Early deformation in the Svecokarelian greenstone belt of the Kiruna iron district, northern Sweden

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The Proterozoic iron ores of the Kiruna district, northern Sweden, occur as discontinous lenses of magnetite and hematite up to 4 kilometers in length within a sequence of felsic porphyries. The association of low-grade felsic volcanics and sedimentary rocks with basaltic pillow lavas and granitic rocks shows a strong similarity to typical Archean greenstone belts. Primary younging indicators, bedding/cleavage relationships, and minor fold symmetries through the district suggest that the area occupies the eastern limb of a major antiform, cored by granitic rocks to the west. A steep regional cleavage, inhomogeneously developed through the district, suggests one major episode of compressional deformation. The cleavage and associated flattened clasts indicate a compression direction plunging 10°WNW. Elongate clasts, boudins, and fibrous veins indicate a strong extension plunging 60°SSE, parallel to fold hinge lines. Boudinage of the major ore bodies to produce their present distribution is compatible with the estimated strain of a single deformation. Diapirism is suggested as a likely explanation of the observed strain patterns. □ *Kiruna iron district, Svecokarelian, Proterozoic, greenstone belt, structure, tectonics, diapirism, boudinage, extension, northern Norrbotten, Lappland, N6745, N6757, E2035, E1957.*

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The Precambrian iron ores of the Kiruna district, Norrbotten County, northern Sweden, constitute the type example of an economically important class of iron deposit found worldwide (Geijer 1931*a*). The Kiruna deposits, predominantly composed of magnetite, occur as discontinuous sill-like bodies, up to 100 m by 4000 m in map view, within a thick sequence of volcanic porphyries. A number of geologic maps of the area have been prepared by several investigators, with the aid of abundant drill core data, mine exposures and rock outcrops (Offerberg 1967; Parák 1975*a*; Frietsch 1979; Paul Forsell, Kiruna, personal communication 1982). Additionally, extensive petrographic and geochemical work has been done on the ores and the associated volcanic rocks (e.g., Geijer 1931*b*; Parák 1975*a*; Frietsch 1980*a*). These studies have led to a basic controversy regarding the origin of the iron ores; one view holds them to be predominantly magmatic (Geijer 1931*b*; Geijer & Ödman 1974; Frietsch 1978), a second view regards them as mainly exhalative–sedimentary (Parák 1975*a*, 1975*b*; Forsell & Godin 1980). Structural studies within the Kiruna area have mainly focused on late stage faulting and joint development (Stephansson & Bäckblom 1978); little or no structural work has been done on minor structures associated with the early, mainly ductile stages of deformation within the district. Our intent here is to report the results of a study of the minor structures associated with the early deformation, and to relate these structures to the present form and distribution of the ore bodies and associated rocks of the Kiruna district.

There is a strong similarity between the regional geology of northern Norrbotten and large areas of Archean rocks in Canada, southern Africa and Australia, where belts of steeply inclined basic to felsic volcanic rocks and volcanically derived sediments ('greenstone belts') appear to be pinched in between intruding granitic bodies. Many recent studies (e.g. Stephansson 1975; Drury 1977) have indicated that diapirism plays a major role in the development of these belts, and model studies (e.g. Ramberg 1967; Dixon 1975) have suggested the types of structures and deformation patterns to be expected due to diapirism. It has been shown, however, that in many cases diapirism alone does not account for the observed deformation patterns. Diapirism is commonly preceded by recumbent fold formation, horizontal shortening and shear deformation (Coward 1976; Archibald et al.

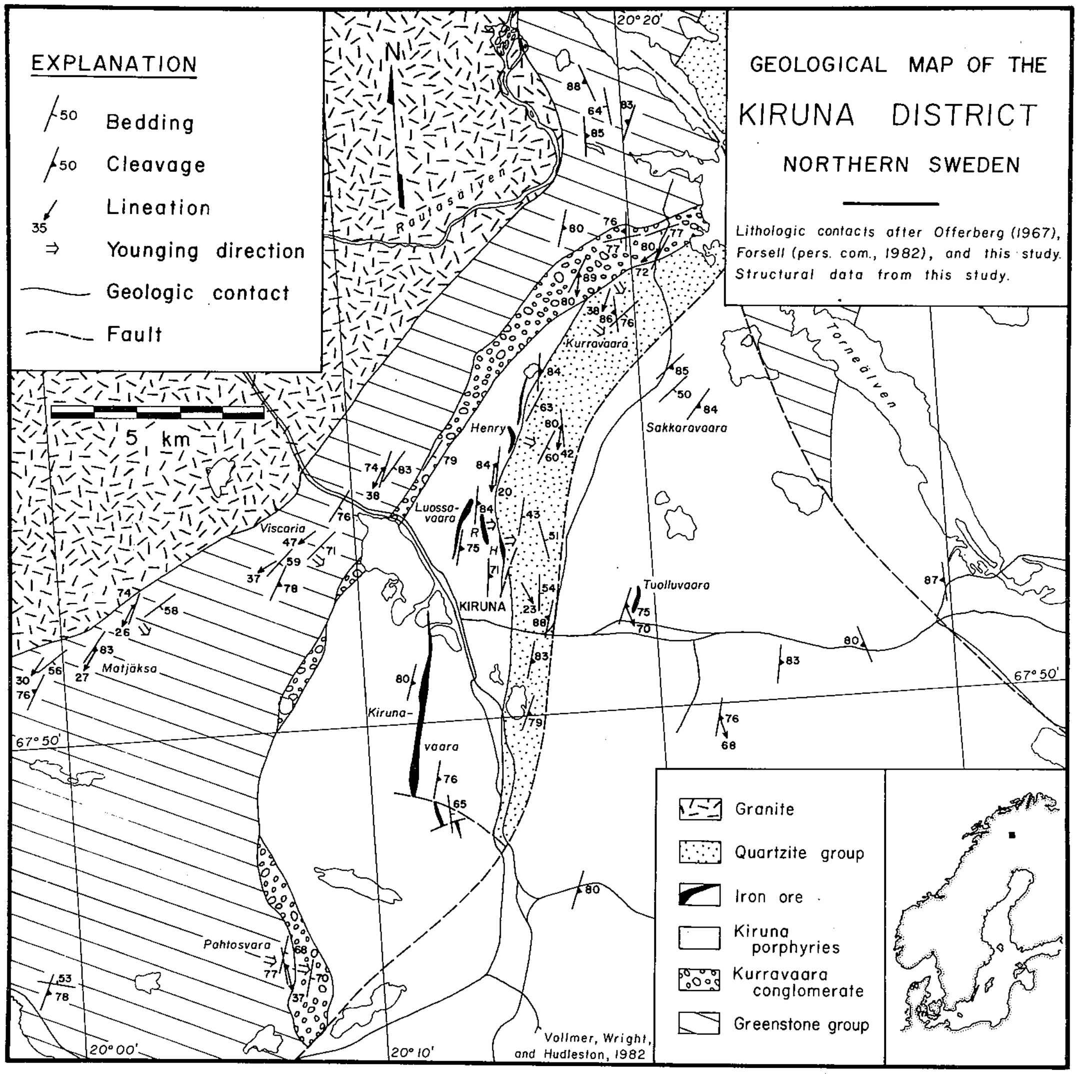

Fig. 1. Geological map of the Kiruna district, northern Sweden. R = Rektorn mine, H = Hauki mine.

1978; Borradaile 1982; DeWit 1982). The regional geology of the Kiruna area (Ödman 1957; Magnusson et al. 1960; Offerberg 1967) is strongly suggestive of diapir-induced deformation with steeply dipping belts of volcanogenic rocks intruded by, and wrapping around, younger plutons. Stephansson and Bäckblom (1978) have suggested that the present distribution of the Kiruna ore bodies may be due to mega-boudinage associated with diapirism. It is therefore of interest to examine the structures associated with these rocks to see if they are compatible with such a mode of origin, and to otherwise try and better constrain models of the deformational history.

The work on which this report is based is currently being continued by one of us (S.F.W.) to include detailed studies of strain and fabric, and to cover a broader area around Kiruna.

Geologic setting

The rocks of the northern part of Norrbotten County can be broadly subdivided into three main units: Archean (pre-Svecokarelian) gneissic basement; a Svecokarelian cover sequence of mafic to felsic volcanic and volcanogenic sedimentary rocks; and intrusive, mainly granitic, plutons. North of Kiruna granitoid gneisses have given U–Pb radiometric ages of about 2750 to 2800 Ma (Welin et al. 1971; Skiöld 1979). These gneisses can be traced southward into the Kiruna area where they appear to form the basement to the overlying volcano-sedimentary section (Offerberg 1967). The Svecokarelian section of the Kiruna area comprises four main lithologic units (Fig. 1). These units have been correlated through large areas of northern Sweden and Finland, with local variations (Eriksson & Hallgren 1975; Offerberg 1967; Lundqvist 1979; Frietsch 1980*b*). The lowermost unit in the Kiruna area is the Kiruna greenstone group. This group is dominated by layered volcanic rocks of spilitic type and pillowed lavas of basaltic composition. Locally peridotites and extrusive ultramafic rocks are found in association with this sequence (Eriksson & Hallgren 1975; Freitsch 1979). Sulfide-bearing graphitic schists, carbonates and small magnetite ore bodies are also found interlayered within the greenstones (Offerberg 1967; Parák 1975*a*). Possibly correlative mafic volcanic rocks in northern Finland have yielded U–Pb zircon ages of 2000 to 2200 Ma (Simonen 1980). The contact of the greenstone group with the underlying basement gneisses, although not well exposed in the Kiruna area, is locally marked by a quartzite–conglomerate unit containing granitic pebbles (Offerberg 1967; Eriksson & Hallgren 1975).

In the Kiruna area the greenstone group is overlain by the Kurravaara conglomerate. This conglomerate, which is up to 600 m thick, consists mainly of rounded felsic volcanic cobbles and pebbles, with occasional clasts of jasper and limestone. Overlying the Kurravaara conglomerate is the main ore-bearing sequence of alkali-rich volcanic porphyries, or keratophyres (Parák 1975*a*). The major magnetite ore bodies of Kirunavaara and Luossavaara lie at a compositional break in this sequence, between lower felsic porphyries and upper quartz-bearing porphyries. These porphyries have given a Rb–Sr whole rock isochron age of 1570 Ma (Welin et al. 1971; Welin 1979). However, correlative units south of Kiruna at Malmberget (1875 Ma, K–Ar; Welin et al. 1972), and in northwestern Finland (1855 Ma, zircon; Skiöld 1981) give much older dates. Skiöld (1981) has suggested that 1800 Ma represents a minimum age for the porphyry group.

A second group of ore bodies, the Per Geijer ores, are found above the quartz-bearing porphyries and below a thinner sequence of volcanic agglomerates and tuff of the Lower Hauki Series. A third ore type, the Hauki hematite, lies mainly within the upper portion of the Lower Hauki rocks (Parák 1975*a*; Geijer & Ödman 1974).

The final, uppermost, sequence consists of a sedimentary section of (from oldest): volcanogenic conglomerates and graywackes, phyllites, and a thick quartzite unit with local conglomerates. These rocks have been variously designated the Vakko Formation, the Upper Hauki Series and the Quartzite group (Frietsch 1979). On its upper side, the quartzite is fault-bounded against a thick section of felsic porphyries, thought to be equivalent to the main Kiruna porphyries (Fig. 1; Offerberg 1967; Paul Forsell, Kiruna, personal communication 1982).

Intrusive igneous rocks of northern Norrbotten have been considered as two main suites (Lundqvist 1979; Frietsch 1980*a*). The Haparanda suite of northeastern Sweden varies in composition from gabbro to granodiorite, and has given a Rb–Sr whole rock isochron age of 1840 Ma (Welin 1979). East of Kiruna, Eriksson and Hallgren (1975) have shown that granitic rocks of this type cut the greenstone unit, but are apparently overlain by quartzites equivalent to those of the Kiruna area. The second granite type, which predominates south of the Kiruna area, is the Lina-type granite. Whole rock isochrons on this granite type have given ages of 1780 and 1530 Ma (Rb–Sr; Welin 1979).

It should be noted here that the above stratigraphic scheme is not the only one proposed for the region (Forsell & Godin 1980; Paul Forsell, Kiruna, personal communication 1982). Forsell has proposed that the Kurravaara conglomerate unconformably overlies the porphyry group, and that the three ore horizons are equivalent and connected by folding. This interpretation will be discussed below.

Methods

Structural analysis of the Kiruna area was done mainly using standard techniques (e.g. Turner & Weiss 1963; Ramsay 1967). The maps of Offerberg (1967) and Parák (1975*a*) were used for outcrop, trench and mine pit locations. 1:20 000 photometric maps were also used for outcrop location and for plotting of data. Underground measurements were taken in the Luossavaara and Viscaria mines. At each outcrop the orientations of primary layering, cleavage and pebble flattening planes were measured. Additionally, linear structures including bedding–cleavage intersections, pebble stretching directions, mineral lineations, and extensional directions from fi-

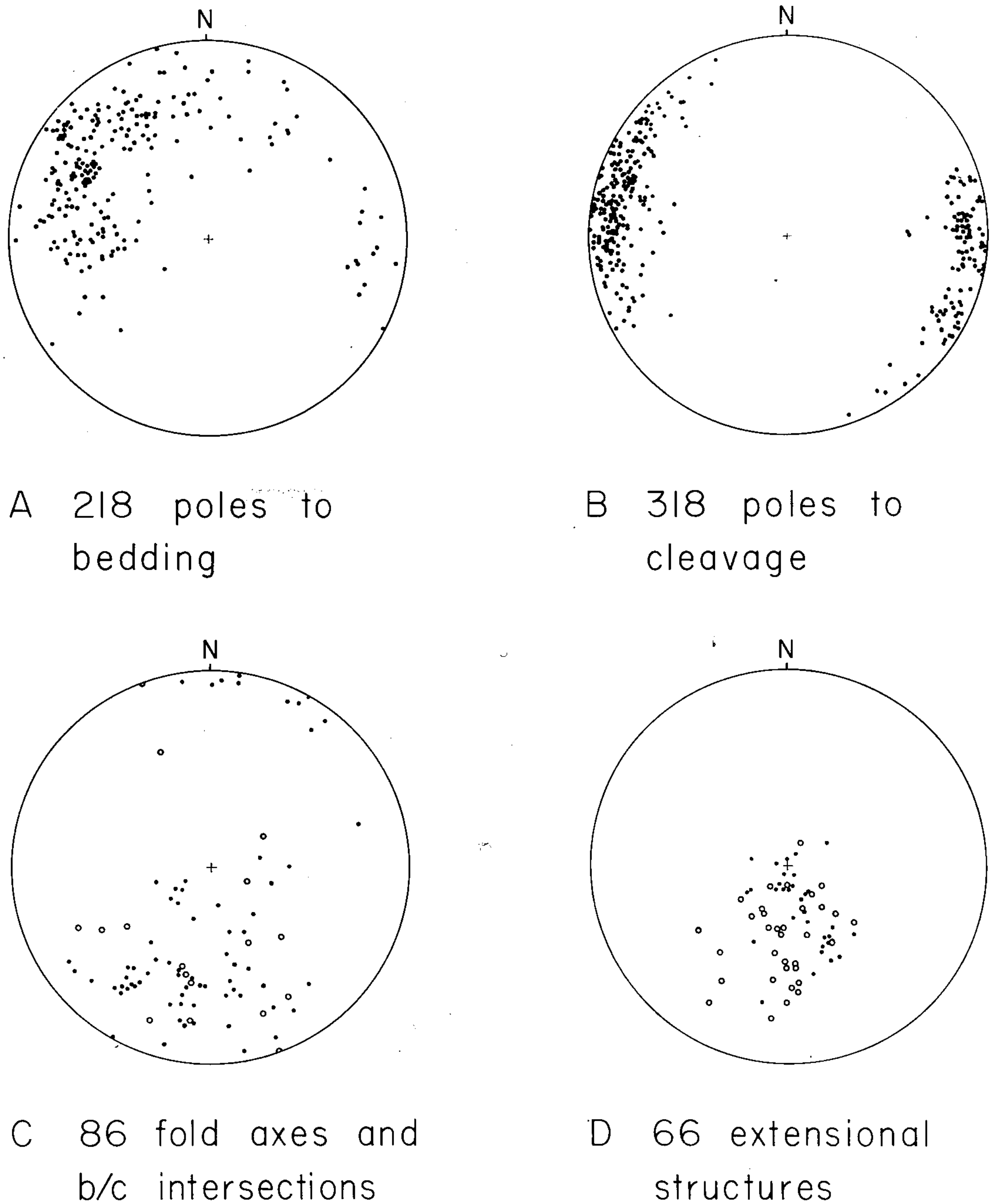

Fig. 2. Equal-area stereograms of structural data from the Kiruna district. C – open circles are fold axes, filled circles are bedding/cleavage intersections. D – open circles are fiber growth directions from vein fillings, filled circles are pebble long axes.

brous veins (Durney & Ramsay 1973) were measured. Bedding–cleavage intersections were calculated from stereographic projections where they could not be directly measured. Finally, the axes and axial surfaces of all observed minor folds were measured, and their vergences recorded. Oriented samples of various deformed conglomerates and porphyries were collected at 17 localities for later strain analysis (in preparation).

As magnetic disturbance is considerable over the region, the magnetic declination was frequently checked by taking bearings on known map locations. Wherever possible, and particularly near the magnetite ore bodies, near which declinations can vary by as much as 90° within less than a meter, strikes were taken with respect to known reference lines. The estimated accuracy of strike is ± 5°.

Results

Bedding and folds

Figure 1 is a summary map showing orientations of bedding, cleavage and linear structures measured in the field area. A lower hemisphere equal-area stereogram of poles to all bedding and primary layering orientations is given in Fig. 2A. Bedding, in general, dips 50° to 70° southeast. The main variation in the strike is related to the broad open flexuring visible from the map pattern (Fig. 1). The secondary variation in bedding orientations is due to the presence of a south-southwest plunging fold at Kurravaara (Fig. 3). This is the only area where large scale folding has been identified. Note the excellent agreement between the fold axis as determined by the poles to bedding, the hinge lines of minor folds, and bedding–cleavage intersections (Fig. 3). This suggests that cleavage formation, major folding and minor folding occurred contemporaneously. The folding at this locality, then, appears to be relatively uncomplicated with a single phase of south-southwest plunging cylindrical folds.

Other minor folds are quite rare throughout the area, although locally they are more common, for example, at the Viscaria and Rektorn mines. The axes of these minor folds are somewhat variable, but are generally parallel to those observed at Kurravaara (Fig. 2C). The symmetry of these folds, where observed, is in all cases of 'Z' sense viewed down plunge (Fig. 4). Also shown in Fig. 2C are bedding–cleavage intersections for the entire area. Again, these are somewhat more variable than at Kurravaara, but suggest a single phase of south-southwest plunging folds.

Cleavage

Cleavage and foliation measurements for the entire area are plotted in Fig. 2B. These measurements include planar schistosity, slaty cleavage, and pebble flattening fabrics. They show a well defined maximum, with cleavage dipping ap-

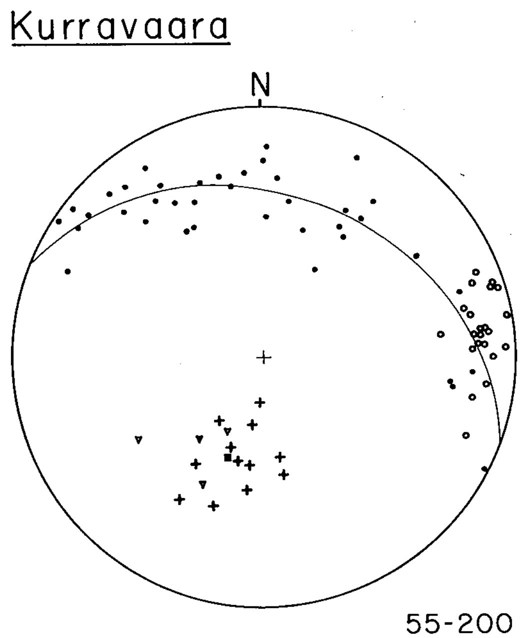

Fig. 3. Equal-area stereogram of structural data from Kurravaara area. Filled circles are poles to bedding, open circles are poles to cleavage, crosses are bedding/cleavage intersections, and triangles are minor fold axes. The square represents the major fold axis, 55° to 200°, as determined from the poles to bedding.

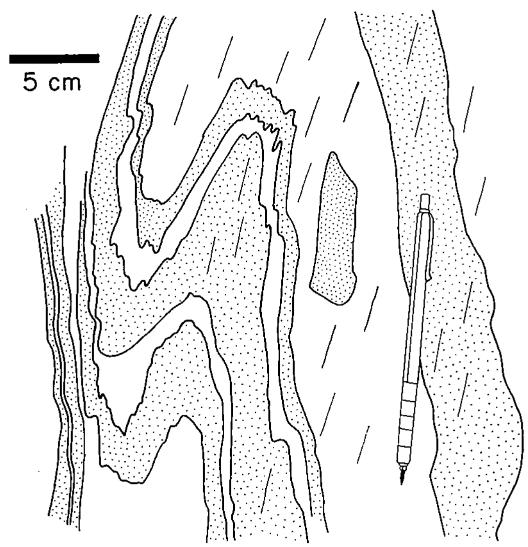

Fig. 4. Line drawing from photograph of asymmetric fold in vertical wall of Rektorn mine pit, south-west end. View is to north. Cleavage shown by light dash. Lithology is banded hematite-apatite ore.

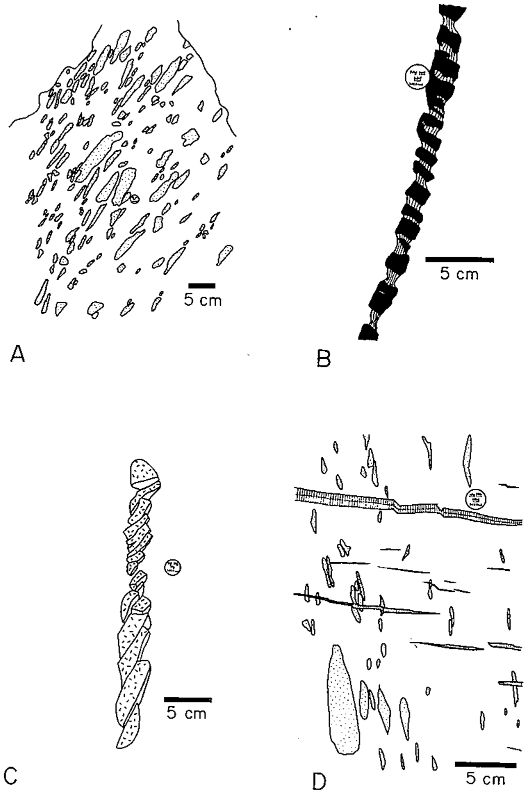

Fig. 5. Line drawings from photographs of extensional structures of the Kiruna district. A – elongate clasts in hematite-apatite ore breccia, Hauki pit. B – boudinaged magnetite vein with fibrous vein infilling, Luossavaara summit area. C – boudinaged and sheared cobbles in Kurravaara conglomerate, northwest of Kurravaara. D – elongate clasts with cross-cutting fibrous veins in hematite ore, Henry pit.

proximately 80° to the east-southeast. This is clearly steeper than average bedding dips (cf. Fig. 2A). More importantly, however, in every locality where primary layering and cleavage could be measured in the same outcrop, cleavage was always found to be steeper. Particular attention was paid to outcrops exposed in areas where folding has been suggested on the basis of possible repetition of the ore body units (Forsell & Godin 1980; Paul Forsell, Kiruna, personal communication 1982). However, the above relationship was found to hold in the vicinity of all three ore horizons. The tight clustering of poles to cleavage planes (Fig. 2B) again suggests a relatively simple deformation history, as the cleavage has not been affected by any later folding. Some departure from perfectly cylindrical folding, however, is shown by the relatively greater scatter in bedding/cleavage intersections (Fig. 2C).

Cleavage intensity is quite variable throughout the area, and is dependent on both lithology and structural position. In general a cleavage, or foliation, is best developed within the conglomerates, phyllites and apatite-rich iron ores (Per Geijer and Hauki types). The greenstones contain a weak cleavage which is often absent, and the porphyries are generally foliated only near their contacts with the magnetite ore bodies. Commonly, the rock type in actual contact with the magnetite bodies is a highly foliated chloritic schist. The Vakko quartzite unit generally only shows cleavage in rare shaly interbeds. No apparent planar fabric has been observed within the magnetite ore bodies.

Linear structures

Extensional structures were measured where possible; these included pebble elongation directions and extensional fibers (Fig. 5). Most of the fibers were measured within the ore bodies, or narrow offshoots of the ore, and occurred as fillings in extensional veins. As these fibers are not always perpendicular to vein walls, care was taken to measure only the extension direction indicated by the fibers. Extensional fibers were also found locally in pull-apart pebbles (Fig. 5), suggesting brittle failure of the pebbles subsequent to plastic deformation. As these directions are approximately parallel (Fig. 2D), it is suggested that the same deformation responsible for plastic deformation of the pebbles locally resulted in brittle failure of units whose fracture strength was exceeded. This included some of the more strongly deformed pebbles as well as the brittle iron ore bodies.

The elongation direction indicated by these features plunges approximately 60° to the south-southeast, and is essentially parallel to the fold axes and bedding-cleavage intersections (cf. Fig. 2C). In several outcrops mineral lineations defined by parallel amphibole laths were measured. These are basically parallel to fiber and pebble axis lineations, suggesting that metamorphism occurred coevally with deformation.

Late structures

Late structures within the Kiruna area include minor kink bands, joints and faults. Faults have been previously mapped through the area (Offerberg 1967; Parák 1975*a*; Frietsch 1979; Paul Forsell, Kiruna, personal communication 1982), and are only briefly mentioned here. Forsell has mapped three main sets of faults. Two sets, a northwesterly trending right lateral set and a northeasterly trending left lateral set, offset a number of the ore bodies. A third, northerly trending set locally causes repetition of major map units (Fig. 1). Joint and fracture sets in the Kirunavaara area have been described by Stephansson and Bäckblom (1978). Minor kink bands occur mainly within the phyllite unit, and may be associated with late faulting. Finally, a single quartzite outcrop north of Haukivaara shows anomalous northerly dips; we attribute this to late stage brittle kinking associated with faulting.

Discussion

Deformation

The orientation of the bulk ductile strain ellipsoid can be deduced from Figs. 2B and 2D. It has been shown that cleavage, in general, forms in the plane perpendicular to maximum shortening, that is the XY plane of the strain ellipsoid (e.g., Wood et al. 1976), although local deviations may be expected (Hobbs et al. 1982). In the Kiruna area cleavage planes and pebble flattening planes are roughly coincidental, so we may assume that the average cleavage pole (Fig. 2B) gives an indication of the major flattening direction, Z, approximately 10° to 280°. The elongation direction from Fig. 2D is approximately 60° to 185°, parallel to fold axes. This pattern of steeply plunging extension parallel to fold axes is common in Archean greenstone belts (e.g. Hudleston 1976; Borradaile 1982), although this does not necessarily reflect a common deformational history.

Preliminary measurements of deformed conglomerates suggest an ellipsoid axial ratio of approximately 4:2.5:1 as being representative of the strain in much of the area. There are, however, clearly important variations in amount of strain. Locally, elongation ratios of over 10:1 have been observed in limestone pebbles of the Kurravaara conglomerate. One of the most striking indications of strain heterogeneity is the development of a strong foliation in the porphyries near the contacts with the magnetite ore bodies, which themselves show little indication of strain. This suggests a high strain gradient between the two rock types, and is what would be expected if the magnetite bodies were stronger and had been subjected to boudinage (e.g. Stephansson & Berner 1971; Selkman 1978).

Stephansson and Bäckblom (1978) have in fact suggested boudinage to explain the present disposition of the ore bodies. If we assume that the two main ore bodies, Kirunavaara and Luossavaara, were originally connected and that internal deformation of the ores was minimal, we can calculate the horizontal strain component necessary to produce the present configuration by boudinage. The present outcrop length of the Kirunavaara ore body (after removing late fault displacements) is 5740 m; that of the Luossavaara ore body is 1720 m; and their present separation is 1240 m to as little as 740 m if late stage faulting accounts for some of the observed offset (calculated from Parák 1975*a* and Offerberg 1967). Taking the centers of the ore bodies as reference points this gives an elongation of from 20 % to 33 % in the horizontal plane. A strain ellipsoid with axial ratio of 4:2.5:1, and an X axis plunging 60° in a vertical cleavage, gives a horizontal elongation of 26 % if no volume change has occurred. Thus, by rough calculation boudinage of the ore bodies seems compatible with the observed bulk strain.

The effect of the strain on the present form and distribution of the ore bodies is also suggested by the Viscaria sulfide ore bodies. These are elongate with steep southerly plunges (Lisbeth Godin, Kiruna, personal communication 1982). It seems likely that their present form is also due to boudinage and ductile deformation in response to the observed strains.

Origin of the ores

Although this study was not conducted primarily to investigate the origin of the ores, several observed structural features are worthy of note. Of particular importance is the ore breccia that occurs at the ore body contacts. The breccias on the western, or footwall, contact of the Kirunavaara ore body, and especially at the Tuolluvaara ore body, show strong evidence for the intrusive nature of the magnetite ore. In these areas veins of magnetite intrude and brecciate the wall rock. At the present summit of Kirunavaara a transition from magnetite veined porphyries to angular breccias can be observed. Farther into the pit, on the upper footwall, the clasts in these breccias become somewhat better rounded as the magnetite content increases. Locally, porphyry blocks occur floating within the magnetite ore. As these breccias are directly related to the ore bodies, it seems difficult to accept a sedimentary origin for these ores. Similar breccias, suggesting forceful intrusion of the ores, also occur at the Rektorn and Hauki mines. Certain aspects of these latter ore bodies make them somewhat more enigmatic than the Kirunavaara-type ores, but it again appears difficult to postulate an entirely sedimentary origin for these ores (see Parák 1975*a*, 1975*b*; Geijer & Ödman 1974; Frietsch 1978 for a more complete discussion).

A number of studies have suggested that liquid immiscibility fields exist under certain conditions in Fe-rich silicate melts, thus giving some theoretical credence for the formation of magnetite–apatite magmas (e.g. Philpotts 1967; Roedder 1980). Lundberg and Smellie (1979) have shown field relationships indicative of liquid immiscibility in Kiruna-type magnetite ores southwest of Kiruna, and suggest this mechanism provides an explanation for the magnetite ores.

Regional structure

No evidence has been found for any major departure from the stratigraphy of the area as outlined by Offerberg (1967). Careful mapping of primary layering throughout the area has not disclosed any evidence for angular unconformities. Parák (1971) reported a 30° angular unconformity between the greenstone unit and the Kurravaara conglomerate south of the field area. This outcrop shows pebbles of the Kurravaara conglomerate elongated at 30° to the contact with the greenstone; this is a *tectonic* elongation parallel to cleavage and not an angular unconformity. Forsell (Forsell & Godin 1980; Paul Forsell, Kiruna, personal communication 1982) has suggested that the Kurravaara conglomerate lies unconformably above the porphyries, based mainly on the predominance of felsic volcanic clasts. Ödman (1957) also believed the conglomerate to be younger than the porphyries for similar reasons. If this were true, it would seem remarkably fortuitous for the outcrop of conglomerate to be restricted to covering the contact between the greenstone and the porphyries. Geijer (1931*b*), Offerberg (1967), Eriksson & Hallgren (1975), and Frietsch (1979) have also discussed the age relationships between the conglomerate and the porphyries and concluded that there is not sufficient evidence to suggest that the pebbles were derived from the porphyries. Field relations indicate that the local volcanic stratigraphy is extremely variable. We thus concur with these authors and prefer to ascribe the complexity to the volcanic history rather than to the structural history.

The possible regional significance of the sub-quartzite nonconformity reported by Eriksson and Hallgren (1975) remains unclear. The 'angular unconformity' reported by Frietsch (1979) at this stratigraphic position is a minor discordance of cleavage to the contact, not of bedding.

Bedding–cleavage relationships and fold symmetries throughout the area consistently show that the entire sequence forms the western limb of a major synform. That is, cleavage is consistently steeper than the eastern bedding dips, and fold symmetries are all of 'Z' form. Additionally, all facing indicators found show eastward younging (Fig. 1). The only major folding within the area occurs in the quartzite of the Kurravaara area. Repetition of the ore bodies through folding (e.g. Forsell & Godin 1980) is not supported by structural data. Such repetition would require the Rektorn ore body to be on the opposite fold limb from the Luossavaara or Haukivaara ore bodies; however fold symmetries and bedding–cleavage relationships (Fig. 4) suggest that this ore body is on the same limb. It would nonetheless be geometrically possible for the ore bodies to be a single unit repeated as a result of an *early* phase of isoclinal folding. However, there is no other evidence of an earlier deformation, and the different ore horizons and wall rock lithologies seem quite distinctive (Geijer 1931*b*; Parák 1975*a*, 1975*b*; Frietsch 1978, 1979). We feel that the interpretation of the rocks as a non-repeated homoclinal sequence fits the data best.

The regional extent of the folding in this area is not known; the other limbs of the adjacent regional anticline and syncline have not been located. Offerberg (1967) shows a single locality east of the present field area with westerly younging. These outcrops, however, consist of amphibolite gneisses and we do not think it possible to distinguish primary layering from tectonic layering in these outcrops. A summary cross-section is presented in Fig. 6.

Tectonics

To the west, the anticlinal structure is cored by granitic basement gneisses, and intrusive igneous rocks, possibly including several age suites. Granitic igneous rocks locally cross-cut the layered rocks above the basement (Offerberg 1967; Eriksson & Hallgren 1975) and drilling has penetrated a granitic offshoot that penetrates the porphyry group (Paul Forsell, Kiruna, personal communication 1982). The main granite body shows no foliation at the three localities examined by us. Several smaller bodies mapped by Offerberg (1967) as equivalent granites, are gneissic and show south-southeast plunging amphibole lineations. These smaller bodies were

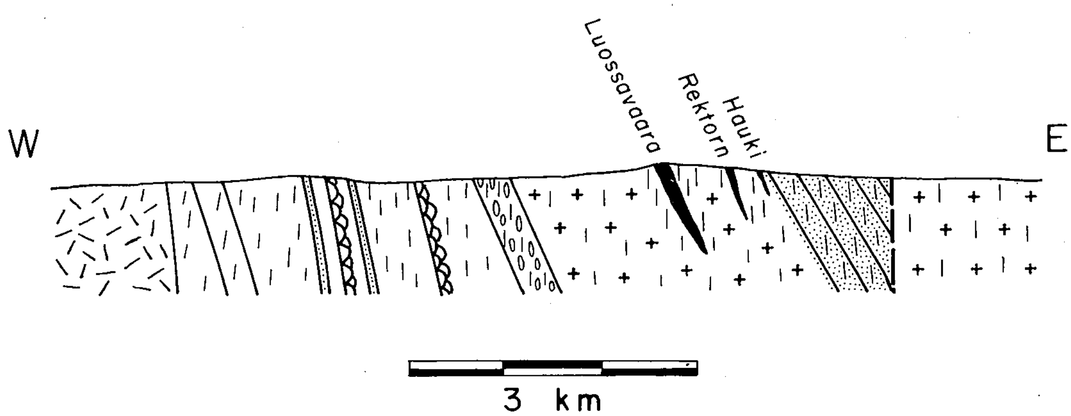

Fig. 6. Cross section through the Kiruna district showing principal stratigraphic and structural relations. From west to east are: granite (random hachure), greenstone with pillow lavas and minor sedimentary rocks, Kurravaara conglomerate, Kiruna porphyries (crosses) with iron ore bodies (black), and the quartzite group sedimentary rocks (stipple). Cleavage is indicated by light dash.

apparently involved in the same deformation as the volcano-sedimentary pile; their age relationship to the main granite, however, is unclear.

Several possibilities exist for the relationship of granite emplacement to deformation of the volcano-sedimentary rocks. Deformation could have occurred mainly prior to intrusion of the granite, which would thus show little or no deformation; it could have occurred after granite intrusion with the granite much more resistant to deformation than the host rocks; or it could have resulted from diapirism of the granite. However, in view of the outcrop pattern, which suggests pinching and folding of the volcano-sedimentary sequence around and between plutons, the possibility of non-involvement seems unlikely. In the Kiruna area the main granitic pluton forms the anticlinal core of the major structure, suggesting association of the pluton with deformation. Model studies of the effect of diapirism on overlying strata by Ramberg (1967) and Dixon (1975), for example, show many of the features noted in the Kiruna district. The models of Dixon predict several important features relevant to the present study. Trajectories of maximum compressional strain within the cover sequence commonly plunge gently toward the pluton, while trajectories of a maximum extension tend to plunge steeply. Strains within a stiffer diapir are generally much lower than within the cover sequence. These features, in general, correlate well with the structures observed in the Kiruna area. We tentatively suggest, then, that the ductile deformation observed within this area is due to a single deformation event associated with diapiric intrusion. A more rigorous assessment of the tectonic history of the region will be attempted following a quantitative study of strain in the rock.

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