicates. Pyrite + fluorite.

For a description of the chemical and mineralogical changes caused by the hydrothermal solutions, see the discussion of the Björklund U-occurrence given above (pp. 20–21). The contents of the major elements and uranium in country-rock, wall-rock and ore are shown in Table 3. At Rävaberget, the episyenitization process, preceding the uranium precipitation, had generated a porous medium, which resulted in a widespread uraninite impregnation.

TABLE 3. Chemical analyses of samples from Rävaberget. All values, except for U, in wt. %. Unpublished SGAB data.

	Countryrock	Wallrock	Ore
SiO_2	73.47	72.3	64.52
Al_2O_3	13.07	13.3	16.62
Fe_2O_3	0.83	1.6	1.90
FeO	1.80	1.3	1.68
CaO	1.00	0.9	1.50
MgO	0.29	0.31	0.46
Na_2O	4.50	5.1	9.56
K_2O	4.33	3.5	0.44
CO_2	0.05	0.25	1.14
S	0.02	0.02	0.27
(ppm) U	6	401	4200
Number of samples	2	1	5

DAY 3. THE ALLEBUODA Mo- AND THE PLEUTAJOKK U-OCCURRENCES IN THE RAPPEN DISTRICT

The largest known Precambrian molybdenite occurrences in Sweden are located in the Rappen district (Fig. 20). The following description of the geology is based on the work of Einarsson in Walser & Einarsson (1982). The area consists of Proterozoic metamorphosed supracrustals intruded by granites. To the north and west the Proterozoic rocks are covered by flatlying autochthonous and allochthonous Caledonian units.

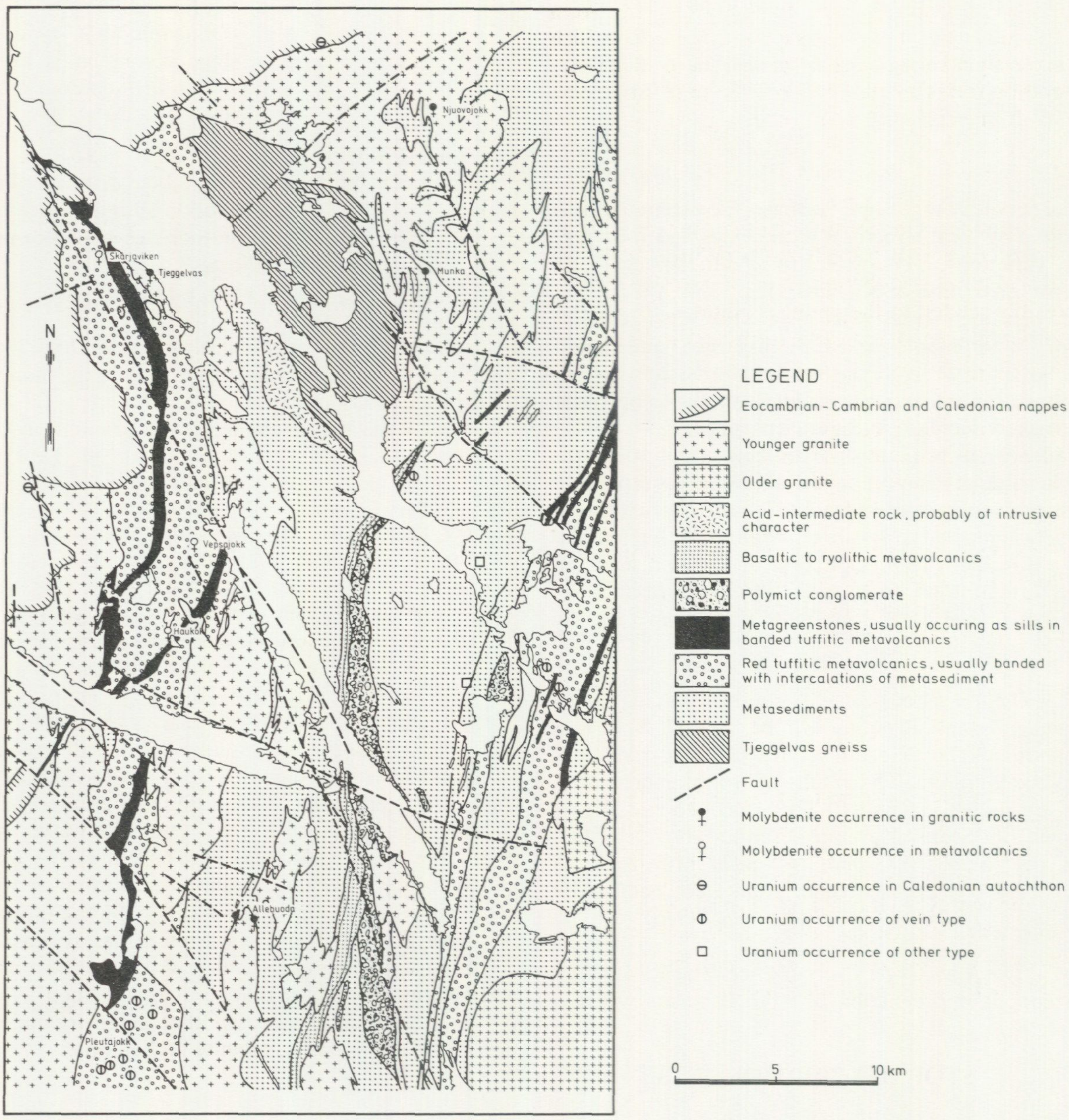


Fig. 20. Geological map and Mo- and U-occurrences in the Rappen district. After Einarsson in Walser & Einarsson (1982), and Gustafsson (1981).

The supracrustal rocks have been folded along NS-trending axes. Within the dominant tectonic feature, a large NS-trending anticline, all lineations and small-scale fold axes plunge shallowly toward the south. The central part of the large antiform is characterized by highly metamorphosed quartz-microcline and mica-rich gneisses (veined gneisses). The upper parts of this metasedimentary sequence include skarn bands, limestones and quartz-banded iron ores. This sedimentary group grades into a dominantly acid volcanic unit, which frequently exhibits tuffitic characteristics. The youngest supracrustal rock unit consists of a polymict conglomerate, followed by a sequence of massive andesitic and rhyolitic lavas.

Two principal generations of granites intrude the supracrustals. The older granite is generally a red medium-grained biotite granite showing foliated textures. At a slightly oblique angle, it cuts the supracrustal rocks, which are not seriously affected by the granite. The younger granite generation forms a heterogeneous group of intrusions, but is usually massive and light pinkish grey. The larger massifs in the northern part of the Rappen area are often surrounded by aureoles characterized by microcline porphyroblasts. The molybdenite occurrences are associated with the younger granites. One intrusion of the younger granites has a U-Pb zircon age of 1.86±0.02 Ga (Wilson & Fallick 1982). An acid porphyry, that might be of intrusive character, is possibly related to the younger granites.

Three different types of molybdenite mineralization occur in the Rappen district:

(1) disseminations or intensive mineralizations in aplites related to the youngest granites,

(2) molybdenite in quartz-veined granite,

(3) veins and disseminations of molybdenite in altered acid volcanics.

The largest deposits, Munka with about 1.5 million metric tons of ore (with 0.10 %–0.15 % Mo) and Allebuoda with more than 1 million metric tons of ore (with 0.15 %–0.20 % Mo), are of type 1. Both deposits are located in the contact zone between the youngest granites and gneissic supracrustals. The granites associated with the molybdenite occurrences form geophysically well-defined diapiric structures representing cupolas on the top of underlying batholiths (Öhlander & Nisca 1985).

The Rappen district is also rich in U-occurrence (Fig. 20). Most common are Proterozoic epigenetic U-enrichments, both of the vein-type and the impregnation type. The excursion will visit the largest of the known deposits, Pleutajokk, which is of the vein type. It contains c. 6 000 metric tons U. In December 1980, LKAB applied for government permission to localize a uranium mine at Pleutajokk. However, this project was finally considered uneconomic.

STOP DESCRIPTION

Stop 3–1. – The Allebuoda Mo-occurrence. At Allebuoda, a granite lobe is surrounded by metamorphosed supracrustal

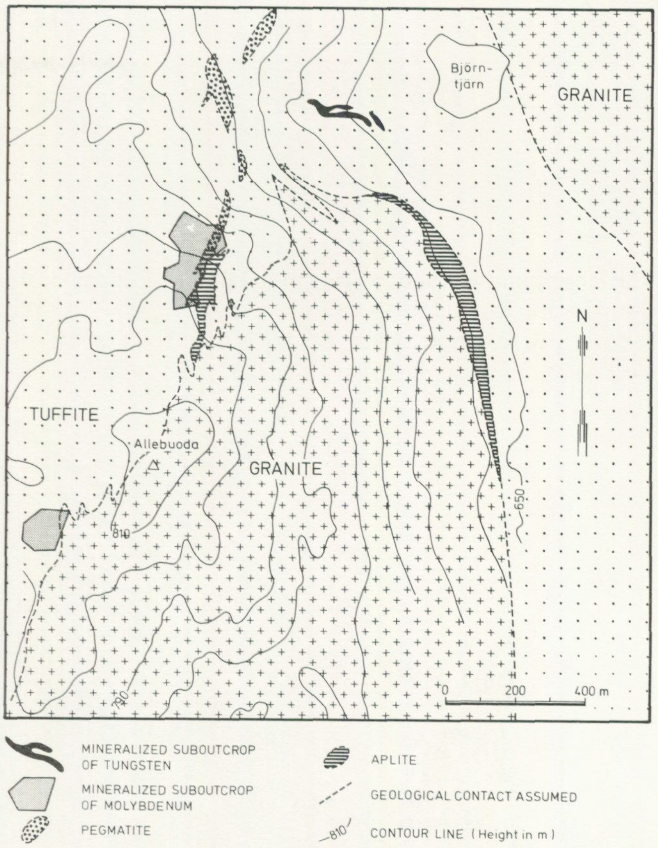


Fig. 21. Geology of the Allebuoda Mo-occurrence. Unpublished LKAB material.

rocks (Fig. 21). Molybdenite is found in aplites located at the contact between the granites and the metasupracrustals. The major molybdenum enrichment is confined to an aplitic apophyse intruding the supracrustal rocks (Fig. 22). This aplite is irregularly, but occasionally, richly mineralized.

The aplite at Allebuoda is more fine-grained and richer in quartz than the aplite at Kåtaberget, which was examined on the first day of the excursion. The molybdenite in the large Allebuoda aplite occurs interstitially, often in rather coarse aggregates. Fluorite is common and small quantities of erratically distributed pyrite occur. Molybdenite-bearing quartz-veins are related to the aplite, and form small zones of enrichment. Pegmatites occur but are, however, subordinate to the aplite. The major minerals of the aplite are rounded quartz grains, perthitic microcline and Na-rich plagioclase (albite-oligoclase). The grain size of the quartz and feldspar varies between 0.5 and 1 mm. A slight sericitization of the plagioclase, and a slight cloritization of the small amounts of biotite that occur are common. The biotite is rich in radioactive haloes. Other accessory minerals are zircon, sphene, apatite, allanite and epidote.

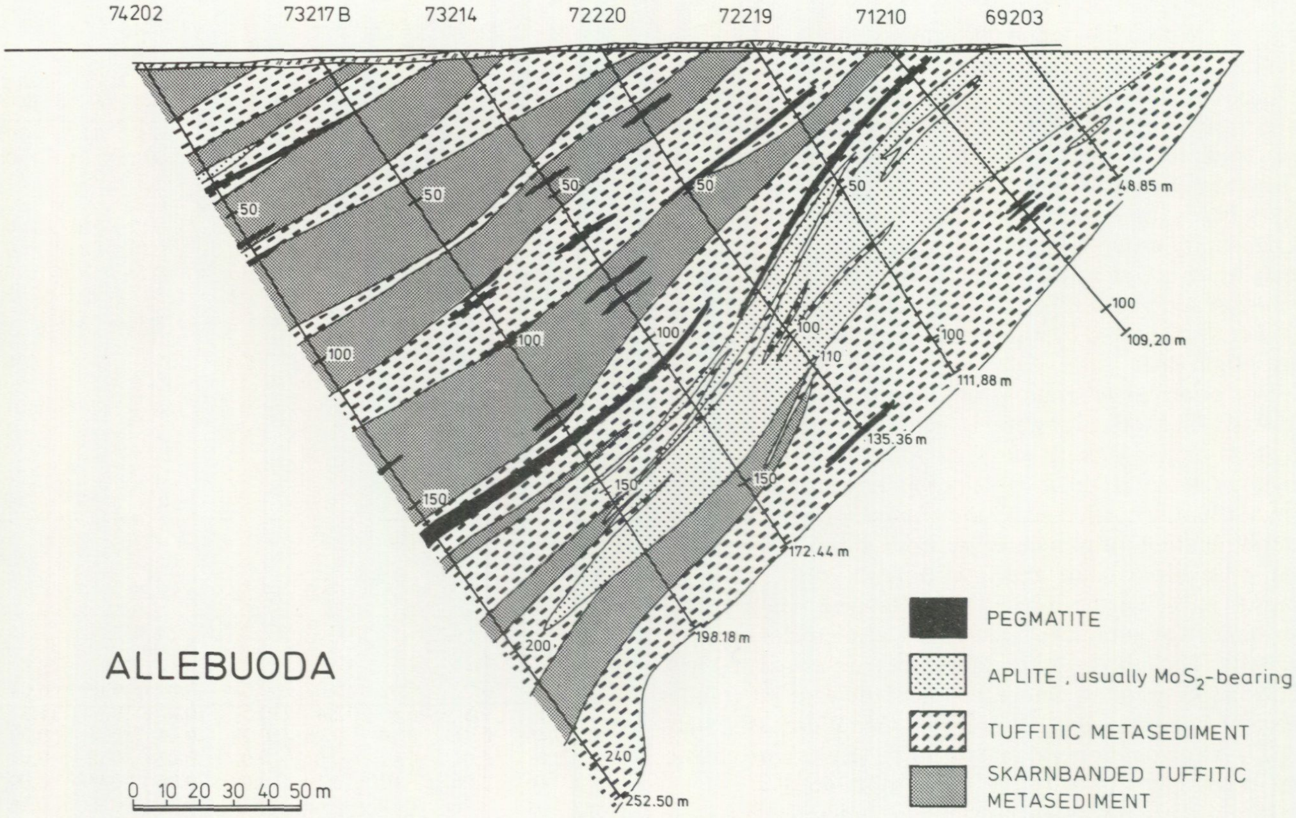


Fig. 22. Profile through the Allebuoda Mo-occurrence. After Einarsson in Walser & Einarsson (1982).

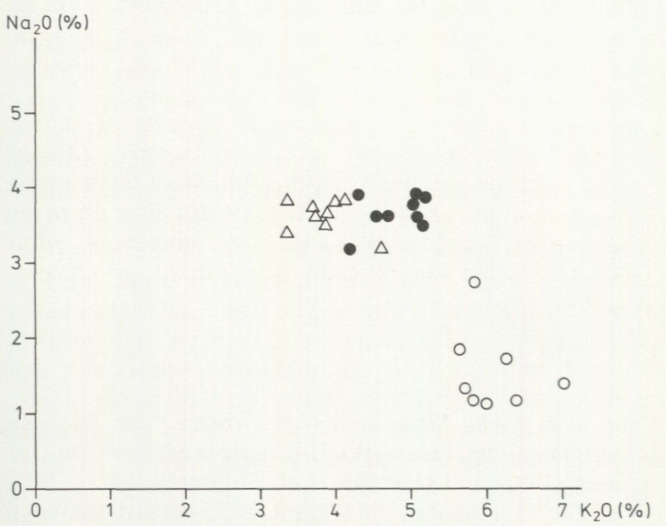


Fig. 23. Na_2O *versus* K_2O for Allebuoda samples. All values in wt.%. Dots represent granites, open circles represent aplites and the triangles represent marginal granites.

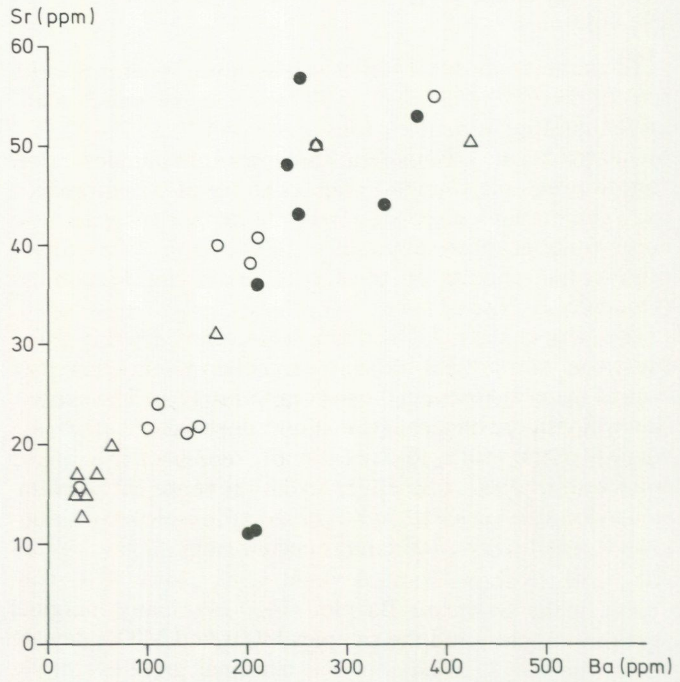


Fig. 24. Sr *versus* Ba for Allebuoda samples. All values in ppm. Symbols as in Fig. 23.

TABLE 4. Major and trace element contents of the molybdenite mineralized aplite at Allebuoda, and of the associated granites. Data from Öhlander (1985), and unpublished analyses.

		Granite									Marginal granite				
Sample		M001	M004	M011	M014	M017	M020	M023	M026	M031	80039	80040	80041	80042	80043
SiO_2	wt. %	76.8	75.8	75.1	72.0	74.9	75.2	78.1	74.4	76.2	76.8	77.9	76.5	77.2	79.0
TiO_2	”	0.03	0.05	0.17	0.16	0.15	0.13	0.15	0.15	0.14	0.06	0.05	0.05	0.05	0.07
Al_2O_3	”	12.6	12.5	13.3	13.0	13.2	13.6	12.3	14.1	13.5	12.4	12.3	13.3	12.8	11.6
Fe_2O_3-tot	”	0.94	0.97	1.80	1.72	1.67	1.45	1.55	1.69	1.55	0.93	0.78	0.70	0.70	0.85
MnO	”	0.01	0.03	0.05	0.05	0.04	0.03	0.04	0.05	0.04	0.03	0.02	0.02	0.02	0.02
MgO	”	0.15	0.15	0.25	0.17	0.23	0.25	0.17	0.30	0.28	0.02	0.01	0.01	0.01	0.03
CaO	”	0.35	0.55	0.84	0.91	0.95	0.76	0.75	0.96	0.88	0.61	0.50	0.55	0.46	0.46
Na_2O	”	3.84	3.87	3.59	3.53	3.66	3.58	3.22	3.86	3.78	3.72	3.75	3.80	3.83	3.39
K_2O	”	5.20	4.27	4.67	5.24	4.54	5.13	4.16	5.06	4.84	3.81	3.67	4.11	4.00	3.34
Ba	ppm	201	202	367	250	243	252	206	268	343	36	37	29	31	64
Rb	”	343	220	255	317	247	257	238	269	246	280	290	270	290	230
Sr	”	11	11	53	57	48	43	36	50	44	15	13	17	15	20
Zr	”	140	90	128	122	126	98	129	122	121	79	77	68	121	107
Cu	”	69	<5	5	6	<5	<5	5	<5	<5	3	3	2	6	4
Zn	”	354	19	24	37	23	23	24	29	26	19	13	22	13	19
Y	”	187	90	38	37	37	27	37	42	42	38	43	31	39	28
Nb	”	71	38	18	20	17	22	19	20	19	25	30	20	55	10

– = not analysed

		Marginal granite (contd.)				Aplites								
Sample		80045	80046	80047	80048	BG129	BG130	BG131	BG132	BG133	BG134	BG135	BG136	84301
SiO_2	wt. %	76.4	78.3	76.8	78.7	82.3	83.4	69.5	75.7	79.2	81.9	78.8	78.0	75.9
TiO_2	”	0.06	0.09	0.14	0.18	0.05	0.02	0.02	0.03	0.04	0.04	0.05	0.04	0.01
Al_2O_3	”	12.4	12.2	13.1	12.4	10.1	9.8	16.6	12.4	10.5	10.8	10.5	11.3	11.9
Fe_2O_3-tot	”	0.89	0.91	1.39	1.78	0.45	0.41	0.10	0.46	0.38	0.44	0.59	0.39	0.30
MnO	”	0.02	0.03	0.04	0.05	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
MgO	”	0.04	0.06	0.16	0.25	0.06	0.06	0.01	0.10	0.08	0.06	0.09	0.09	0.05
CaO	”	0.55	0.63	0.68	1.06	0.34	0.26	0.30	0.40	0.49	0.27	0.27	0.16	0.46
Na_2O	”	3.72	3.50	3.20	3.83	1.21	1.16	1.96	1.41	1.33	1.75	1.81	1.20	2.74
K_2O	”	3.79	3.79	4.58	3.30	5.81	5.99	9.45	7.03	5.73	6.25	5.61	6.35	5.77
Ba	ppm	50	167	422	274	168	99	210	202	152	109	138	392	26
Rb	”	220	230	280	230	450	490	630	530	440	410	380	400	550
Sr	”	17	32	56	50	40	22	41	38	22	24	21	55	15
Zr	”	95	78	124	135	75	64	72	64	64	64	69	81	90
Cu	”	2	3	3	3	9	10	8	13	8	9	11	8	23
Zn	”	19	22	28	40	32	25	17	36	17	17	29	25	–
Y	”	23	26	24	26	44	37	28	23	33	24	24	19	43
Nb	”	20	15	<10	10	<10	–	–	20	25	–	<10	<10	–

– = not analysed

In Table 4, geochemical analyses of samples from Allebuoda are shown. The samples M001–M031 represent a profile across the granite lobe, with M001 lying very close to the major mineralized aplite. The samples 80039–80049 were taken from a drillcore through the contact zone of the granite, at a place where no aplite has been developed. These samples are called “marginal granite” in the table. The samples 80039–80045 were taken from the complex contact zone with intermingled granitic and gneissic lenses, while 80046–80048 were from a homogeneous granite. The samples BG121–BG128 and 84301 represent the major mineralized aplite. Clear differentiation trends from granite to aplite can be seen (Figs. 23 and 24). However, the marginal granite (except, the samples taken from the homogeneous granite) shows some deviations, e.g. lower K_2O-content. In the Sr *versus* Ba plot (Fig. 24), many marginal granite samples, and the samples M001 and M004, deviate from the major trend. Several marginal granite samples have even lower Sr values than the aplites.

The REE patterns (Fig. 25) are similar to the ones presented for the Kåtaberget samples (Fig. 14). However, one aplitic sample lacks the large negative Eu-anomaly. In the aplites and the granite sample M001 taken near the mineralized aplite, the heavy REE are enriched and the light REE depleted relative to the “normal” granites.

It is probable that the aplite and its molybdenite enrichment at Allebuoda have been derived by magmatic differentiation from the granite. The development of the marginal granite, and the lack of a large negative Eu-anomaly in one of the aplitic samples indicate that hydrothermal solutions have sometimes obliterated the primary geochemical patterns.

Stop 3–2. – The Pleutajokk U-occurrence. The following description of the Pleutajokk U-occurrence is based on Gustafsson (1981) and Hålenius *et al.* (in press).

The development of the Pleutajokk U-occurrence was in many respects similar to that described for the Rävaberget and Björklund U-occurrences (pp. 20–21), although the country-rock at Pleutajokk is composed of rhyolites. The

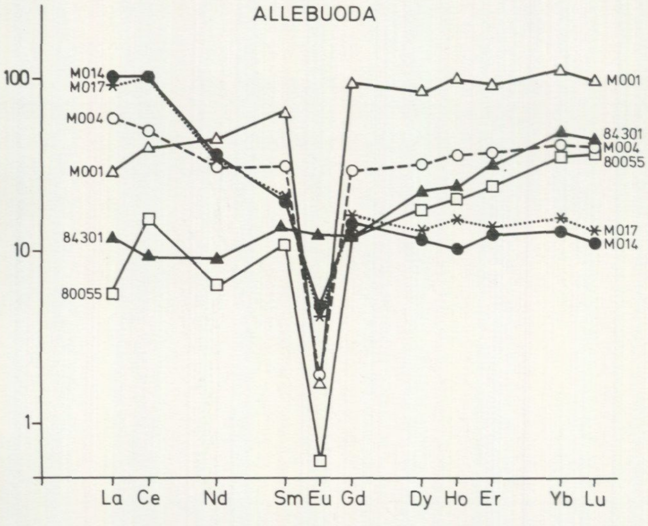


Fig. 25. Chondrite normalized REE patterns for Allebuoda samples. Normalizing values from Boynton (1984). The samples M004, M014 and M017 represent granites taken at some distance from the mineralization, M001 is a granite sample taken very near the mineralized aplite, and 84301 and 80055 represent the mineralized aplite.

uraninite is observed as concentrations along fractures and fissures.

The rocks of the Pleutajokk area consist of a sequence of metavolcanics, mostly rhyolites, but with minor intercalations of dacites (Fig. 26). The sequence is isoclinally folded with subhorizontal axes. After the volcanic period, deep seated faults were generated, some of which were filled with dolerites. Later the area was intruded by granites accompanied with numerous pegmatites. Both the granites and the pegmatites are, like the rhyolites, anomalously rich in U and Th. The strong U-enrichments have generally been deposited in the vicinity of the dolerites. Seven occurrences (A–G) have been found in the Pleutajokk area (Fig. 26). Of these, only A and B have been investigated in detail. The B-occurrence is the largest deposit with reserves of about 6000 metric tons U (Fig. 27). The U-bearing veins in the B-occurrence form part of a tabular body dipping from 70° to 75°. During the summer of 1980, LKAB drove a test tunnel through the ore body in the B-deposit. Economic feasibility studies showed, however, that mining was uneconomic and the tunnel was refilled. The excursion will visit the A-deposit.

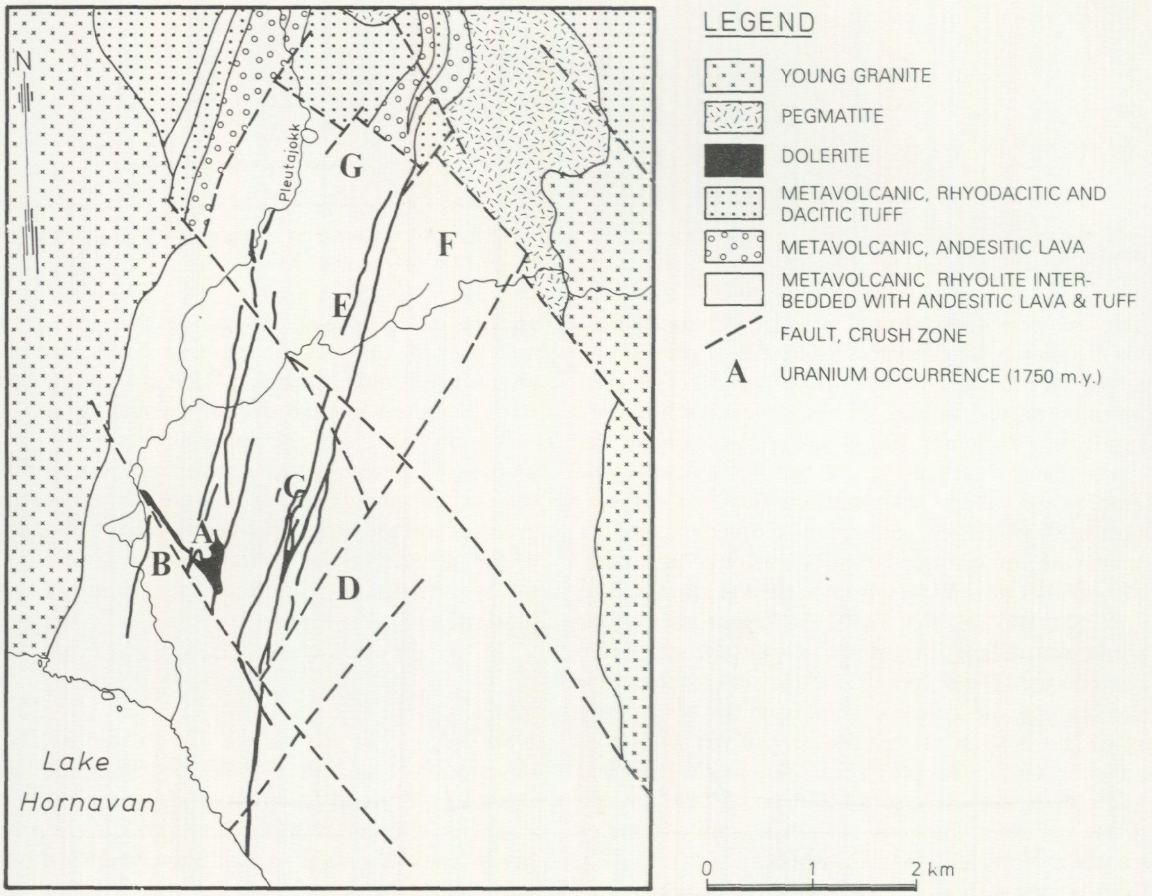


Fig. 26. Geology and U-occurrences in the Pleutajokk area. After Gustafsson (1981).

The age of the mineralization at Pleutajokk has been determined as 1.75±0.1 Ga (U-Pb). A summary of the main mineralogical characteristics is as follows:

Metamorphic stage:	Albite + augite + riebeckite + epidote
Hydrothermal U-mineralization stage:	1) Uraninite + calcite + fluorite + hematite + FeOOH. Oxidation and alteration of mafic minerals. 2) Uranotitanates (Different types of fracture infillings accompanied by sphene).
Late-stage low-temperature hydrothermal stage:	Remobilized radiogenic galena, chlorite, hematite and FeOOH. Alteration of uraninite to complex uranotitanates and secondary U-silicates. Pyrite.

The metasomatic alterations at Pleutajokk have resulted in enrichment in Na whereas K (and to some extent Si) have been depleted. See Fig. 28 for a discussion of the chemical changes caused by the hydrothermal solutions. See also the description of the Björklund U-occurrence (pp. 20–21).

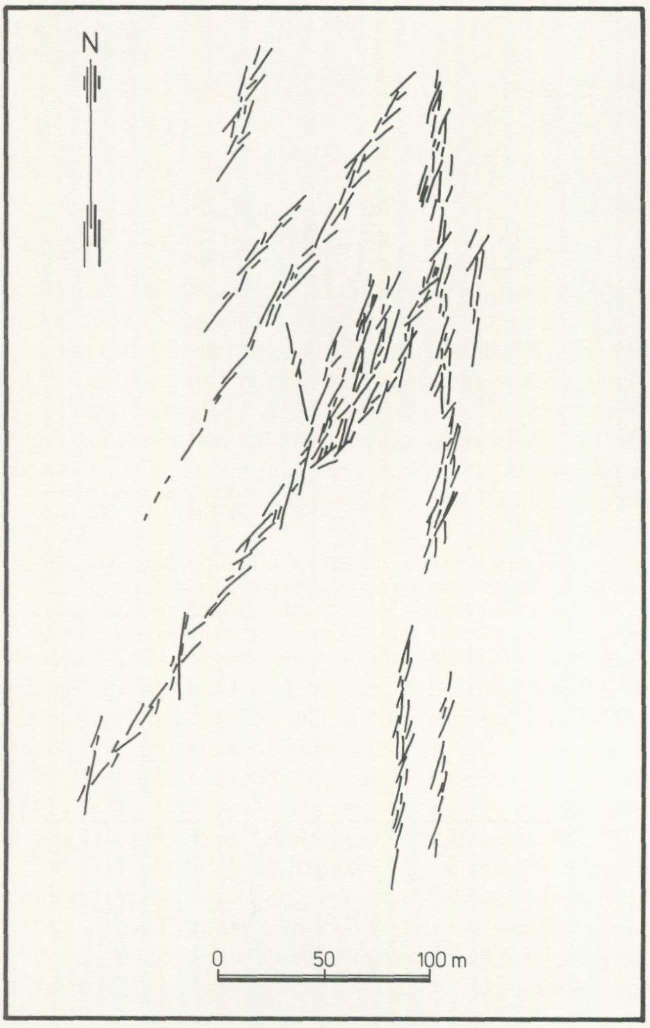


Fig. 27. Structural pattern of uranium-bearing veins in area B, Pleutajokk. After Gustafsson (1981).

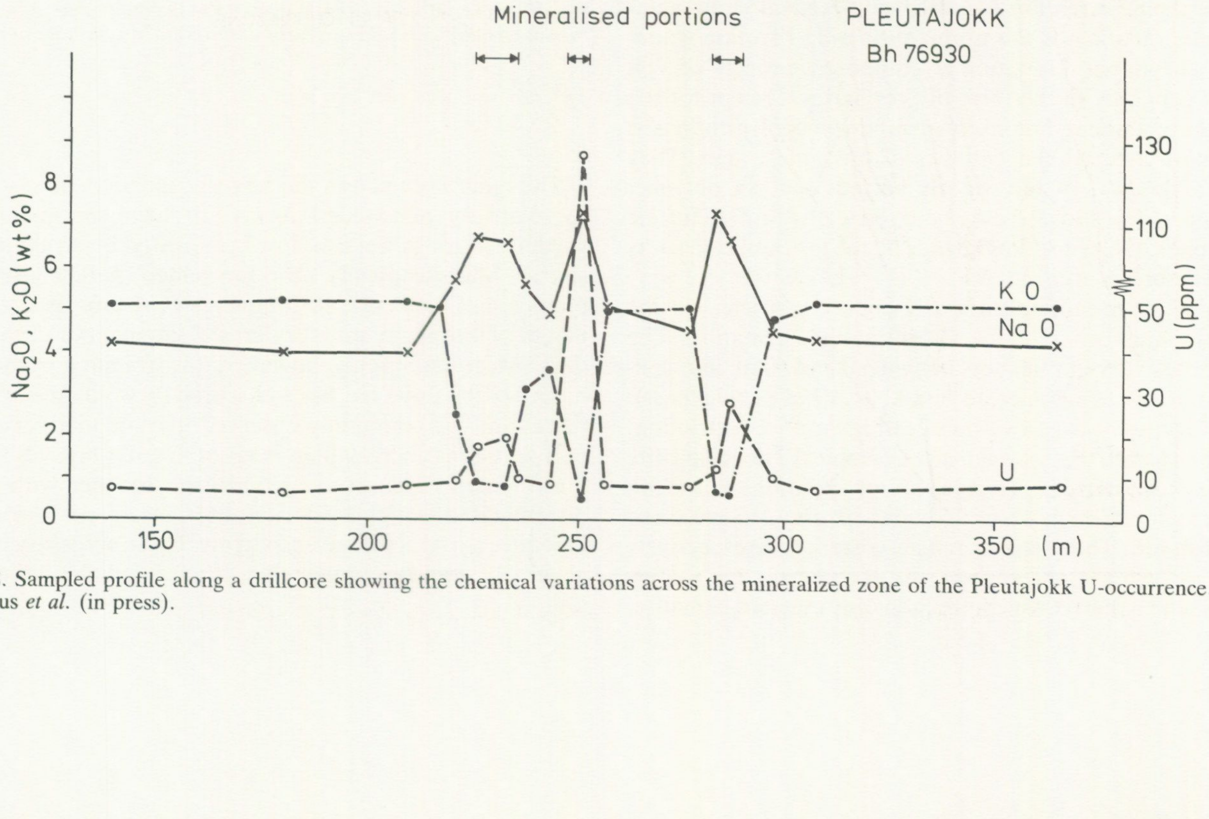


Fig. 28. Sampled profile along a drillcore showing the chemical variations across the mineralized zone of the Pleutajokk U-occurrence. After Hålenius *et al.* (in press).

DAY 4. THE DOBBLON AREA

The Dobblon area is situated on the southern part of the Karelian continent, immediately northwest of Skellefte district (Fig. 29). Rhyolitic volcanics, volcanoclastics and red-bed type sediments clearly overlie a granite dated to 1.75 Ga (Einarsson 1979, Welin *et al.* 1971, 1977), and must therefore be significantly younger than the Svecokarelian supracrustal rocks. The major U-mineralization at Dobblon occurs in a thin but extensive rhyolitic ignimbrite.

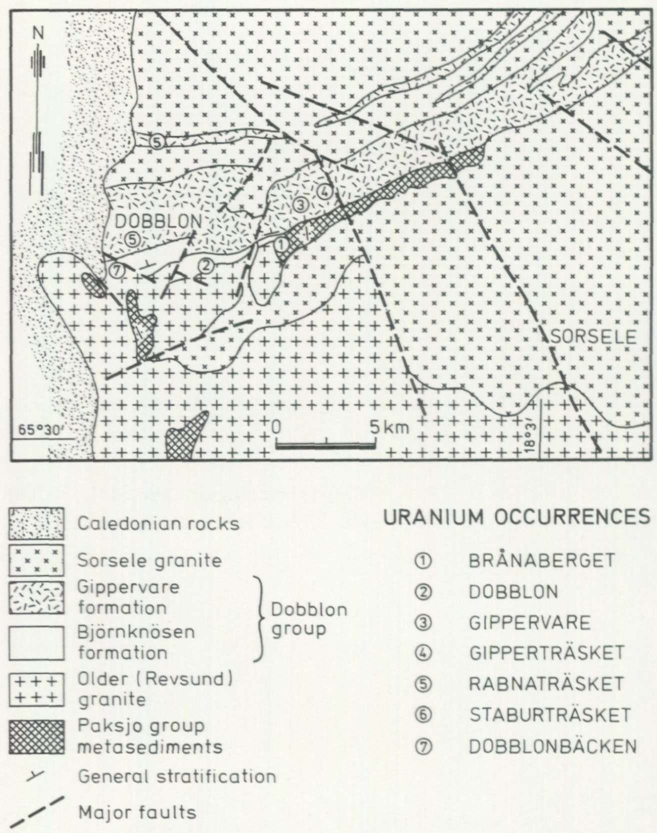


Fig. 29. Generalized geological map of the Dobblon area. After Lindroos & Smellie (1979). The excursion stop is at U-occurrence number 2.

STOP DESCRIPTIONS

Stop 4–1. – The Dobblon U-occurrence. The following description is based on the work of Lindroos and Smellie (1979) and Smellie (1982). The general geology and the stratigraphy of the Dobblon area are shown in Figs. 30 and 31. The stratigraphic scheme is modified after Einarsson. The radiometric ages are obtained from Welin *et al.* (1971, 1977). The so-called "older granite" in the Figs. 31 and 32 actually belongs to the younger granitoid group (1.8–1.75 Ga) of the Svecokarelian orogeny. The "older granite" forms the basement to the Dobblon group. Thus the Dobblon group was deposited on a deeply weathered basement of the "older granite". The lowest unit of the Dobblon group consists of a basal breccia.

According to Einarsson (1979), the Dobblon group is separated into two formations: the Björnknösen Formation (at the base) and the overlying Gippervare Formation. The Björnknösen Formation is further separated into four members, one of which is the uranium-bearing rhyolitic ignimbrite. The upper formation is composed entirely of volcanics, generally in the form of porphyries. Except for the basal breccia, the sedimentary members of the Björnknösen Formation are red-bed deposits of fluviatile origin. They occur as coarse, mainly poorly sorted, reddish polymict conglomerates, and also as grey to red well-stratified tuffitic sandstones. Dolerite dikes intrude all the Precambrian rocks of the Dobblon area.

The uranium-mineralization is mainly restricted to the rhyolitic ignimbrites of the Björnknösen Formation. The ignimbrites vary in thickness between 0 and 60 m, and contain a narrow conglomerate bed (1 to 10 m in thickness). This indicates at least two phases of ignimbrite deposition, but the situation may be even more complex. The ignimbrite (or ash-flow tuff) shows typical colour variations from dark olive-green, through several shades of grey, to pink and brownish red. These colour ranges correspond respectively to a chlorite- to sericite-rich matrix, a quartzose feldspathic matrix, and a matrix which is rich in disseminated hematite.

The ignimbrite shows the largest gradation from welded to relatively nonwelded forms. In hand-specimens, the welded nature of the ash flow is indicated by a subvitreous lustre. Microscopically, the unwelded part consists of pumice and broken rock fragments (1–4 mm in size) in a matrix of fine glassy splinters, crystal fragments and volcanic dust. More commonly however, the primary pyroclastic nature of the flows has been obscured by welding and devitrification. It is commonly observed that the matrix consists of a dense microcrystalline mass of angular crystals (c. 0.1 mm in size) of quartz and feldspar, together with finely disseminated sericite-chlorite and accessory magnetite, ilmenite, pyrite, epidote and zircon. These accessory minerals are of common occurrence throughout the ignimbrite unit.

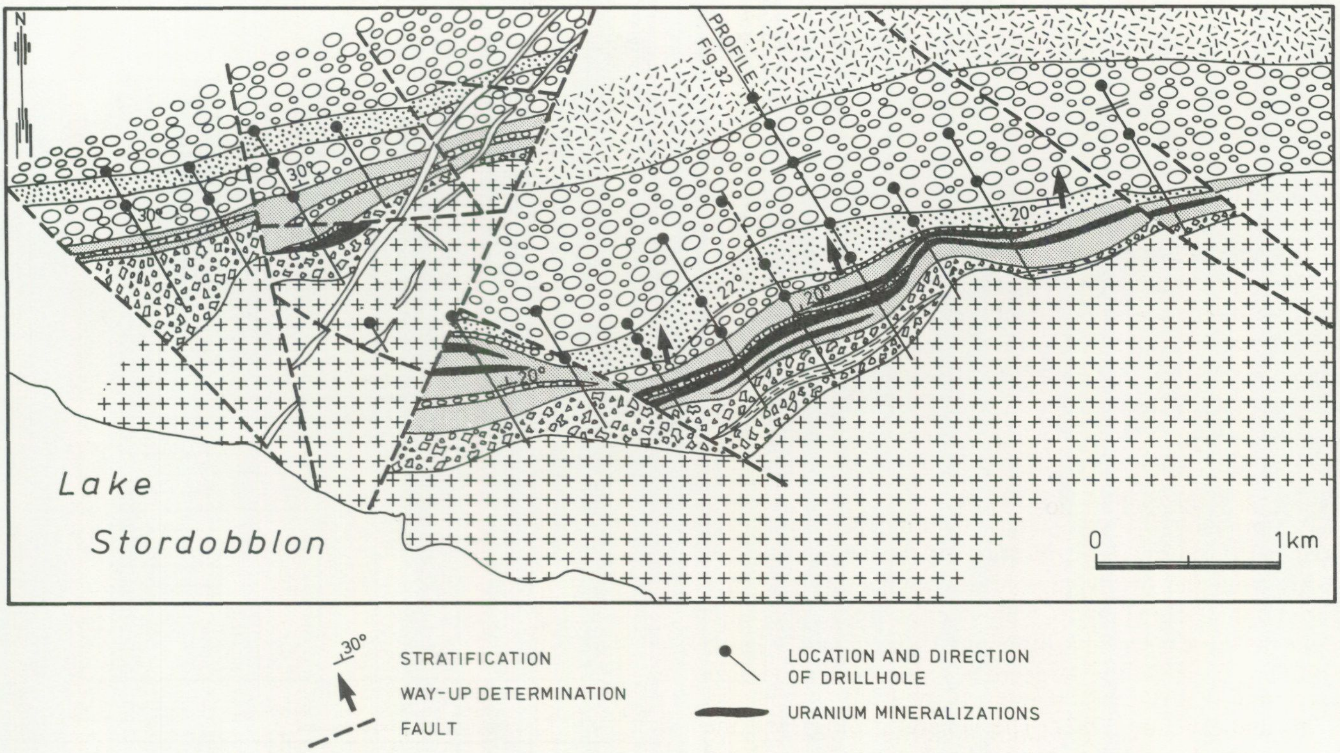


Fig. 30. Geological map of the Dobblon area. After Lindroos & Smellie (1979). Legend as in Fig. 31.

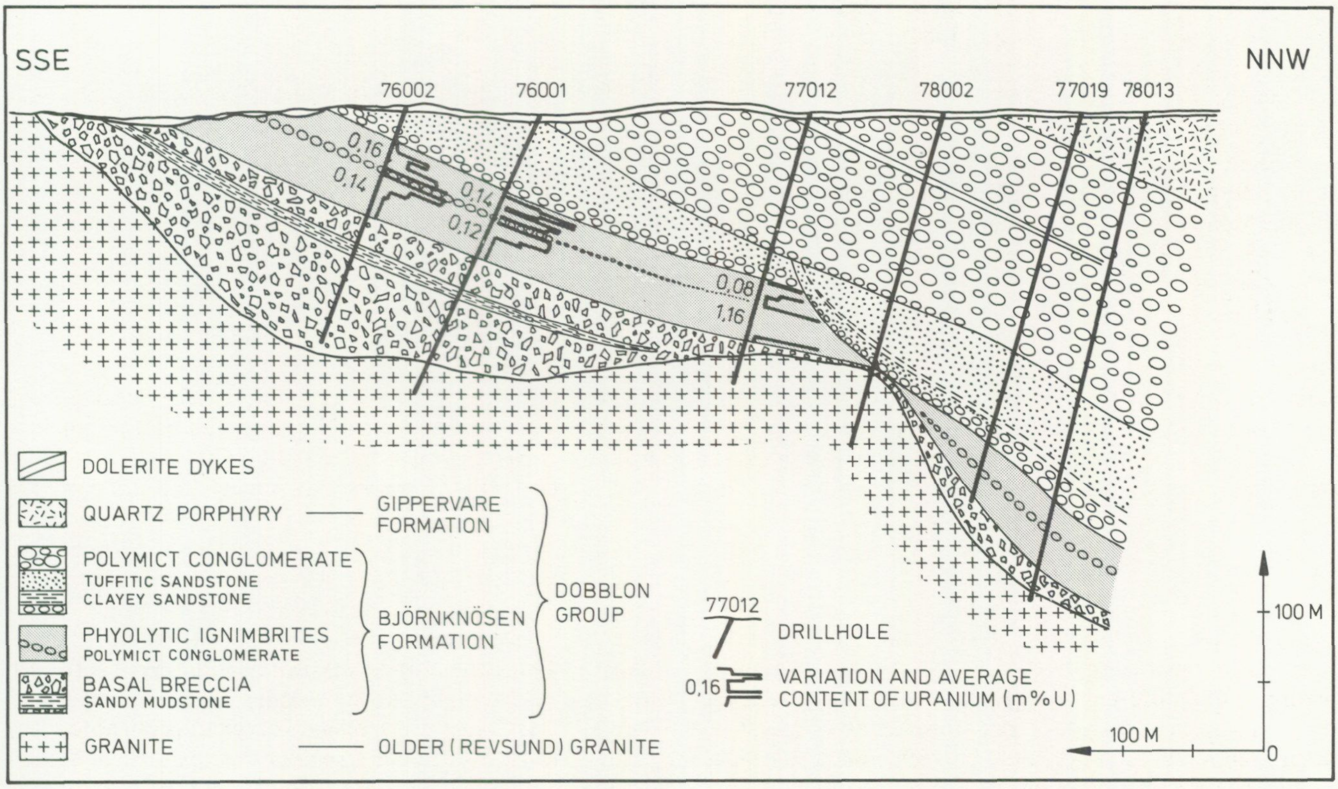


Fig. 31. Profile through the Dobblon U-occurrence. After Lindroos & Smellie (1979).

A striking feature of the ignimbrites is the presence of lithophysae and vapour-phase cavities. The lithophysae are restricted to the welded areas of the ignimbrite, and range in size from 5 mm to 15 cm in diameter. The shape varies from spheroidal, ellipsoidal to lenticular. The mineral assemblages within the lithophysae are dominated by quartz with subordinate feldspar. These can commonly constitute a concentric layering within the lithophysae, the layering reflecting an alternation of fine and coarse quartz aggregates.

Uranium enrichments of up to 3000 ppm U occur within two or three peneconcordant tabular horizons, mostly lithophysae-bearing, within the ignimbrite (Fig. 31). The uranium occurs as fine pitchblende disseminations, as complex uranotitanates associated with Fe-Ti-Mn oxides, and also as coatings associated with matrix sericite. Small quantities of uranium are present in primary accessory minerals such as sphene, apatite and zircon.

It is probable that oxidizing U-bearing solutions, generated partly during devitrification of the ignimbrites and partly from the overlying volcano-sedimentary pile, produced the U-enrichments with later sulphide deposition along the more permeable lithophysal horizons in the ignimbrite. Fig. 32 shows the paragenetic sequence of mineralization within the Dobblon ignimbrites.

Within the Dobblon rhyolitic ignimbrites sporadic enrichments of up to 70 ppm Mo occur, although these do not necessarily coincide with U-enrichments. In one case, 2000 ppm Mo was determined from a section containing 241 ppm U, the Mo occurring as finely disseminated molybdenite.

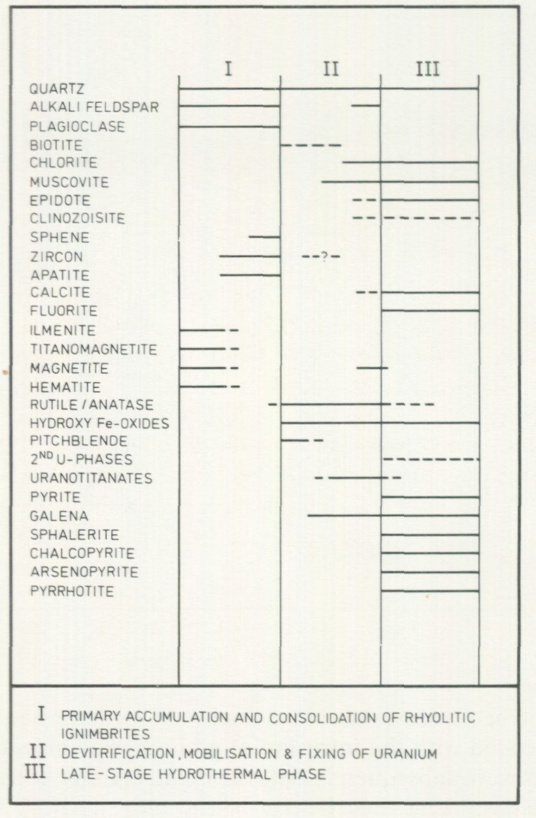


Fig. 32. Paragenetic sequence of mineralization within the Dobblon ignimbrites. After Smellie (1982).

DAY 5. W-OCCURRENCES IN THE STORUMAN AREA

The Storuman area belongs to the Bothnian basin metasedimentary domain (Fig. 33). The oldest rocks in this area are metasediments with intercalated basic metavolcanics (Löfgren 1979, Fors & Ihre 1982). Metasediments of the arenitic greywacke-type predominate. These greywackes are often very well-preserved, with primary sedimentary structures such as graded bedding, load cast and cross-bedding. Intercalated in the arenitic metagreywackes are argillitic metagreywacke horizons which contain small amounts of graphite, pyrite, pyrrhotite and occasionally chalcopyrite and sphalerite. The basic metavolcanics are dominated by low-K tholeiites of sub-marine origin; pillow lavas have been found. Tuffs and tuffites have also been found.

All the supracrustals are deformed. This deformation was associated with the intrusion of granodioritic massifs. The latter were subsequently deformed and are now foliated. It is believed that they belong to the older (1.89–1.84 Ga) group of Svecokarelic granitoids, but no radiometric age determinations have been made.

However, in the Storuman area, as in the entire Bothnian basin, the younger granite intrusions are the dominant granitoid type. The most common type is a coarse grey porphyritic granite, which was probably generated from the sediments as source material. It is generally called Revsund granite and belongs to the 1.8–1.75 Ga granitoid group (Welin 1979 , T. Skiöld, Stockholm, pers. comm 1986). The Revsund granite group is less homogeneous than was previously thought. However, all the younger granites in the Storuman part of the Bothnian basin are peraluminous and have a $\delta^{18}O$ value between 9 and 12 which supports the hypothesis that sediments were the source material for the granites (Wilson *et al.* 1985).

Several W-occurrences have been discovered in the Storuman area. They are associated with "anomalous" intrusions of the Revsund granite group. The intrusions are "anomalous" in the sense that they e.g. are rich in U, Th, Sn, Li and Rb. The excursion will study the following three W-occurrences (Fig. 33):

(1) A scheelite occurrence at Svärtträsk associated with a two-mica granite which has been U-Pb zircon dated to c. 1.77 Ga (Wilson *et al.* 1985).

(2) The Rostberget wolframite occurrence associated with the Joran dome which has been U-Pb zircon dated to 1.74±0.4 Ga (Wilson *et al.* 1983).

(3) The Storträsket wolframite occurrence associated with a granite similar to the Joran dome.

The youngest rocks in the Storuman area are dolerite dykes that cut all the other rocks.

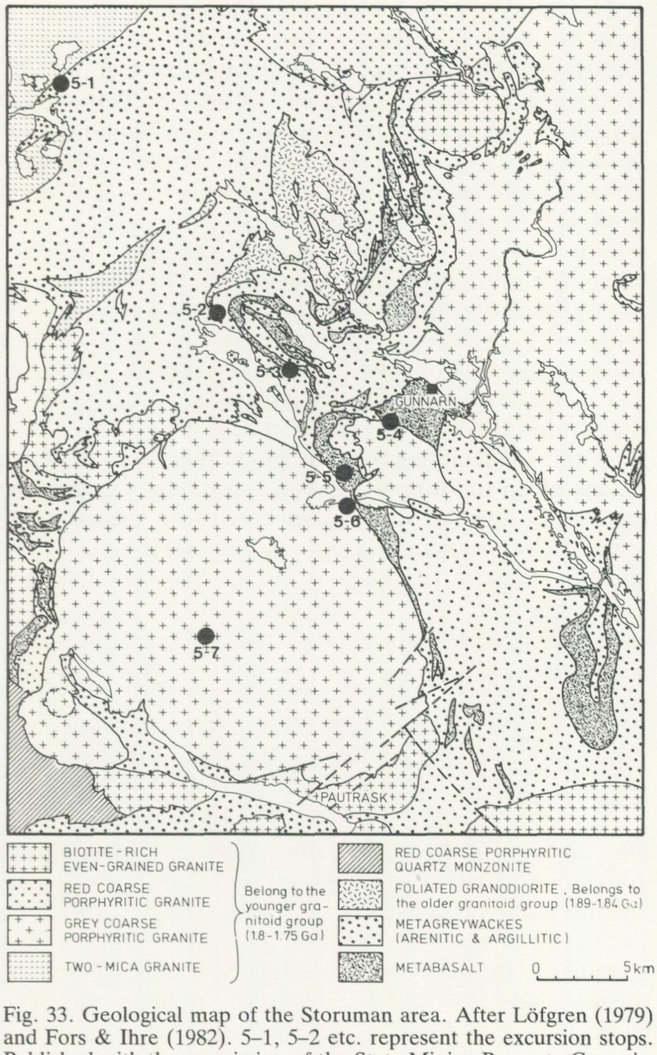


Fig. 33. Geological map of the Storuman area. After Löfgren (1979) and Fors & Ihre (1982). 5–1, 5–2 etc. represent the excursion stops. Published with the permission of the State Mining Property Commission (NSG).

STOP DESCRIPTIONS

Stop 5–1. – The Svärtträsk W-occurrence. The following description of the Svärtträsk W-occurrence is based on the work of Holmqvist (1979). The Storuman two-mica granite forms part of a multiple intrusion. It has developed in an irregular roof zone adjacent to locally migmatized metasediments. The two-mica granite is heterogeneous, and has abundant metasediment xenoliths. The intrusion is partly surrounded by metagreywackes (Fig. 33), in which conformable metabasites and ultrabasites occur. In a tabular ultrabasic hornblendite body situated 600 m from the contact with the two-mica granite, a scheelite occurrence has been found.

The mineralized tabular hornblendite body is steep, and is at least 150 m long. Its width varies between 5 and 12 m. The hornblendite is medium- to coarse-grained. It consists mainly of Mg-rich hornblende. However, accessory minerals such as sphene and opaque minerals are commonly found.

In a number of locations, the hornblendite is penetrated by quartz veins and dykes, whose widths vary from a few centimetres to roughly one metre. Veins and dykes of pegmatites, and rarely aplites, rich in grey feldspar also occur. All of these veins and dykes are almost barren with respect to scheelite. The scheelite is bound to extensively fractured heterogeneous zones. It occurs both in the fractures and as impregnations in the hornblendite. The 1–2 cm wide, light-grey veins characterized by the development of secondary mica are particularly rich in scheelite.

It is probable that the Svärtträsket W-occurrence is epigenetic and was generated by late-stage hydrothermal solutions from the adjacent granite intrusion. The hornblendite acted as a trap for these solutions.

Stop 5–2. – Supracrustal rocks near Barsele. Near Barsele, several road outcrops with metamorphosed supracrustal rocks occur (Fig. 33). Arenitic metagreywackes and a black argillitic metagreywacke rich in graphite will be shown. The latter also contains sulphides. Certain horizons of the meta-arenite may actually be acid metatuffites. An outcrop consisting of a foliated granodiorite will be visited. It represents what is believed to be the "older granitoids" (1.89–1.84 Ga) in the area.

Stop 5–3. – Metamorphosed agglomerates and lapilli-tuff (Fig. 33).

Stop 5–4. – The Storträsket W-occurrence. The following description is based on the work of Sandahl *et al.* (1982). The Storträsket W-occurrence is associated with the Grundfors granite intrusions, 8 km long and 4 km wide (Fig. 33). The granite is leight grey, medium- to coarse-grained, porphyritic; the largest grains, 0.5–2 cm, consist of microcline. The matrix consists of quartz, plagioclase (albite-oligoclase), microcline and biotite. Accessory minerals are epidote, amphibole, chlorite, muscovite, sericite, apatite, zircon, fluorite and opaque minerals.

In comparison with "normal" Revsund granites, the Grundfors granite has higher SiO_2- and Na_2O-contents and lower TiO_2, Fe, MgO and CaO; its K_2O-content is also slightly lower.

A leucogranite has developed in a contact zone of the intrusion (Fig. 34). It is medium-grained and not porphyritic. It consists mainly of quartz, albite, light green mica (muscovite) and small quantities of microcline. Accessory minerals are epidote, chlorite, biotite, sericite, fluorite, calcite, talc, apatite, zircon, goethite and opaque minerals. The contact zone is up to 200 m wide. The leucogranite is greisenized to varying extent; its texture is granoblastic. Light fine-grained barren aplites cut the leucogranite and the surrounding metagreywackes.

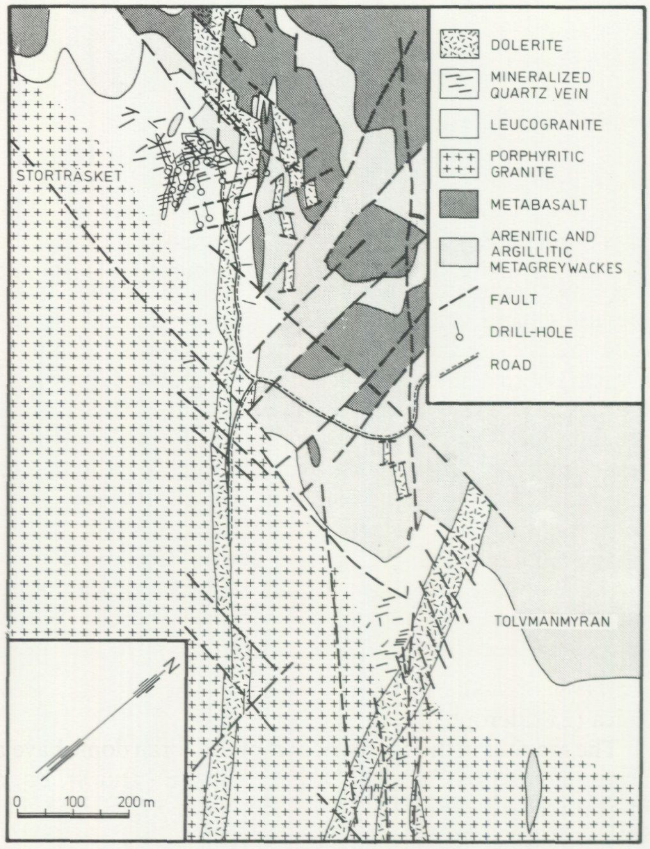


Fig. 34. Geology of the area surrounding the Storträsket W-occurrence. After Sandahl *et al.* (1982). Published with the permission of the State Mining Property Commission (NSG).

In the Grundfors intrusion, steeply dipping quartz veins with two major directions occur, N 40–50°W and N 10–20°E. The latter vein system forms a swarm of veins which is mineralized in the leucogranite (Fig. 34). Two major W-occurrences have been located at Storträsket and Tolvmanmyran.

The most important mineral is wolframite but scheelite also occurs. The wolframite is concentrated in the boundaries of the quartz veins. It forms tabular plates that are occasionally as large as 10×10 cm. Scheelite occurs as separate grains and as inclusions in the wolframite. Mainly scheelite, but also wolframite, can be seen in the leucogranite close to the quartz veins. Arsenopyrite, molybdenite, pyrite, pyrrhotite, chalcopyrite and galena have been observed in the quartz veins. Fluorite is very common, and tourmaline is also sometimes found. The quartz veins often have anomalously high contents of Au and Ag.

Stop 5–5. – Metabasalt with preserved pillow-lava structures near Grundfors.

Stop 5–6. – Fluorite enrichment in the Joran dome. A granite intrusion, called the Joran dome (Fig. 33), is in certain locations highly enriched in fluorite. Violet fluorite has impregnated the matrix of this coarse porphyritic granite. The fluorite content can be as high as 10–20 %. For a description of the Joran dome, see stop 5–7.

Stop 5–7. – The Rostberget W-occurrence. The following description is based on the work of Simeonov (1984), Gerdin & Triumf (1984), and also on unpublished material at the Luleå University. The Rostberget W-occurrence is situated in the Joran granite dome (Fig. 33).

The northern part of this dome consists of a coarse-grained porphyritic granite (microcline up to 4 cm in size is common). It is homogeneous and resembles normal Revsund granites. In the southern part of the massif, somewhat younger, medium- and fine-grained granites appear as late differentiation products. All these rocks are peraluminous, albite-microcline granites with low K/Rb ratios. The dark mica is presumably a Li-rich biotite and/or a Li-siderophyllite. Fluorite, zircon, ilmenite, monazite, bastnaesite and topaz are typical accessory minerals. Secondary sphene, apatite and allanite are present. In metasomatically altered parts, native silver, argentite and cassiterite occur (Simeonov 1984). Cassiterite occurs only in association with a dark mica (Li-siderophyllite).

The granites in the southern part of the Joran dome have a lower content of CaO, MgO, Fe*, TiO_2, Ba and Sr, but a higher content of SiO_2, K_2O, Li, Rb, Be and F compared to normal Revsund granites. The coarse-grained porphyritic granite from the northern part of the Joran dome is intermediate between the granites in the south and the normal Revsund granites.

The Rostberget W-occurrence is located at 5–7 in Fig. 33. The W-enrichment is associated with a swarm of undeformed, thin greisen veins. The orientation of the mineralized veins is N20°E, and follows that of the mineralized veins at Storträsket, stop 5–4. The greisen veins are exposed over a 250 m long and 25 m wide zone. Their total length is unknown. The individual greisen veins are 0.5–2 cm wide. They are surrounded by a 2–5 cm wide, clearly visible alteration zone. The vein frequency is displayed in Fig. 35. The greisen veins are younger than the aplites that cut the granite.

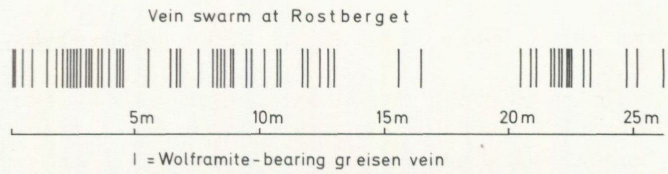


Fig. 35. Frequency of veins in the greisen vein swarm at Rostberget. After Gerdin & Triumf (1984). The figure represents a small section of an outcrop seen from above. The width of the vein swarm is approximately 25 m. Published with the permission of the State Mining Property Commission (NSG).

The granites surrounding the veins are mainly composed of quartz, microcline, biotite and muscovite replacing feldspar. The biotite is chloritized and rich in inclusions of sphene, zircon and monazite. Fluorite, allanite, epidote, apatite and ilmenite, are common accessory minerals.

The greisen veins are dominated by quartz and light mica, the latter replacing feldspar. Chloritized biotite, rich in monazite and zircon occur. The W-enrichment is caused by erratically distributed wolframite aggregates about 1 cm in size. Fluorite is very common and pyrite and chalcopyrite have been observed. Other accessory minerals are topaz, epidote and allanite.

Table 5 includes results of chemical analyses of greisen veins as well as granite and aplite in the greisen zone. Despite the mineralogical differences between the greisen veins and the granites, the chemical differences are not significant. The greisen veins are slightly richer in Fe_2O_3, CaO, Rb and Cu. However, they have a lower Na_2O-, K_2O- and Sr-content than the surrounding granites. The granite samples were collected from regions so close to the veins that they were also affected by the mineralizing fluids. This might, to some extent, explain the small chemical differences observed. The greisen veins do not show the very low La-contents typical of late magmatic differentiates such as aplites. For example, compare this with the aplite or the Mo-mineralized aplites at Kåtaberget (p. 17) and Allebuoda (p. 23).

TABLE 5. Major and trace element analyses of greisen veins, granites and an aplite from Rostberget. The granite samples are taken very near the greisen veins, within the swarm of veins.

		Greisen veins			Aplite	Granites				
Sample		84403	84404	84408	84405	84401	84402	84406	84407	84409
SiO_2	wt. %	73.8	74.8	72.4	76.2	74.1	72.6	76.5	74.8	74.5
TiO_2	”	0.08	0.12	0.10	0.03	0.07	0.07	0.08	0.10	0.12
Al_2O_3	”	13.0	12.0	14.6	13.2	13.1	14.0	12.4	12.7	13.1
Fe_2O_3-tot	”	2.15	2.85	2.95	0.23	1.14	1.07	0.76	1.41	1.68
MnO	”	0.03	0.04	0.04	0.01	0.02	0.01	0.10	0.02	0.02
MgO	”	0.06	0.08	0.07	0.02	0.05	0.05	0.16	0.07	0.07
CaO	”	1.23	1.15	1.23	0.25	0.74	0.70	0.89	0.87	0.79
Na_2O	”	2.17	2.09	1.98	4.06	2.89	2.82	3.17	2.97	2.70
K_2O	”	4.31	4.14	4.24	4.29	5.83	6.60	4.53	5.08	5.25
Ba	ppm	200	100	215	27	333	386	214	152	275
Rb	”	920	740	1080	470	630	900	540	660	580
Sr	”	38	29	33	23	71	77	72	51	64
Cu	”	42	23	42	1	10	19	4	13	19
Sc	”	1.4	1.9	1.4	0.4	0.8	0.6	1.8	1.8	1.1
V	”	11	12	18	8	5	6	19	18	22
Zr	”	154	251	103	99	171	188	299	125	225
La	”	21	47	31	6	28	18	87	35	39
Yb	”	2.1	3.8	2.4	3.3	3.1	1.5	4.0	4.6	2.4

DAY 6. THE TALLBERG PORPHYRY TYPE Cu-MINERALIZATION

P. Weihed

The Tallberg mineralization is located in the outer, older zone (called the G1 zone by Wilson *et al.*, in press) of the Jörn granitoid complex, see Fig. 36, which has a compositional range from tonalite to granodiorite. Some gabbroic intrusions also occur. The regional geology of the Tallberg area is outlined in Figs. 36–37. The mineralization is of porphyry type, with the following characteristics:

* Low grade, 0.27 % Cu (at a cut off of 0.20 % Cu) and large tonnage, 43.8 million metric tons.
* Ore minerals: chalcopyrite, pyrite, molybdenite, sphalerite, galena and magnetite.
* Ore minerals occur in veinlets as stockwork mineralization (gangue minerals quartz, calcite and chlorite) and disseminated, mainly chalcopyrite and pyrite.
* Hydrothermal alteration: phyllic-quartz, pyrite and sericite; propylitic-clorite, epidote and calcite.
* Associated with quartz-feldspar porphyritic granitoid stocks.
* A weak metal zonation with Cu-Mo in the central parts and higher Zn-Pb contents in the outer zones.
* Probably related to syngenetic faults or lines of weakness.

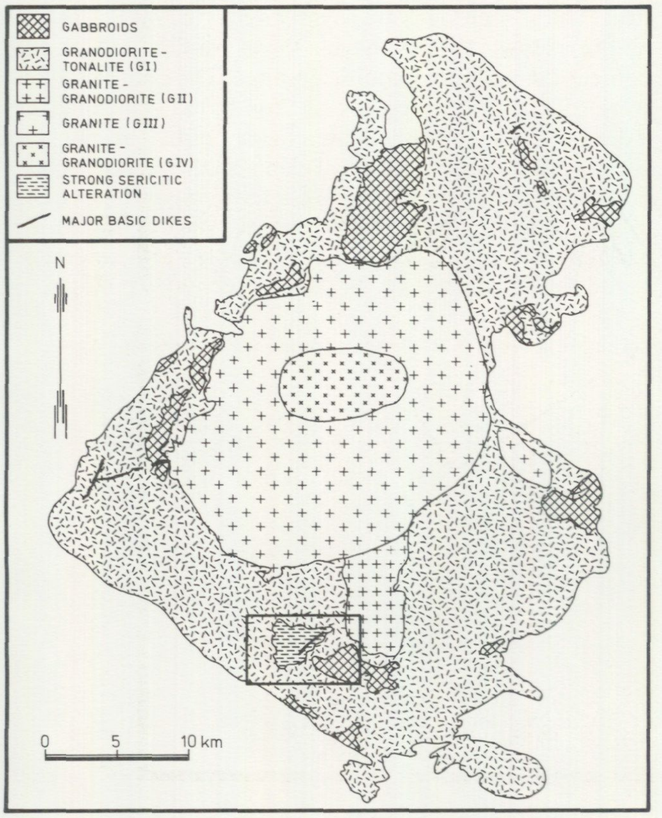


Fig. 36. Geological map of the Jörn granitoid massif. Modified after Wilson *et al.* (in press). The location of Fig. 37 is indicated.

At the interception of a WNW–ESE and a NE–SW trending line of crustal weakness the granodioritic border zone is intruded by a number of small quartz-feldspar porphyritic stocks less than 50 m wide and slightly elongated in an ENE direction, see Figs. 37 and 38. Around these stocks an intense quartz veining occurs, which is mineralized in its central parts. The area was later intruded by mafic post-mineralization dikes, <20 m wide, trending in an ENE direction. The mineralization is separated into two bodies, a larger one, approximately 500×300 m in size, NW of a smaller one with a somewhat higher Au-content, 2–3 g/ton. The Mo content is approximately 0.01–0.02 % in both bodies. Zn-content is variable, but sometimes reaches 2.5 % in analyzed sections (c. 5 m). The higher Au-content seems to be related to strongly schistose zones, parallel and adjacent to the post-mineralization dikes. These zones often show a phyllic alteration in contrast to the main mineralization, which shows a propylitic to mixed phyllic-propylitic alteration. The Au-content is interpreted as remobilized into these shear zones.

Because of the many similarities with Phanerozoic porphyry copper deposits, the mineralization is interpreted as being a Proterozoic equivalent of the former. However, some differences exist e.g. no supracrustal host rocks occur, the grade is lower and there is no obvious alteration zoning. These discrepancies may be explained by a deeper erosion level compared with more recent porphyry deposits, and the fact that a number of small porphyritic stocks with associated hydrothermal systems have intruded, and overprint each other.

STOP DESCRIPTIONS

Stop 6–1. – Granodiorite in the G1 zone. At this locality, a granodiorite in the G1 zone will be demonstrated. Although the granodiorite is unaffected by hydrothermal alteration, it has been altered by regional greenschist metamorphism. It is often difficult to distinguish this from granodiorite with a propylitic hydrothermal alteration. Mineralogically it is composed of quartz, oligoclase, biotite, hornblende and microcline as main minerals and of epidote, apatite, sphene, zircon and ore minerals as the accessories (Wilson *et al.*, in press). The regional metamorphism is evident in the sericitic alteration of the feldspars and chloritic alteration of biotite and hornblende.

Stop 6–2. – Drill cores from the Tallberg deposit. Since the mineralization is situated in a topographically low area under bogs, no exposures of the deposit can be shown. Instead, a drill core (DDH 91) will be demonstrated. The different lithological units can be identified in this drill core as well as mineralization and alterations. A cross section through the southern mineralization is given in Fig. 39.

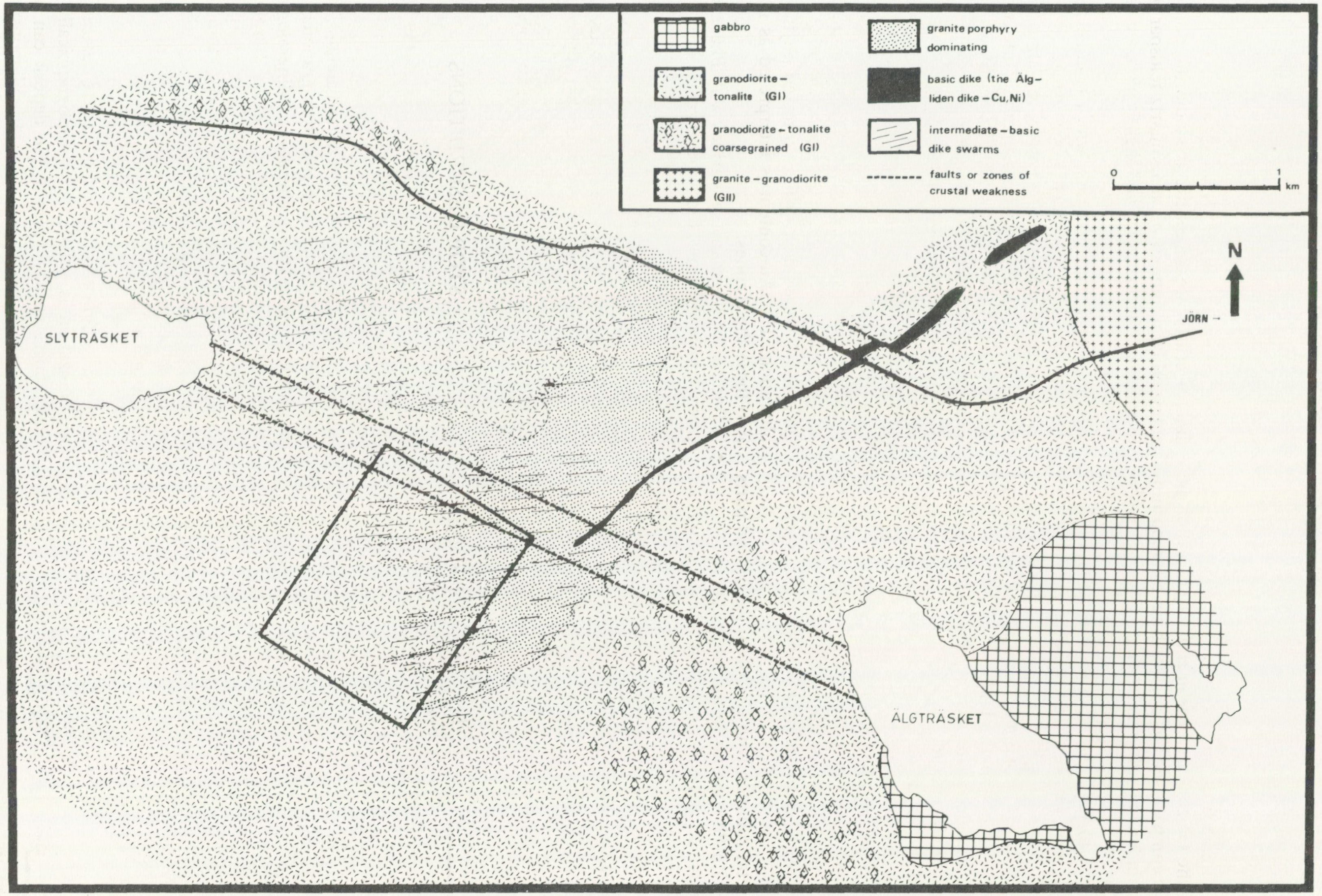


Fig. 37. The geology of the Tallberg area. The location of Fig. 38 is indicated.

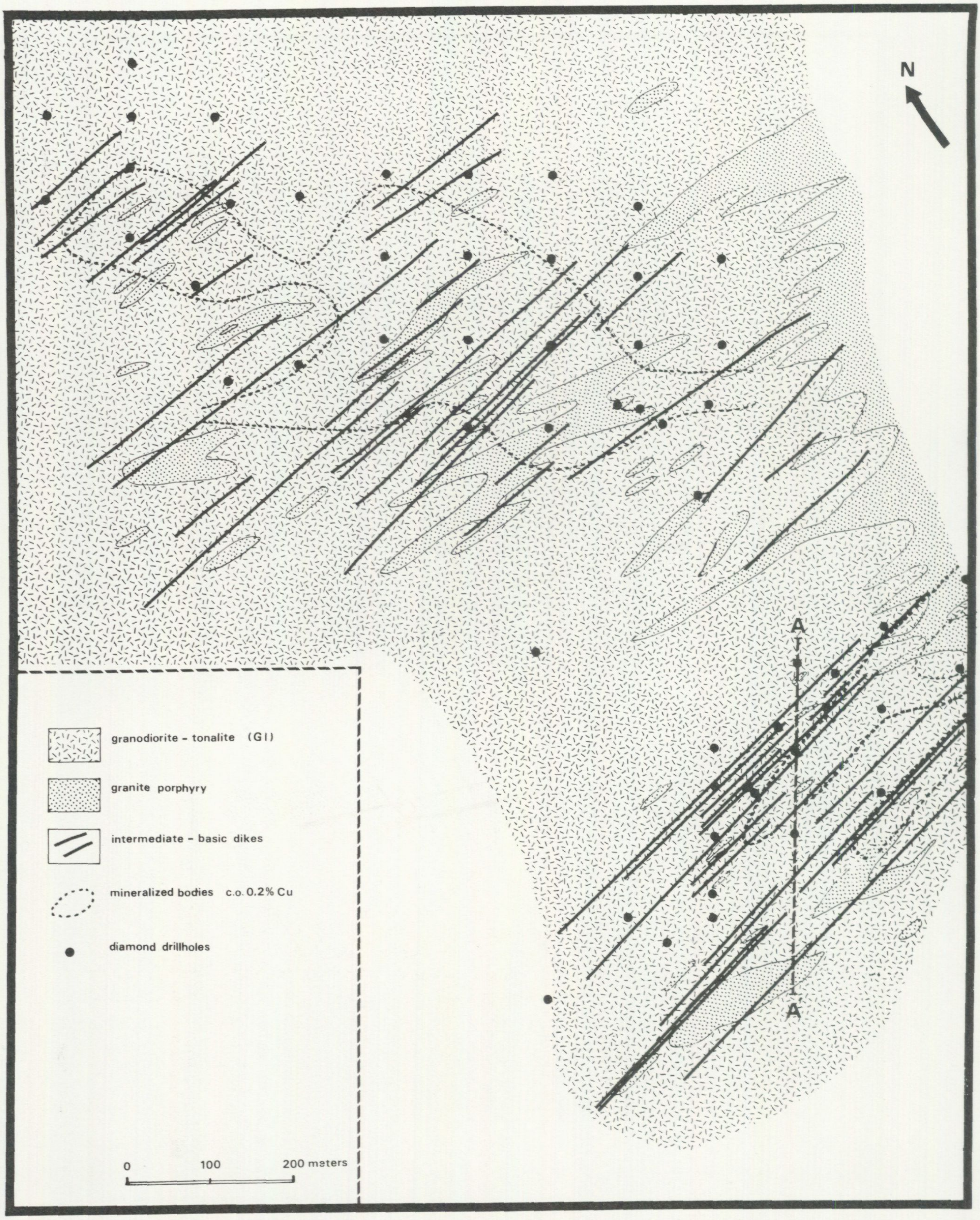


Fig. 38. Detailed geological map of the Tallberg Cu-deposit. The location of the cross section in Fig. 39 is indicated (A-A).

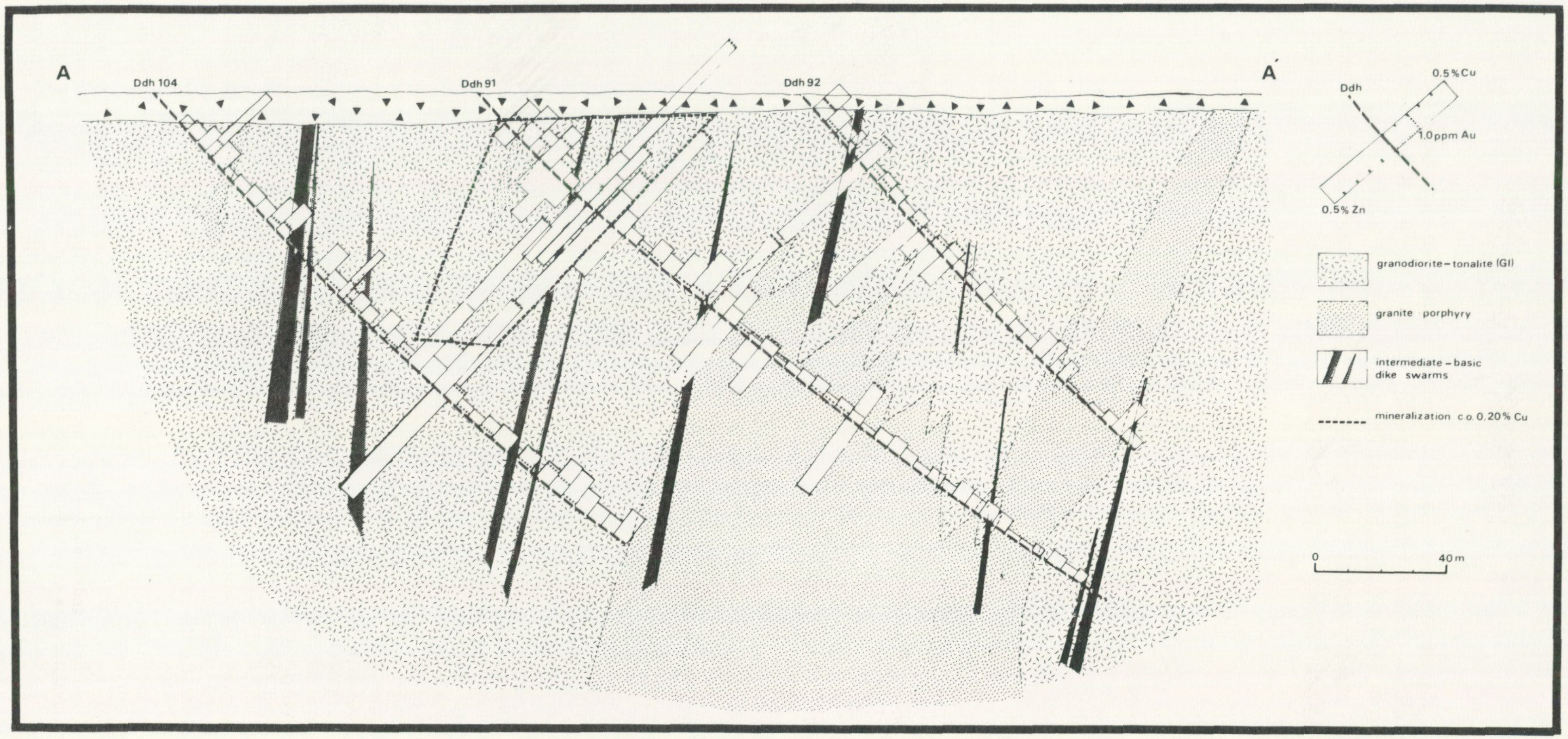


Fig. 39. Cross section through the Tallberg Cu-deposit.

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REFERENCES

SGU = Sveriges Geologiska undersökning
GFF = Geologiska Föreningens i Stockholm Förhandlingar

ADAMEK, P.M. & WILSON, M.R., 1977: Recognition of a new uranium province from the Precambrian of Sweden. *In:* Recognition and Evaluation of Uraniferous Areas. – IAEA-TC-25-26, 199–215, Vienna.

ADAMEK, P.M. & WILSON, M.R., 1979: The evolution of a uranium province in northern Sweden. – Phil. Trans. Royal Soc. London A 291, 355–368.

BOWDEN, P. & TURNER, D.C., 1974: Peralkaline and associated ring-complexes in the Nigerian-Niger province, West Africa. *In:* The Alkaline Rocks, H. Sörensen (ed.), 330–351, Wiley, London.

BOWDEN, P. & WHITLEY, J.E., 1974: Rare-earth element patterns in peralkaline and associated granites.

BOYNTON, W.V., 1984: Cosmochemistry of the rare earth elements: Meteorite studies. *In:* Rare earth element geochemistry, P. Henderson (ed.), 63–114, Elsevier, Amsterdam.

CLAESSON, L-Å., 1982: Stratigraphy and petrochemistry of the ore-bearing Skellefte group volcanites. – GFF 104, p. 378.

– 1985: The geochemistry of early Proterozoic volcanic rocks hosting massive sulphide deposits in the Skellefte district, north Sweden. – J. Geol. Soc. London 142, 899–909.

DEBON, F. & LEFORT, P., 1982: A chemical mineralogical classification of common plutonic rocks and associations. – Trans. Roy. Soc. Edinburgh: Earth Sciences 73, 135–149.

DE LA ROCHE, H., LETERRIER, J., GRANDCLAUDE, P. & MARCHAL, M., 1980: A classification of volcanic and plutonic rocks using R_1-R_2 diagram and major element analyses; its relationships with current nomenclature. – Chem. Geol. 29, 183–210.

DEPAOLO, D.J., 1981: A Nd and Sr isotopic study of Mesozoic calc-alkaline granitic batholiths of the Sierra Nevada and Peninsular Ranges, California. – J. Geophys. Res. 86, 10470–10488.

EINARSSON, Ö., 1979: Den Prekambriska berggrunden i Dobblonområdet, Västerbottens län. – SGU C 748.

ENMARK, T., 1982: A preliminary model of the deep structure of the Arvidsjaur granite intrusion in northern Sweden. *In:* Development of Optimizing Procedures for Gravity and Magnetic Interpretation and their Application to some Geological Structures in Northern Sweden. – Doctoral Thesis 1982: 019D, Luleå University, 130–141.

FORS, K. & IHRE, P., 1982: Beskrivning till berggrundskarta 22H Järvsjö NV och NO. – SGU, Internal Report BRAP 82530.

GERDIN, P., & TRIUMF, C-A., 1984: Rostberget. – Sveriges Geologiska AB. Internal Report PRAP 84087.

GUSTAFSSON, B., 1981: Uranium exploration in the N. Västerbotten–S. Norrbotten province, northern Sweden. *In:* Uranium Exploration Case Histories. – IAEA-AG-250/4, 333–352, Vienna.

HAFFTY, I. & NOBLE, D.C., 1972: Release and migration of molybdenum during the primary crystallization of peralkaline silicic volcanic rocks. – Econ. Geol. 67, 768–775.

HÅLENIUS, U., SMELLIE, J.A.T. & WILSON, M.R., in press: Uranium genesis within the Arjeplog-Arvidsjaur-Sorsele uranium province, northern Sweden. *In:* Vein Type Uranium Deposits. – IAEA, Vienna.

HIETANEN, A., 1975: Generation of potassium-poor magmas in the northern Sierra Nevada and the Svecofennian of Finland. – J. Res. U.S. Geol. Surv. 3, 631–645.

HOLMQVIST, A., 1979: Volframförekomsten vid Svärtträsk, beskrivning och preliminär malmberäkning. – SGU, Internal Report 1979-03-12.

HÜBNER, H., 1971: Molybdenum and tungsten occurrences in Sweden. – SGU Ca 46.

ISAKSSON, H., 1982: Kåtaberget, geofysisk undersökning. – SGU, Internal Report FM 8204.

JAHNS, R.H. & BURNHAM, W.C., 1969: Experimental studies of pegmatite genesis: A model for the derivation and crystallization of granitic pegmatites. – Econ. Geol. 64, 843–864.

KRAUSKOPF, K.B., 1979: Introduction to geochemistry, 2nd ed. – McGraw-Hill, New York.

LILLJEQUIST, R. & SVENSSON, S.-Å., 1974: Exceptionally well preserved Precambrian ignimbrites and basic lavas in N. Sweden. – GFF 96, 221–229.

LINDROOS, H. & SMELLIE, J.A.T., 1979: A stratabound uranium occurrence within middle Precambrian ignimbrites at Dobblon, northern Sweden. – Econ. Geol. 74, 1118–1130.

LÖFGREN, C., 1979: Berggrundskartering på kartbladet 23H Stensele. – SGU, Internal Report BRAP 79502.

LUNDBERG, B., 1980: Aspects of the geology of the Skellefte field, northern Sweden. – GFF 102, 156–166.

MITCHELL, A.M.G. & BELL, J.D., 1973: Island arc evolution and related mineral deposits. – J. Geol. 81, 381–405.

MUETSCHLER, F.E., WRIGHT, E.G., LUDINGTON, S. & ABBOTT, J.T., 1981: Granite molybdenite systems. – Econ. Geol. 76, 874–897.

MULLER, J.P.E., 1980: Geochemical and Petrophysical study of the Arvidsjaur granitic intrusion, Swedish Lapland. – Doctoral Thesis No. 1965, Université de Geneve.

NOYES, H.J., FREY, F.A. & WONES, D.R., 1983: A tale of two plutons: Geochemical evidence bearing on the origin and differentiation of the Red Lake and Eagle Peak Plutons, central Sierra Nevada, California. – J. Geol. 91, 487–509.

ÖHLANDER, B., 1984a: Geochemical analyses of rocks of the Haparanda suite, northern Sweden. – GFF 106, 167–169.

– 1984b: Proterozoic molybdenite occurrences in northern Sweden – derived from acid volcanics or granites? – GFF 106, 67–72.

– 1985a: Geochemical characteristics of granites associated with Proterozoic molybdenite mineralization in northern Sweden. – Chem. Geol. 51, 247–263.

– 1985b: Geochemistry of Proterozoic molybdenite mineralized aplites in northern Sweden. – Mineral Dep. 20, 241–248.

ÖHLANDER, B. & NISCA, D.H., 1985: Tectonic control of Precambrian molybdenite mineralization in northern Sweden. – Econ. Geol. 80, 505–512.

ÖHLANDER, B., HAMILTON, P.J., FALLICK, A.E. & WILSON, M.R., in press: Crustal reactivation in northern Sweden: the Vettasjärvi granite. – Precamb. Res.

PEACOCK, M.A., 1931: Classification of igneous rock series. – J. Geol. 39, 54–67.

PEARCE, J.A., HARRIS, N.B.W. & TINDLE, A.G., 1984: Trace element discrimination diagrams for the interpretation of granitic rocks. – J. Petrol. 25, 956–983.

PHAROA, T.C. & PEARCE, J.A., 1984: Geochemical evidence for the geotectonic setting of early Proterozoic metavolcanic sequences in Lapland. – Precamb. Res. 25, 283–308.

RICKARD, D.T., 1979: Scandinavian Metallogenesis. – Geo Journal 3.3, 235–252.

RICKARD, D.T. & ZWEIFEL, H., 1975: Genesis of Precambrian sulphide ores, Skellefte district, Sweden. – Econ. Geol. 70, 255–274.

RITTMANN, A., 1962: Volcanoes and their activity. – Wiley, London.

SANDAHL, K.A., MARKKULA, H. & TRIUMF, C-A., 1982: Storträsket. – SGU, Internal Report BRAP 82551.

SHATKOV, G., SHATKOVA, L.N. & GUSCHIN, E.N., 1970: The distribution of uranium, thorium, fluorine, chlorine, molybdenum and niobium in liparites and acid volcanic glasses. – Geochem. Int. 7, 1051–1063.

SIMEONOV, A., 1984: En jämförelse mellan Jorandomens tennanomala graniters och Revsundsgraniters (Västerbotten) mineralogiska och petrografiska karaktär. – Examensarbete i geologi vid Lunds Universitet, NBGO-5003.

SKIÖLD, T., 1979a: Zircon ages from an Archaean gneiss province in northern Sweden. – GFF 101, 169–171.

– 1979b: U-Pb zircon and Rb-Sr whole rock and mineral ages of Proterozoic intrusives on map sheet Lannavaara, northeastern Sweden. – GFF 101, 131–137.

– 1981a: Radiometric ages of plutonic and hypabyssal rocks from the Vittangi-Karesuando area, northern Sweden. – GFF 103, 316–328.

– 1981b: Chronostratigraphic correlations based on radiometric data from northern Sweden. – GFF 103, 523–524.

– in press: Aspects of the Proterozoic geochronology of northern Sweden. – Precamb. Res.

SKIÖLD, T. & CLIFF, R.A., 1984: Sm-Nd and U-Pb dating of early Proterozoic mafic-felsic volcanism in northernmost Sweden. – Precamb. Res. 26, 1–13.

SMELLIE, J.A.T., 1982: The mineralogy and genesis of uranium in rhyolitic ignimbrites of Precambrian age from Dobblon, Sweden. – Mineral. Mag. 46, 187–189.

THOMPSON, M. & WALSH, J.N., 1983: A handbook of inductively coupled plasma spectrometry. – Blackie & Son Ltd, London.

WALSER, G. & EINARSSON, Ö., 1982: The geological context of molybdenum occurrences in the southern Norrbotten region, northern Sweden. – Geol. Rundsch. 71, 213–229.

WEIHED, P., in prep: The Tallberg porphyry type Cu- Mo- Au-mineralization.

WELIN, E., 1979: Tabulation of recalculated radiometric ages published 1960–1979 for rocks and minerals in Sweden. – GFF 101, 309–320.

– 1985: The depositional evolution of the Svecofennian supracrustal sequence. – Abstract, Helsinki Symposium on the Baltic shield, 4–6 March, 1985.

WELIN, E., CHRISTIANSSON, K. & NILSSON, Ö., 1971: Rb-Sr radiometric ages of extrusive and intrusive rocks in northern Sweden 1. – SGU C 666.

WELIN, E., EINARSSON, Ö., Gustafsson, B., Lindberg, R., Christiansson, K., Johansson, G. & NILSSON, Ö., 1977: Radiometric ages of intrusive rocks in northern Sweden 2. – SGU C 731.

WESTRA, G. & KEITH, S.B., 1981: Classification and genesis of stockwork molybdenum deposits. – Econ. Geol. 76, 844–873.

WILSON, M.R., 1980: Granite types in Sweden. – GFF 102, 167–176.

WILSON, M.R. & ÅKERBLOM, G.V., 1982: Geological setting and geochemistry of uranium-rich granites in the Proterozoic of Sweden. – Mineral. Mag. 46, 235–247.

WILSON, M.R. & FALLICK, A.E., 1982: The relationship between uranium-enriched granites and hydrothermal mineralizations in northern Sweden. *In:* Uranium Exploration Methods. – NEA-IAEA.

WILSON, M.R., HAMILTON, P.J., FALLICK, A.E., AFTALION, M. & MICHARD, A., 1985: Granites and early Proterozoic crustal evolution in Sweden: evidence from Sm-Nd, U-Pb and O isotope systematics. – Earth Planet. Sci. Lett. 72, 376–388.

WILSON, M.R., ÖHLANDER, B., CUNEY, M. & HAMILTON, P.J., in press: Geodynamic significance of contrasting granitoid types in northern Sweden. – J. Geophys. Res.

WILSON, M.R., CLAESSON, L-Å., SEHLSTEDT, S., SMELLIE, J.A.T., AFTALION, M., HAMILTON, P.J. & FALLICK, A.E., in press: Jörn: an early Proterozoic intrusive complex in a volcanic arc environment. – Precamb. Res.

WITSCHARD, F., 1984: The geological and tectonic evolution of the Precambrian of northern Sweden – a case for basement reactivation? – Precamb. Res. 23, 273–315.

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