SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 812 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 80 NR 1

PAUL FORSELL

THE STRATIGRAPHY OF THE PRECAMBRIAN ROCKS OF THE KIRUNA DISTRICT NORTHERN SWEDEN

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ABSTRACT

A suite of spilites and keratophyres form the dominating part of the Svecokarelian rocks of the Kiruna district. A study of the age relations between these Proterozoic volcanics and their intercalated sediments has implied a radical modification of earlier conceptions of the stratigraphy that accepted a normal position of the east-dipping rock units. The stratigraphy presented here is based on the inferred existence of overturned isoclinal folds.

Based on lithological and chemical similarities a correlation is proposed of

a) the Luossavaara-Kiirunavaara apatite iron ores with the Per Geijer apatite ores and
b) the foot wall syenite-porphyries of the former with the Lower Hauki syenite-porphyries.

Xenoliths of both Luossavaara-Kiirunavaara and Per Geijer ores occur in the quartz-bearing porphyry, indicating that the latter is younger than the ores; the porphyry is therefore interpreted to occur in a syncline between the iron ore deposits. The Lower Hauki Formation is interpreted as an adjoining anticline.

The Kurravaara Conglomerate is considered coeval or younger than the porphyries occurring in the Luossavaara-Kiirunavaara foot wall, as the clasts of the conglomerate undoubtedly were derived from these porphyries. The almost identical composition of the pebble material of the Kurravaara Conglomerate and that of the Hauki Conglomerate has been interpreted as indicating their contemporaneous deposition.

The existence of syenite-porphyry dikes in the Tuolluvaara quartz-porphyries suggests a closer relation to the basal members of the Kiruna porphyries than to the quartz-bearing porphyry, which is younger than the above-mentioned dikes.

The isoclinal folding is considered to be connected with the emplacement of the Lina granites.

INTRODUCTION

The huge deposits of apatite iron ores in the Kiruna district have attracted the interest of many geologists. Lundbohm (1910), Stutzer (1906), de Launay (1903), Geijer (1910), Daly (1915) and many others were pioneers in the study of these ores at the beginning of this century. Geijer (1910) became an authority on this type of apatite iron ores with his exhaustive description of the ores and their country rocks. He continued throughout his life to take part in discussions of the geology of the Kiruna area, which many important papers bear witness to. The work by Ödman (1957) and his assistants during the nineteenfifties resulted in the first modern geological map of Norrbotten county, and started a new discussion regarding the stratigraphy of the Kiruna area. In the last two decades contributions by Geijer (1960, 1968), Frietsch (1978, 1979a, 1979b) and Parák (1960, 1971, 1975a, 1975b) have stimulated interest in the origin of the Kiruna apatite iron ores.

A summary is presented below of the prevailing theories regarding the genesis of the iron ores and their relation to the country rocks.

1. According to Geijer (1910), the ores were products of magmatic differentiation. The following emplacement sequence of the iron ores and the volcanics was proposed (from the oldest, a, to the youngest, e):

e) Per Geijer iron ores	Intrusive
d) Quartz-bearing porphyry	Extrusive
c) Porphyry dikes	Intrusive
b) Luossavaara-Kiirunavaara iron ores	*Extrusive*
a) Syenite-porphyry	Extrusive

This older hypothesis received renewed interest with the discovery and interpretation of the El Laco iron ore deposits in Chile (Park 1961).

2. Later, Geijer (1919) revised his earlier hypothesis and proposed an intrusive origin for all the iron ores.

e) Per Geijer iron ores	*Intrusive* (rest solution)
d) Porphyry dikes	Intrusive
c) Luossavaara-Kiirunavaara iron ores	*Intrusive*
b) Quartz-bearing porphyry	Extrusive
a) Syenite-porphyry	Extrusive

The "ore breccias", which consist of smaller and larger fragments of porphyry in a "matrix" of iron ore, were considered to exemplify the intrusive character of the ore.

3. Parák (1975a) saw the iron ores as products of volcanic exhalative-sedimentary processes and proposed the following age relations:

e) Per Geijer iron ores	*Exhalative-sedimentary*
d) Quartz-bearing porphyry	Extrusive
c) Porphyry dikes	Intrusive
b) Luossavaara-Kiirunavaara iron ores	*Exhalative-sedimentary*
a) Syenite-porphyry	Extrusive

The intense exploration activities, started at the beginning of the nineteensixties by LKAB, have greatly increased our knowledge of the geology of the Kiruna district and led to the discovery of new deposits of iron and copper ores. This exploration has given us a quantity of geological information unparalleled in other Precambrian areas of Norrbotten.

The iron ores occur as strata bound units in a succession, which dips to the east. In the dominating hypothesis, as proposed by Geijer (1919), regarding the stratigraphy of the Kiruna district, the supracrustal rocks, the iron ores excluded, have been seen as a normal suite, younging eastwards. The oldest (Kiruna greenstones) occur in the west and the youngest (Hauki quartzites) in the east (Fig. 1 and Fig. 2). Fig. 1 is based on the geological map in Plate I.

Upper Hauki Formation	Syenite-porphyry
Lower Hauki Formation	Kurravaara conglomerate
Quartz-bearing porphyry	Kiruna greenstone

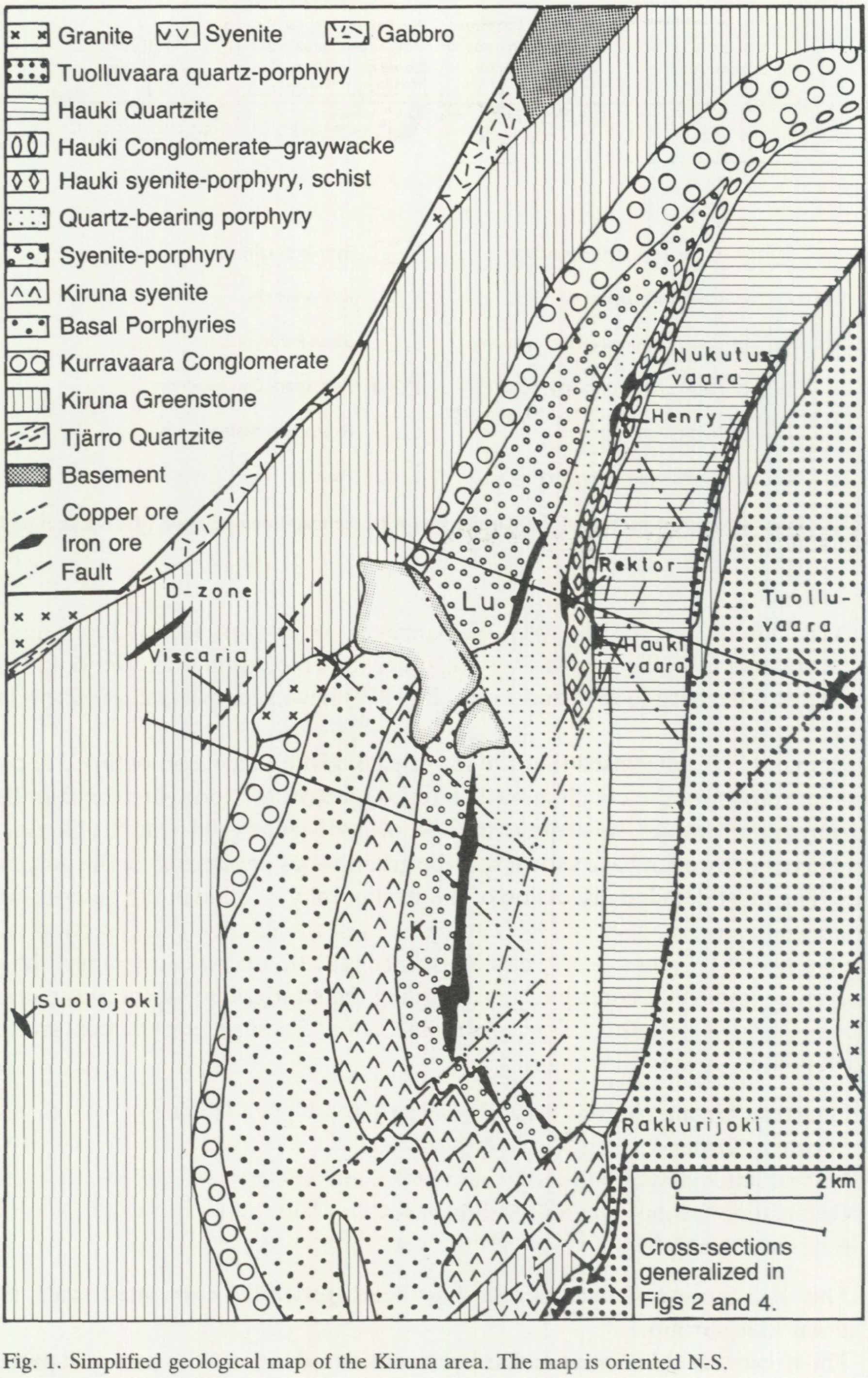

Fig. 1. Simplified geological map of the Kiruna area. The map is oriented N-S.

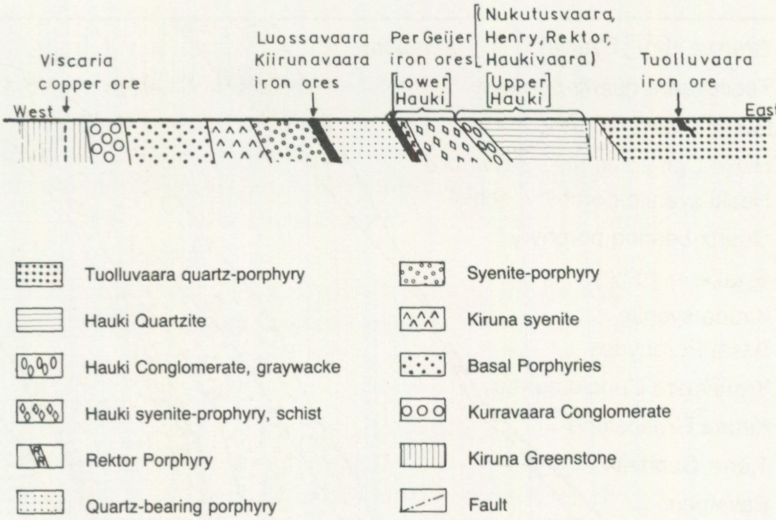

Fig. 2. Generalized cross-section of the Kiruna area with the traditional division of the Hauki rocks (Geijer 1919; see Fig. 1).

As a consequence of this theory the Kurravaara Conglomerate was considered to be younger than the greenstones and older than the porphyries. Geijer (1910) and later Offerberg (1967) and Frietsch (1979) have supported this interpretation.

Ödman (1957) proposed that the lower part of the succession outlined above was inverted, i.e. the conglomerate and the greenstone were younger than the porphyries. However, subsequent investigations by geologists from the Geological Survey of Sweden have shown that the greenstones are older than the porphyries. The most detailed discussion of the stratigraphy is found in the descriptions of the geological map sheet 29K Vittangi, east of the Kiruna area (Ericsson and Hallgren 1975). Padget (1970) and Witschard (1979), among many others, have also made important contributions regarding the stratigraphy of the Svecokarelian rocks in Norrbotten. They maintained that the supracrustal rock groups accumulated in the following order:

Quartzite Group (Mattavaara, Rissavaara and Upper Hauki)
Porphyry Group
Metasedimentary Group (Kilavaara and Pahakurkkio)
Greenstone Group (Kiruna, Veikkavaara and Vittangi)
Basement Complex

The Kurravaara Conglomerate has been generally correlated with the Pahakurkkio Group.

The Lower Hauki Formation has been considered to form the youngest part of the Porphyry Group and the Hauki Conglomerate and graywacke the basal part of the Upper Hauki Quartzite Group, thus taking us back to the traditional age relations first proposed by Geijer and his contemporaries (Fig 1).

During the last two decades, exploration work at the Per Geijer iron ores (referred to as the Nukutusvaara, Henry, Lappmalmen, Rektor and Haukivaara ores) and later of the Viscaria copper ore in the Greenstone Group has given us a more detailed picture of the geology of the Kiruna area.

Parák (1975a) was mainly concerned with geological evidence relevant to his discussion of the origin of the iron ores. However, he contributed several new observations that indicate a more complex stratigraphy than had been previously accepted. A description of the geology of the Henry ore by Ginet and Kunzle (1978) has further increased our knowledge of the Lower Hauki Formation and Upper Hauki Group (Fig. 2), the stratigraphic position of which is of great importance for the interpretation of the age relations of the rocks in the region.

The terminology here is adopted from the works by Geijer, because his rock names are well defined and accompanied by thorough descriptions. The marked spilitic-keratophyric character of the igneous rocks is, however, somewhat obscured by this terminology.

Detailed descriptions of the rocks can be found in the works of Geijer (1910), Sundius (1912, 1915), Offerberg (1967), Parák (1975a) and Frietsch (1979a). The most up-to-date and abundant geochemical data are given by Parák (1975a).

In the following text some of the most frequently used names have been abbreviated: Lu = Luossavaara; K = Kiirunavaara; PG = Per Geijer.

Fig. 2 shows how the steep to vertical dip of the bedding in the west decreases to the east. This variation is consistent with folding. In a tectonic study of the greenstone belt of the Kiruna district, Vollmer, Wright and Hudleston (1983), conclude (p. 116): "We feel that the interpretation of the rocks as a non-repeated homoclinal sequence fits the data best". However, Koark *et al.* (1978) recorded isoclinal folds in the Tuolluvaara mine. Exploration work at the Puoltsa iron deposit, situated immediately outside the map-area, has furthermore indicated isoclinal folding of the porphyries (Hallgren 1973). Geophysical airborne surveys in the greenstone area north of the river Torneälven have demonstrated the existense of repeated folds that plunge c. 10° SE.

In the open pit of the Nukutusvaara deposit folding of the ore has been recorded. The distance between the two limbs at the upper part of the 12 m high pitwall was 10 m and the trough of the fold 2 m above the pit bottom. The axial plunge is here about 10° to the south-southwest. In the Rektor deposit, in the southern part of the same formation, small scale folds plunge 45° SE. Besides the above–mentioned observations, small, centimeter-scale folds are sometimes found in the apatite-rich parts of the Ki ore. They are rather irregular and seem to have been formed in connection with the mobilization and recrystallization of the apatite.

DISCUSSION

AGE RELATIONS OF THE KIRUNA GREENSTONE, THE KURRAVAARA CONGLOMERATE AND THE KIRUNA PORPHYRIES

Sundius (1912, 1915), who was the first to present a thourough description of the Kurravaara Conglomerate, found that 60–70 % of the clasts consist of albite-rich porphyries or felsites. Pebbles of greenstone are also rather common, at least in the basal, western parts of the conglomerate and the matrix is largely composed of material from the greenstones. The clasts are thus dominated by rocks resembling those of the bedrock east of the conglomerate.

This early work was based on the few outcrops of the basal parts of the Kiruna porphyries; comparison between the rock types in the conglomerate clasts and the porphyries in the east was difficult. Today, several drillholes in this area have provided a better knowledge of the variation of these rocks. In one drillhole, that intersects both the porphyries and the underlying conglomerate, located 2.5 km west of the northern end of the Ki ore, the volcanics display a rich variety of volcanic rocks. This and other drillholes clearly demonstrate the similarity between the pebbles in the Kurravaara Conglomerate and the felsites, quartz-porphyries, syenite-porphyries and Kiruna syenite, that are found overlying the conglomerate to the east. The observation of Kiruna syenite clasts in the conglomerate is especially interesting as this rock must be younger than the main part of the older porphyries.

Sundius (1912, 1915) recorded pebbles of a rock type, which Geijer (1910) called magnetite-syenite-porphyry. This rock, which consists of albite needles in a matrix of magnetite, is found only in the uppermost parts of the syenite-porphyry that forms the foot wall of the Lu-Ki ores.

Sundius (1912, 1915) also observed pebbles of what he called apatite-magnetite ore, which he considered to be of the same type as Lu-Ki apatite iron ores. His description of these ore pebbles does not support this suggestion. Unlike the fine-grained dissemination characteristic of the Lu-Ki ores, the apatite in these clasts occurs in small cavities together with amphibole and epidote. Ore pebbles tested by Parák (1975a, p. 11) were all found to have very low phosphorous content. It thus seems unlikely that clasts of Lu-Ki ores occur in the Kurravaara Conglomerate, the age of which thus may be older than the Lu-Ki ores.

These observations suggest that deposition of the Kurravaara Conglomerate, ended prior to or very near the time of emplacement of the Lu-Ki ores.

Frietsch (1979), in his description of the petrology of the Kurravaara area, has defended the interpretation that the Kurravaara Conglomerate is older than the Kiruna Porphyry Group. He summed up his arguments for this hypothesis in five points (ibid. p. 78).

1. "The Kiruna greenstone contains intercalations of conglomerate, indicating that the formation of the conglomerate began while the basic volcanism was still active".

This statement is based on two observations, one by Parák (1969, p. 48) in the area northwest of Nukutusvaara and the other by Sundius (1915, Fig. 21) at Valkeasiipivaara, 2 km north of the lake Luossajärvi. In the first case, Parák interpreted a dark, schistose layer in the Kurravaara Conglomerate as a greenstone implying the existence of alternating greenstones and conglomerates. Later examination of the two drill-cores (No 487 and 569), which were the basis for this interpretation has shown, however, that the interferred greenstone is a much deformed conglomerate. In the other case, Sundius recorded a small occurrence of conglomerate in the greenstone at Valkeasiipivaara. A search of this area found a variolitic greenstone but no conglomerates.

No intercalations of the Kurravaara Conglomerate have been found in the greenstones during the exploration of the Viscaria area, which included a great number of drillholes in the greenstones located between the Viscaria deposit and the Kurravaara mountain.

2. "Even if the volcanic rock pebbles of the Kurravaara conglomerate and the volcanic rocks in the overlying Kiruna porphyries in many cases are similar, mineralogical and textural differences exist as shown by Geijer (1931a) as well as Eriksson and Hallgren (1975)".

Geijer (1931a) observed that the albitophyric rocks are more abundant in the conglomerate than in the overlying porphyries. However, during Geijer's early work, the development of the porphyries situated in the west, was little known. Later exploration has shown that albitophyric rocks are much more common than Geijer thought.

The second reference must be due to some misunderstanding. Eriksson and Hallgren (1975) do not claim any differences between the porphyries occurring as pebbles in the Sautusvaara conglomerate, which they correlate with the Kurravaara Conglomerate, and those in the overlying Porphyry Group. On the contrary, they say (p. 33; the author's translation): "The pebble material consists largly of salic effusives and leptites resembling those overlying the conglomerate".

The same relationships were emphasized by Ödman (1957, p. 62), who studied the Kurravaara Conglomerate in the area north of the lake Luossajärvi; he commented (the author's translation): ". . . the pebbles of the conglomerate are petrographically identical with the adjoining, syenite-porphyry in the east".

In the same paragraph Frietsch wrote: "It should also be pointed out that the volcanic rocks in the Kiruna porphyries are chemically somewhat different. The syenite porphyry (albitophyre) in the conglomerate is sodium extreme whereas at Kiirunavaara and Luossavaara it is alkali intermediate (Table 6). There are, however, nodule-bearing syenite-porphyries at Nukutusjärvi and west of Syväjärvi, which are sodium dominant (analyses Nos. 4 and 5, Table 6). The Kiruna porphyries have also a somewhat higher content of magnesium and calcium than the porphyry pebbles, this being related to a higher content of femic minerals".

These differences in chemistry, emphasized by Frietsch, are only found between analyses No. 1 and No. 2 from the conglomerate and No. 3 from the syenite-porphyry (Table 1). No. 3 was first published by Geijer (1910) and it seems rather doubtful whether it is meaningful to compare analyses from the beginning of this century with those made 1973. Five new analyses from the basal porphyry west of Kiirunavaara are given in Table 2. They are of nodule-free porphyries. These analyses as well as those in column 4 and 5 (Table 1) do not differ significantly from the analyses of the conglomerate clasts (column 1 and 2).

3. "In the northern part of the Kurravaara area, where no Kiruna porphyries are present, the content of porphyry pebbles in the conglomerate is the same as in the southern part. There is thus no direct spatial relationships to the rocks of the Porphyry group".

The fact that the amount of porphyry pebbles in the Kurravaara Conglomerate is the same in the northern part of the Kurravaara area as in the south, is not a convincing argument for Frietsch's hypothesis, when consideration is taken of the large porphyry area immediately to the south. If it has any significance for the interpretation of the age of the conglomerate, it may as well indicate the existence of Kiruna porphyries below the conglomerate of this area (see Fig. 8).

4. Here, Frietsch points to the fact that "the composition of the matrix indicates relationships with the rocks of the greenstone group".

The contemporaneous denudation of the greenstones and the porphyries is the cause of this mixture of greenstone and porphyry material in the Kurravaara Conglomerate (Fig. 6).

5. About the existence of two conformable intercalations of sericite quartzite in the Kurravaara Conglomerate, Frietsch (1979, p. 23) says: "The sericite quartzite in the Kurravaara conglomerate is identical to that of the Lower Hauki Formation. Probably the sericite quartzite in both formations is of magmatic origin, being an altered acid lava. The sericite quartzite in the Kurravaara conglomerate thus represents an intrusion related to the lavas in the Lower Hauki Formation. This raises the question as to why the sericitization-silification that altered the lava rock did not affect the surrounding Kurravaara conglomerate".

A possible explanation is that these sericite quartzites are exposed digitations of the isoclinally folded, underlying, older Lower Hauki units (see Fig. 8, cross-section A).

Finally Frietsch concludes: "In summary, it seems more reasonable to consider the Kurravaara conglomerate as a clastic deposit, formed at a late stage of the volcanism, which produced the Kiruna greenstone, and it is thus older than the Kiruna porphyries".

This statement implies a correlation of the Kurravaara Conglomerate with the

TABLE 1. Chemical analyses of syenite-porphyries occurring as pebbles in Kurravaara Conglomerate and foot wall unit to Lu-Ki ores (weight per cent). Analyst: LKAB. From Frietsch 1978a, Table 6.

Syenite porphyry

	Kurravaara Conglomerate		Foot wall unit to Lu-Ki ores		
	1	2	3	4	5
SiO_2	50.0 -59.8	52.2 -57.2	59.71-61.24	45.2 -48.5	57.1 -60.8
TiO_2	0.08- 0.29	0.44- 0.74	0.66- 2.14	1.12- 1.29	0.62- 1.12
Al_2O_3	17.0 -19.5	17.9 -19.7	13.95-16.18	15.11-16.1	16.4 -17.3
Fe_2O_3	1.80-19.62	6.96-10.29	3.20- 4.89	15.47-17.74	2.60- 8.37
FeO	0.04- 4.98	2.51- 3.54	1.19- 2.96	5.91- 6.56	1.07- 3.12
MnO	0.03- 0.10	0.03- 0.04	0.07- 0.36	0.06- 0.12	0.02
MgO	0.33- 3.24	1.54- 1.60	1.17- 4.23	0.51- 1.19	0.48- 2.25
CaO	2.26- 4.04	2.17- 3.10	2.91- 5.04	0.98- 2.88	2.24- 3.16
BaO	0.01- 0.04	0.01- 0.03	0.05	0.02- 0.03	<0.01- 0.01
Na_2O	7.85- 9.64	6.98- 7.71	5.13- 7.25	5.60- 8.00	8.20- 8.52
K_2O	0.08- 1.18	0.33- 0.59	2.04- 4.53	0.08- 1.08	0.46- 1.05
P_2O_5	0.16- 0.46	0.25- 0.37	0.01- 0.44	0.46- 1.26	0.50- 0.53
CO_2	0.24- 2.96	0.28- 1.26	0.51	0.31- 2.75	1.14- 2.00
H_2O	--	--	0.22- 0.74	--	--
Cl	--	--	--	--	--
F	0.02- 0.08	--	--	0.01- 0.02	0.15- 0.19

1. Pebbles of albitophyre. Kurravaara and Valkeasiipivaara. Parák 1975, Table 3, analyses Nos 1, 2, 6 and 7.
2. Pebbles of syenite-porphyry. Kurravaara and Valkeasiipivaara. Parák (1975, Table 3, analyses Nos 5, 9 and 10).
3. Syenite-porphyry, Kiirunavaara and Luossavaara. Geijer (1931a, p 180, analyses 14.18).
4. Syenite-porphyry with magnetite nodules, west of Henry. Parák (1975, Table 6, analyses Nos 1-3).
5. Nodular syenite-porphyry, west of Syväjärvi. Parák (1975, Table 6, analyses Nos 4-6).

Pahakurkkio Group, which is undoubtedly younger than the Greenstone Group and older than the Porphyry Group. The Pahakurkkio sediments are dominated by quartzites and schists, often rich in andalusite or sillimanite and with conglomerates as a very subordinate element. There is thus little lithologic similarity between the Pahakurkkio Group and the Kurravaara Conglomerate Formation.

The Kurravaara as well as other similar conglomerates outside the Kiruna district are most likely derived from the porphyries. Thus, they often mark the border zone between the greenstones and the porphyries, a relationships demon-

TABLE 2. Chemical analyses from the basal porphyry east of the Kurravaara Conglomerate (weight per cent). Analyst: LKAB.

	50 m east of the Kurravaara Conglomerate			500 m east of the Kurravaara Conglomerate		
	1	2	3	4	5	6
SiO_2	63.5	63.5	52.7	64.4	62.3	62.3
TiO_2	1.86	1.10	1.03	0.29	2.26	1.78
Al_2O_3	18.1	18.2	15.5	19.2	18.6	18.3
Fe_2O_3	1.7	1.6	9.9	0.9	2.0	2.0
FeO	0.8	0.8	4.9	0.5	1.0	1.0
MnO	0.01	0.01	0.02	0.01	>0.01	<0.01
MgO	0.13	0.37	0.23	0.19	0.24	0.32
CaO	1.13	0.77	1.25	0.60	0.65	0.94
Na_2O	10.1	10.2	7.97	9.77	8.90	8.66
K_2O	0.22	0.34	1.37	1.70	2.26	2.59
P_2O_5	0.01	0.03	0.15	<0.01	<0.01	0.01
CO_2	-	-	-	-	-	-
H_2O	-	-	-	-	-	-

1. Red syenite-porphyry with small nodules (drillhole 1811, 118 m)
2. Red-grey syenite-porphyry (" 1811, 129 m)
3. Grey, dense syenite-porphyry (" 1810, 193 m)
4. Red, dense syenite-porphyry (" 1810, 218 m)
5. " " " (" 1810, 228 m)
6. " " " (" 1810, 231 m)

strated in many geological map sheets (Ambros 1980; Eriksson and Hallgren 1975; Offerberg 1967; Padget 1977, 1979 and Witschard 1970). One exception is the Saurusvaara conglomerate, about 15 kilometers southeast of Kiruna (Eriksson and Hallgren 1975). This rock, which strongly resembles the Kurravaara and Hauki Conglomerates, is deposited on vesicular syenite-porphyries similar to those found in the foot wall of the Lu-Ki ores. Lundberg and Smellie (1979) described a similar conglomerate from the Painirova area and commented "... this material represents locally derived and deposited products from early Porphyry Group volcanism".

The isoclinal folding found in the greenstones and also in the porphyries makes it reasonable to accept a similar deformation of the conglomerate. The position of

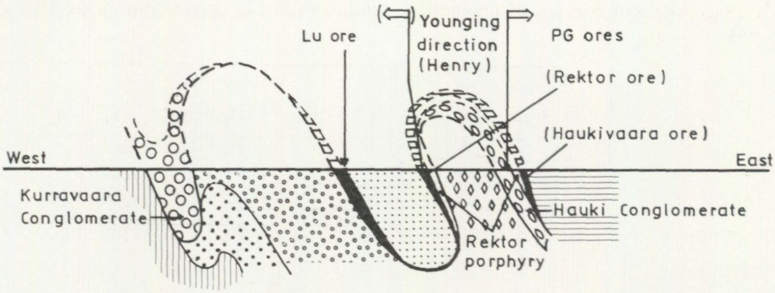

Fig. 3. Simplified cross-section showing the relations between the Kurravaara and the Hauki conglomerates and the Lu ore and the PG ores respectively. Legend, see Fig. 2.

the conglomerate below the older porphyries in the Kiruna area is thus best explained as a consequence of synformal folding (Fig. 3).

The possibility that the porphyry is thrust over the conglomerate is rejected here, because no trace of thrust planes has been observed in the porphyry-conglomerate contact zone, which has been studied in a drillhole south of the lake Luossajärvi.

AGE OF THE KIRUNA SYENITE

The Kiruna syenite is found between the basal porphyries and the middle syenite-porphyries. The eastern border is well exposed in tunnels driven from the mine to the hoisting plant; here, the relationships between the syenite and the syenite-porphyry are transitional. The conditions along the western border-zone are not known. The syenite was probably formed by recrystallization of the syenite-porphyries prior to the intrusion of the porphyry-dikes.

COMPARISON OF THE ORES AND THE HOST ROCKS OF THE LUOSSAVAARA-KIIRUNAVAARA AND LOWER HAUKI MEMBERS

CHARACTER OF THE IRON ORES

The magnetite of the PG ores occurring in the Lower Hauki units, has been partially transformed to hematite in some deposits. However the magnetite-dominated ores (Nukutusvaara, Rektor, Lapp) are lithologically identical with the apatite-rich parts of the Lu-Ki ores.

The trace-elements contents (Table 3) of the magnetite in the Lu-Ki ores and the PG ores are strikingly similar (Parák 1975a). The predominance of potassium in the ores also points to a common origin, this being particularly remarkable in view of the sodium-dominant character of the host rocks of the Lu-Ki ores.

TABLE 3. Trace element content of magnetite, median values in ppm (from Parák 1975a, Table 24–26, 28–34).

	Cu	Zn	Ti	V	Cr	Mn	Co	Ni	Al	Mg
Kiirunavaara ores	40	50	700	1400	0	720	120	300	200	700
Luossavaara ores	4	60	800	1200	5	440	60	135	200	400
Lower Hauki ores (Per Geijer ores)	15	40	950	960	3	175	80	400	350	100
Kiruna syenite-porphyries	10	40	1100	1300	90	90	60	110	1200	800
Lower Hauki syenite-porphyries	16	40	1500	1100	20	130	50	470	700	300

CHARACTER OT THE HOST ROCKS

Although the strong schistosity of the Lower Hauki units has obliterated most of the primary structures, the latter are locally preserved. East of the Nukutusvaara ore, a vesicular rock occurs, very similar to the nodular syenite-porphyry from Lu-Ki. In the same deposit there are also observations of rock types resembling the "normal" syenite-porphyries of the Lu-Ki zone. The trace-element content of the magnetite in the syenite porphyries from the two areas also suggests a close affinity (Table 3).

The similarity in lithology and trace element content between the ores and the syenite-porphyries of the two areas makes a stratigraphic correlation plausible.

In contrast to the sedimentary of the trace-element composition between the syenite-porphyries from Lu-Ki and those from the Lower Hauki area, all Lower Hauki rocks are potassium-rich, whereas those from the Lu-Ki are sodium-dominated. The difference in alkali content may be related to the existence of potassium-rich ignimbritic volcanics, occurring between the PG ores and the Hauki syenite-porphyries. Mobilization of potash felspar in these ignimbrites is thought to have taken place during folding, producing the present schistose character of the Lower Hauki units and leading to potassium-metasomatism of its rocks.

CHARACTER OF THE CONGLOMERATES

The Kurravaara Conglomerate, with its pebble-free intercalations (see Frietsch 1979), and the basal conglomerate of the Hauki graywacke show such lithological similarity that a common source and contemporaneous deposition seem inevitable. The most striking similarity between the two conglomerates is the predominance (40–60 %) of pebbles consisting of porphyries strongly resembling the types found in the basal part of the Kiruna Porphyry Group. Furthermore the pebbles of hematite in the Hauki Conglomerate and magnetite in the Kurravaara Conglomerate as well as clasts of greenstone, jaspilite and white quartzite in both conglomerates are also suggestive of a common source for the two conglomerates.

There is, however, neither in the Kurravaara nor the Hauki Conglomerates any observation of pebbles of apatite iron ores of the Lu-Ki or the PG types. This suggests that the deposition of the conglomerates took place before the emplacement of the ores. Likewise, the lack of clasts of Rektor Porphyry in the Hauki Conglomerate (Ginet, pers. comm.) may also imply conglomerate deposition prior to the emplacement of this porphyry.

Cross-bedding in the graywackes in the Henry open pit of the uppermost, eastern part of the Lower Hauki Formation verifies that the top of these beds are to the east.

On the western side of the Lower Hauki Formation, however, a recent find of cross-bedding in stratified ore in the same deposit is interpreted as evidence of younging to the west.

In Fig. 3, an attempt is made to illustrate the age relations and folding that seem to be in best agreement with the above-mentioned observations. Correlation of the Kurravaara and the Hauki Conglomerates has been especially emphasized. This interpretation implies that the quartz-bearing porphyry is younger than the Hauki Conglomerate-graywacke and thus separates it from the Upper Hauki Quartzites, where the intercalated conglomerates clearly show that they derive from the quartz-bearing porphyry. This requires the Hauki Conglomerate-graywacke to be a part of the Lower Hauki Formation, which is contrary to the traditional interpretation (see Fig. 4).

Fig. 4 presents a schematic cross-section (compare with Fig. 2) of the structure, illustrating the age-relations of the rocks as interpreted herein. It also shows some of the features discussed in the following chapters.

AGE OF THE QUARTZ-BEARING PORPHYRY

Geijer (1910), in his first description of the Kiruna ores, saw them as "eruptions of magnetite, spreading out as somewhat irregular beds" over an earlier flow of syenite-porphyry. The ores were later covered by extrusions of the quartz-bearing porphyry. Later (Geijer 1919), he revised this first hypothesis and proposed an intrusive origin of the ore.

Consequently, the quartz-bearing porphyry in the hanging wall had to be older than the ore. This made it difficult to explain the origin of the xenoliths, found in the quartz-bearing porphyry (see Fig. 4), consisting of apatite magnetite ore,

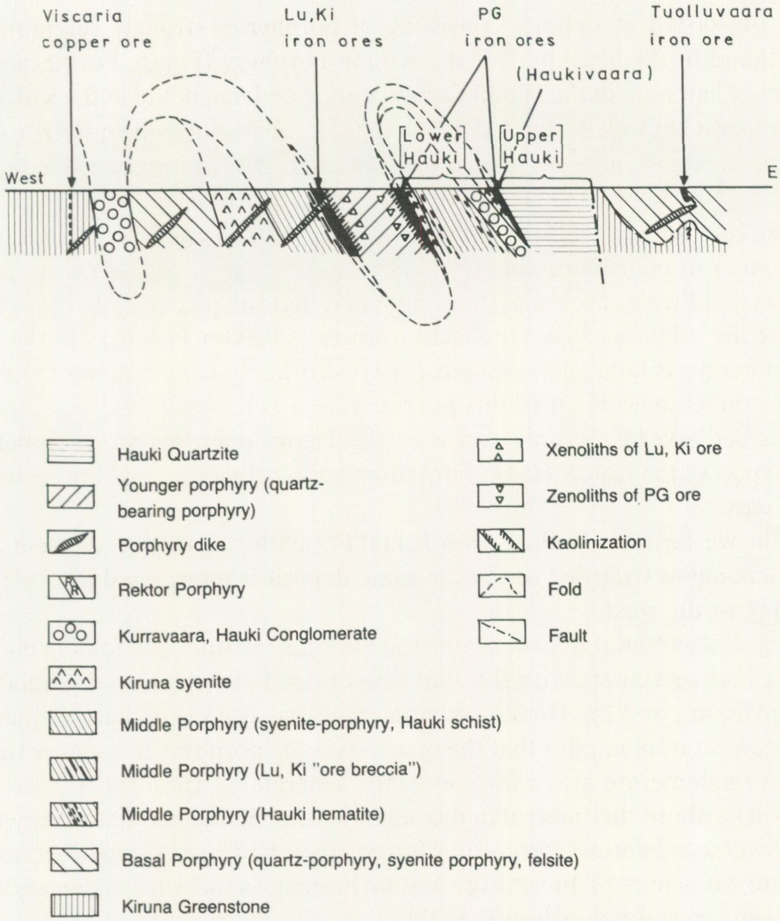

Fig. 4. Generalized cross-section of the Kiruna area (including the Haukivaara deposit), demonstrating the inferred folds and the new grouping of rock units (cf. Figs 2 and 3).

similar to that of the main ore bodies. Parák (1975a) provided a detailed description of these ore-xenoliths, which he interpreted as inclusions originating from the Lu-Ki iron ores. This and other arguments, put forward by Parák to support this hypothesis that the ores are of syngenetic origin, seems convincing enough, and requires that the ore is older than the quartz-bearing porphyry.

The relationships between the Lower Hauki Formation and the quartz-bearing porphyry was treated by Stutzer (1907). He observed xenoliths (see Fig. 4) in the quartz-bearing porphyry, which he compared with the rock-types he found in the Lower Hauki Formation. Parák (1975a) presented detailed descriptions of these inclusions; according to him, they are derived from the Lower Hauki units and thus, like the Lu-Ki ores, are older than the quartz-bearing porphyry.

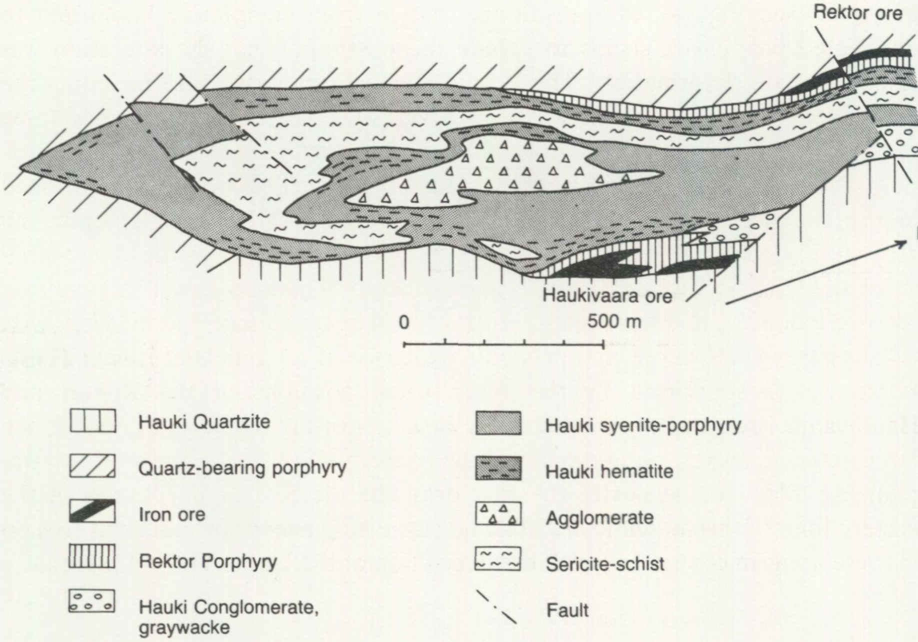

Fig. 5. Geological map of the southern part of the Lower Hauki Formation (modified from P. Geijer 1910).

The hypothesis that the ores are intrusive implies that the porphyry dikes, which intersect the Ki ore, are younger than the quartz-bearing porphyry. Although the latter is known from a great number of outcrops and more than 30 km of tunnels and drillcores, from Nukutusvaara in the north to Konsuln in the south, no porphyry dikes have been found. The absence of these dikes in the quartz-bearing porphyry thus indicates that the latter is younger than the dikes and consequently even than the ore.

The Lower Hauki Formation is correlated here with the ores and older porphyries of the Lu-Ki zone (see above) and should therefore be expected to be crosscut by porphyry dikes. However, no such observations have been made. One explanation suggests that the intense deformation of the Lower Hauki rocks obliterated all traces of these dikes. Another possibility is that these dike systems are local in character. Thus, no such dikes have been found in the foot wall rocks of the Lu ore; in the Ki ore, they are only observed in its northern part.

The hypothesis that the quartz-bearing porphyry occurs in a syncline between the Lu-Ki and the Lower Hauki zones and thus is younger than the surrounding rock units is supported by the similarities between its western and eastern contact zones. A more or less complete kaolinization (from a few decimeters to several meters thick) of this porphyry is found in the contact with both the Ki ore and the

PG ores (see Fig. 4). A transitional change from completely kaolinized to unaffected porphyries seems to exlude the possibility that the alteration was caused by late deformation. The Lower Hauki Formation, here including the Hauki conglomerate and graywacke (see Fig. 4), is therefore interpreted to be older than the quartz-bearing porphyry. The western part of the Lower Hauki Formation must thus be overturned and younging to the west. As mentioned before, the eastern part of the Lower Hauki Formation with its conglomerate and graywacke clearly demonstrate younging to the east, thus suggesting the possibility of an anticline. The single observation of cross-bedding in the Henry ore (see above and Fig. 3), that has been interpreted to indicate younging to the west, may be questioned. However, the probable existance of an anticlinal Lower Hauki Formation is supported by the symmetrical positions of the Rektor and Haukivaara ores and their underlying Rektor porphyries (Fig. 5), which are interpreted as corresponding parts of the western and eastern limbs of a south-plunging fold. To the north, the iron ores and the Rektor porphyries of the eastern limb of this anticline are missing, suggesting a more pronounced erosion in these areas in connection with the deposition of the Upper Hauki Quartzites.

TUOLLUVAARA QUARTZ-PORPHYRY COMPARED TO THE QUARTZ-BEARING PORPHYRY

Geijer (1910, 1920) emphasized the lithological and chemical similarities between the Tuolluvaara porphyries and the quartz-bearing porphyries of the Ki and Lu hanging wall, although he also pointed out several differences. One example of the latter is the size and frequency of the phenocrysts, which are large (4–10 mm) and common in the quartz-bearing porphyry, but small (1–3 mm) and sparse in the Tuolluvaara porphyry. The quartz-porphyries in the basal parts of the Ki foot wall, which were unknown to Geijer, strongly resemble the Tuolluvaara quartz-porphyries texturally. The occurrence of porphyry dikes in the Ki foot wall porphyries as well as in the porphyries of the Tuolluvaara area also favours correlation of those two formations. As already has been mentioned above, the quartz-bearing porphyry is devoid of these porphyry dikes.

A drillhole to 950 m below the surface at the Tuolluvaara mine reached a metabasite, which resembles the more metamorphosed members of the Kiruna Greenstones; thus the overlying Tuolluvaara quartz-porphyries probably are related to the basal porphyry units.

This evidence does not favour the interpretation (Geijer 1920) that the Tuolluvaara quartz-porphyry is contemporaneous with the Lu-Ki quartz-bearing porphyry. Correlation with the units in the basal parts of the Kiruna porphyries seems more likely.

There is a consistent difference in the average sodium/potassium ratio (Table 4)

TABLE 4. Fe-, P-, Na_2O-, K_2O-content (weight %) and Na_2O/K_2O-ratio of iron ores. Average of yearly production (from the last obtainable year of production). Analyst: LKAB.

Ore Products (Year)		Fe	P	Na_2O	K_2O	Na_2O/K_2O
Tuolluvaara B	(1981)	67.5	0.07	0.20	0.10	2.00
*Malmberget B	(1981)	69.4	0.04	0.10	0.05	2.00
*Svappavaara D	(1980)	65.2	0.51	0.14	0.12	1.17
Kiirunavaara D	(1982)	60.9	1.43	0.17	0.18	0.94
" B	(1982)	66.7	0.08	0.15	0.17	0.88
Luossavaara C	(1962)	63.5	0.33	0.16	0.22	0.73
" B	(1962)	64.8	0.06	0.17	0.22	0.77
Rektor	(1962)	44.9	4.70	0.13	0.23	0.57

* outside the Kiruna district

C, B, D refer to products differing in P-content.

between the Tuolluvaara and Malmberget group of ores and the Svappavaara, Lu-Ki and PG ores (the last represented by the Rektor ore). This suggests a difference in the depositional conditions and thus also a possible age-difference.

UPPER HAUKI QUARTZITE AND ITS CONGLOMERATES

The conglomerate beds of the Upper Hauki Quartzite are well-known through diamond drillings in connection with exploration of the Lapp ore, which represents the deeper (by faulting subsequently uplifted) parts of the Rektor and Henry ore (Fig. 5, cross-section C). Apart from the basal part of the quartzite, where fragments of phyllite occur, the conglomerate pebbles consist almost exclusively of quartz-bearing porphyry. However, Parák (1975a) reported the rare occurrence of clasts of hematite, the latter sometimes banded. The predominance of quartz-bearing porphyry-pebbles and the absence or scarceness of Lower Hauki rocks show that the latter unit probably was covered by quartz-bearing porphyry, when the quartzite was deposited. The small porphyry area in the quartzite, 200 m east of Haukivaara, may be a relict of this porphyry-cover; however, it may also be interpreted as an upthrust sheet of the quartz-bearing porphyry underlying the overturned Lower Hauki Formation. An outcrop of a schistose polymict conglomerate northeast of lake Ala Lombolo is considered to be a thrust unit of the Hauki Conglomerate, thus illustrating similar large fault movements (Fig. 8, cross-section D).

TRADITIONAL STRATIGRAPHY IN THE LIGHT OF THE PRECEDING DISCUSSION

The following seven points summarize the problems connected with the hitherto accepted stratigraphy (see Fig. 2).

1. The clasts of the Kurravaara Conglomerate undoubtedly seem to originate from the older members (the Basal and Middle Porphyry) of the Kiruna Porphyry Group. No observations of an even older porphyry complex have been reported.
2. A hypothesis involving magmatic injection of the Lu-Ki ores implies that the porphyry dikes must be younger than the quartz-bearing porphyry; this contradicts all observations. The occurrence of xenoliths similar to the Lu-Ki ores in the quartz-bearing porphyry also conflicts with the hypothesis, that the ores are intrusive.
3. The inclusions of Lower Hauki rocks in the quartz-bearing porphyry are, in the same way, incompatible with the older concept that the former are younger than the latter.
4. The almost identical composition of clasts in the Kurravaara and Hauki Conglomerates points to contemporaneous deposition. According to the hitherto accepted stratigraphy (Frietsch 1979), the former is placed below and the latter above the Kiruna Porphyry Group.
5. The absence of pebbles of the Rektor porphyry and the PG ores in the Hauki Conglomerate may suggest that the conglomerate is older than these units.
6. The symmetric positions of the Rektor and Haukivaara ores as well as the Rektor Porphyry (Fig. 5) are consistent with their occurrence in the limbs of a south-plunging antiform.
7. The pebbles in the conglomerates of the Upper Hauki Quartzite consist almost entirely of quartz-bearing porphyry. The rare occurrence of the underlying Hauki rocks in the clasts seems difficult to explain in terms of the prevailing stratigraphic interpretation.

GEOLOGICAL EVOLUTION OF THE SVECOKARELIAN ROCKS OF THE KIRUNA DISTRICT

The nature of the predepositional environment is a question outside the purpose of this paper. Witschard (1984) has proposed a model, where the first tensional episode of the Svecokarelian cycle was characterized by incipient rifting, resulting in the extrusion of basic magma and deposition of quartzitic sediments.

A schematic picture of the inferred geological evolution of the Proterozoic rocks is summarized below (see Fig. 6).

I. Deposition of Tjärro Quartzites (B) and extrusion of Kiruna Greenstones (C) on an Archean basement (A). Deposition of sulphide (C_1) and iron ores (C_2).

II. Deposition of Pahakurkkio sediments (Hietavaara schists), (D). Extrusion of Basal Porphyries (E) and deposition of iron ores (E) and intrusion of andesite porphyry (F). Extrusion of Middle Porphyries (G) and laharic formation of Kurravaara (H_1) and Haukivaara (H_2) Conglomerates. Minor folding and denudation.

III. Emplacement of Rektor Porphyry (I) and deposition of Lu, Ki (J_1) and PG (J_2) iron ores. Intrusion of Kiruna syenite (K) and extrusion of syenite porphyry (K_1) in the initial phase of iron ore deposition.

IV. Intrusion of porphyry dikes (L_1) and incipient extrusions of quartz-bearing porphyry (L_2) contemporaneously with the final phase of iron ore deposition.

V. Erosion of iron ores and the initial pyroclastics of the quartz-bearing porphyry, followed by the main phase of extrusion of the latter (M).

VI. Faulting and folding connected with the emplacement of the quartz-bearing porphyry. Erosion of this rock provided the source for the Upper Hauki Quartzite (N).

VII. Folding connected with intrusion of Lina granites (O) and related quartz-porphyry (granophyric) dikes (O_1).

Here follows a short description of the rock units and their depositional environments together with a summary of the likely tectonic evolution (cf. Fig. 6).

BASEMENT COMPLEX

Archean rocks, mostly granites and gneisses, are known from the northern part of the Kiruna area. New investigations in the contact between the Kiruna greenstones and the migmatitic granite at Såkevaara have identified granites resembling the types found in the basement areas north of Kiruna (L. Godin, pers. comm. 1986).

KIRUNA GREENSTONE GROUP

Prior to and partly contemporaneously with the volcanic activity that produced the Kiruna Greenstones, deposition of clastic sediments of the so-called *Tjärro Quartzites,* took place. Light grey quartzites (3–10 m thick) alternating with

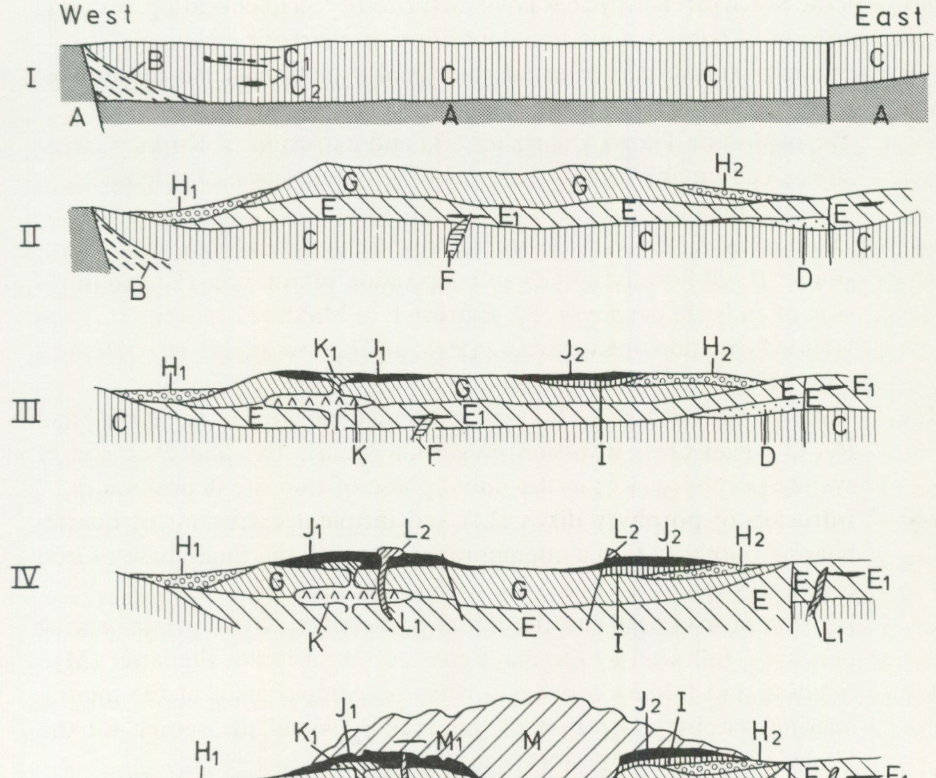

Fig. 6. Cross-sections showing the geological evolution in the Kiruna area.

greenstones, recorded in drillholes from Såkevaara, west of Viscaria, belong to this formation.

The deposition of the Tjärro sediments was followed by extrusion and intrusion of basalts (all now spilitic in character) alternating with sedimentary intercalations, composing an up to 3 km thick pile. In the higher levels of the succession, well-preserved pillow structures are to be found. In the basal parts, more or less altered peridotites and pyroxenites, chemically komatiitic in character, occur. In drillholes penetrating these ultrabasic rocks a few short sections of quartz-porphyry, as well as a small granite intrusion are found. It is probable that these acid intrusions are related to the Lina granite.

The sedimentary intercalations in the greenstones consist of basaltic tuff, tuffite, albite-fels ("chert"), graphite-schist and carbonates. Pyrrhotite is common in these layers.

Copper mineralizations (chalcopyrite) with an average Cu-content between 0.7 and 4 % are found in five of these metasedimentary units. The stratified nature as well as other characteristics of these copper deposits indicates a synsedimentary origin. Four major intercalations (10–200 meters thick) are named the A-, B-, C-, D-zones, of which the A-zone in the eastern part of the greenstone pile contains the Viscaria copper ore. Well preserved sedimentary structures show that this east-dipping succession is the right way up.

Disseminated magnetite, sometimes forming small iron ore deposits, are common in these metasediments. The Suolajoki magnetite-deposit, west-southwest of Kiirunajärvi, and the magnetite-chalcopyrite ore in the D-zone west of the Viscaria mine are examples of these (Fig. 1). A small magnetite lens at Pahtavara similar to that of Suolajoki has been described by Sundius (1915). In the more magnetite-rich parts of the Viscaria ore, a phosphorus-content of over 1 % is recorded.

Geophysical measurements at Ripakkajärvi, southwest of Ki, have discovered a gravity anomaly, which is interpreted to be related to greenstones occurring in an antiform within the basal porphyries.

Scapolitization is a common feature of the greenstones.

PAHAKURKKIO GROUP

The andalusite schist at Hietavaara in the northeastern part of the Kiruna area is the only observed member of the Pahakurkkio Metasedimentary Group, which elsewhere in Norrbotten has been interpreted as younger than the Greenstone Group and older than the Porphyry Group. Recent investigations of the Pahakurkio units at the type locality have, however, demonstrated the difficulties in defining the limits between these rocks and those of the Greenstone and Porphyry Groups (Niiniskorpi 1986).

PORPHYRY GROUP

The deposition of the Pahakurkkio sediments was followed by a period of volcanism during which the Kiruna porphyries, together with large deposits of apatite iron ore, were emplaced. The Kiruna porphyries are composed of the Basal Porphyry, the Middle Porphyry, the Rektor Porphyry and the Younger Porphyry. The deposition of the Kurravaara and Hauki Conglomerates is also closely connected with this volcanic phase. The observation in the Hauki Conglomerate of a pebble of ignimbrite (Ginet and Kunzle 1978), differing from those of the Rektor Porphyry, shows that ignimbritic rocks also occur in the older porphyries, i.e. in the Basal and/or Middle Porphyries.

The gabbro in the northwestern part of the area is tentatively compared with the basic members of the Haparanda "series" and thus, according to Witschard (1980), is of similar age to the Porphyry Group.

BASAL PORPHYRY

Quartz-porphyry and syenite-porphyry together with agglomerate, form the oldest known rocks of the Porphyry Group. A leucocratic tuff (more than 200 m thick) found east of the Rakkurijoki deposit also belongs here. West and southwest of Ki, quartz-rich felsites are found together with syenite-porphyries similar to those occurring at levels immediately below the Ki deposit. The basal porphyries seem to be missing north of lake Luossajärvi. In the Tuolluvaara area, the quartz-porphyries dominate the bedrock.

In the hanging wall of the Rakkurijoki iron ore, there occurs a 50–200 m thick quartzitic unit with a SiO_2-content varying between 73 and 91 %. It is probably a clastic sediment but a volcanic origin can not be precluded.

Dikes of *andesite porphyry,* with 1–3 cm long plagioclase-phenocrysts, are often observed in these basal porphyries; thus these dikes are at least younger than the basal parts of the Porphyry Group. The andesite porphyry, occurring in an area southwest of Pahtavaara, are interpreted as extrusions of the same age.

The Rakkurijoki iron ore body, often intersected by andesite porphyry dikes, is situated just above the Kiruna Greenstones and separated from them by a 5–25 m thick bed of a partly vesicular syenite-porphyry. This iron ore, with its high content of sulphur (an average of 1.9 %), differs from the main iron ores of the Porphyry Group, which normally are very low in sulphur.

MIDDLE PORPHYRY

The Basal Porphyry in the Kiirunavaara area is separated from the Middle Porphyry by the *Kiruna syenite,* which is either an intrusion between the Basal and the Middle Porphyry or, more likely, a recrystallization of the lower part of the latter.

Red to grey syenite-porphyries, together with vesicular rocks, are the most common lithologies in the foot walls of the Lu and Ki ores. The vesicles are filled with magnetite, actinolite, sphene and apatite. These vesicular units are considered to form contact zones between the lava beds.

Tuff and agglomerates are subordinate elements of the Middle Porphyry, forming the foot wall of the Lu-Ki ores. The more or less schistose rocks found in the Lower Hauki Formation may have originated from volcanics, consisting of tuffs and agglomerates.

Intercalations of sericite quartzite mark interruptions in the volcanic activity that produced the Lower Hauki syenite-porphyries. The quartz-banded iron ores, which have been observed close to or near the ores, may also be an example of these sedimentary phases.

A magnetite-syenite-porphyry (Geijer 1910), consisting of albite needles in a matrix of magnetite, is considered here to have formed by a simultaneous precipitation of iron solutions and volcanic ash. A small lens observed in a drillhole from the Ki foot wall, showing a distinct layering of magnetite and albite, is interpreted to result from a cyclic sedimentation of the same type.

The much discussed "ore dikes", found in the foot wall of the Lu ore, have been interpreted as apophyses from the main ore body and thus of an epigenetic nature (Geijer 1910). The observations "of up to ten centimetres thick, grey-green, chloritized, schistose layer of altered rock" in two of the thicker "ore-veins" by Parák (1975a, p. 50–51) indicate, however, a syngenetic origin of these "ore dikes".

The cross-cutting ore dikes observed in the foot wall in the northern part of the Ki ore body are, however, quite distinctly epigenetic and are interpreted as feeder dikes for the solutions or emanations that produced the main ore.

The "Hauki hematites", consisting of conformable layers of quartz-hematite ore in the partly silicified Lower Hauki units, may be the equivalents to the Lu "ore-dikes". In both cases the absence or very low content of apatite distinguishes these "ores" from the Lu-Ki and PG ores.

The syenite-porphyries of the Hauki zone, at least the less altered ones, are similar in many ways (in lithology and in trace element content of the magnetite) to the syenite-porphyries of the Lu-Ki zone (Table 3). The Hauki porphyries show, however, a much higher potassium-content. This difference is probably caused by mobilization of the potassium of the Rektor porphyries as indicated by the growth of potash-felspar porphyroblasts in the Lower Hauki volcanics. The occurrence of tourmaline is also much more common in the Hauki syenite-porphyries than in the Lu-Ki porphyries, where it is rare.

The dominance of schistose rocks in the Lower Hauki Formation is, as mentioned above, partly explained by sedimentary intercalations, but may also indicate a more tuffitic environment than in the Lu-Ki ores. These discrepancies are most likely explained by the fact that the Lower Hauki syenite-porphyries partly represent a somewhat higher stratigraphic level than the Lu-Ki syenite-porphyries, which were more deeply eroded. The existence of the Rektor Porphyry, which is interpreted as the youngest member of the Middle Porphyry, and its absence in the Lu-Ki zone points in the same direction.

The more or less altered intermediate porphyries found in the Tuolluvaara area, i.e. east of the Upper Hauki Quartzite, have been correlated here, with some hesitation, with the Basal Porphyries. However, the possibility that they are down-faulted parts of the Middle Porphyries cannot be excluded.

The disconformity between the Lu-Ki ores and their foot wall porphyries (Parák 1975) reflects a period of folding and denudation prior to the deposition of the ores (Parák 1975a, p. 144).

KURRAVAARA AND HAUKI CONGLOMERATES

Deposition of the Kurravaara and Hauki Conglomerates most likely coincided with extrusion of the Basal and Middle Porphyries but terminated after or at the end of this volcanism. Two subparallel basins which converge in the north, seem to have existed. In the western one, the Kurravaara Conglomerate received its material from the foot wall porphyries of the Lu-Ki ores and the greenstones. In the eastern depression, rock material from elevated areas to the east and west of the basin was deposited to form the conglomerates and graywackes of the Lower Hauki Formation. In both cases, older porphyries and greenstones must have been extensively exposed as those two rock types dominate the clast material (Fig. 6).

Later folding seems to have affected the Kurravaara Conglomerate to a greater degree than the surrounding greenstones and porphyries, the sediments forming tight synforms between the greenstones and the porphyries. This was most likely due to differences in competence between the conglomerates and the surrounding rocks. According to Parák (1971), there is a marked discordance between the Kiruna Greenstones and the Kurravaara Conglomerate at Pahtavaara.

The geological map of the Henry area (Ginet and Kunzle 1978) also suggests an unconformity between the Hauki Conglomerate and the underlying Hauki syenite-porphyry, thus implying that both the Hauki and Kurravara Conglomerates were deposited on a more or less eroded surface of greenstones and porphyries.

REKTOR PORPHYRY

After the previous eruptions that had produced only sodium–dominated rocks, new volcanic activity was characterized by a potassium-rich product, the Rektor Porphyry. This rock-unit is only found in the Lower Hauki Formation. According to Ginet and Kunzle (1978) the Rector Porphyry is "a volcanic complex with lava, ignimbritic rocks and tuffitic or reworked volcanic deposits".

APATITE-IRON-ORES: LUOSSAVAARA, KIIRUNAVAARA AND PER GEIJER ORES

The deposition of the Lu-Ki ores and the PG (Haukivaara, Rektor, Henry, Nukutusvaara and Lapp) ores are interpreted as contemporaneous events. Regarding the processes that gave rise to these apatite iron ores, the author favours Parák's (1975a, 1975b) hypothesis, involving a exhalative-sedimentary origin. The syenite-porphyry seems to have been subjected to folding and denudation before the deposition of the apatite iron ores, as demonstrated by the disconformity between the vesicular foot wall porphyries and the Ki ore body (see Parák, 1975a, Fig. 2).

In Luossavaara, where the "ore dikes" are considered to be syngenetic deposits, the disconformity is still more pronounced (see Parák 1975a, Fig. 34).

The strong shearing in the Hauki Formation has made it impossible to establish a possible unconformity between the ores and the Rektor Porphyry, which is considered to have formed the primary foot wall of the PG ores. Observations of fragments of Rektor Porphyry in a matrix of iron ore can, however, be interpreted as deposition on a more or less disintegrated Rektor Porphyry surface. A similar phenomenon is still more pronounced in the foot wall contact of the Ki ore. Here the foot wall often exhibits a transition from thin cross-joints with actinolite to thicker joints filled with magnetite, that gradually changes to a conglomerate-like rock with pebbles of different syenite-porphyry-types in a matrix of magnetite (Parák 1975a, p. 3, 14, 15).

These contact relationships are considered to be caused by a precipitation of iron solutions on a fractured, partly blocky surface. The most conspicuous ore breccias are found in connection with the concordant porphyry dikes. They are interpreted as talus-like debris sliding down from the fronts of the extruding syenite-porphyries (which implies that these "dikes" are lava beds) into the unconsolidated precipitate, that formed the iron ore.

Decimetre- to metre-thick layers of actinolitic skarn are found in the foot wall contacts of all the ore bodies.

The Ki ore body is characterized by repeated, abrupt changes from homogeneous, apatite-free magnetite (B-ore) to stratified apatite-rich magnetite layers (D-ore). Exactly the same stratified apatite iron ores are found in the Lu deposits as well as in the PG ores. Almost pure apatite-layers (0.1–0.5 m thick) are not unusual in the Ki and the PG ores.

Both the Lu-Ki as well as the PG ores show two generations of apatite. One is a primary type, forming a grey, fine grained (0.05–0.15 mm) dissemination in an equally fine-grained magnetite; it is often distinctly laminated. The other is a recrystallization product of the former, as the existence of many transitional types demonstrates. It is generally more coarse-grained and forms stringers and veins with reddish or greenish colours. In the most extreme cases, a "breccia" consisting of magnetite fragments in a matrix of apatite is formed. In the northern part of the Ki ore body an area of more than 100 m^2 consisting of a red, extremely coarse-grained (up to 1 cm long prisms), of almost magnetite-free apatite occurs. Another typical example of an apatite-magnetite intergrowth is the "skeleton ore", i.e. magnetite needles in a matrix of apatite, observed in the Lu-Ki ores as well as in the PG ores. A similar type, where the matrix consists of calcite instead of apatite, is more rare.

Actinolite, calcite and to a lesser degree biotite are very subordinate, but persistent, gangue minerals in the Lu-Ki ores. In the PG ores, calcite is more common. Although the calcite normally appears as a dissemination in the ore, the apatite-free ore often exhibits more or less horizontal thin veins of calcite. At one locality, 20 m above the foot wall, a 2 m thick layer of calcite, underlain by a 3 m thick calcite-iron ore-breccia, is observed.

Thin intercalations (1–10 cm thick) of anhydrite occur in the ore (B-ore) in the northern part of the Ki ore body.

A few beds of a tuffitic rock up to one meter thick have been recorded in the Ki ore by S. Liedberg (pers. comm. 1985). A similar rock-type has been reported by Parák (1975a) to occur in the Lu and the Lapp ores. In the Nukutusvaara deposit, the discovery of a lens (2 m thick) consisting of rounded quartz grains (1–5 mm large) in a matrix of more fine-grained magnetite emphasizes the sedimentary nature of the ore. Another observation from the Ki mine of thin chlorite layers (0.5–2 mm thick) in the B-ore, together with monazite, likewise favours the synsedimentary interpretation for the ore genesis.

A trough-like feature of the quartz-porphyry in the underlying ore suggests that erosion of the ore took place before the emplacement of the quartz-bearing porphyry (Parák 1975a, Fig. 51). There are, however, other observations in both the Ki ore and the Rektor ore, suggesting that deposition of the iron ore continued after the beginning of the quartz-porphyry volcanism. One example of this has been described by Parák (1975a, Fig. 6). Still more striking evidence of this phenomenon has been observed by S. Liedberg (pers. com. 1985) from a cross-drift in the middle of the Ki ore body. Pillow-like slabs of quartz-bearing porphyry are recorded to be intercalated with several 5–50 cm layers of apatite laminated magnetite ore. In this case, fragments and blocks of quartz-bearing porphyry also occur in the ore. They are interpreted as volcanic ejecta.

The contact between the Rektor ore and the quartz-bearing porphyry also provides an example of contemporary emplacement of iron ore and porphyry. A lens-like body of a conglomerate-like rock occurs, 5–8 m thick and about 30 m long, which consists of clasts of quartz-bearing porphyry in a matrix of extremely apatite-rich (8 % P), banded iron ore (Parák 1975a, Fig. 10). The clasts are slightly rounded, rectangular, 2–20 cm in length and often exhibit one protracted end and a marginal reaction rim. They are interpreted as volcanic bombs, which fell into an unconsolidated apatite iron ore sediment.

The change from a sodium- to a potassium-dominated environment, implied by the Rektor Porphyry may be important for the conditions that gave rise to the large deposits of apatite iron ores (Parák 1975a). The predominance of potassium compared to sodium is evident even in the Lu-Ki ores, although they have been emplaced on sodium-rich syenite-porphyries.

The lean ores ("ore breccias", "ore dikes") in the foot wall of the Ku-Ki deposits, in contrast to the main ores, are sodium-dominated and mostly low in phosphorus.

A possible genetic connection between the sulphide deposits in the Kiruna Greenstones and the iron ores in the porphyries is suggested by the occurrence of disseminated pyrite in the northern part of the Ki ore body. Although generally rare, the amount of pyrite in the apatite magnetite ore can be as high as 50 %.

PORPHYRY DIKES

The term porphyry dikes is adopted from Geijer (1910), who used it even for intrusives that in modern terminology are named sills or sheets. The occurrence of the porphyry dikes is restricted to the northern half of the Ki deposit and the Tuolluvaara area.

At least some of the conformable sheets that are found in the ore, or in the contact between the ore and its foot wall, are probably extrusions, more or less contemporaneous with the deposition of the iron ore. Texturally, they are similar to the foot wall syenite-porphyry and differ quite distinctly from the cross-cutting dike-porphyries; the latter have larger, white phenocrysts in a much more fine-grained, green matrix.

Chemically, the porphyry dikes occupy a position between the syenite porphyries and the quartz-bearing porphyry. The possibility that some of the cross-cutting dikes are feeders to the quartz-bearing porphyry can not be precluded.

YOUNGER PORPHYRY (QUARTZ-BEARING PORPHYRY)

Prior to the emplacement of the quartz-bearing porphyries, local or even extensive erosion of the Lu-Ki ore bodies may have taken place. As mentioned above, the presence of a channel-like trough in the hanging wall of the Ki ore body can be interpreted as the result of erosion (perhaps fluvial). However, other observations indicate a more transitional change from the ore to the volcanics, with an alternating emplacement of iron ore and pyroclastics. Higher up in the Younger porphyries, small iron deposits occur. An example is the Neptunus ore, east of the Lu ore.

The quartz-bearing porphyries often exhibit flow structures. Agglomeratic beds are common. Conglomerate beds are also found, east of the Lu ore body.

In a drill hole penetrating the Luossajärvi ore, a unique occurrence of a 6 m long intercalation of a red, faintly banded anhydrite, about 60 m above the ore body, is observed in the quartz-bearing porphyry. The Luossajärvi ore is situated 500 m below the lake Luossajärvi; it forms a direct continuation of the Ki ore body to the north.

The quartz-bearing porphyries are mostly sodium-dominant, but in the eastern areas near the Lower Hauki units rhyolitic types also occur (Parák 1975a, Table 9).

BASIC DIKES

Small dikes of diabase are known from the hanging wall of the Lu ore and from the northern end of the Ki ore. In the foot wall of the latter locality, a peculiar basic dike with 2–5 cm long, rounded inclusions of porphyry was observed. S. Liedberg (pers. comm. 1984) has found a slightly undulating composite dike that intersects the ore and its country rocks at about 600 m below ground level in the northern part of the Ki ore body. Metabasite composes the marginal parts of this dike and granophyric quartz-porphyry the central part. Xenoliths of the basic dike are sometimes found in the acid part, showing that the latter is younger, and most likely of the same age as the quartz–porphyry dikes found in the southern parts of the Ki ore body (se below).

UPPER HAUKI QUARTZITE GROUP

The extrusion of the Younger Porphyry was followed by the deposition of the Upper Hauki sediments (the Upper Hauki Quartzite Group). Phyllites make up the basal part of these sediments, overlain by a thick pile of quartzites. The frequent occurrence of conglomerate beds (up to 50 m thick) are a characteristic feature of these quartzites. The pebbles of the conglomerates consist almost exclusively of quartz-bearing porphyry. Material from the underlying Lower Hauki rocks are lacking or very rare, suggesting that the Lower Hauki Formation was more or less covered by the Younger Porphyry, when the period of denudation started.

LINA AND PERTHITE GRANITE SUITE

Deposition of the Upper Hauki Quartzites was followed by intrusions of granites, syenites and monzonites. The granophyric quartz-porphyry dikes in the southern part of the Ki ore body belong to this intrusive period. The same type of dike cross-cuts the Upper Hauki Quartzite at a road-cut 700 m NNE of lake Ala Lombolo. The largest of these dikes (thickness about 30 m) can be followed 2 km northwards to the hoisting shafts, where, at a depth of 600 m below ground-level, it has changed to a homogeneous, medium-grained granite.

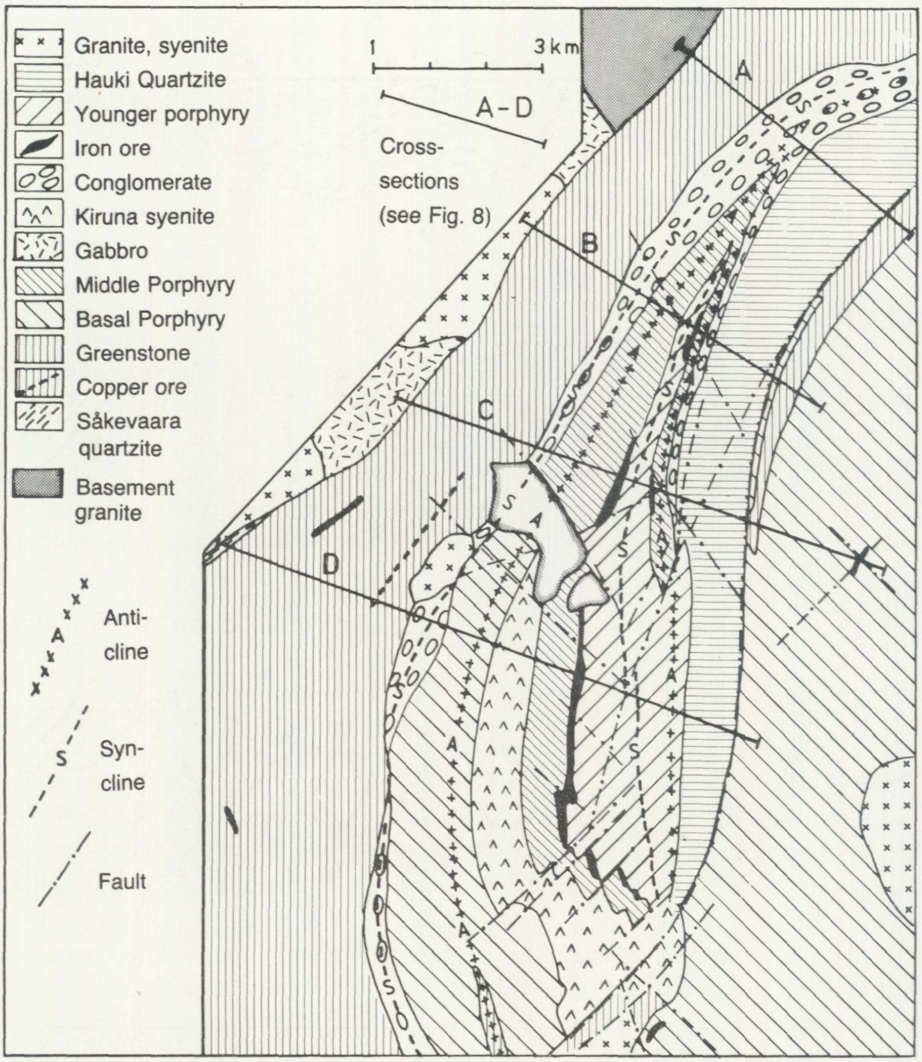

Fig. 7. Schematic tectonic map of the Kiruna area (cf. Fig. 1). The map is oriented N-S.

TECTONIC EVOLUTION

The disconformity between the Lu-Ki ores and their foot wall porphyries suggests that folding and denudation preceded the deposition of the apatite iron-ores. This tectonic episode may be connected with the emplacement of plutonic rocks belonging to the Haparanda suite. The gabbro to the northwest of Kiruna is a possible member of the latter.

The intense deformation demonstrated by the isoclinal folding of the green-

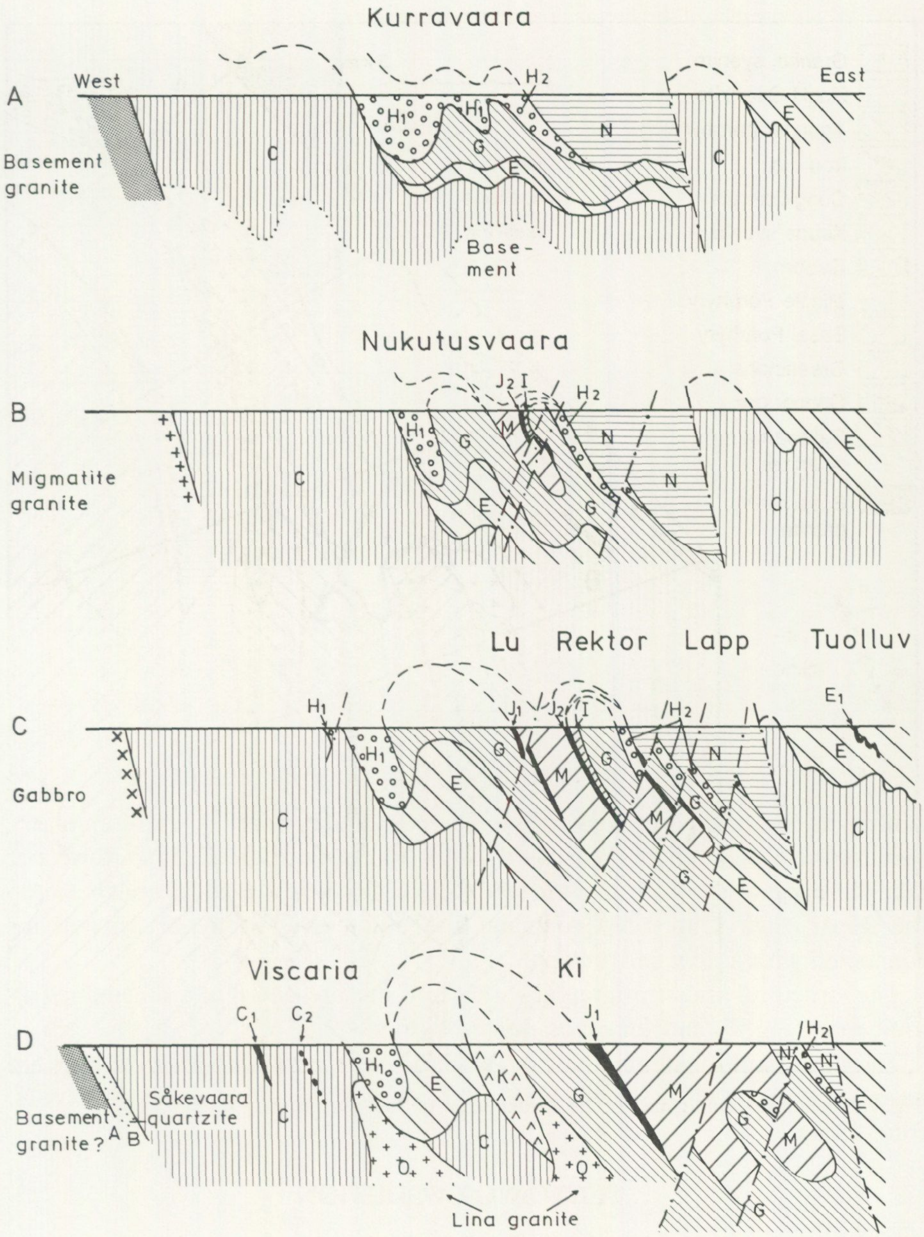

Fig. 8. Cross-sections of the Kiruna area (see Fig. 7). Legend, see Figs 4 and 6.

TABLE 5. Stratigraphy of the Precambrian of the Kiruna district.

Age Ga	Group	Stratigraphic units	Plutonic rocks	Hypabyssal rocks	Volcanic rocks	Exhalative-sedimentary deposites	Sedimentary rocks
1.8		Lina and Perthite Granite Suite	Granite, syenite	Quartz-porphyry (Ki)			
		Hauki Quartzite Group					Phyllite, quartzite, conglomerate
	Porphyry Group	Metabasite		Metabasite (Lu,Ki)			
	Porphyry Group	Younger Porphyry			Quartz-bearing porphyry, agglomerate (Ki, Lu)	Iron ore (Neptunus) Anhydrite	Conglomerate
	Porphyry Group	Porphyry dikes		Porphyry (Ki, Tuolluvaara)			
	Porphyry Group	Apatite iron ore			Tuff, pyroclastics (Ki Lu, Lower Hauki)	Iron ores (Ki, Lu) Per Geijer ores (Lower Hauki)	
	Porphyry Group	Quartz-banded iron ore				Quartz-banded iron ore (Lower Hauki)	
	Porphyry Group	Rektor Porphyry			Ignimbrite (Lower Hauki)		Tuffite (Lower Hauki)
	Porphyry Group	Kurravaara, Hauki Conglomerates					Conglomerate, graywacke
1.9	Porphyry Group – Older porphyries	Middle Porphyry	Kiruna syenite Gabbro?		Syenite-porphyry, tuff (Ki, Lu, Lower Hauki), agglomerate (Lower Hauki)	Magnetite-syenite-porphyry, ore-dikes (Ki, Lu, Nukutus), Hauki hematite (Lower Hauki)	Sericite quartzite (Lower Hauki)
	Porphyry Group – Older porphyries	Basal porphyry		Andesite-porphyry (Rakkuri)	Quartz-porphyry (Ki Tuolluvaara), syenite-porphyry, agglomerate (Ki, Lu), tuff (Rakkuri) Andesite-porphyry (Pahtavaara)	Iron ore (Tuolluvaara) Iron ore (Rakkuri)	Quartzite? (Rakkuri)
		Pahakurkkio Kilavaara Groups					Andalusite-schist (Hietavaara)
	Greenstone Group	Kiruna Greenstone		Basic and ultrabasic intrusives	Basaltic greenstone, pillow lava, agglomerate, tuff, albite-fels	Copper ore (Viscaria) Iron ore (Viscaria D-zone, Suolajoki, Pahtavaara)	Graphite-schist, limestone, dolomite
2.0	Greenstone Group	Tjärro quartzite					Quartzite (Såkovaara)
2.7		Basement Complex					

stones and the porphyries is thought to be a consequence of the diapiric emplacement of the Lina granites (Witschard 1980). The large dislocations southwest of lake Oinakkajärvi and north of the lake Rakkurijärvi, as well as the fault between the Upper Hauki Quartzite Group and the Tuolluvaara porphyries, are perhaps connected with a later movements.

The structural and stratigraphical relations are presented in a schematic tectonic map (Fig. 7) and four cross-sections (Fig. 8).

The stratigraphy is summarized in Table 5. The radiometric ages given here are based on Welin (1970), Skiöld (1981, 1982), Witschard (1984) and Wilson (pers. com. 1984).

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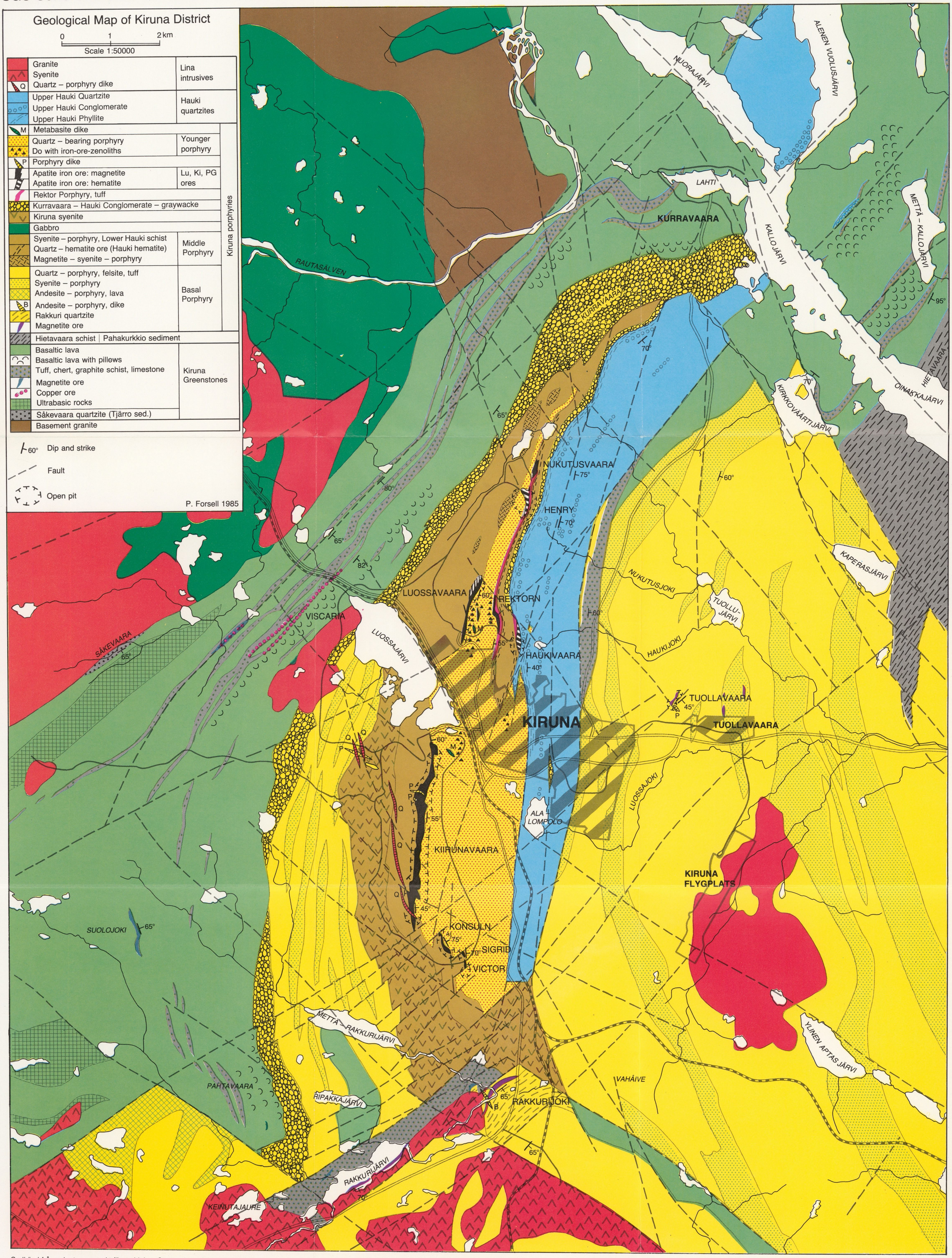

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