Classification of Uranium Mineralization in Norway

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NGU has carried out exploration for uranium on a small but varying scale since the second World War. An attempt is made to classify types of uranium mineralization occurring in Norway, following a system based on genetic types. Although difficulties are encountered in applying the classification, it has proved possible to categorize many of the occurrences in this way. Information on some occurrences is limited, and future revisions must be expected. The uranium mineralizations described are from all parts of the country, and range from Proterozoic to Lower Paleozoic in age. The most prominent and promising occurrences are largely of sedimentary, intrusive, metamorphic and supergene origin, the most promising of which are found in the region of northern Nordland. As yet no uranium deposits of importance have been found, based on prevailing metal prices, but insufficient work has been done on a number of known occurrences and the potential for the existence of economic deposits in Norway has been assessed as good.

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Introduction

Early in the last century geologists and mineralogists became interested in the pegmatites in the Precambrian shield of southern Norway because of their many rare minerals, often developed as large idiomorphic crystals. Several new minerals were identified and described from these deposits, some of them containing uranium and thorium. Minerals with uranium and thorium as main constituents were also recognized. Quartz and feldspar were produced from small quarries in the pegmatites. Uranium was a by-product at a few of them and used mostly as a glass-colouring agent.

After the World War II, previously known occurrences of uranium-bearing minerals in southern Norway were reexamined. Drilling programmes were conducted on the Einerkilen and Vats pegmatites in Telemark and Rogaland, and on the alum shale in the Oslo region (Rosenquist 1948). The Norwegian Defence Research Establishment (FFI), the Joint Establishment for Nuclear Energy Research (IFA), and the Geological Survey of Norway (NGU) were involved in this work. This intensive prospecting campaign culminated in 1951 when IFA contracted for supply of uranium to their experimental reactor (Sverdrup et al. 1967).

In the 1950's there was a boom for uranium among amateur prospectors. A minor programme was initiated at NGU in 1954 (Sverdrup et al. 1967), and systematic work was done throughout the country. The activity slowed down towards the end of the 1950's, and by the end of the 1960's prospecting activity was very limited. An attempt to evaluate the possible and speculative resources of uranium in Norway was made in 1975 (NOU 18:1972). The potential for economic uranium mineralization in Norway was regarded as small. However, NGU pointed out in comments to this publication that the conclusions had been based on very limited background information.

The present uranium exploration programme at NGU commenced in 1975. Geological reasoning indicated the possibility of finding resources of uranium to be good. Since 1975 a small prospecting effort has been in progress. In addition, NGU has evaluated specific occurrences on behalf of the USB programme (Investigation of state owned mining claims).

One of the aims of the Ore Section at NGU is to give an estimate of available resources of metallic elements in Norway, among them uranium and thorium. No mining company or other institution has prospected for uranium, and therefore most of the information on uranium and thorium in Norway has been collected by, and is recorded at, the Survey. There has been close contact between Norway and the UN-body IAEA (International Atomic Energy Agency), the IEA (international Energy Agency), and the OECD/NEA (Nuclear Energy Agency). The problems with uranium supply in the 1970's resulted in the creation of IUREP (International Uranium Resources Evaluation Project).

The IUREP-report from the 'orientation phase' was completed in 1978, a report signed by a joint steering group on uranium resources from OECD/NEA and IAEA. Countries with different potentials for uranium deposits were grouped; Norway was assigned to the group 'Countries with good potential where exploration is to be encouraged'. The IUREP programme offered expert missions to countries falling in this classification. Norway welcomed experts financed by the IUREP-programme, who visited the Survey early in 1980 and participated in a two week field trip in the summer of 1980. The IUREP-mission resulted in a report by the three experts, M. Cuney from CREGU (Centre de Recherches sur la Géologie de l'Uranium), France, D. M. Taylor, secretary to OECD/NEA, and M. Wilson, head of the uranium prospecting group at SGU (Geological Survey of Sweden), Sweden (Cuney et al. 1981).

The purpose of this paper is to classify the types of uranium mineralizations in Norway according to one of the proposed international systems (Dahlkamp 1978).

Geological Models

The most important factors in selecting initial targets for uranium prospecting in Norway have been geological environments and age of formation of the unit. These have been compared with the milieu and age of known uranium deposits on a global scale. Uranium mineralizations in neighbouring countries, especially Sweden, were particularly considered. The philosophy of this programme was presented by Lindahl & Heier (1977).

One possible position for uranium is along unconformities and major tectonic discontinuities, either in the weathered zone just beneath the peneplain, or in the basal parts of the overlying sediments in the case of unconformities. Examples of this type of deposit on a global scale include quartz pebble conglomerates and uranium in basal sandstones and more fine-grained sediments. Certain geological discontinuites in Norway could be favourable. One is on the Baltic Shield in Finnmark between the dome of supposed Archaean age (between Kautokeino and Karasjok), and the overlying Proterozoic rocks. Conglomerates, but not of the quartz pebble type, have been found on the northern margin by Skålvoll (1971). The border of the basal sequence around this dome lies in terrain heavily covered by till, and possibility for uranium concentrations along the zone cannot be excluded. Other domes in Finnmark of possible Archaean age could have similar potential. The Lofoten–Vesterålen province contains important geological discontinuities (Tveten 1978), but the rock units in this region have very low radio-element content.

Another major age discontinuity is at the boundary between Precambrian basement of varying ages and overlying late Precambrian and Cambrian rocks along or east of the Caledonian front. In some places nappes directly overlie the contact, but in most cases thin sequences of autochthonous sediments are found. A number of uranium anomalies, mineralizations and deposits are located in a relatively narrow zone along this discontinuity, both in the basement and in the sediments above. Deposits of this type have been described by several authors (Gee 1972, IAEA symposium in Athens 1974, Barbier 1974, Lindahl & Heier 1977, Cuney et al. 1981).

Uranium in its oxidized state is one of the most mobile of elements, and is concentrated under favourable geochemical conditions during peneplanation, either in the sediments above or in the basement (Barbier 1974). Other locations for concentration may be along tectonic zones, thrust planes, nappe structures, breccias and geotectonic lineaments. The potential should be even better where two or more of these favourable conditions coincide (Lindahl & Heier 1977). However, a favourable geological structure for deposition of uranium is not sufficient alone; a uranium source is needed to form a deposit. It is therefore more likely that basement with high uranium concentration would produce deposits in younger overlying rocks than basement with low uranium contents. The same suggestions have been put forward for the lead deposits along the Caledonian front (Bjørlykke 1977).

The investigations have included follow-up studies in previously recognized anomalous areas and provinces. Killeen & Heier (1975) described a belt from Båhus–Iddefjord to Flå containing granites with anomalously high radio-element contents. In the uranium programme a study was made of the Flå granite area, with special interest paid to the overlying rocks of Late Precambrian and Cambro–Silurian age.

The study of several regions with intrusive granites and granitoids showed that the basement granitoids (1,700–1,800 m.a.) in the region from Rana to north of Rombak in Nordland are anomalously high in uranium and thorium. This may be an extension of the uranium province in northern Sweden described by Adamek & Wilson (1979). Further, we have examined areas with Devonian and younger sediments on the western coast of Norway between Sognefjorden and Nordfjorden, on Ørlandet and on Andøya (Fig. 1). A parallel has been drawn with the uranium mineralization in the Old Red Sandstone in Scotland, including the Orkneys (Gallagher et al. 1971, Michie 1972). So far the results have been negative.

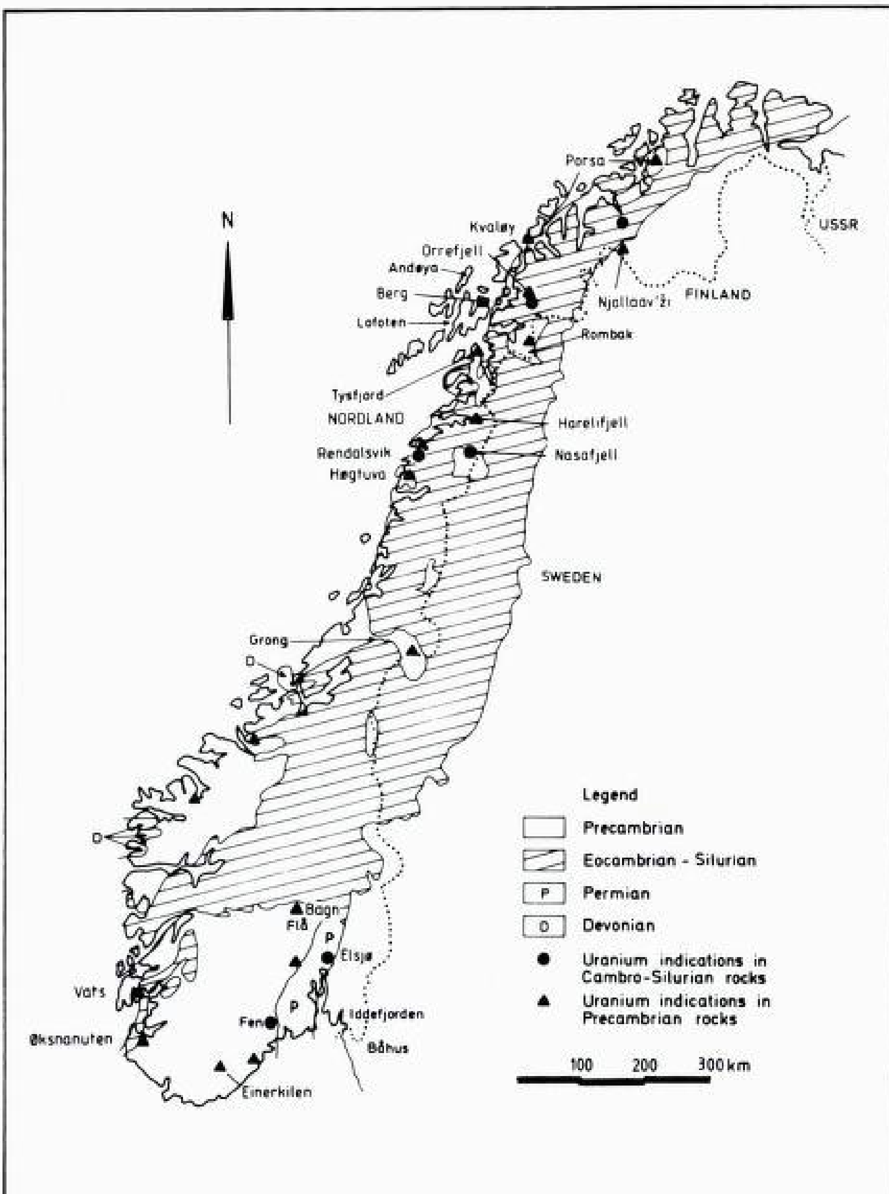

Fig. 1: Main geological features of Norway with uranium occurrences plotted.

Types of Mineralization

Several authors have made an attempt at classification of uranium deposits. Dahlkamp (1978) proposed a relatively extensive but uncomplicated classification table based on genetic types which are not time related. It embraces the following groups:

1) Sedimentary – Deposits in conglomerates. Potentials in black shale and phosphatic sediments.
2) Effusive – Mineralizations in acidic volcanics.
3) Intrusive – Deposits in alaskites and acid intrusives including related hydrothermal phases (veins).
4) Contact metasomatic – Deposits in calc-silicate rocks.
5) Metamorphic – Remobilized deposits in phyllite, schist, etc. (veins).
6) Supergene – Deposits in sandstone (rolls), calcrete etc.

It is difficult to classify many Norwegian occurrences, partly because insufficient work has yet been done. The classification system of Dahlkamp (1978) does not seem to be fully applicable, nor does the classical system (Cuney et al. 1982). In the following, some selected occurrences and areas of uranium potential are concidered in the light of the Dahlkamp classification.

SEDIMENTARY DEPOSITS

Dahlkamp's (1978) classification includes in this group detrial weathering products more than 2,200 m.a. in age. We have as yet found no example of this type of deposit. However, the younger alum shales, of varying metamorphic grade, contain uranium. Two occurrences of this type will be described briefly. Pelitic and psammitic sediments may host uranium mineralization, but no examples are known, neither in the late Precambrian arkosic sediments along the Caledonian front nor in the Devonian sandstones in western Norway.

Black shale and graphitic schist of various, in some cases uncertain, age occur in or along the Caledonian mountain belt. These rocks show wide ranges of uranium and other trace element content. The only graphite deposit in operation, at Skaland in Troms county, is low in uranium as are other smaller deposits in the same region, all of presumed Precambrian age.

Rendalsvik in Nordland county is another coarse-grained, high-metamorphic graphite deposit in strongly tectonized and partly granitized terrain. The graphite schist is thought to be of Cambro-Silurian age (Skjeseth & Sørensen 1958). The Rendalsvik graphite schist is a mica schist with up to 10% graphite and 8% ore minerals (Sverdrup et al. 1967). Uraninite was identified as occurring in well defined crystals. In the heavy mineral fraction obtained from systematic resampling uraninite could not be identified, but the presence of the minerals rutile, sphene, apatite, sphalerite, uvarovite, clinozoisite, and tourmaline was determined by X-ray (Gust & Thoresen 1981).

The resampling of the Rendalsvik graphite schist (75 profile samples) gave an average of 45 ppm U (range 8–183 ppm) as analysed by gamma-spectrometer. A typical profile is shown in Fig. 2 with analytical results for the samples and radiometric measurements in situ. Analytical results for other elements are on average:

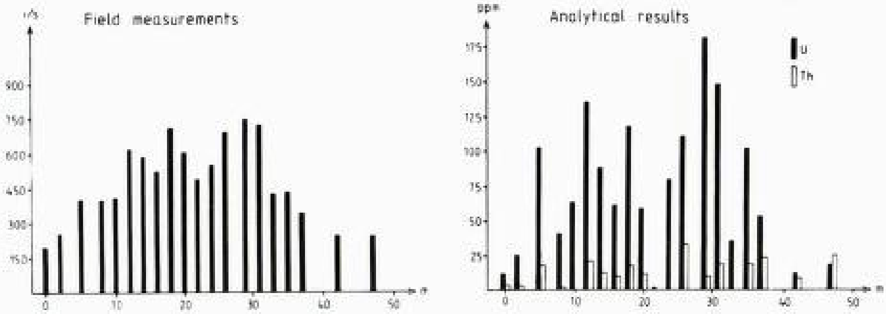

Fig. 2: An example of a profile across the graphite schist in Rendalsvik, Nordland county, showing the results of scintillometer registration (Knirps instrument) compared with U/Th analyses of samples from the same points.

Cu – 85 ppm (AAS), Zn – 105 ppm (AAS), Pb – 40 ppm (AAS), Mo – 85 ppm (AAS), V – 450 ppm (XRF) (max. 0.3%). On the basis of drilling, geophysics and geological interpretation the potential of crystalline graphite ore was estimated to be 3 mill. tons. Assuming the tonnage to average 45 ppm uranium, this amounts to a total of about 100 tons of uranium.

The Cambrian–Ordovician alum shales of the Caledonian front are enriched in uranium. The unit cannot be followed continuously, but has been registered in several places. The deposits in the Tåsjø area in Sweden have been described by Gee (1972). The alum shales near Østersund have been studied in recent years (Gee & Zachrisson 1979). Both these deposits are phosphorus-bearing (Armands 1970). The alum shale in the Østersund area shows an average content of 150–200 ppm U, with subordinate layers of up to 250 ppm. Typical for the shale is a high vanadium content, reaching 0.34%, and molybdenum averaging 0.04–0.05%.

Remnants of alum shale units enriched in uranium have been registered along parts of the borders around Precambrian windows in the Caledonian mountain belt, e.g. the Olden window, the Tømmerås window, the Nasafjell window, and parts of the Rombak window. On the southern part of the Baltic Shield the alum shales, of Upper Cambrian and Lower Ordovician age, are less disturbed by tectonism and metamorphism. The alum shales originally covered an extensive area, with remnants now in central Sweden and along the margins of the Oslo region. The uranium content in the alum shales depends on the availability of uranium and on conditions during sedimentation. The highest contents are found in the Ranstad deposit as described by several authors (Edling 1974), with an average of 300 ppm U.

The alum shale in the Oslo region, 40–50 m thick and deposited during a period of 40–50 mill. years, has been described by Rosenquist (1948), Siggerud (1956) and Skjeseth (1958). The uranium content was found to be 50–100 ppm, with a maximum of 170 ppm in layers of up to 10 cm thick. The highest values are found in the Peltura–Leptoplastus beds (stage 2c–2d) of

Upper Cambrian age. Random samples taken during car-borne surveys, however, gave higher uranium values, and reanalyses of old samples showed the previous analyses to be too low.

Skarn deposits of zinc in the Elsjø and Kirkeby areas have been studied by Olerud (1982). In the Elsjø area contact-metamorphosed Cambro–Ordovician sediments are surrounded by Permian intrusives. In the Kirkeby area they rest on Precambrian gneisses, but border Permian intrusives on the west. Fig. 3 shows Olerud's map of the area. The zinc deposits occur in skarn-

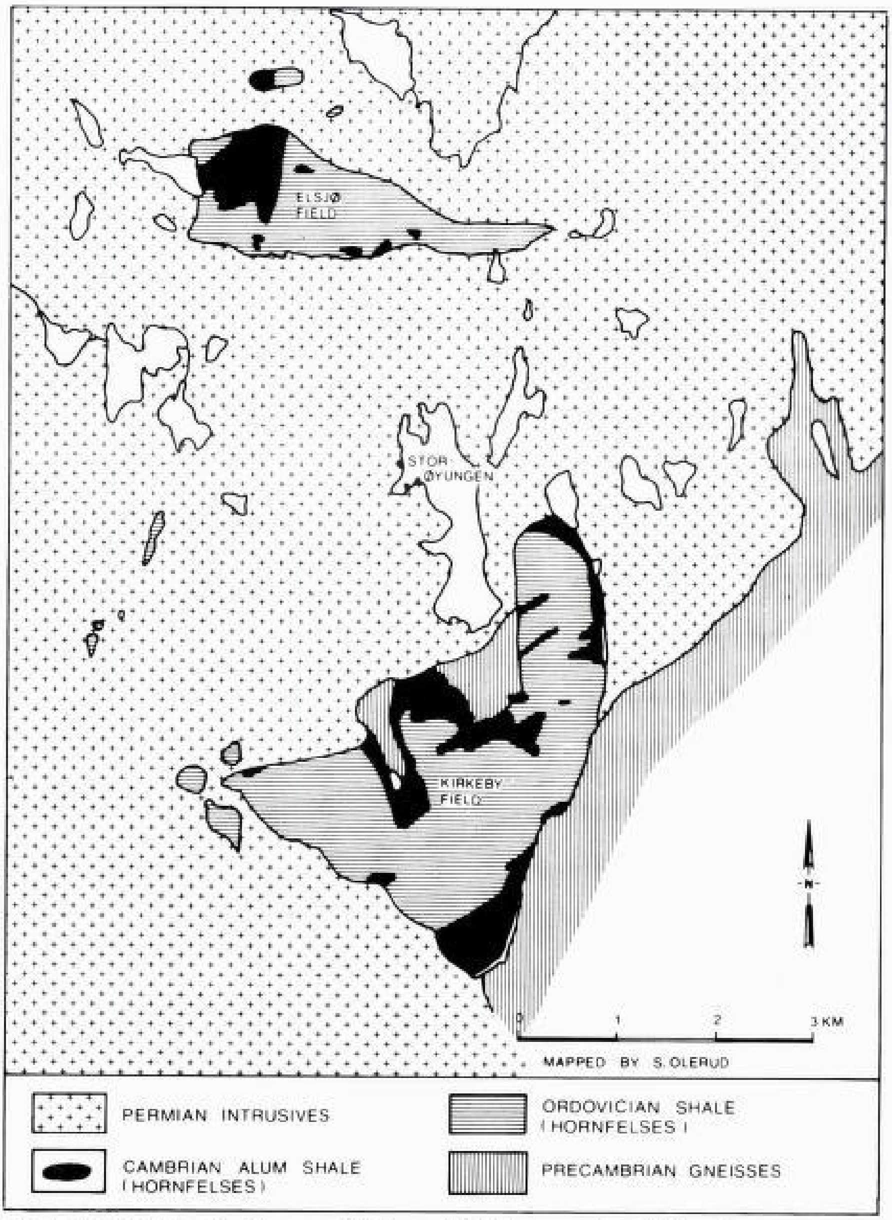

Fig. 3: Simplified geological map of Elsjø and Kirkeby areas; by S. Olerud.

altered limestone lenses and layers at various levels in the sediments, but special interest was paid to the uranium-rich Dictyonema to Olenid zones. The alum shales in the Elsjø area are intensely folded along ENE–WSW axes, and also thrusted (Olerud 1982). The total tectonic thickness of the shales is locally more than 150 m, and thus more favourable than in many other parts of the Oslo region. Limestone layers and lenses are also more abundant. The zinc-bearing skarn was formed locally in limestone lenses through metasomatism. There is no sign of remobilization of uranium in the black shales. In 1978 three holes were drilled in the Elsjø area (Olsrud 1982). The maximum uranium value in drill-core samples was 240 ppm, but the average value of certain 10–20 m sections was 150 ppm U. The average grades for other metallic elements are: 200 ppm Mo, 800 ppm V (max. 0.2%), 150 ppm Ni and 150 ppm Co. A positive correlation is found between uranium and molybdenum, and between vanadium and molybdenum.

EFFUSIVE DEPOSITS

No significant uranium mineralizations have so far been found in rocks which can be definitely classified as effusive. It is, however, difficult to identify acid volcanics in Precambrian basement areas, where the rock units have been subjected to several episodes of tectonism and metamorphism.

An albite fels associated with greenstone in the western part of Finnmarksvidda is thought to be of acidic volcanic origin. Mathiesen (1970) identified a local occurrence of a uranium-bearing mineral in this rock at Bidjovagge. In the uranium exploration programme anomalies were found in boulders of a similar rock near Biggeluobbal west of Masi. Bidjovagge was developed for its deposits of copper and associated gold. There seems to exist a correlation between the gold and higher than background values of uranium. In the Biggeluobbal locality molybdenum is present.

The Duobblon uranium deposit in northern Sweden is located within rhyolitic ignimbrites of Middle Precambrian age (between 1,725 and 1,785 m.a.) (Lindroos & Smellie 1979). In this area, clear primary structures can be found confirming association with the effusive volcanic rocks. It is possible that a grey, medium-grained, granitic gneiss with unusual chemistry, outcropping in the Høgtuva Precambrian window just west of Mo i Rana in Norway could be an acidic volcanic rock. This rock has anomalously high uranium contents. Acidic volcanics have been mapped in the Nasafjell window in basement of the same age (M. Wilson pers. comm.). The Høgtuva area has not yet been studied in detail, but work is in progress.

The Permian rocks of the Oslo region are thorium-enriched and constitute a thorium province. At Sæteråsen west of Holmestrand in Vestfold county, a radiometric anomaly was found by airborne surveys in the 1960's. Later work showed the anomaly to be related to two fine-grained trachytic lava flows (Ihlen 1982) with average uranium contents of 40–50 ppm and thorium contents of 400 ppm. In addition to thorium and uranium, approximately 1% REE and 0.25% Nb are present.

INTRUSIVE DEPOSITS

According to Dahlkamp (1978) deposits of this group are associated with peralkaline syenites, carbonatites, alaskites, alkali granites, granites, pegmatites and hydrothermal veins derived from such intrusions. The most differentiated intrusives, i.e. the youngest ones, are thought to be the best prospecting targets.

The oldest granites in Norway that we know of as highly radioactive are the granites and granitoids in the northern Nordland region from Mo i Rana to the Rombak window, as well as some of the granitoids in the Olden window. The age of this basement is 1,700–1,800 m.a. The granites are usually coarse-grained, but also medium-grained and porphyritic types are found. In the Rombak and Tysfjord region fluorite is a common accessory mineral. The windows in the Meløy–Gildeskål area have typically magnetite crystals up to 5 mm across in the granitoids, and even 3–4 mm crystals of uraninite are found. This province, showing high background values for uranium and thorium, has been subjected to car-borne surveys, field work and a large analytical programme. The northern part of the province shows an approximately normal crustal U/Th ratio, but in the southernmost parts, in the Rana region, the U/Th ratio is close to 1.

So far, no occurrence of economic significance has been discovered, but the province contains large areas of granitoid rocks with 10–50 ppm U. Hydrothermal activity and alteration has only been effective on a small scale, and only limited mobilization of uranium has been recognized. Local enrichments have been found in pegmatites, thin veins, and along the borders of amphibolite bodies. Significant mineralizations are found within a zone along the basement/cover contact, in foliated granitoids or gneisses of uncertain origin, and occasionally in arkoses. The mineralizations are probably in most cases of younger age, and could be derived from sources other than intrusives. They should therefore be classified as sedimentary or metamorphic.

Leucogranites, often pegmatitic, including Orrefjell, intrude several windows(?) of basement gneiss along a N–S, 15 km long trend in the Salangen valley in Troms county. In one intrusion at Orrefjell a uranium deposit was discovered in the 1960's and described by Sverdrup et al. (1967). In this region the Caledonian nappes are thin and authochthonous basement outcrops in some of the valleys (Gustavson 1974). Slices of basement rocks are also included in the nappes. The Orrefjell basement could be such a slice; it occurs on top of a hill approximately 300 m above the valley floor of presumed autochthonous basement.

Fig. 4 presents a simplified geological map of the Orrefjell area by Rundberg and Rindstad (Rindstad 1982). The uranium mineralization occurs irregularly over a length of 1.5 km along the western margin of the window(?), with a thickness up to 20 m. The host rock is the leucogranite pegmatite, and the contact with the Caledonian rocks dips at 45° towards the west. The host rock consists of coarse-grained white microcline, albite and quartz, with small but varying amounts of biotite, muscovite and chlorite. Locally in the mine-

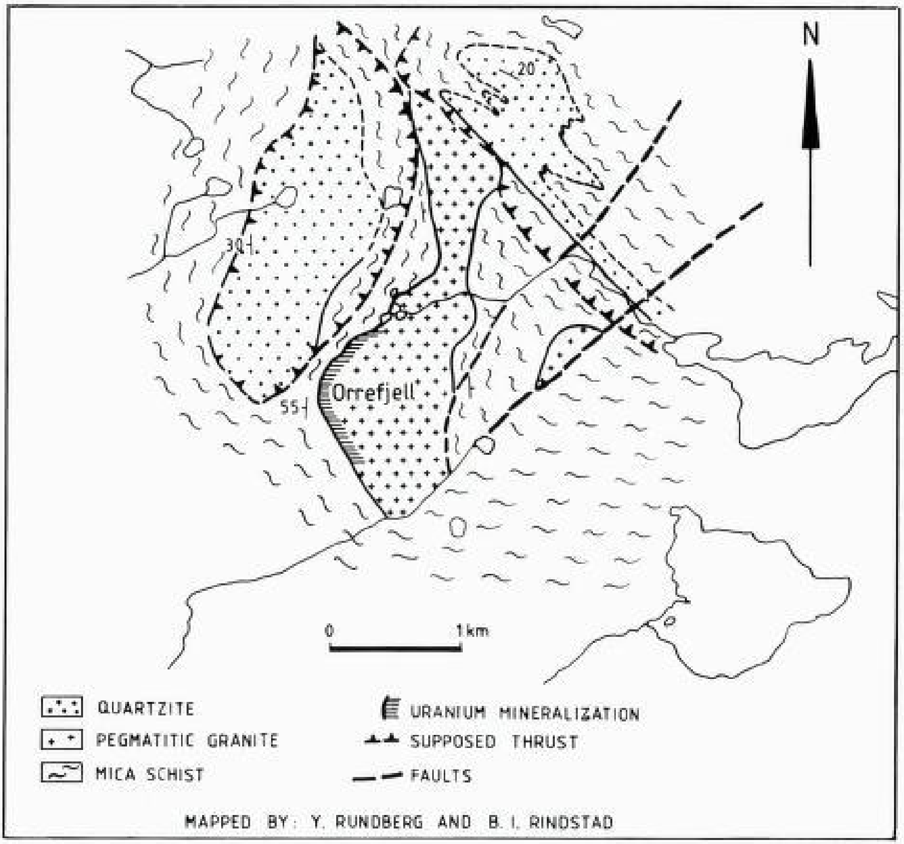

Fig. 4: Simplified geological map of the Orrefjell area; by B. I. Rindstad.

ralized zone, magnetite and iron sulphides occur (Rindstad 1982). Lenses and bands of Precambrian intermediate gneiss and amphibolite are also found. Evidence of propyllitic alteration in the amphibolite has been observed. In the Caledonian mica schist several percent of iron sulphides occurs, and also some graphite. The main uranium mineral seems to be uraninite, which can occur in crystals up to 2–3 mm in size. So far, however, no mineralogical study has been done. The secondary mineral uranotile was identified by Thorkildsen (Sverdrup et al. 1967). Molybdenite is observed locally within the mineralized zone.

The deposit was drilled during the years 1979–81, and split drill-core from the pegmatite was analysed in lengths of 1–2 m. The results of a typical section are given in Table 1. The mineralogy of the leucogranite pegmatite corresponds to the definition of alaskite (Spurr 1900), and the analyses are nearly identical to those of the alaskites in the Rössing uranium deposit in Southwest Africa (Berning et al. 1976, M. Cuney pers. comm.).

Age determinations were made on the Orrefjell pegmatite by the Rb–Sr method and on the uraninite from the mineralization by the U-Pb method. The sampling and Rb–Sr determinations were made by A. Andresen. Urani-

Table 1: Analyses of 1–2 m long samples of drill-core from Orrefjell. Analysed at NGU by XRF-method (All values in wt. percent. L.O.I. = loss of ignition. – = less than).

Sample nr. Element	114	115	116	117	118	119	Average
SiO_2	75.23	73.39	73.62	75.04	77.50	74.55	73.9
Al_2O_3	13.03	14.37	14.46	13.36	12.25	13.78	13.5
Fe_2O_3	0.13	0.23	0.27	0.23	0.27	0.60	0.3
TiO_2	0.03	0.01	0.01	0.03	0.05	0.04	0.03
MgO	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01	−0.01
CaO	0.34	0.54	0.83	0.23	0.67	0.58	0.5
Na_2O	2.70	3.10	3.60	2.40	3.20	4.40	3.2
K_2O	7.17	7.42	6.38	9.17	5.64	4.73	6.8
MnO	−0.01	−0.01	−0.01	−0.01	−0.01	0.22	−0.01
P_2O_5	0.02	0.03	0.03	0.05	0.03	0.02	0.03
L.O.I.	0.39	0.50	0.61	0.21	0.38	0.29	0.4

nite concentrates for U-Pb dating were separated at NGU and the isotope determination was made at IGS (Institute of Geological Science) in London by I. G. Swainbank. The data are in preparation for publication (Andresen, Lindahl et al.). A Rb/Sr isochron age of 1,600 m.a. is indicated. There is a large scatter around the isochron due presumably to the sericitization of the feldspar. The U-Pb dating gives an age of 1,745 m.a. The mineralization crystallized at that time, but either lost lead or gained uranium during a late Caledonian episode (360 m.a.). The results indicate that alaskite intrusion in the Precambrian basement took place at around 1,750 m.a. ago and that the uranium mineralization belongs to the same intrusive event.

Several granites in southern Norway were emplaced during the last stages of the Sveconorwegian orogeny. Some of these have an anomalously high radio-element content (Killeen & Heier 1975a), e.g. the Båhus–Iddefjord–Flå belt. Killeen & Heier (1975b) have studied ten granites in southern Norway, some of them enriched in uranium and thorium. The Bessefjell granite analysed by Killeen & Heier (1975b, 13 samples) gave an average of 13.3 ppm U and 54.7 ppm Th. Grid-sampling of the granite (87 samples) by NGU gave 10 ppm U and 51 ppm Th (gamma-spectrometer). The Homme granite, which has been studied by Falkum & Rose-Hansen (1978), also gave anomalously high uranium and thorium values.

The enriched granites described from southern Norway have lower radio-element contents than those in northern Nordland. Economically significant grades have not been registered. Late-stage hydrothermal alteration connected with the granites is limited, but a number of pegmatites with uranium-bearing minerals have been studied, in some cases in detail. These are the pegmatites in the counties of Øst- and Vest-Agder, e.g. Einerkilen and Rogaland.

A pegmatitic uranium mineralization of this type has been found at Bagn in Valdres, and belongs to the late stage of the Flå granite (D. van der Wel, pers. comm.). One uraninite sample gave an isotopic composition indicating crystallization at about 900 m.a., influenced by the late-stage Caledonian event. Uranium occurs in the pegmatite as primary uraninite, but is also found in fractures. The uranium content exceeds that of thorium.

Parts of the Fen carbonatite complex are enriched in uranium and should genetically be classified as intrusive deposits. The complex is thorium dominated, and niobium and REE occur in significant amounts.

CONTACT METASOMATIC DEPOSITS

Typical contact metasomatic mineralization in calc-silicate rocks has not yet been identified in Norway.

METAMORPHIC DEPOSITS

The Proterozoic rocks in Norway, containing most of the uranium occurrences, are always metamorphosed to some extent. Depending on geochemical conditions, uranium may or may not be leached and moved by metamorphic fluids. Examples in which the uranium has not moved include the alum shale of the Oslo region and graphitic schists of the Caledonides. In the Elsjø area (Olerud 1982) it has not been possible to register mobilization of uranium even where the host rock is completely hornfelsed. Fluids have passed through the alum shale without moving the uranium.

Under oxidizing conditions fluids can leach uranium, and precipitate it elsewhere under reducing conditions. If uranium is available and the geochemical trap is effective, uranium deposits can be formed. When the rock units are overprinted by several metamorphic events it is difficult to classify, for example, the vein deposits. Fluids may have been generated through metamorphic processes, as well as from intrusives.

Rock may be depleted in uranium during metamorphism. Some investigators regard depleted rocks with less than Clark values as a guide to ore, assuming the uranium to have been mobilized and deposited elsewhere. Other geologists look for regions with anomalously high uranium contents, as such rock types may be a protore to deposits if hydrothermal processes have been active. Both lines of reasoning may have merit.

Krause (1980) discovered a vein uranium mineralization in the Porsa sulphide deposits of the Komagfjord window in west Finnmark. The mineralized veins cut the sulphide layers, and the highest uranium contents are found at intersections with the sulphides, which act as a reducing agent on the fluids. Most likely the fluids were of metamorphic origin. Krause (1980) believes that black shales in the area were the source rock for the uranium. Experience from other areas shows that leaching of uranium from the black shales is an ineffective mechanism.

On Kvaløya west of Tromsø a uranium mineralization has been found in a shear zone in granitized basement (Sverdrup et al. 1967). The background radiation in the basement is moderate, but with several anomalous points and narrow veins. The uranium was probably mobilized by the process of granitization.

The Berg copper mine, located at Borkenes in Kvæfjord west of Harstad, has been studied by Often (1982). During the sulphide exploration, localli high radiation was discovered. The Precambrian country rock comprises gneisses of mafic to intermediate composition, with layers interpreted as agglomerates. The sulphide deposit, located where a granite intrudes the gneisses, contains up to 2% Cu, up to 100 ppm Ag and traces of gold. The uranium content is on average low, but some samples gave up to 0.3% U. U-Pb dating on uraninite (3 samples) from the Berg mineralization indicates a Caledonian age. If that is correct, the uranium must be epigenetic and deposited in late Caledonian time. No granites of this age are known in the region, and the fluids are thought to be of metamorphic origin.

Studies of basement/cover relations in northern Nordland have led to the discovery of occurrences of molybdenum and uranium. One promising mineralization is located at Harelifjell SE of Straumen in Sørfold (Fig. 5). The host rock belongs to the Rishaugfjell basement window. The locality is near the basement/cover border zone, and influenced by the Caledonian thrusting. The basal sedimentary sequence occurs as remnants below the thrust-plane on Harelifjell mountain, with meta-arkoses and in one locality a thin conglomerate. The Harelifjell occurrence has not yet been mapped in detail. The mineralization is located in a vein or series of veins steeply dipping to the east. A schematic section is shown in Fig. 6. The mineralization outcrops continuously over a length of 300 m, and the radiometric anomaly, as determined by the helicopter-borne surveys, extends about 5 km further to the south. The mineralization lies in a relatively finely grained gneissic rock of granitic composition, which originally may have been arkose. In the mineralized zone 1–3% sulphides are present, and the main uranium mineral is uraninite. The isotope composition has been determined, indicating the deposition age to be late Caledonian (400 m.a.). No intrusion of that age is known in the region; thus the mineralization is thought to have been deposited by metamorphic fluids, with the sulphides acting as a chemical trap.

The Øksnanuten uranium occurrence has been described (Sverdrup et al. 1967) as a series of thin quartz veins intersecting rocks of several types, partly ultramafic (serpentinite). The contrast in chemistry may also here have caused deposition.

SUPERGENE DEPOSITS

According to Barbier (1974), supergene deposits could be expected to be found along old discontinuities as a result of recent weathering, along breccia zones and in permeable rocks with groundwater perculating through them.

The Njallaav'ži uranium deposit in western Finnmark is thought to belong to the supergene type. The geology in the region has been described by Fareth et al. (1977) and the prospecting by Lindahl et al. (1979). The mineralization was first described by Gjelsvik (1957). The uranium mineralization occurs within brecciated albite dolerite. In addition, uranium concentrations occur in outcrop in brecciated syenite and carbonate breccia (Gjelsvik 1957).

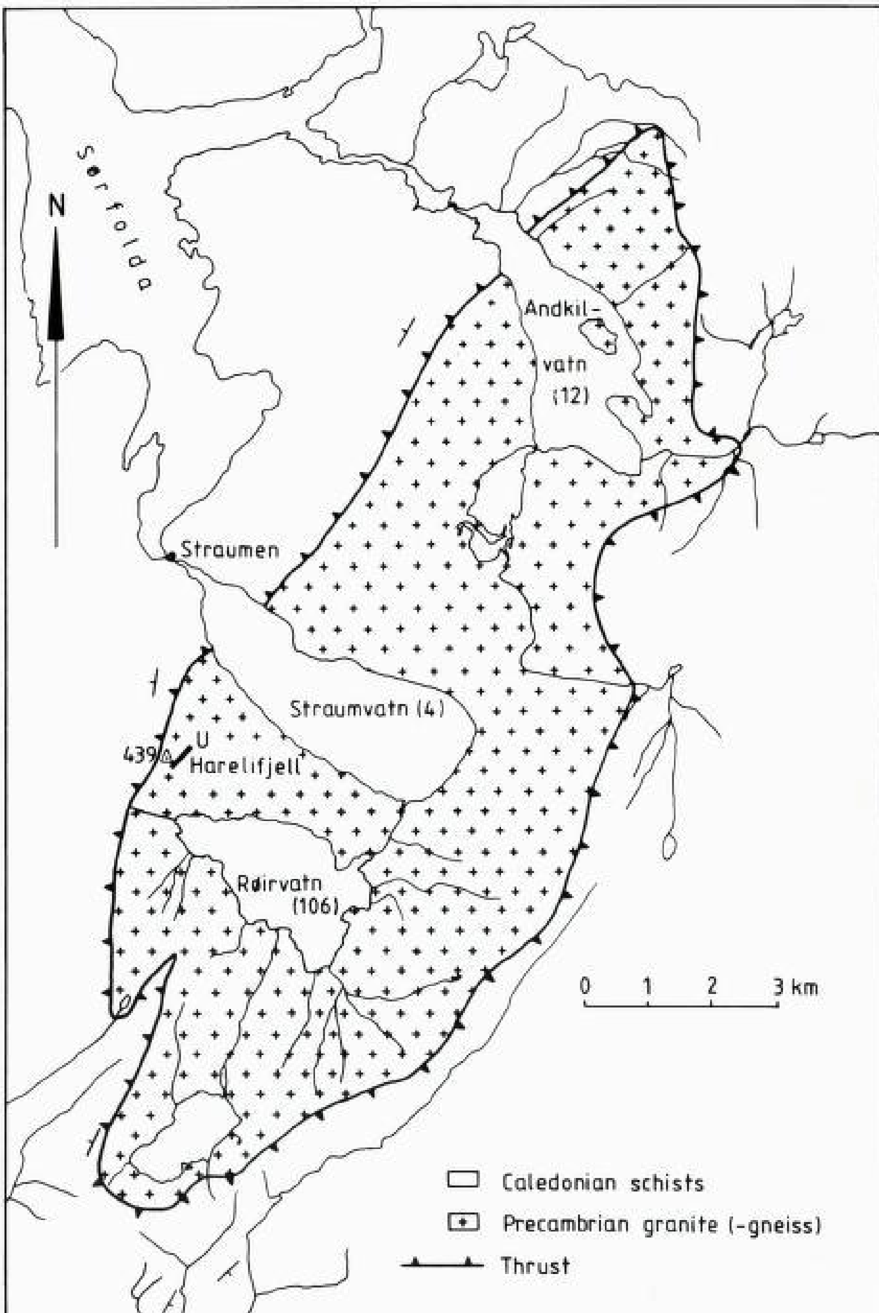

Fig. 5: Location of the Harelifjell uranium occurrence within the Rishaugfjell Precambrian window. Anomalies continue 5 km towards the south.

North of the deposit a circular dome structure mapped by Fareth et al. (1977) consists of granite and acidic gneisses. A quartzite, with or without fuchsite, occurring along the rim, especially towards the east, is overlain by green-

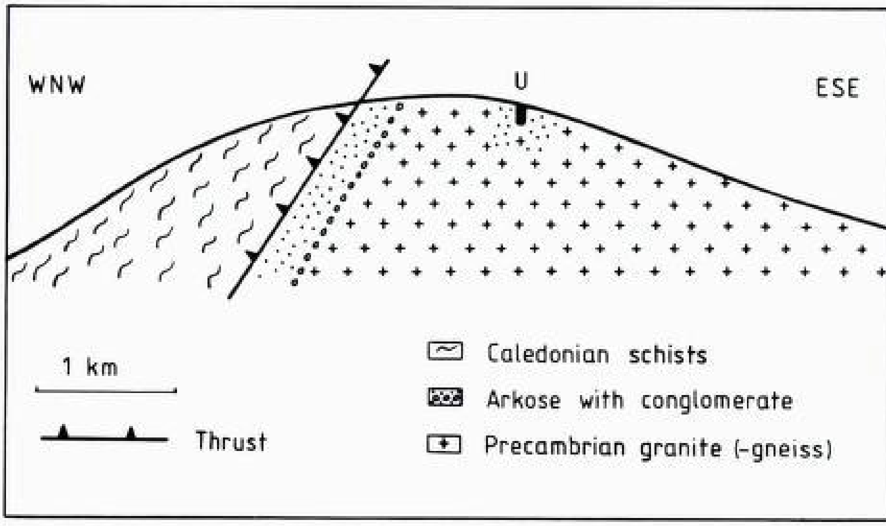

Fig. 6: Schematic profile of the Harelifjell uranium occurrence. The host rock is fine-grained gneiss within coarse-grained granite with weak foliation.

stone. The gneisses and granite could be of Archaean age; the quartzite and greenstone are probably younger.

Two diamond drill-holes intersect the mineralization. The best of these contained 1,800 ppm U over a 1 m thick zone (Th less than 20 ppm). The breccia contains colloidal pitchblende and, as gangue minerals, fine-grained haematite, calcite and chlorite (± biotite). Accessory minerals such as pyrite, chalcopyrite, bornite and galena have been identified locally (Gjelsvik 1957). Other uranium minerals are rare, but Thorkildsen (Sverdrup et al. 1967) identified uranotile and Often (1975) identified liebigite. The intensely brecciated host rock has undergone hydrothermal alteration. Preglacial weathering of sulphide deposits in this part of Finnmarksvidda has been described by Gjelsvik (1956) and Lindahl (1976), indicating that glacial erosion was locally slight. In the greenstone belt of the Råggejav'ri area, north of the supposedly Archaean dome and 12 km NW of Njallaav'ži, there is an iron sulphide deposit outcropping approximately 100 m below the late Precambrian peneplain. From this deposit Lindahl (1976) described slightly metamorphosed weathering textures in pyrrhotite below the preglacial weathering zone. The metamorphism is thought to be Caledonian and the weathering late Precambrian.

The uranium mineralization in Njallaav'ži, where the depth below the peneplain is greater or of similar magnitude to the depth in the Råggejav'ri area, could have the same origin. Dating of the uraninite in Njallaav'ži (two samples) indicates a deposition age of 990 m.a., with influence from either lost lead or gained uranium in late Caledonian time. This age fits with the model described above and a deposition of uranium during late Precambrian peneplanation. We do not know of younger intrusives of this period.

As yet we have no other examples of deposits of supergene origin.

Discussion

Geological modelling is important for selecting target areas for uranium prospecting. Experience will lead to better models, for which high-quality geological maps are very important. Mapping programmes have advanced markedly in recent years, providing better structural and genetic understanding. This is of great help for geological modelling in all prospecting. In Norway coverage by the various exploration methods is uneven, and is areally very limited for the more expensive techniques. Stream sediment coverage is relatively good, but many areas regarded as promising from a uranium resource point of view have not yet been sampled. This paper has attempted to assign the classification system of Dahlkamp (1978) to Norwegian occurrences based on limited information regarding geological and mineralogical data and preliminary age dating using the U-Pb method. The grouping of the deposits is speculative, and future revision must be expected.

The Precambrian granitoid rocks of 1,700–1,800 m.a. age in northern Nordland seem to define a uranium metallogenic province, possibly an extension of the uranium province in the Arjeplog–Arvidsjaur district defined in Sweden by Adamek & Wilson (1979). The province relates to the SSW margin of an early Proterozoic continent which continues towards the west beneath the Caledonian mountain belt.

The present prospecting campaign has been operating for eight years, of which the last 2–3 years have given some success. The potential for uranium deposits in Norway has been assessed by Cuney et al. (1981), and it is regarded as good. They foresee that further prospecting will lead to the discovery of new occurrences, and point to favourable areas. Rock samples collected in the uranium programme and other programmes have been analysed for 15–20 elements. An important spin off is that our results can be used in prospecting for other metals. Correlations have been found to exist between uranium and such metals as Mo, W, REE and Sn in certain provinces, a relationship which will be further studied. Radiometric survey could therefore be important in prospecting for certain metals.

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REFERENCES

Adamek, P. 1975: Geology and mineralogy of the Kopparåsen uraninite–sulphide mineralization, Norbotten county, Sweden, *Sveriges Geol. Unders., ser. C, nr. 712, 69 pp.*

Adamek, P. M. & Wilson, M. R. 1979: The evolution of a uranium province in northern Sweden. *Phil. Trans. R. Soc. Lond. A. 291, 355–368.*

Armands, G. 1970: A uranium-bearing layer from the Lower Ordovician, Sweden. *Geol. För. Forh. 92,* 481–490.

Barbier, M. J. 1974: Continental Weathering as a possible origin of vein-type uranium deposits. *Mineral. Dep. 9,* 271–288.

Berning, I., Coole, R., Hiemstra, S. A. & Hoffmann, U. 1976: The Rössing deposit, South West Africa. *Econ. Geol. 71*, 351–368.

Bjørlykke, A. 1977: Om blyforekomster i Eokambriske/Kambriske sandsteiner på det Baltiske Skjold. In: Bjørlykke, A., Lindahl, I. and Vokes, F. M., eds. Kaledonske Malmforekomster: BVLI-Malmsymposiet, 72–76.

Cuney, M., Taylor, D. M. & Wilson, M. 1981: IUREP-Orientation Phase report, NORWAY. *IUREP-report 1981*, 102 pp.

Dahlkamp, F. J. 1978: Classification of uranium deposits. *Mineral Dep. 13*, 83–104.

Edling, B. 1974: Uranfördelningen i överkambrisk alunskiffer från Ranstad, Billingen, Västergötland. *Publ. Paleont. Inst. Univ. Uppsala, spec. vol. 2*, 118 pp.

Falkum, T. & Rose-Hansen, J. 1978: The application of radioelement studies in solving petrological problems of the Precambrian intrusive Homme granite in the Flekkefjord area, South Norway. *Chemical Geology, 23*, p. 73–86.

Fareth, E., Gjelsvik, T. & Lindahl, I. 1977: Cier'te. Description to map sheet 1933 II – 1:50000. *Norges geol. Unders. 331*, 28 pp.

Gallagher, M. J., Michie, U. M., Smith, R. T. & Haynes, L. 1971: New evidence of uranium and other mineralization in Scotland. *Trans./Sect. B, Inst. Min. Mt. 80*, 150–173.

Gee, D. 1972: The regional geological context of Tåsjø uranium project, Caledonian front, Central Sweden. *Sveriges geol. Unders. C671*, 1–36.

Gee, D. G. & Zachrisson, E. 1979: The Caledonides in Sweden. *Sveriges geol. Unders. C769*, 48 pp.

Gjelsvik, T. 1956: Pre-glacial forvitringsfenomener i kopperforekomster i den syd-vestlige del av Finnmarksvidda. *Geol. För. Förhandl. 78*, 659–665.

Gjelsvik, T. 1957: Pitchblende mineralization in the Precambrian plateau of Finnmarksvidda, Northern Norway. *Geol. För. Förh. 79*, 572–580.

Gust, J. & Thoresen, H. 1981: Radiometriske målinger og prøvetakning i Rendalsvik grafittfelt, Meløy, Nordland. *Unpubl. NGU-rapp. nr. 1650/59A*, 16 pp.

Gustavson, M. 1974: Geologisk kart over Norge, berggrunnskart NARVIK 1:250000. *Norges geol. Unders.*

Ihlen, P. 1982: Sæteråsen niob-forekomst. *Unpubl. NGU-rapp. nr. 1800/76A*, 11 pp.

Killeen, P. G. & Heier, K. S. 1975a: A uranium and thorium enriched province of Fennoscandian shield in Southern Norway. *Geochim. Cosmochim. Acta. 39*, p. 1515–24.

Killeen, P. G. & Heier, K. S. 1975b: Th, U, K and heat production measurements in Ten Precambrian granites of the Telemark area, Norway. *Norges geol. Unders. 319*, 59–82.

Krause, M. 1980: Some uranium mineralizations in the Raipas Suite of the Komagfjord tectonic window, Finnmark, Norway. *Norges geol. Unders. 355*, 49–52.

Lindahl, I. 1976: Prospektering på kartblad Cier'te 1974. *Unpubl. NGU-rapp. nr. 1243/1A-I*, 18 pp.

Lindahl, I. & Heier, K. S. 1977: Possible uranium mineralizations in the light of recognized geological and geotectonic structures in Norway. In: «Recognition and evaluation of uraniferous areas» – IAEA p. 123–129.

Lindahl, I., Bergstrom, B., Fareth, E. & Often, M. 1979: Heavy-metal exploration in the western part of Finnmarksvidda, northern Norway. In: Prospecting in areas of glaciated terrain 1979. *Inst. Min. Met.*, 59–66.

Lindroos, H. & Smellie, J. 1979: A stratabound uranium occurrence within Middle Precambrian ignimbrites at Duobblon, northern Sweden. *Econ. Geol. 74*, 1118–1130.

Mathiesen, C. O. 1970: An occurence of unusual minerals at Bidjovagge, Northern Norway. *Norges geol. Unders. 266*, 85–104.

Michie, U. M. 1972: Further evidence of uranium mineralization in Orkney. *Trans./Sect. B. Inst. Min. Met. 81*, 53–54.

Often, M. 1975: Geokjemisk U-prospektering i Njallaav'ži, Nordreisa, Troms. Unpubl. thesis, Technical Univ. of Norway, Trondheim, 65 pp.

Often, M. 1982: Geologiske undersøkelser og diamantboring ved Berg Gruve, Borkenes. *Unpubl. NGU-rapp. nr. 1575/1B*, 19 pp.

Olerud, S. 1982: Elsjøfeltets geologi, tektonikk og innhold av sporeelementer i Kambro-Ordoviciske skifre. *Unpubl. NGU-rapp. nr. 1650/16D*, 49 pp.

Rindstad, B. I. 1982: Geologiske undersøkelser på Orrefjell, Salangen, Troms. *Unpubl. NGU-rapp. nr. 1800/48D, 12 pp.*

Rosenquist, I. 1948: Uranforekomster i Norge. *Tidsskr. Kjemi, Bergvesen og met.*. 7, 116–119.

Siggerud, T. (1956): The occurence of Uranium and Thorium in Norway. Proc. Int. Conf. on Peaceful use of Atomic Energy, Geneve, 8.-20. aug. 1955, 6 UN, 178-182.
Skjeseth, S. & Sørensen, H. 1953: An example of granitization in the Central zone of the Caledonides of Northern Norway. *Norges geol. Unders. 184,* 154-187.
Skjeseth, S. 1958: Uran i kambrisk alunskifer i Oslofeltet og tilgrensende områder. *Norges geol. Unders. 203,* 100-111.
Skålvoll, H. 1971: Geologisk kart over Norge, berggrunnskart KARASJOK 1:250000. *Norges geol. Unders.*
Spurr, J. E. 1900: Classification of igneous rock according to composition. *American Geol. 25,* 229-230.
Sverdrup, T. L., Thorkildsen, C. D. & Bjørlykke, H. 1967: Uran og thorium i Norge. *Norges geol. Unders. 250A,* 31 pp.
Tveten, E. 1978: Geologisk kart over Norge, berggrunnskart SVOLVÆR 1:250000. *Norges geol. Unders.*