Geological Survey of Finland

Bulletin 364

Proterozoic lithostratigraphy and sedimentation of Sariola and Jatuli-type rocks in the Nunnanlahti – Koli – Kaltimo area, eastern Finland; implications for regional basin evolution models

by Jarmo Kohonen and Jukka Marmo

Geologian tutkimuskeskus
Espoo 1992

Geological Survey of Finland, Bulletin 364

PROTEROZOIC LITHOSTRATIGRAPHY AND SEDIMENTATION OF SARIOLA AND JATULI-TYPE ROCKS IN THE NUNNANLAHTI – KOLI – KALTIMO AREA, EASTERN FINLAND; IMPLICATIONS FOR REGIONAL BASIN EVOLUTION MODELS

by

JARMO KOHONEN and JUKKA MARMO

with 39 figures, 8 tables and 2 appendices

GEOLOGIAN TUTKIMUSKESKUS
ESPOO 1992

Vammala 1992, Vammalan Kirjapaino Oy

Kohonen, J. and Marmo, J., 1992. Proterozoic lithostratigraphy and sedimentation of Sariola and Jatuli-type rocks in the Nunnanlahti-Koli-Kaltimo area, eastern Finland; implications for regional basin evolution models. *Geological Survey of Finland, Bulletin 364,* 67 pages, 39 figures, 8 tables and 2 appendices.

The Early Proterozoic supracrustal rocks of the northeastern part of the North Karelia Schist Belt have been classified lithostratigraphically into the Kyykkä Group and the overlying Herajärvi Group. These formations constitute the lowermost part of the Karelian sequence and were deposited nonconformably upon the Archean basement complex. The age of the studied sequence can be bracketed between 2.5 Ga and 2.0 Ga.

The Ilvesvaara, Urkkavaara and Hattusaari formations comprise the Kyykkä Group (maximum thickness 400 m). These arkoses, conglomerates and minor argillites were deposited during a period of glaciation and their preservation appears to be restricted to penecontemporaneous rift basins. Both the detritus and the chemical composition of the metasediments suggest a source area consisting dominantly of Archean felsic plutonic rocks.

The Herajärvi Group (maximum thickness 2500 m) consists of four formations. Three formations (Vesivaara Fm., Koli Fm. and Puso Fm.) are dominantly quartzitic in nature, but the arkosic Jero Formation between these indicates alluvial deposition and represents a rift phase interrupting platform-style sedimentation. The Jero Formation is both stratigraphically and spatially related to mafic intrusions of the karjalite-type.

The Kyykkä and Herajärvi Groups are separated by the quartz-sericite schist of the Hokkalampi Paleosol. The paleosol grades from its parent rocks through zones of increasing chemical alteration, and the profiles show enrichment of aluminium toward the top. Field relations, mineral compositions and chemical data indicate that the regolith was the source for the lowermost formations of the Herajärvi Group.

The sedimentation in the studied system took place dominantly in a cratonic fluvial environment, and, according to paleocurrent data, the direction of the basin axis was nearly parallel to the main strike (NW-SE) of the mafic dykes ('Jatulian diabases') intruding the sequence. The supracrustal sequence indicates phases of rifting alternating with periods of intermittent stability. In spite of later compressional deformation, the geometry of the basement-cover interface in the study area still retains features inherited from early extensional block movements.

The lithostratigraphic correlation presented is based on extraordinary associations: glaciogenic deposits, paleosol with aluminous quartzites and arkosic conglomerates spatially associated with karjalitic (gabbro-wehrlite) mafic intrusions. The Kurkikylä-Siikavaara area in the northeastern part of the Kainuu Schist belt is lithostratigraphically similar to the study area, while correlation to the nearby Kiihtelysvaara-Värtsilä area in North Karelia is not straightforward. Consequently, these adjacent parts of the North Karelia Schist Belt seem to have had partly independent histories of uplift-subsidence and basin development in the course of repeated block movements related to early stages of continental margin development.

Key words (GeoRef Thesaurus, AGI): metasedimentary rocks, lithostratigraphy, chemical composition, paleosedimentology, deposition, provenance, tectonics, mineral deposits, genesis, Proterozoic, Koli, Kaltimo, Nunnanlahti, Finland

The authors's adress:
Geological Survey of Finland
Betonimiehenkuja 4
SF-02150 Espoo
Finland

CONTENTS

INTRODUCTION

The paper is based on almost ten years of field work. Initial investigations (GSF, 1979—1984) focussed on aluminosilicate reserves in the Hokkalampi area, followed by an evaluation of paleoplacer gold potential of the entire study area (GSF, 1984—1987), and concluding with a joint GSF and University of Oulu project examining the regional geology and ore potential of the North Karelia region (1985—1989). Much of the data have already been published elsewhere but in this paper we summarize the results of sedimentological studies, present additional chemical data and redefine the formal lithostratigraphic units. A short summary of the economic potential of the area is also included. Finally, ideas concerning tectonics and basin models developed during the work are discussed.

The Nunnanlahti-Koli-Kaltimo area is located in the north-eastern part of the North Karelia Schist Belt (Fig. 1). The supracrustal rocks studied represent part of the early Proterozoic (Karelian) cover of the Archean basement complex. The age of the rock units discussed herein can be bracketed between 2600 Ma and 2000 Ma, which are the U-Pb ages for the Late Archean basement granitoids and the mafic intrusions underlying and intruding these Early Proterozoic sedimentary rocks, respectively (cf. Simonen, 1980; Gaál and Gorbatchev, 1987).

Field work was mainly carried out by detailed mapping along selected profiles through the sedimentary sequences; the profiles were chosen in order to represent sequences that were as complete as possible. The environmental interpretations presented in this paper are based on determinations of lithofacies associations published in earlier papers (Kohonen, 1987; Marmo et al. 1988).

Although all rocks in the study area have been metamorphosed, the classification used in this paper are based on well-preserved primary depositional features. Because of this, and the lack of a well-established terminology for metamorphosed sedimentary rocks, we feel justified in using »mixed» sedimentary and metamorphic rocknames, thus avoiding both the misleading term 'sandstone' for a recrystallized orthoquartzite and the repeated use of the prefix meta.

REGIONAL GEOLOGY AND REVIEW OF STRATIGRAPHIC NOMENCLATURE

The Karelian sequences in eastern Finland were deposited on an Archean basement consisting of more or less gneissose granitoids, so-called basement gneisses, and small supracrustal remnants ('greenstone belts'). The basement gneisses typically comprise granodiorites, tonalites and granites, but migmatites, veined paragneisses, mafic inclusions, pegmatites and abundant leucogranite veins make these terrains heterogenous (e.g. Nykänen, 1971; Pekkarinen, 1979). The greenstone belts are also variable in composition, and the relative proportions of volcanic, both

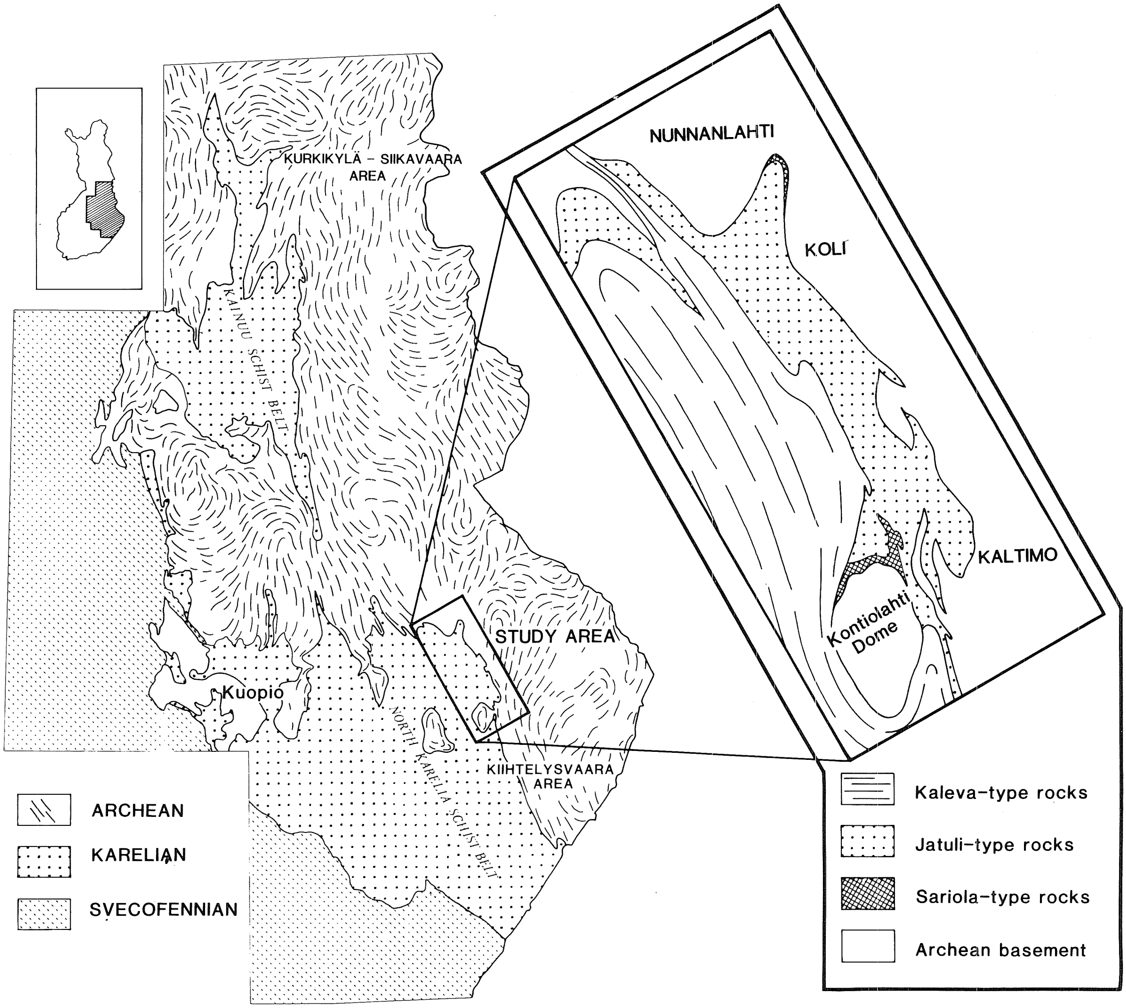

Fig. 1. The principal geological units of eastern Finland (modified from Luukkonen and Lukkarinen, 1985) and location of the study area.

mafic and felsic, and epiclastic rocks differ greatly from belt to belt. Apart from the extensive region to the east of the study area, the basement complex is exposed within the study area as isolated domes and narrow zones within the Early Proterozoic rocks (Fig. 1).

The lower part of the Proterozoic sequence comprises conglomerate, quartzite and arkosite (»Sariola» and »Jatuli»). These cover rocks were deformed against the basement complex during the Svecofennian Orogeny (2.0 — 1.8 Ga) and now generally dip moderately (20° — 50°) to WSW. However, the rocks are imbricated rather than folded and cross-bedding invariably indicates normal younging away from the basement. Despite the greenschist facies regional metamorphism, the primary sedimentary features are generally well preserved.

The western part of the North Karelia Schist Belt consists of interbedded metagraywackes and metapelites traditionally called »Kaleva» or »Kalevian». The contact relations of the Jatuli-and Kaleva-type rocks has been a matter of controversy and interpreted as thrusted (Frosterus and Wilkman, 1920; Gaál, 1964), gradational (Piirainen, 1968), erosional (Väyrynen, 1933; Piirainen et al., 1974; Pekkarinen, 1979) and normally faulted and reactivated (Kohonen et al., 1990).

The Sariola and Jatuli rocks are cut by numerous mafic sheets and intrusions, which seem to be absent from the Kaleva association. Intrusions have been divided into two associations: karjalites (Vuollo and Piirainen, 1992; spilites of Piirainen, 1968, 1969; gabbro-wehrlites of Hanski, 1982, 1984) and tholeiites (Piirainen, 1968, 1969) with ages about 2.2 Ga and 2.1 — 1.97 Ga, respectively (Vuollo et al., 1992).

The stratigraphic nomenclature of Karelian formations has been subjected to much revision over the years (see reviews by Laajoki, 1986 and Simonen, 1986), which has led to confusion regarding the basic concepts involved. Following initial investigations by Eskola (1919) and Väyrynen (1933, 1939, 1954) Jatuli and Kaleva became the main Karelian stratigraphic units, commonly with further subdivision of the former into Sariola, Kainuu and marine Jatuli associations. This framework was adapted for decades as a norm to classify nearly every rock deposited or extruded on the Archaean basement, especially in eastern Finland (e.g. Simonen, 1955, 1980 and Meriläinen, 1980). The cornerstone of this stratigraphy has been the use of the so-called Jatuli-type (or Kainuu-type) quartzites as a key horizon for correlation over wide areas.

However, with the increasing emphasis on depositional systems in stratigraphic mapping it has became obvious that accurate and meaningful correlations demand a formal lithostratigraphical nomenclature based on type areas and sections (cf. Laajoki, 1988a). Moreover, the poorly defined traditional terms (Sariola, Sumi-Sariola, Kainuu, Jatuli, Ladoga, Kaleva etc.) have been variously used to name sedimentary facies, chronostratigraphic units and lithostratigraphic groups. It seems to us that in order to avoid further confusion, the use of these traditional terms should be restricted to broad, informal discussions or rendered as terms for tectofacies as suggested by Laajoki (1988a, 1988b).

The formations discussed in this paper have been defined in Marmo and Ojakangas (1983, 1984), Marmo (1986), Kohonen (1987) and Marmo et al. (1988). Marmo et al. (1988) still adopted the traditional Sariola and Jatuli as group names. However, in this paper these units are renamed the Kyykkä Group and the Herajärvi Group, respectively. The type sections (or reference exposures) for every formation are defined and their locations are presented in Appendix 1.

LITHOSTRATIGRAPHIC UNITS AND ROCK DESCRIPTIONS

Kyykkä Group

Field relations show that the Kyykkä Group was deposited directly on the Archean basement. The upper contact of the group is gradational into the Hokkalampi Paleosol, which, in turn is overlain by the lowermost quartzites of the Herajärvi Group. Thus, the Kyykkä Group forms the lowermost Proterozoic unit in the study area. It is relatively well exposed in an area covering nearly 100 km², north of the Kontiolahti basement dome (Figs. 2 and 3). The Kyykkä Group has been named after a village and farmhouse which served for several summers as our fieldbase.

The total measured thickness of the group is about 400 m, although there is some uncertainty

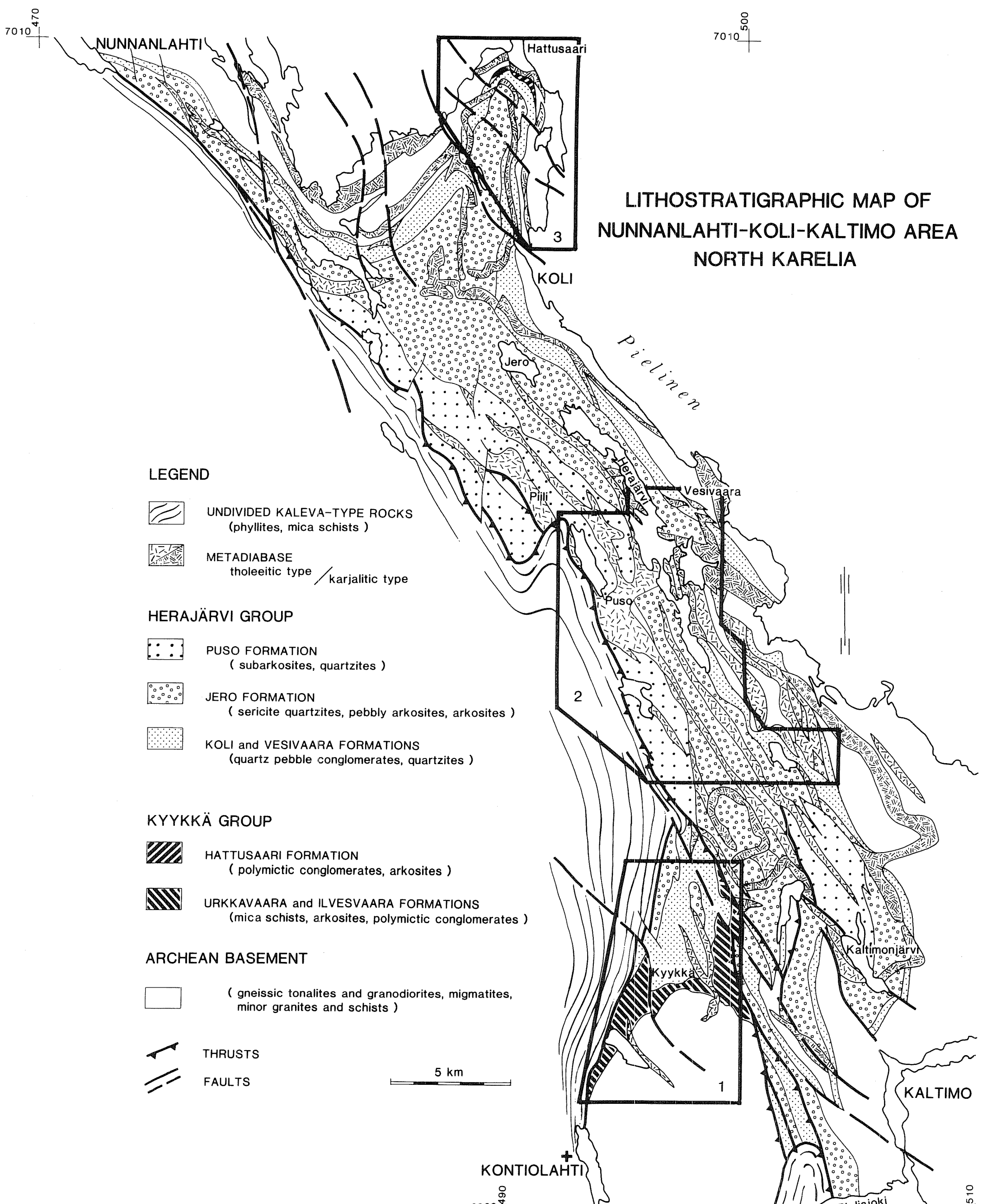

Fig. 2. Lithostratigraphic map of the Nunnanlahti-Koli-Kaltimo area in the northeastern part of the North Karelia Schist Belt. Locations of more detailed maps of the type areas are indicated: 1 = Kyykkä (Fig. 3), 2 = Herajärvi (Fig. 18) and 3 = Hattusaari S (Fig. 14). Symbol for Koli and Vesivaara Formations also includes the Hokkalampi Paleosol.

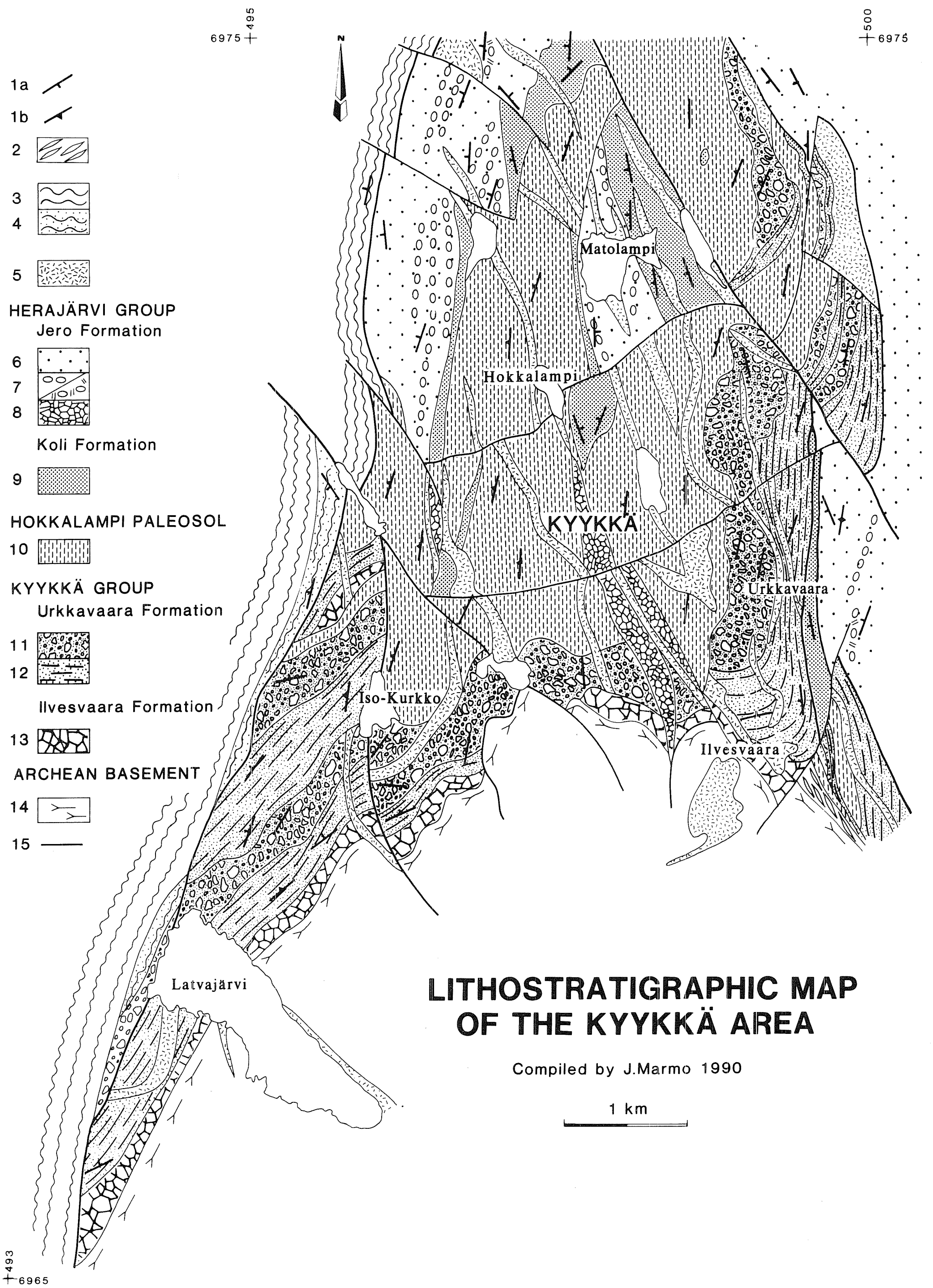

Fig. 3. Lithostratigraphic map of the Kyykkä area. 1 = strike and dip of bedding (a) and schistosity (b); 2 = mylonite; 3 = mica schist; 4 = interbeds of arkosite and mica schist; 5 = metadiabase; 6 = arkosite; 7 = quartz/quartz-feldspar pebble conglomerate; 8 = quartzite block breccia-conglomerate; 9 = quartzite; 10 = quartz-sericite schist; 11 = polymictic conglomerate; 12 = arkosite and micaschist; 13 = conglomerate; 14 = porphyritic granodiorite; 15 = fault.

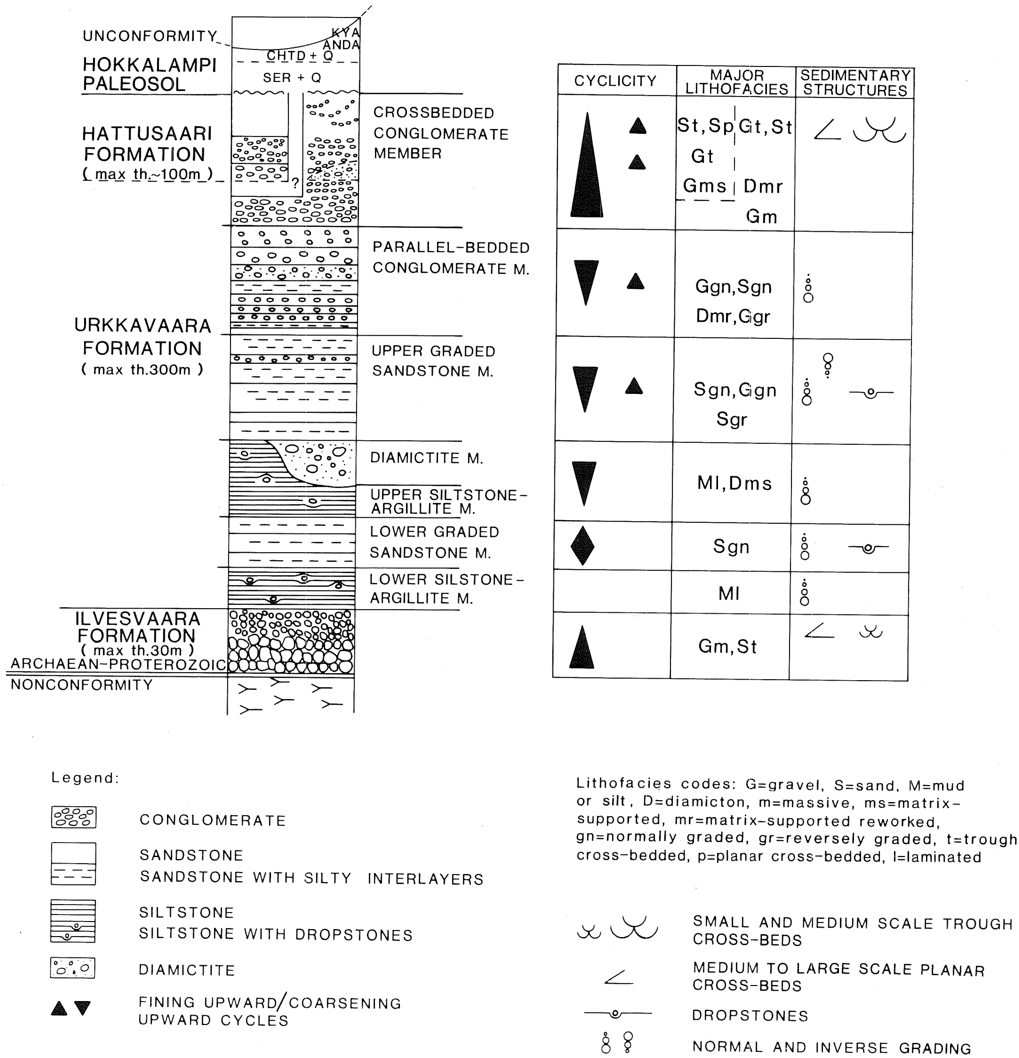

Fig. 4. Column illustrating the formations and members within the Kyykkä Group. Respective depositional cycles, major lithofacies associations and sedimentary structures are also shown. KYA — kyanite, ANDA — andalusite, CHTD — chloritoid, Q — quartz, SER — sericite.

due to complex block faulting and the gradational upper contact. Two formations have been distinguished: the Ilvesvaara Formation and the Urkkavaara Formation. In addition, the Hattusaari Formation in the northern part of the study area has been correlated with the group (Fig. 4).

Ilvesvaara Formation

The formation takes its name from the hill Ilvesvaara, on the northeastern edge of the Kontiolahti dome, where the type locality is exposed as a sequence of conglomerate and arkosite. The base of the formation is generally sharp, but commonly shows gradational features, as the con-

Fig. 5. Fine, silty material filling the spaces between large, angular granitoid blocks in the basal part of the Ilvesvaara Formation. Scale is 5.5 cm in diameter. Hirvitarha, Latvajärvi SW, Kontiolahti.

glomerate resembles mechanically disintegrated basement rock, with arkosic sand or silty material filling the cavities and joints between the big, angular granitoid fragments (Fig. 5). Unfortunately, the Ilvesvaara Formation is poorly exposed and consists of only two groups of solitary outcrops at its type locality and at the western contact of the dome. The maximum thickness of the formation has been estimated as less than 30 meters.

The Ilvesvaara Formation consists of immature and massive arkosite and conglomerate (Fig. 6) which have a mineralogy very similar to that of the underlying local basement granodiorite and tonalite. They are composed of quartz, potassium feldspar, plagioclase, biotite and sericite with minor amounts of carbonate and accessory minerals (Table 1 and Fig. 7). The original outlines of subangular to angular sand-sized grains are generally visible. Conglomerate clear-

Fig. 6. Massive, poorly sorted conglomerate of the Ilvesvaara Formation. Length of the compass is 12 cm. Hirvitarha, Latvajärvi SW, Kontiolahti.

Table 1. Mineral composition of the metasediments in the Kyykkä Group. Determined by point-counting method.

	1	2	3	4	5	6	7	8	9
Quartz	63.8	60.1	48.8	64.2	51.8	56.6	61.4	51.8	47.2
Feldspars		21.7		14.6				23.0	24.8
Plagioclase	4.0		14.1		8.8	13.6	5.8		
K-feldspar	16.2		20.0		22.6	16.0	14.4		
Biotite	11.0	3.2	8.5	0.4	—	13.4	18.4	7.0	9.2
Sericite	5.0	11.7	8.6	20.8	16.8	—		17.2	18.0
Chlorite	*	*	*	*	*	*	*	*	*
Carbonate	—	3.3	—	—	—	—	—	1.0	0.8
Accessories	—	—	—	—	—	0.4	—	—	—

*) included in biotite

1. Matrix of conglomerate; JSM-81-182; Ilvesvaara Fm.
2. — » — OTR-82-84.11; Urkkavaara Fm., cross-bedded conglomerate mb.
3. — » — JJK-81-43; — » — cross-bedded conglomerate mb.
4. — » — JSM-81-234; — » — parallel-bedded conglomerate mb.
5. Arkosite; JSM-84-10; — » — upper graded sandstone mb.
6. — » — JSM-81-194; — » — lower graded sandstone mb.
7. Metasiltstone; JSM-81-191; — » — lower siltstone-argillite mb.
8. Matrix of conglomerate; JJK-82-76; — » — diamictite mb.
9. — » — JSM-81-194; — » — diamictite mb.

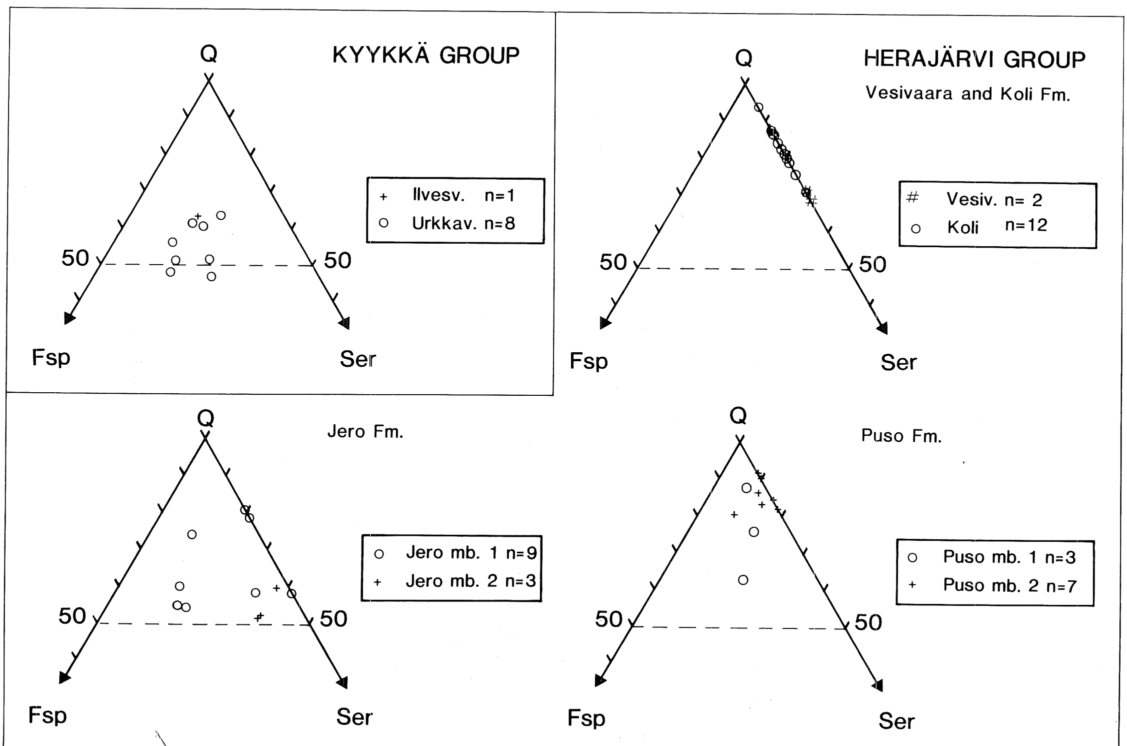

Fig. 7. Quartz (Q) — feldspars (Fsp) — sericite (Ser) plot for the metasediments of the studied formations. Minor biotite, chlorite and kaolinite are included with Ser.

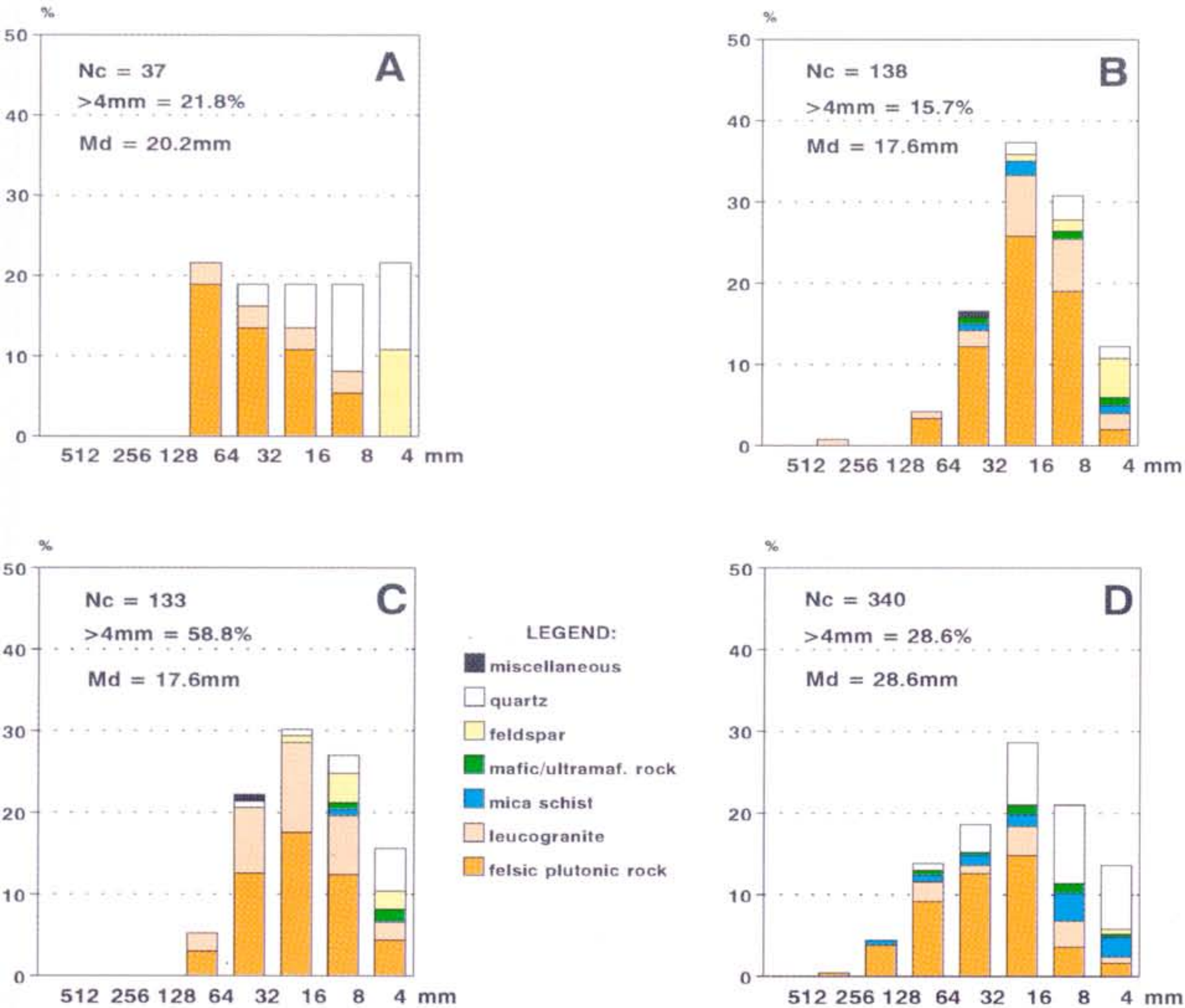

Fig. 8. Composition and size variation of fragments in conglomerates of the Kyykkä Group. The percentage of fragments (clasts larger than 4 mm) was determined by measuring along a line. Nc = number of fragments counted, Md = median size of fragments in millimeters. A. Basal part of Ilvesvaara Formation, Pesinpyttylampi, Ilvesvaara, Kontiolahti; B. Diamictite member of Urkkavaara Formation, Kyykkä, Kontiolahti; C. Lower part of cross-bedded conglomerate member of Urkkavaara Formation, Kyykkä, Kontiolahti; D. Upper part of cross-bedded conglomerate member of Urkkavaara Formation, Verkkovaara, Kontiolahti.

ly dominates over arkose. The abundance of matrix, which consists of coarse clasts of quartz and feldspar and minor sericite is high (up to 80%) in the lower part of the formation, but may be as low as 20 to 30% in the upper portions. The size and roundness of rock fragments vary considerably even within a single exposure. Pebble count for a representative conglomerate from the lower part of the formation is shown in Figure 8. The conglomerates generally lack internal features. Arkoses are present as thin lenticular intercalations, especially in the upper part of the formation where the conglomerate is better sorted, with generally rounded pebbles and cobbles.

Urkkavaara Formation

This formation takes its name from the hill Urkkavaara (2 kms north of Ilvesvaara), where the primary nature of this sequence consisting mainly of ortho- and paraconglomerates was first established. In its type area, the formation is truncated in the east by a fault zone, while the lower contact is poorly exposed. However, on the western side of the Kontiolahti basement dome, conglomerate of the Ilvesvaara Formation seem to be overlain by a siltstone-argillite containing dropstones. The location of the type section is given in Appendix 1.

Within the Urkkavaara Formation (maximum thickness 265 m), the following seven informal members have been established, with the cross-bedded conglomerate member at the top:

Cross-bedded conglomerate member	> 50 m
Parallel bedded conglomerate member	50 m
Upper graded sandstone member	50—70 m
Diamictite member	0—10 m
Upper siltstone-argillite member	2—40 m
Lower graded sandstone member	10—20 m
Lower siltstone-argillite member	15 m

The two **siltstone-argillite members**, now mica schists but still displaying some original clastic textures, share similar features. They consist of planar laminations of gray siltstone and darker grey argillite with variable amounts of quartz, feldspar, biotite and sericite. The mineral composition of a siltstone is presented, together with other Urkkavaara samples, in Table 1. Many of the siltstone laminae exhibit graded bedding, with grain sizes of 0.1 — 0.2 mm fining upwards to 0.05 — 0.02 mm. Isolated, oversized clasts (Fig. 9) are common; pebbles and cobbles of felsic plutonic rocks and coarse sand grains, generally feld-

Fig. 9. Dropstones in lower siltstone-argillite member. Coin is 2.4 cm in diameter. Urkkavaara, Kontiolahti.

spar or quartz, are most abundant. Lonestones consisting of greywacke and elongated phyllitic clasts up to as 10 cm are also present.

The **lower graded sandstone member** now consists of intercalated beds of pink arkosite, grey biotitic metagreywacke and dark gray biotite-rich metasiltstone. The psammitic beds are 5 — 60 cm thick and commonly display good grading, with only interval A of the Bouma sequence being present. Oversized clasts occur almost exclusively in the finer-grained siltstone intercalations. Both the bottom and top of this member are gradational over a few metres.

The **diamictite member** is characterized by very poor sorting, with grain size ranging from boulders as large as 60 cm down to silt- and clay-sized particles. The matrix is effectively a 'greywacke' and its abundance varies between 50 and 80 %, resulting in a matrix-supported framework. Detrital sand grains as well as boulders and pebbles are subangular to rounded. Lithologies of fragments and the mineral composition of the matrix are shown in Figures 7 and 8 and in Table 1. The boundaries of the graywacke clasts with the matrix are indistinct, partly because of original primary textural gradation (see Ovenshine, 1970), and partly because of recrystallization. The diamictite lacks original internal structures, but locally contains a few sandstone lenses. The contact of the diamictite with the underlying siltstone-argillite member is clearly gradational over an interval of less than 1 m (Fig. 10). Just north of Ilvesvaara, the diamictite overlies chaotic beds composed of distorted angular slabs of thinly laminated siltstone-argillite similar to that making up the siltstone-argillite members. Some of those slabs even contain lonestones.

The **upper graded sandstone member** consists of beds of very coarse-grained arkosite from 10 to 100 cm thick and usually displaying good grading; commonly they consist of a lower massive graded part and an upper laminated part. Original detrital outlines of the sand-sized grains, which vary from angular to subrounded, are generally visible. Thin silty interbeds and laminae many of which contain oversized fragments, are present in the lower half of the member (Fig. 11). The contact of the upper graded sandstone member with the underlying diamictite is sharp and erosional, but to the north, where it is in contact with the upper siltstone-argillite member, the contact is clearly gradational. Conglomeratic interbeds, which become thicker and coarser and more frequent upwards, appear in the upper half of the member. The majority of the pebbles in the minor conglomeratic intercalations are well-

Fig. 10. Graditional contact between the upper siltstone-argillite member and overlying diamictite member of the Urkkavaara Formation. Compass is 12 cm long. Urkkavaara, Kontiolahti.

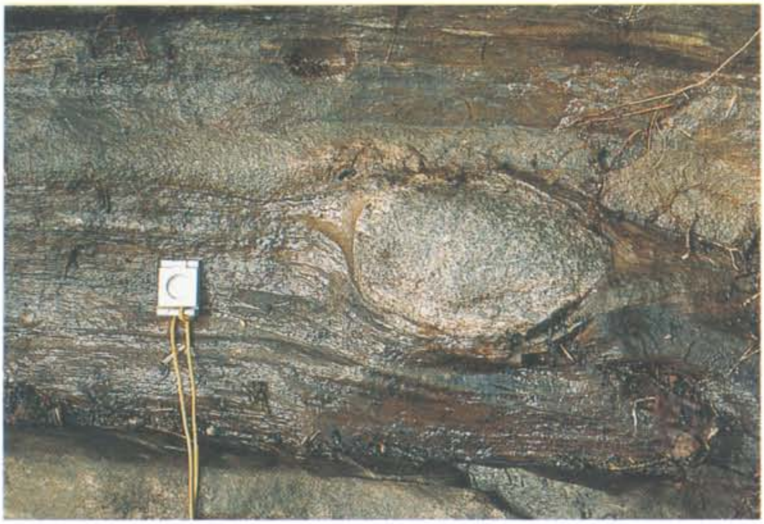

Fig. 11. Interbedded sandstone and argillite with a lonestone in argillite. Transition zone between lower graded sandstone member and upper siltstone-argillite member of the Urkkavaara Formation. Handlens is 3.5 cm long. Urkkavaara, Kontiolahti.

rounded, felsic plutonic rocks. Elongated phyllite and siltstone fragments are also present, sometimes in appreciable quantities. Finally, the upper graded sandstone member passes gradationally upward into the parallel bedded conglomerate member.

The **parallel-bedded conglomerate member** is composed of thick to very thick beds of conglomerate, which in the lower part of the member are occasionally intercalated with coarse-grained and very coarse-grained arkosite. The thickness of the conglomerate beds increases gradually upward and units show a concomitant change from pebble-dominated into cobble- or boulder-dominated types. In addition, beds and lenses of sandy diamictite are present. The gradually increasing size of the fragments is associated with a progressive decrease in the amount of matrix, occasionally resulting in a clast-supported framework in the upper portions. Erosional contacts between the individual beds and internal structures such as grading, often inverse or inverse-normal (Fig.12), characterize the member, especially its upper portions. Clasts in the conglomerate are usually subrounded and consist dominantly of felsic plutonic rocks (Fig. 8), but occasionally rip-up siltstone-argillite clasts con-

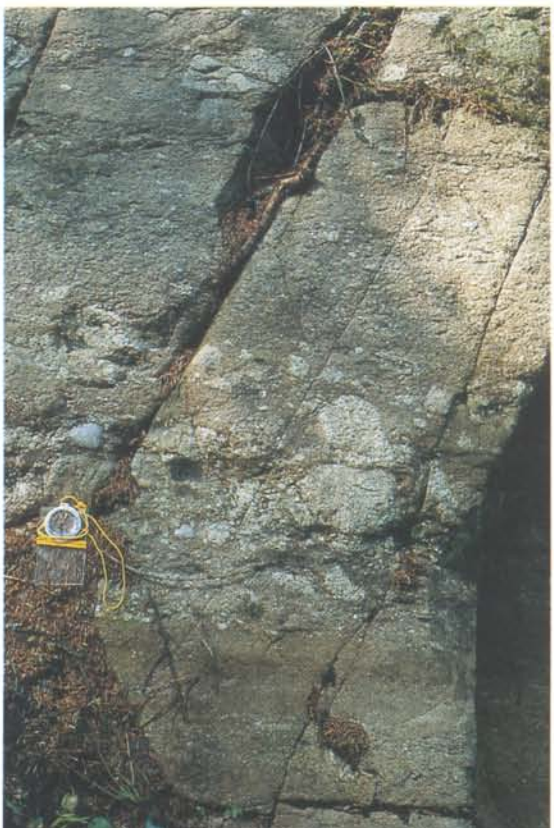

Fig. 12. Inverse-normal grading in parallel-bedded conglomerate member of Urkkavaara Formation. Compass is 12 cm long. Verkkovaara, Kontiolahti.

Fig. 13. (A) Massive conglomerate and (B) trough cross-bedded, conglomeratic arkose in cross-bedded conglomerate member of the Urkkavaara Formation. Hammer in A is 55 cm long and lens cap in B is 5.5 cm in diameter. Verkkovaara, Kontiolahti.

stitute as much as one third of the clasts. In the upper part of the member in particular the contacts between the individual beds are erosional. The parallel-bedded conglomerate member grades over several metres into a cross-bedded conglomerate member, and at the contact zone erosional features are common.

The **cross-bedded conglomerate member** consists of a lower massive cobble-to boulder-dominated conglomerate unit (thickness between 10 and 30 m; Fig. 13 A) and an upper cross-bedded conglomeratic arkosite unit (minimum thickness several tens of meters; Fig. 13 B). Also present are interbeds and lenses of mainly sandy diamictites, which sometimes show bedding. The lower part is characterized by crudely defined very thick beds and a well-developed clast-supported framework, the well-rounded clasts invariably consisting of felsic plutonic rocks. The upper part begins with conglomeratic sandstones. The subrounded to rounded clasts are mainly composed of felsic plutonic rocks, but occasionally siltstone-argillite fragments may account for 20 % to 30 % of the clasts. Common primary

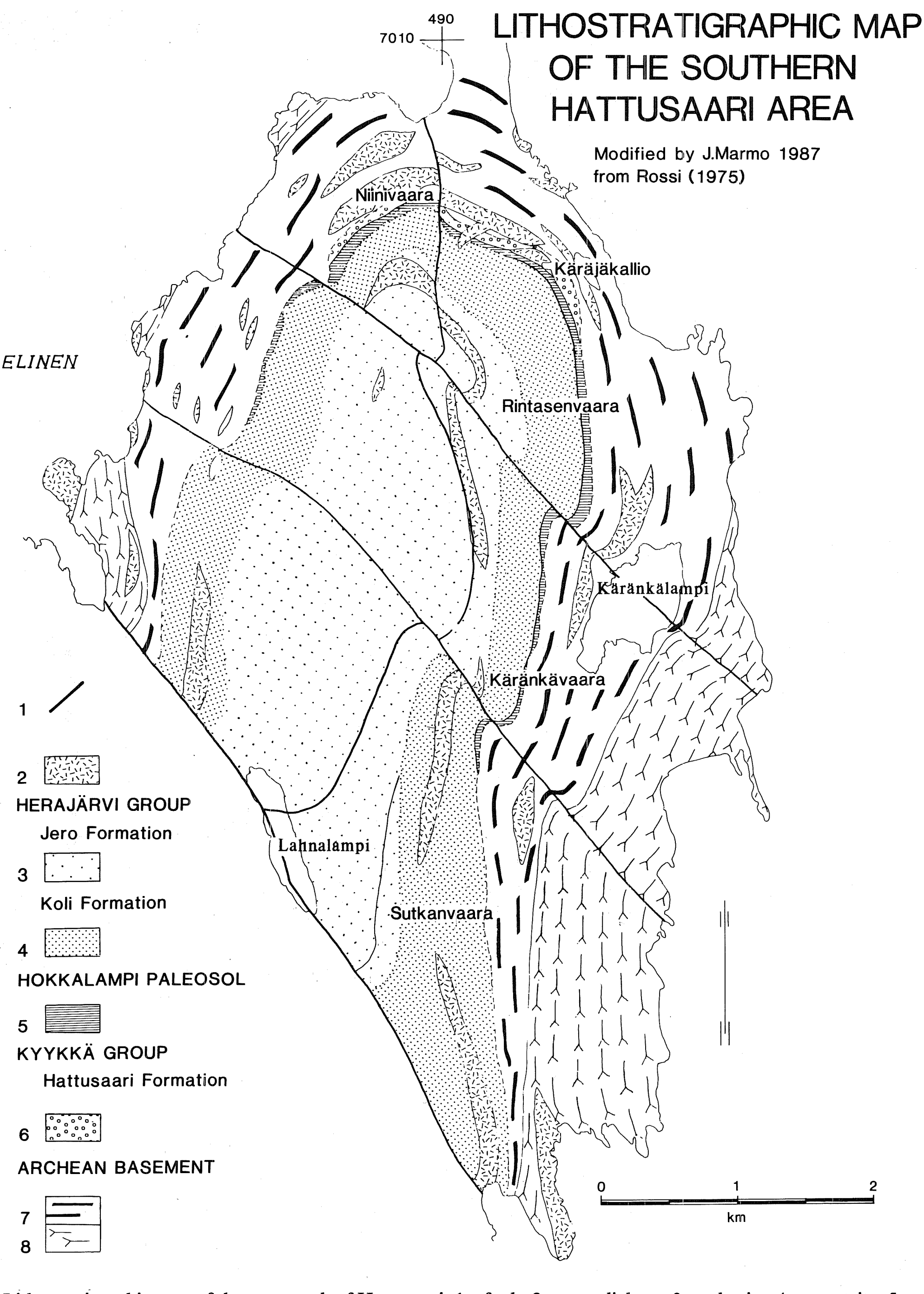

Fig. 14. Lithostratigraphic map of the area south of Hattusaari. 1 = fault; 2 = metadiabase; 3 = arkosite; 4 = quartzite; 5 = quartz-sericite schist; 6 = polymictic conglomerate, arkosite and mica schist; 7 = metavolcanics (mainly felsic); 8 = gneissic tonalite and migmatite.

features are horizontal bedding, large-scale low-angle cross-bedding and trough cross-bedding. The most typical broad and open troughs form both solitary structures and cosets. Winnowed surfaces are common. Conglomeratic sandstones are overlain by trough cross-bedded arkosic sandstones, in which the beds usually form cosets. The cross-bedded conglomerate member was originally thicker, since it grades upwards into a paleosol.

Hattusaari Formation

The Hattusaari Formation is the basal Proterozoic rock unit in the northern part of the study area, forming a nearly 100 m thick unit bordering the Kolinniemi syncline (Fig. 14). The rocks are named after an island north of the type area and the location of the type section is shown in Appendix 1. A well-defined nonconformity (Fig. 15) separates the Hattusaari Formation from the Archean basement, which here consists of metavolcanic rocks (»the Ipatti Greenschist Belt»; cf. Väyrynen, 1933, Piirainen et al., 1974). The Hattusaari Formation grades upwards into a paleosol. The precise relationship between the Hattusaari Formation and the Ilvesvaara and Urkkavaara Formations to the south has yet to be resolved. However, its stratigraphic position with regard to the Hokkalampi Paleosol and the overlying Koli quartzite justifies correlation with the Kyykkä Group.

The formation comprises an upward-fining sequence, consisting of a lower, ten meter thick unit of matrix-supported conglomerate, a middle 15 m thick unit of orthoconglomerate and an upper 70 m thick unit of arkosite. The lower unit is characterized by crudely defined beds, which become thinner upwards along with a simultaneous decrease in the size of the clasts. Most of the variably rounded lithic fragments up to 60 cm in diameter are felsic metavolcanics, but felsic plutonic rocks are more common in the upper portion.

In the middle unit nearly half of the fragments, which become increasingly rounded upwards, are granitoids. Sorting also improves upward. The conglomeratic beds in the lower part of the middle unit commonly show crude, horizontal bedding, and rarely cross-bedding. The bed thickness typically varies from 15 to 50 cm. The upper part shows medium to large scale trough cross-bedding. The individual beds are clearly upward-fining and much thinner than in the lower part of the unit. In the middle unit as a whole,

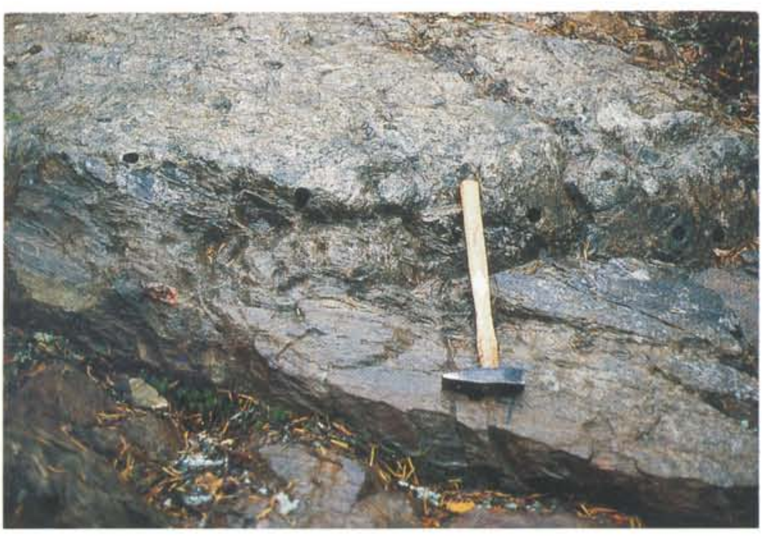

Fig. 15. Nonconformity between Archean greenstones and basal conglomerate of the Hattusaari Formation. Hammer is 55 cm long. Rintasenvaara, Lieksa.

there is a tendency for overall grain size to decrease upwards and the contact with the arkosic upper unit is gradational. Characteristic primary structures within the upper arkosite are thick, horizontal bedding and medium to large scale trough cross-bedding, which typically occurs as cosets.

Hokkalampi Paleosol

Quartz-sericite schist invariably underlies the quartzites and conglomerates of the Herajärvi Group. This schist is called the Hokkalampi Paleosol after the small lake at the type locality at Kyykkä (see Appendix 1 for coordinates). The Hokkalampi Paleosol is not included in the Kyykkä or the Herajärvi Group, because it has an indistinct boundary with the protolith and does not represent a depositional unit in the strict sense. This informal usage is similar to that of

Table 2. Mineral composition of various rocks in the Hokkalampi Paleosol, Vesivaara Formation and Koli Formation. Determined by point-counting method.

	1	2	3	4	5	6	7	8	9	10
Quartz	52.1	57.6	72.6	62.2	70.0	61.0	87.0	86.0	94.1	77.9
K-feldspar	6.4									
Biotite	5.8									
Sericite	35.7	41.8	24.6	10.6	29.0	28.1	13.0	13.5	5.9	19.0
Kaolinite			0.6	2.0	0.2					
Andalusite				5.0						0.9
Kyanite				20.2						1.2
Chloritoid			2.6							
Chlorite		0.4								
Apatite							+			+
Zircon					+		+	+	+	+
Rutile			0.2							
Titanite							+			
Tourmaline							+	+		
Opaque		0.2	0.2		0.8	10.3	+	0.5	+	+

+ = detected

1. Quartz-sericite schist;	OTR-82-84.46;	Hokkalampi Paleosol,	basal zone
2. — » —	JSM-81-35;	— » —	intermediate zone
3. — » —	JSM-81-57;	— » —	intermediate zone
4. Quartz-kya-sericite schist;	DH-301-2.2 m;	— » —	uppermost zone
5. Conglomeratic quartzite;	JJK-84-62.2;	Vesivaara Fm.	
6. Hematite bearing quartzite;	JJK-84-62.6;	— » —	
7. Quartzite;	JJK-84-2.2;	Koli Fm., quartzite mb.	
8. — » —	JJK-84-25.1;	— » —	
9. — » —	JJK-84-25.8;	— » —	
10. — » —	JJK-84-63.2;	— » —	

Fig. 16. (A) Paleoweathered conglomerate of the Urkkavaara Formation. Verkkovaara, Kontiolahti. (B) Intensively altered Archean tonalite (?) with a less weathered leucogranite vein at lower contact of Hokkalampi Paleosol. Paukkajanvaara, Eno. Lens cap 5.5 cm in diameter.

Senior and Mabbuth (1979), who discussed the problem of mapping paleosols.

In the type locality the paleosol was developed on the Urkkavaara Formation and reaches its maximum preserved thickness of 80 metres. The base of the paleosol in its type area has been observed to occur at various stratigraphic levels within the Urkkavaara Formation. In the middle part of the study area the paleosol developed on the Archean rocks, where the maximum thickness attains 45 metres, although it is generally much thinner. However, thicker profiles have been preserved at Hirvivaara, Höllärinvaara and Paukkajanvaara. In the north, where the paleosol formed on sedimentary rocks of the Hattusaari Formation, the maximum thickness does not exceed 40 metres.

The Hokkalampi Paleosol consists of quartz-sericite schist with an increasing proportion of kyanite, andalusite, and, sometimes chloritoid, toward the top (Marmo, 1986, 1992). The paleosol grades upward from its parent rocks through zones of increasing alteration.

The paleosol is typically more intensively deformed than either the underlying or overlying more competent rocks. The deformation has resulted in a strong schistosity, and alternating gray quartz-rich and white kyanite-rich bands are

typical for the upper parts of the paleosol. Three chemical-mineralogical zones (see Table 2) with gradual contacts have been established:

	plutonic parent rock	sedimentary parent rock
Zone 1 (top) quartz-aluminous silicate schist	0 — 20 m	40 m
Zone 2 quartz-sericite schist	< 15 m	< 20 m
Zone 3 (bottom) carbonate-bearing quartz-feldspar-sericite rock	< 6 m	< 15 m

The **basal zone** is characterized by a gradual vertical transition from relatively unaltered parent rock into a greenish gray quartz-sericite schist. The transition is due to the increasing disintegration of feldspars and micas, which have been replaced by sericite, carbonate, epidote and chlorite. In sedimentary rocks, the clastic texture and margins of the pebbles first become indistinct and finally, along with increasing sericite content, the rocks change upward into quartz-sericite schist (Fig. 16 A). In granitoids, the increasing alteration first results in a texture where the partly altered mineral grains are embedded in a matrix consisting of fine-grained quartz and sericite. In outcrop the altered granitoids may be easily misinterpreted as sedimentary in origin, but the less weathered leucogranite veins often reveal the true nature of the protolith (Fig. 16 B).

In the **intermediate zone**, feldspar is absent and the monotonous, light gray or green rock, lacking internal features inherited from the protoliths, consists entirely of quartz and sericite. Diagnostic features are scattered quartz clasts of variable size and form in a matrix of sericite and fine-grained quartz. Light-green elongated sericitic lenses are also present.

The **uppermost paleosol**, zone 1, differs from zone 2 mostly in the abundance of aluminosili-

17. Quartz-sericite-kyanite schist ıppermost part of Hokkalampi ːosol. Coin is 2.4 cm in diameter. ‹kalampi, Kontiolahti.

cates due to the increasing substitution of sericite by kyanite or andalusite, which may locally constitute 25% of the rock. The color of the rock is light gray or white (Fig. 17) with pink mottling due to andalusite. Scattered pebble to cobble-size monomineralic quartz and black tourmaline-quartz fragments are common in the type area. A chloritoid-rich quartz-sericite schist often occurs between the upper and the intermediate zones, the chloritoid content locally being sufficiently high to impart a dark green color to the rock.

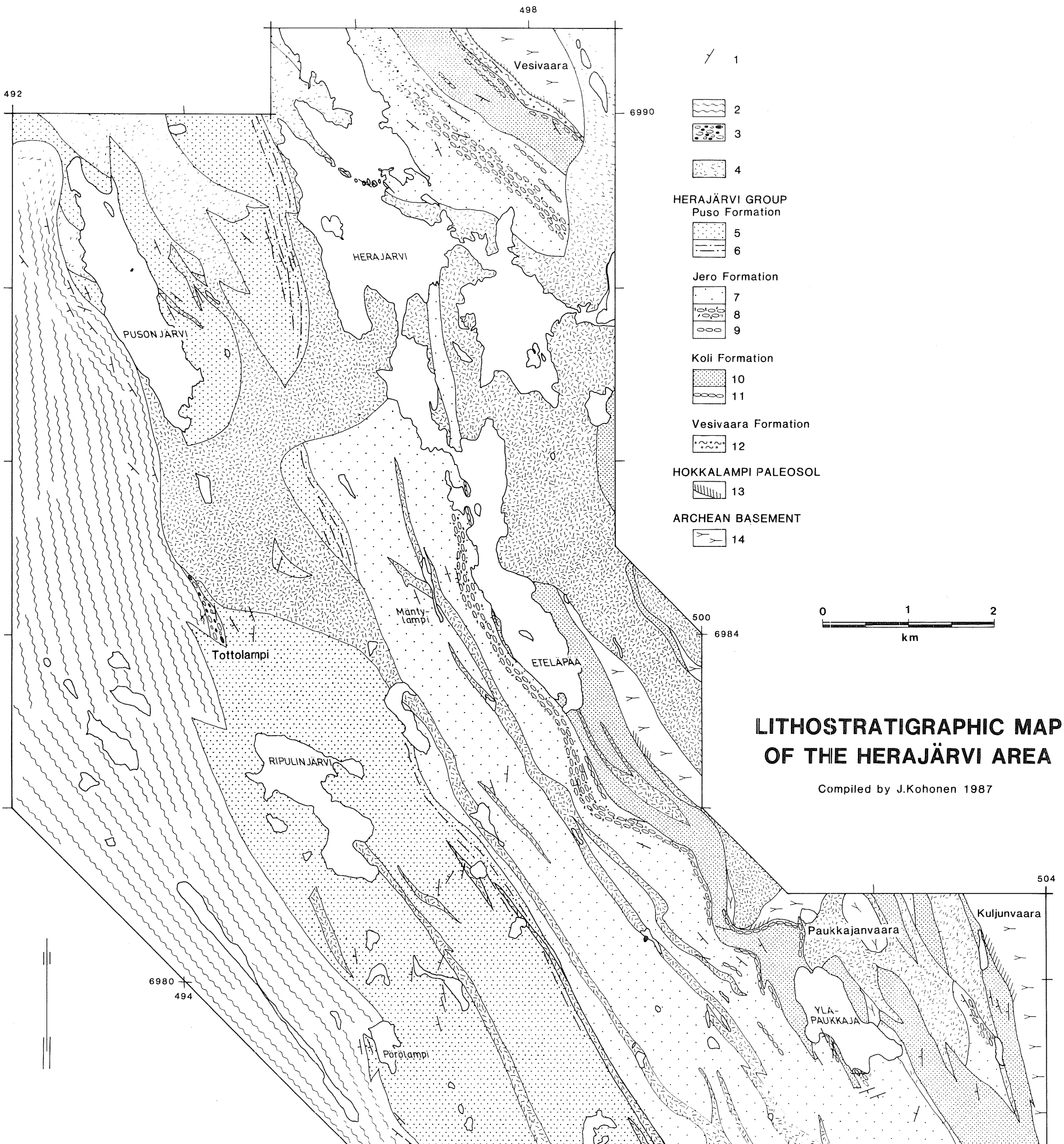

Fig. 18. Lithostratigraphic map of the Herajärvi area 1 = strike and dip of bedding; 2 = mica schist; 3 = quartzite-pebble conglomerate; 4 = metadiabase; 5 = quartzite; 6 = subarkosite; 7 = arkosite; 8 = quartz-feldspar pebble-conglomerate; 9 = quartz-pebble conglomerate; 10 = quartzite; 11 = quartz-pebble conglomerate; 12 = sericitic quartz-pebble conglomerate; 13 = quartz-sericite schist; 14 = migmatite and gneissic tonalite.

Herajärvi Group

The quartzites and arkosites overlying the Kyykkä Group and the Hokkalampi Paleosol are called the Herajärvi Group named after a lake in the type area (Fig. 18). A detailed study of the Herajärvi area including the type sections has been presented by Kohonen (1987). Four formations have been established within the group (Fig. 19). The measured and tilt corrected estimation of the total thickness of the group exceeds 2 500 metres, but some tectonic imbrication is evident so that originally thickness may have been less. The Koli and Jero Formations are laterally ex-

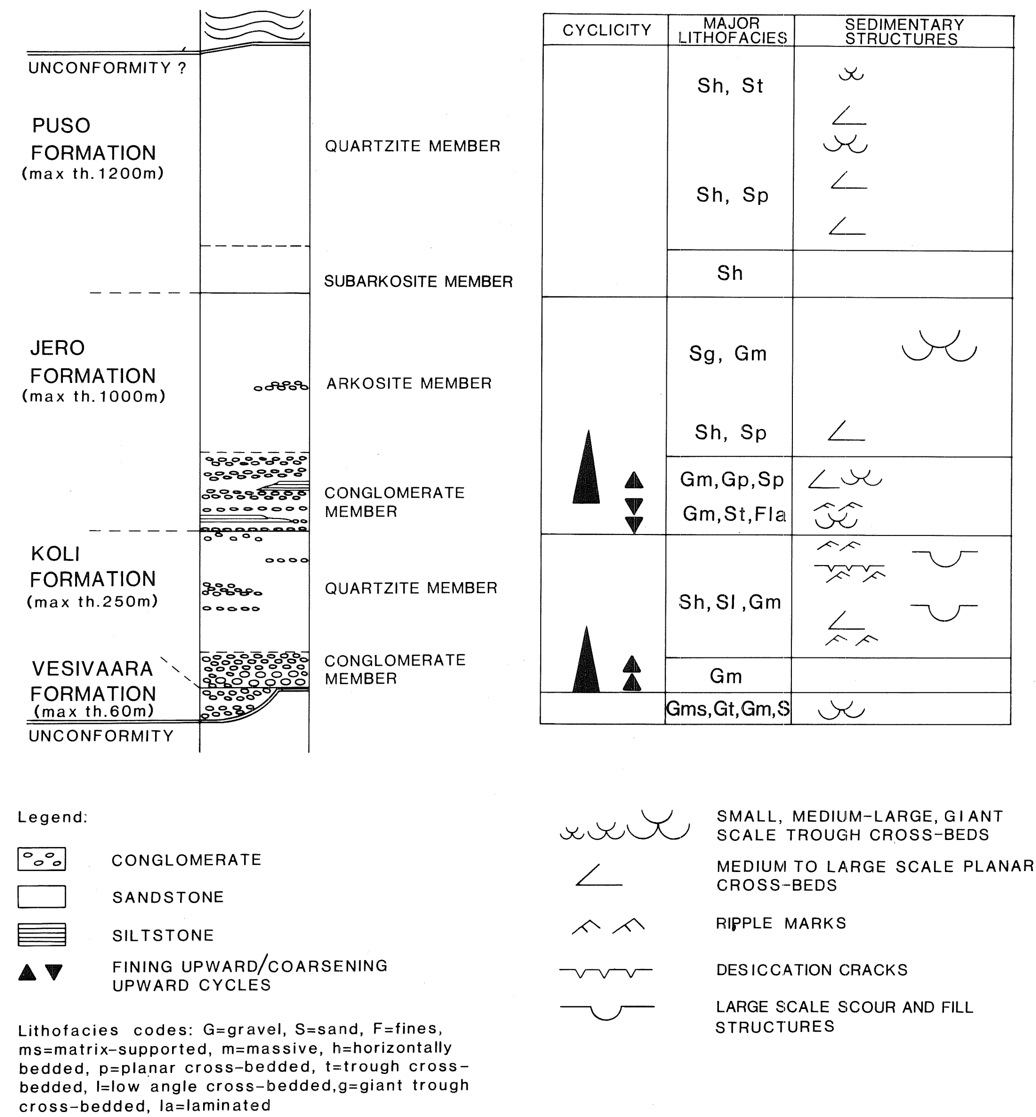

Fig. 19. Column illustrating the formations and members within the Herajärvi Group. Respective depositional cycles, major lithofacies associations and sedimentary structures are also shown.

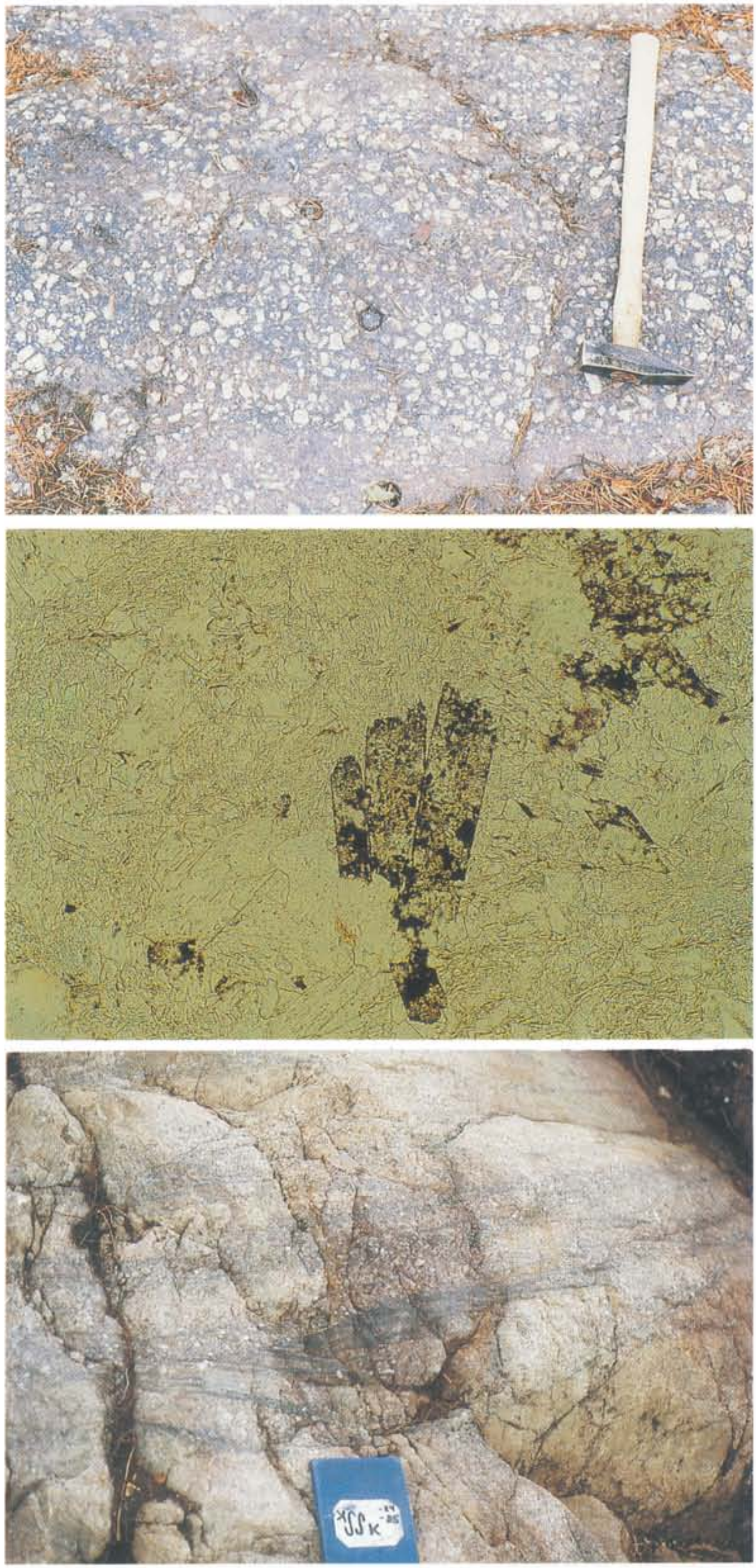

Fig. 20. The Vesivaara Formation; (A) Quartz-pebble conglomerate with abundant hematite. The hammer is 55 cm long. Hirvivaara, Eno. (B) Pseudomorph after kyanite composed mainly of kaolinite and opaques. Width of view is 1.35 mm. (C) Erosional scour. Notebook is 10 cm wide. Vesivaara, Kontiolahti (B and C).

tensive and can be followed from Kaltimo in the south to the Nunnanlahti in northern corner of the study area (Fig. 2).

Vesivaara Formation

The type section of the Vesivaara Formation is located on eastern slope of the hill Vesivaara (see Appendix 1 for other sections and coordinates). The formation is here separated from the Archean basement by a phyllonitic quartz-sericite schist which grades upwards into a very coarse-grained, sericitic quartzite, which clearly is blastoclastic and sedimentary in origin.

The Vesivaara Formation is characterized by coarse quartzites and conglomerates containing aluminosilicates (mostly kyanite) and sericite (Table 2). In places heavy mineral zones rich in hematite (sometimes up to 20%) are present and ferrioxide pigment imparts a reddish color to most of the formation (Fig. 20 A). The clasts are almost exclusively quartz (Fig. 21). In places additional black tourmaline-quartz clasts and occasional brownish fragments, consisting of kaolinitized aluminumsilicates or sericite, are present. Usually the boundaries between these originally clayey clasts and the matrix are indistinct and gradational. In addition, peculiar, rare clasts of very fine-grained quartz containing titanium minerals have been found.

Matrix is composed of sericite, kaolinite, fine-grained quartz and kyanite or andalusite, often retrogressed to kaolinite (Fig. 20 B). Sediments of the Vesivaara Formation are generally poorly sorted, but the formation exhibits a gradual upward increase in degree of sorting and the roundness of the clasts. The simple mineral composition associated with the absence of feldspars represents high mineralogical maturity.

The lower part of the Vesivaara Formation is characterized by sericite rich quartz-pebble conglomerates, whereas in the upper part matrix-poor conglomerates and coarse, massive sandstone beds become dominant. Recrystallization of the matrix has destroyed most of the primary structures, but some trough cross-beds with a set thicknesses of 10 to 20 cm and isolated erosional scours (Fig. 20 C) have been observed.

A section at Hirvivaara comprises a 60 metres thick sequence with rather well-preserved primary features. The pebble conglomerates and coarse quartzites form upward-fining cycles typically several metres in thickness. Superimposed large scale conglomeratic troughs are typical, but some planar cross-beds and massive beds similar to the type section have also been observed. The Vesivaara Formation wedges out toward the south, where quartzites and the conglomerates of the Koli Formation directly overlie the Hokkalampi Paleosol.

Koli Formation

The Koli Formation is named after the highest hill on a prominent ridge of quartzite, renowned for its panoramic views over Lake Pielinen; the type section is however, located about 20 km to

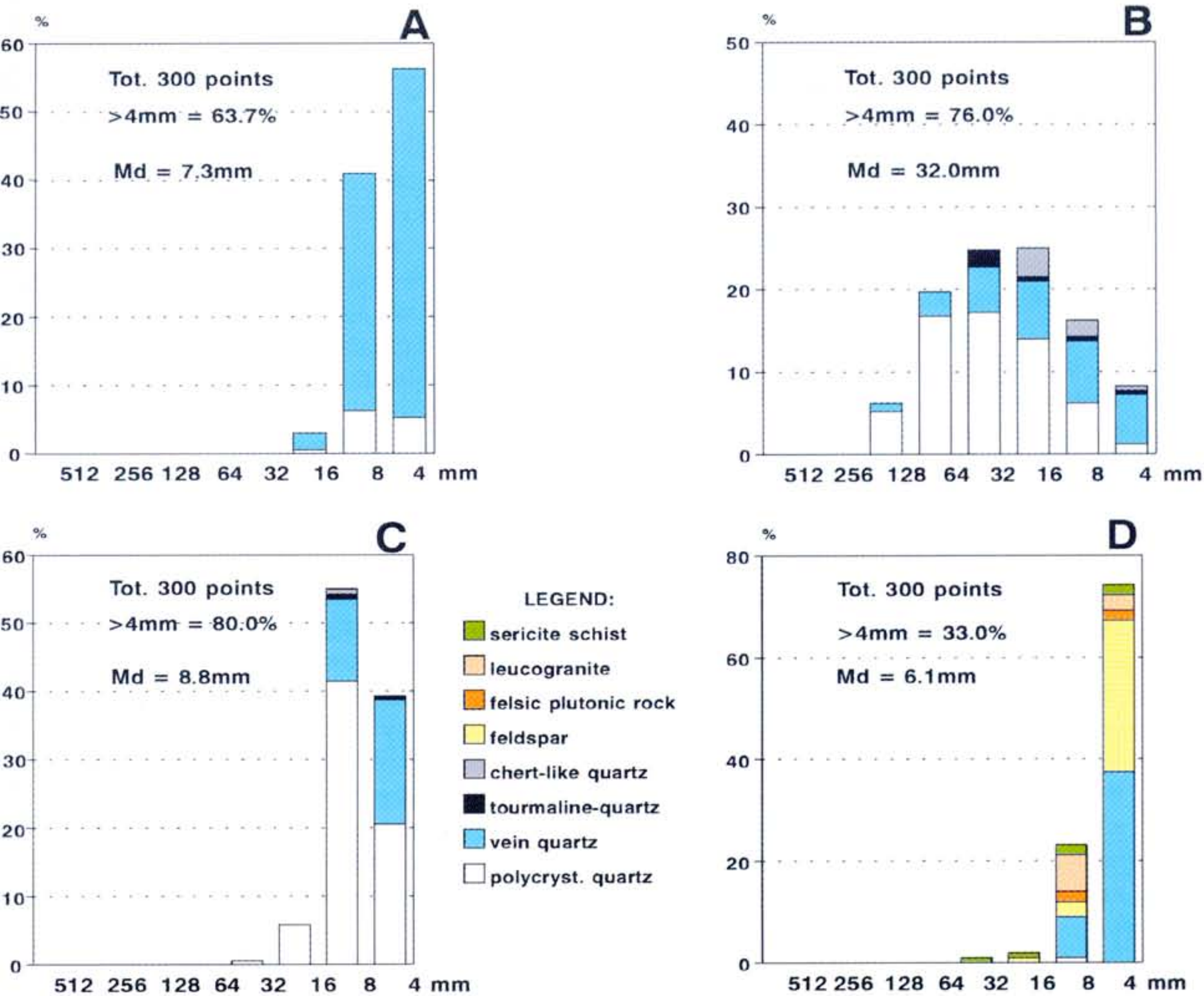

Fig. 21. Composition and size variation of fragments in conglomerates of the Herajärvi Group. The percentage of fragments (clasts larger than 4 mm) was determined by the point-counting method. Md = median size of fragments. (A) the Vesivaara Formation, Vesivaara, Kontiolahti; (B) lower part of conglomerate member of the Koli Formation, Paukkajanvaara, Eno; (C) upper part of conglomerate member of the Koli Formation, Paukkajanvaara, Eno; (D) conglomerate member of the Jero Formation, Eteläpää, Eno.

the southeast of Koli on the northeastern flank of the hill Sikovaara. The formation largely corresponds to the »Koliquartzit» of Gaál (1964) and the »Orthoquartzitschicht I» of Piirainen (1968).

The Koli Formation has been divided into two members, a lower conglomerate member (maximum thickness 30 m) and an upper quartzite member (maximum thickness 250 m). The conglomerate member is present only in the central part of the study area. The member has either an erosional contact with the Hokkalampi Paleosol, or it grades from the rocks of the underlying Vesivaara Formation. The white to greenish coloured quartz pebble conglomerates of Koli Formation show clearly better sorting and rounding in comparison to the Vesivaara Formation. In the south, the conglomerates are mostly lacking and quartzites lie directly on the Hokkalampi Paleosol. The contact is sharp, but erosional features seem to be absent.

The **conglomerate member** is characterized by pebble to cobble-sized quartz-conglomerates, but at Paukkajanvaara boulder-sized clasts are locally dominant (Fig. 22). Well rounded quartz clasts with variable degrees of recrystallization predominate (Fig. 21) but black tourmaline-quartz clasts, light brown, very fine-grained quartz clasts resembling chert, and, in basal units, rare clasts of quartz-sericite schist are also present. The matrix is composed of fine-grained quartz and sericite.

Good sorting has typically resulted in a clast-supported framework. In outcrops, upward-fining cycles are readily observed. The thickness of cycles generally ranges between 50 and 150 cm although some exceed 5 metres. The beds are usually massive, but some trough cross-bedded conglomerates and thin, coarse grained sandstone interbeds are locally present. The member grades upward into horizontally bedded quartzites with thin conglomeratic interbeds.

The **quartzite member** is characterized by a pale-green, gray or pink moderately sorted sericite-quartzite, which in the north also contains kyanite and kaolinite. Texturally the quartzites are blastoclastic (Fig. 23 A) and sometimes, where strained and recrystallized, nearly granoblastic. The average grain size corresponds to that of medium sand, although lateral variation in grain size occurs. Pebble-size conglomeratic interbeds are also present, becoming more frequent toward the north and rare in the south. In addition to quartz, rare clasts of sericite-schist, typically forming pseudomatrix, are present. Acces-

Fig. 22. Conglomerate in lowermost part of the Koli Formation. Fragments dominantly of recrystallized vein quartz. Note also light brown chert-like pebbles (cq) and black tourmaline-quartz pebble (tq). Paukkajanvaara, Eno. A pebble count of this conglomerate is presented in Fig. 21 B.

Fig. 23. (A) Quartzite showing blastoclastic texture and depositional layering. Width of view is 6.2 mm. Kuljunvaara, Eno. (B) Low-angle cross-bedded, laminar sericite-quartzite in quartzite member of the Koli Formation. Sikovaara, Eno.

sory zircon and tourmaline are typical heavy minerals (Kohonen 1987).

The of mainly sericitic matrix usually comprises more than 10 percent of the rock (Table 2), but quartz-cemented varieties are also present in the upper part of the member. As indicated by the total absence of feldspars, the quartzites of the Koli Formation are mineralogically mature. However, the relatively high content of sericite and aluminosilicates indicating an originally clayey matrix, represents textural immaturity and most of the quartzites may accordingly be classified as quartzwackes rather than true quartzarenites (classification of Pettijohn 1975; see Fig. 7).

Amongst primary features, thick horizontally laminated units, consisting originally of medium sands, dominate. Some laminar sands form low-angle cross-beds with set thicknesses often in excess of 1 m (Fig. 23 B). These cross-bedded cosets may be observed laterally for tens of metres. Scour and fill structures are also locally present. Ripple marks occur in the horizontally laminated units, which are interbedded with planar cross-bedded sandstones. Some trough cross-bedded sandy units, often associated with conglomeratic interbeds, have also been observed. Fine-grained interbeds are rare, and some of them exhibit desiccation cracks. The rock types and characteristic primary features are quite similar throughout the whole area studied, although the relative abundance of the individual lithofacies varies between different mapping profiles.

Jero Formation

The Jero Formation has been named after a lake surrounded by arkosites (see Fig. 2) and has been subdivided into a lower conglomerate member (thickness exceeding 100 metres) and an upper arkosite member. The total thickness of the formation has been estimated not to exceed 1000 metres. With the exception of the Kyykkä area in the south, the Jero Formation corresponds to the »Arkose bis Serizitquartzite» of Gaál (1964) and the »Arkosequartzite — Grauwackenkonglomeratschicht» of Piirainen (1968). The type section of the lower member is located on the western side of the southern end of the Lake Herajärvi (see Appendix 1 for other sections and coordinates). No continuous sections of the thick upper member are exposed, but typical outcrops are present west of the lakes Jero and Herajärvi.

The base of the formation is typically gradational over 5 — 15 metres with the underlying Koli Formation, but an erosional contact was also observed (see Appendix 1 for location of the contact outcrops). Fragments of Koli quartzite

Table 3. Mineral composition of the metasediments in the Jero Formation. Determined by point-counting method.

	1	2	3	4	5	6	7	8	9	10
Quartz	71.0	20.0	69.9	59.0	52.4	49.6	55.5	52.6	51.3	50.5
Plagioclase				5.6*	15.3*	13.2*	6.9*	1.3	7.0	7.9
K-feldspar				2.8	10.6	7.7	21.8	1.2	2.8	3.2
Biotite				0.9	2.3					
Sericite	29.0	78.4	30.1	31.7	15.0	11.2	15.8	30.0	34.5	34.5
Kaolinite								2.1	1.0	0.6
Carbonate					4.1	18.3		11.9	1.9	3.3
Epidote					0.3			0.3	0.6	
Apatite	+	+		+	+	+			+	
Zircon	+	+	+	+	+	+	+	+	+	+
Rutile				+						+
Tourmaline	+			+	+			+	+	+
Opaque		1.6	+	+	+	+	+	0.6	0.9	+

+ = detected, *) partly authigenic albite

1. Quartz-pebble conglomerate;	JJK-84-25.16;	Jero Fm., conglomerate mb.
2. Sericite schist;	JJK-83-114.2;	— » —
3. Conglomeratic sericite-quartzite;	JJK-84-68.3;	— » —
4. Sericite-quartzite;	JJK-84-31.3;	— » —
5. Conglomeratic arkosite;	JJK-84-32.1;	— » —
6. Arkosite;	JJK-84-70.3;	— » —
7. Conglomeratic arkosite;	JJK-84-72.2;	— » —
8. Sericite-arkosite;	JJK-84-18;	— » —
9. — » —	JJK-84-36.2;	— » —
10. — » —	JJK-83-101;	— » —

Fig. 24. Subarkosic material between quartzite blocks at the lower contact of the Jero Formation. The block margins are marked by chalk. Sikovaara, Eno.

are, however, rare even in the lower parts of the formation. The only place, Kasikangas, with undisputable quartzite pebbles is in the southernmost part of the study area where the Koli Formation is locally absent, and the Jero Formation was deposited directly on the basement. In places, the uppermost part of the Koli Formation has been fragmented and sericitic coarse subarkosite forms the matrix between quartzite blocks (Fig. 24).

The sheared conglomerate near Kyykkälampi (see Fig. 3) including boulder sized clasts of orthoquartzite, quartz-sericite schist and some smaller basement fragments (the Kyykkä Conglomerate of Frosterus and Wilkman, 1920) is included in the lower member of the Jero Formation. This conglomerate is spatially associated with brecciated quartzite and quartz-sericite schists of the Hokkalampi Paleosol.

The **conglomerate member** immediately overlies the Koli Formation, as sericite quartzites having variable grain size and containing intercalations of quartz-conglomerate with pebble- to cobble-sized clasts. The amount of feldspar gradually increases upward (Table 3), but lateral variations also occur. The upper part of the member is characterized by a coarse, commonly conglomeratic arkosite with variably rounded clastic grains (Fig. 25). Rare, thin sericite-schist interbeds, representing original fine grained sediments, are present throughout the member (Fig. 26).

The clastic feldspar is mainly microcline, with minor plagioclase of albite or oligoclase composition (Table 3). A common feature is the presence of both fresh and altered K-feldspar, even in the same specimen. Sericite and fine-grained quartz in variable amounts form the matrix. Lithic fragments are rare except for the fine-grained sericitic intraclasts. Within the pebbles, quartz and microcline clearly dominate (see Fig. 21).

Based on their mineral compositions the rocks of the lower part of the conglomerate member can be classified as primary quartzwackes. These gradually pass upward into subarkosites and arkosites (see Fig. 7).

The relative abundance of primary features varies when comparing the lower sericite-quartzite-dominated and the upper arkosite-conglomerate parts of the member. The former is characterized by trough cross-bedding, quartz-pebble lag conglomerates and fine grained interbeds. In the upper and coarser part of the member, thick bedded (10 to 80 cm) pebbly arkose is dominant. These rocks are massive, trough cross-bedded or planar cross-bedded (Fig. 27 A). In the subordinate sandy intercalations, planar cross-bedding is commonly observed. The fine-grained sediments within the member exhibit

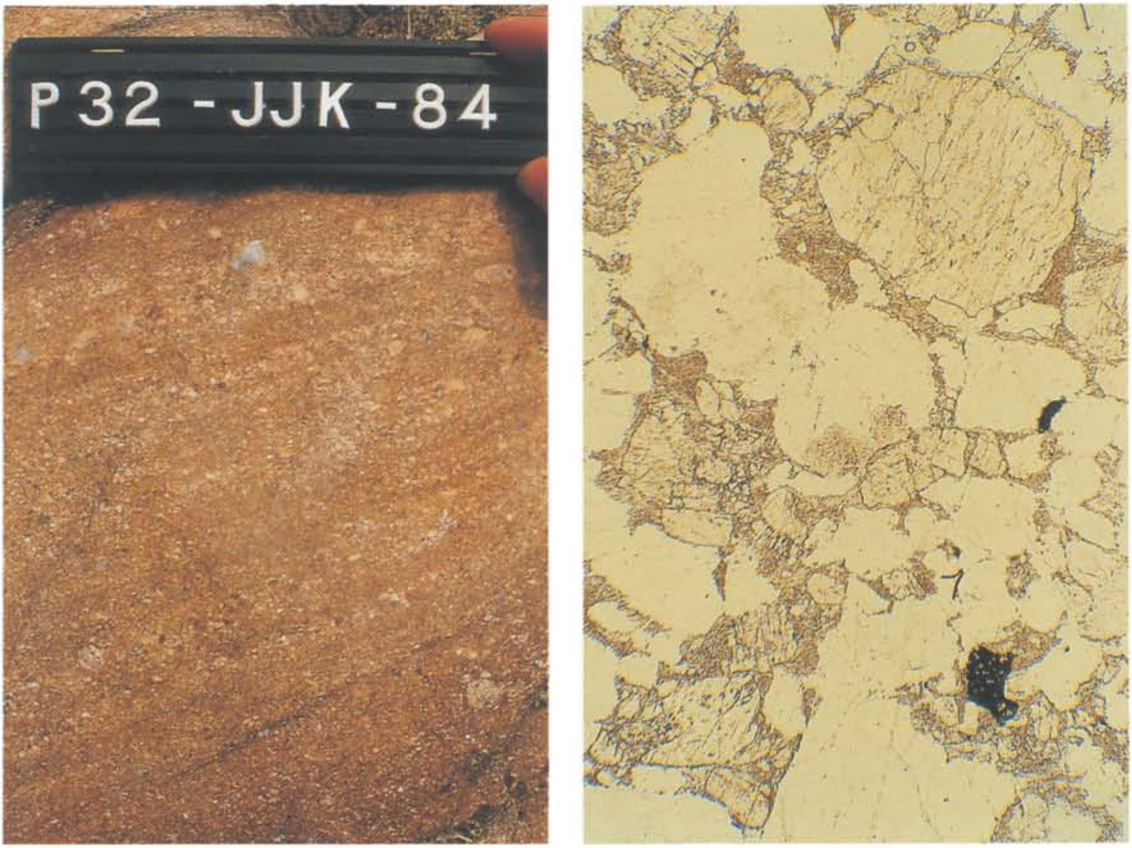

Fig. 25. (A) Photo and (B) photomicrograph of pebbly arkosite in conglomerate member of the Jero Formation. Letters in A are 13 mm high and field of view in B is 6.2 mm wide. Eteläpää, Eno.

Fig. 26. Remnant of fine-grained interbed (presently sericite schist) truncated by subsequent erosion of a channel system. Letters are 13 mm high. Vesivaara W, Kontiolahti.

lamination and in places strongly asymmetric ripples (Fig. 27 B). In the lower part of the conglomerate member, the cycles almost invariably coarsen upwards. In the upper parts, however, upward fining cycles with erosional bases become common and, finally, predominate.

The upper **arkosite member** is lithologically monotonous. Excluding some quartzitic interbeds in the lower part and minor conglomeratic units towards the top, the member consists of sericite-rich, medium-grained arkosites. The contact with the underlying conglomerate member is gradational over an interval of several metres with a corresponding decrease in overall grainsize. Among the feldspars, albitic plagioclase is clearly dominant (Table 3). Feldspars are commonly altered to sericite, saussurite and kaolinite, and in some cases alteration has been sufficiently extensive to have resulted in the formation of a pseudomatrix.

The rare lithic fragments present consist mainly of plagioclase and quartz, but in the conglomeratic units some K-granite pebbles have been observed. Clasts are moderately rounded and the

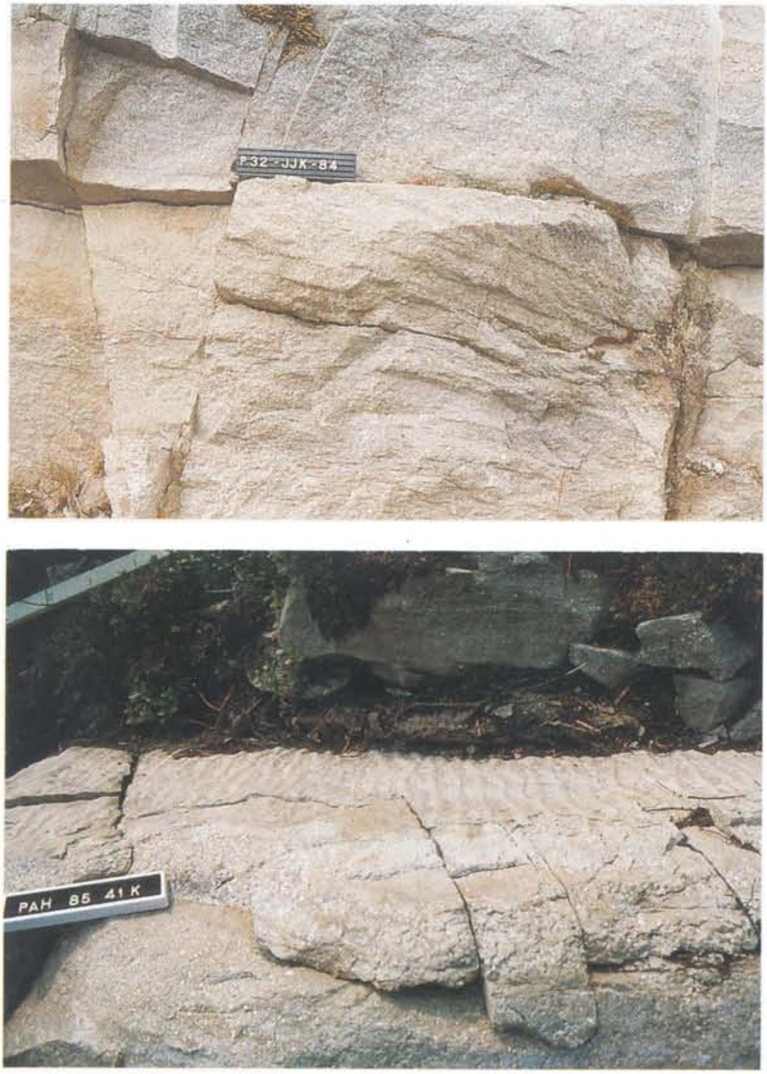

Fig. 27. (A) Planar cross-bedding of pebbly arkosite. Eteläpää, Eno. (B) Rippled fine sediments on top of conglomerate bed in conglomerate member of Jero Formation. Rapuvaara, Juuka. Tag is 16 cm long. Photo B by Paavo Härmä.

Fig. 28. Giant-scale trough cross-bedding in arkosite member of Jero Formation. Tag is 16 cm long. Some layers are traced by chalk. Rautaportti, Kontiolahti.

amount of matrix, consisting of sericite, kaolinite and fine-grained quartz, may exceed 20 percent. The alternation of coarser, commonly quartz-cemented layers with finer grained layers rich in mica forms distinct bedding, still visible even in rather strongly foliated rocks. Bed thickness varies typically between 0,5 and 1,5 centimeters.

With the exception of small to medium scale

Table 4. Mineral composition of the metasediments in the Puso Formation. Determined by point-counting method.

	1	2	3	4	5	6	7
Quartz	76.4	88.0	63.4	90.4	82.6	92.0	86.3
Plagioclase	1.0	0.3	17.8*				
K-feldspar	8.0	4.7		+	3.6		2.9
Biotite	3.6	0.4	14.2	+	0.3		
Sericite	11.0	5.1	4.4		12.4	7.5	9.9
Kaolinite		0.1				0.5	0.5
Chlorite		1.4	+	9.6			
Apatite	+	+	0.2		+		+
Zircon	+	+	+	+		+	+
Rutile		+		+		+	+
Opaque	+	+	+	+	1.1	+	0.4

+ = detected, *) mainly authigenic albite

1. Subarkosite;	JJK-84-43.1;	Puso Fm., subarkosite mb.
2. — » —	JJK-84-43.6;	— » —
3. — » —	JJK-84-85.1;	— » —
4. Quartzite;	JJK-84-46.1;	Puso Fm., quartzite mb.
5. — » —	JJK-84-55.16;	— » —
6. — » —	JJK-84-52.4;	— » —
7. — » —	JJK-84-100;	— » —

planar cross-bedding in the lowermost part of the member, giant trough cross-bedding is ubiquitous (Fig. 28). The thickness of individual sets may reach several metres with cosets tens of metres in thickness. Horizontally bedded or low angle cross-bedded units are evidently also present, but the large scale of these structures causes difficulties when defining the geometry of primary bedforms from small outcrops. The conglomeratic interbeds are typically lenticular and laterally discontinuous.

Puso Formation

The Puso Formation is named after a small village near Lake Pusonjärvi (see appendices for the location of type sections) and is roughly equivalent to the »reiner Quartzit» of Gaál (1964) and the »Orthoquartzitschicht II» of Piirainen (1968). Two members have been distinguished: the lower subarkosite member and the upper quartzite member. Due to poor exposure, the thickness of the individual members cannot be accurately

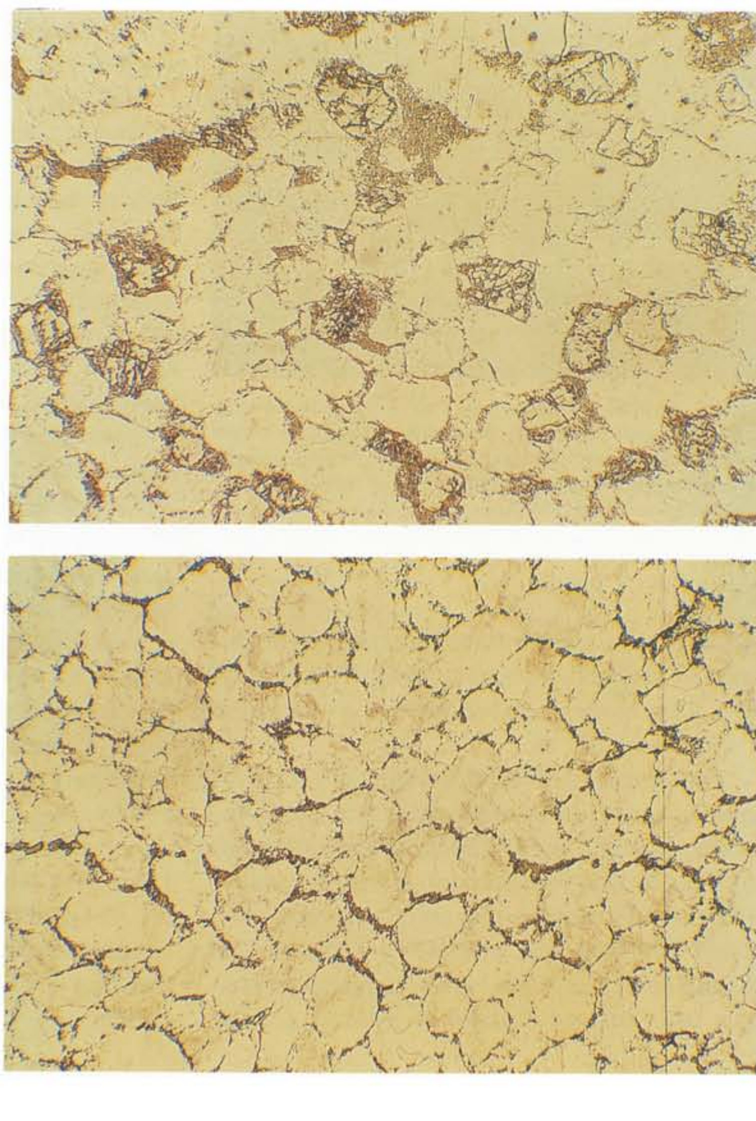

Fig. 29. Photomicrographs of (A) subarkosite and (B) quartzite of the Puso Formation showing well rounding and sorting. Width of both views is 6.2 mm. Haukilampi (A) and Pukkivaara (B), Kontiolahti.

Fig. 30. Typical quartzite of the Puso Formation showing alternating beds of pure white quartzite and grey to brown beds containing some feldspar and sericite. Note the coarse bed cemented by carbonate in upper half of the picture. Letters are 13 mm high. Pörövaara, Kontiolahti.

measured, but the maximum thickness of the formation probably does not exceed 1200 m, with the subarkosite member having a maximum thickness of 200 m.

The base of the Puso Formation is poorly exposed. According to observations on the northeastern side of Lake Kaltimonjärvi and northeast of Lake Hautajärvi, the contact with the underlying Jero Formation appears to be gradational. The Puso Formation is bordered in the west by a fault zone; hence the nature of the upper contact has remained obscure. In addition, Kohonen et al. (1990) have suggested that the westernmost part of the formation, west of Piili (see Fig. 2), might represent a separate stratigraphic unit with a conformable or interbedded relationship to the adjacent mica schists.

The arenites of the Puso Formation typically show well-preserved blastoclastic textures with good sorting of rounded or well-rounded clasts (Fig. 29). The rocks of the subarkosite member differ clearly from Jero arkosites in being better sorted and a having lower feldspar contents (see Fig. 7). K-feldspar dominates over plagioclase. The subarkosites grade upward into the orthoquartzite through a zone 10 — 20 m in thickness consisting of interbedded subarkosite and quartzite beds.

Clastic K-feldspar is present in small amounts in the quartzite member, as are lithic fragments composed of chert-like quartz or sericite-phyllite. Sericite, fine-grained quartz, chlorite and minor biotite form the matrix, which comprises only a minor part of the rock (Fig. 29. and Table 4). The rocks are commonly cemented by quartz, or quartz-cemented laminae alternate with those having a micaceous matrix. Coarse sandy beds are commonly cemented with carbonate (Fig. 30).

Lamination both members usually ranges from thin to thick. The solitary thicker (up to 8 cm) and coarse-grained interbeds show sharp boundaries to the laminated quartzite. Bedding is typically horizontal, although individual planar cross-beds with set thicknesses up to 150 cm are present. The upper parts of the sets dip moderately, with the lower contact being tangential (Fig. 31 A). Also present are rare small scale planar cross-beds (set thickness 10 to 30 cm). The upper part of the Puso Formation is characterized by cosets several meters in thickness consisting of small-scale trough cross-bedded sets 5 to 15 cm thick (Fig. 31 B). Rocks representing original fine-grained sediments are almost absent. Conglomeratic quartzites with scattered quartz clasts up to 25 mm in diameter are sporadically present.

Fig. 31. (A) Large-scale and (B) small-scale cross-bedding in quartzite member of Puso Formation. Tag is 16 cm long. Pörövaara (A) and Pörölampi W (B), Kontiolahti.

CHEMICAL CHARACTERISTICS

More than 400 XRF silicate analyses are available for rocks from the study area, most of which are from the Hokkalampi Paleosol or sedimentary units adjacent to it; these results are discussed in detail by Marmo (1992). Unfortunately, there are no analyses from the Hattusaari Formation and data from the Ilvesvaara and Puso Formations are also quite limited. Consequently, the chemical characteristics presented here are to be seen in the overall context of mineral compositions and geological information.

The major geochemical features in the rocks studied correlate with their degree to chemical maturity. This maturity or degree of chemical alteration may be semiquantitatively measured by using the Chemical Index of Alteration (CIA) introduced by Nesbitt and Young (1982). Values for the index are given as a percentage for the ratio of molecular percentages of (Al_2O_3 / (Al_2O_3 + CaO + Na20 + K_2O)) x 100 calculated from whole rock silicate analyses, where CaO refers only to lime incorporated within silicates.

One of the main problems related to geochemical studies of sedimentary rocks is the fractionation of minerals by sorting into different grain sizes and much of the variation in Figs. 32 and 33 may be attributed to this.In order to minimize this bias the following discussion is based mainly on comparisons of psammitic units.

For comparison, some analyses from Archean basement granitoids are presented in Table 5, together with results from the overlying **Ilvesvaara** and the **Urkkavaara Formations.** The CIA values for the basement rocks and the metasediments are both low, thus indicating a low degree of chemical alteration. When compared to the granodioritic-tonalitic basement rocks, the arkosites are slightly depleted in iron, calcium and aluminum and enriched in silica. However, when comparing the arkosites to leucogranites the contents of both silica and alumina are similar.

The chemical compositions of representative samples from the **Hokkalampi Paleosol** and the overlying Vesivaara and Koli Formations are shown in Table 6. The CIA values for the paleosol are low at the bottom, moderate in the middle and high to very high in the upper portions. Thus the vertical profiles clearly indicate a gradual upward increase in degree of chemical alteration. Silica and alumina constitute nearly all of the uppermost paleosol and the Al_2O_3 content may reach 30%. Relative to its parents, the Archean granitoids and the rocks of the Kyykkä Group, the paleosol is consistently

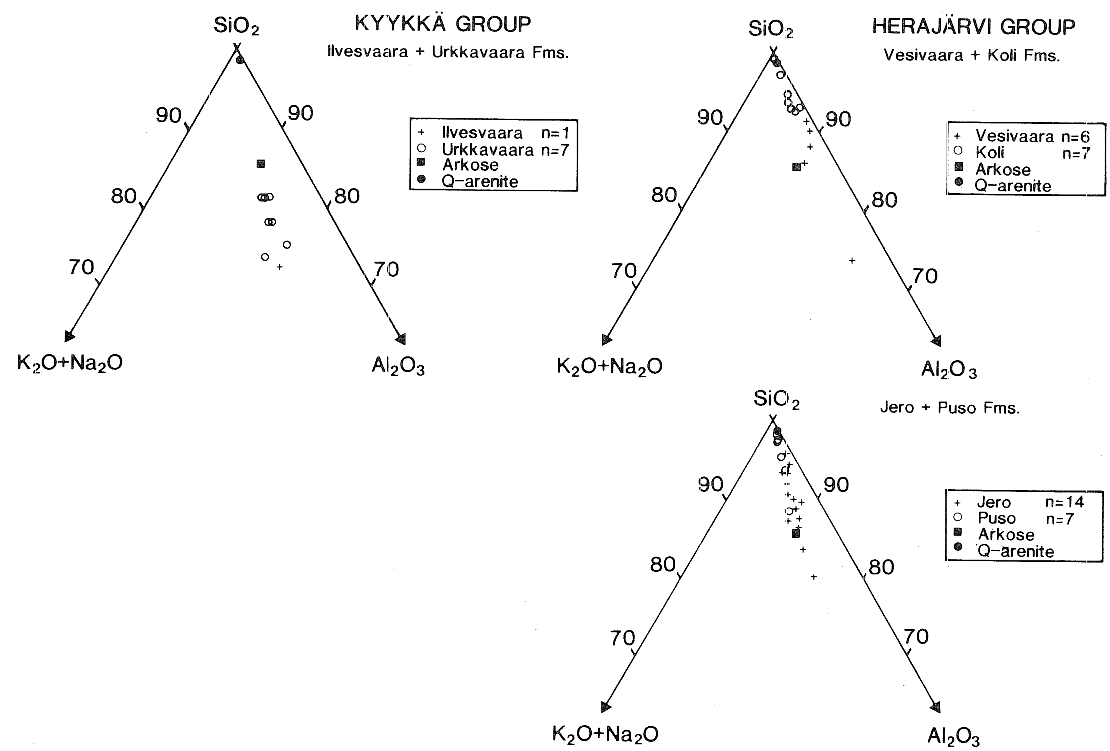

Fig. 32. SiO_2 — $K_2O + Na_2O$ — Al_2O_3 plot of the studied formations. Compositions of average quartz-arenite and arkose (Pettijohn et al. 1972) are also indicated.

depleted in ferrous iron, sodium, calcium and magnesium. In the upper portions, ferric iron and potassium abundances are also observed to decrease, in some profiles considerably. Compared to the protoliths the contents of alumina and silica have increased in the middle and upper portions of the paleosol.

The poorly sorted quartzite and conglomerate of the **Vesivaara Formation** and the moderately sorted quartzite of the **Koli Formation** consist mainly of quartz, sericite and aluminosilicates; i.e. the same minerals that constitute the upper zones of the paleosol. Not surprisingly, the rocks of the proximal Vesivaara Formation and the more distal quartzites of the Koli Formation give moderate to high CIA values, suggesting intense chemical weathering of the source rocks. Compared to the paleosol, the Vesivaara Formation and the Koli Formation show a gradual vertical increase in silica with a concomitant decrease in alumina. However, the sericite quartzites of the Koli Formation differs from the average quartz arenite (Pettijohn et al., 1972), having somewhat higher contents of Al_2O_3 and K_2O. As with the

Table 5. Major component XRF-analyses of various rocks in Archean Basement Complex and Kyykkä Group. XRF-analyses by Rautaruukki and GSF. Oxides in weight%. See Appendix 2 for location of analyzed samples.

	Archean Basement				Ilves-vaara Fm.	Urkkavaara Formation								
	1[1]	2[2]	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	69.19	76.04	72.84	74.15	66.07	59.48	75.33	65.72	76.18	75.01	62.46	77.62	74.82	70.91
Al_2O_3	15.60	14.61	14.38	13.17	16.80	22.78	12.00	15.56	14.03	11.19	18.24	11.91	14.10	15.55
TiO_2	0.39	0.06	0.26	0.22	0.37	0.78	0.16	0.29	0.16	0.10	0.55	0.13	0.27	0.28
Fe_2O_3(t)	3.78	0.70	1.76	1.52	3.08	3.59	3.22	4.88	1.20	2.17	5.33	1.83	2.28	1.34
Fe_2O_3	1.29	0.30	—	—	—	—	—	—	0.36	0.52	—	0.50	—	0.26
FeO	2.24	0.38	—	—	—	—	—	—	0.76	1.49	—	1.19	—	0.97
MgO	1.38	0.29	0.78	0.75	1.42	2.78	2.09	3.50	0.72	0.94	4.03	0.65	0.92	0.51
CaO	2.25	1.49	0.87	1.97	1.92	0.88	1.29	0.62	0.13	3.24	0.54	1.31	0.72	1.08
Na_2O	3.36	5.73	4.57	3.95	3.70	3.68	3.76	4.78	0.89	2.70	4.51	2.93	1.13	3.99
K_2O	3.80	1.02	3.10	1.68	4.50	5.97	1.52	1.17	6.34	3.50	2.03	3.22	5.62	5.77
MnO	0.05	0.01	0.01	0.01	0.05	0.00	0.04	0.06	0.01	0.07	0.05	0.03	0.06	0.02
P_2O_5	0.20	0.02	0.08	0.05	0.09	0.05	0.05	0.08	0.04	0.05	0.09	0.06	0.08	0.12
SUM			98.65	97.47	98.01	99.88	99.47	96.87	99.56	98.94	97.83	99.70	100.00	99.58
CIA	53.2	52.5	53.6	52.5	53.8	61.7	54.0	60.3	62.1	—*	63.2	52.7	60.4	51.3

[1] average of 8 samples
[2] average of 3 samples
* sample contains carbonate, CIA not calculated

1. Average of 8 granodiorite-tonalite samples from the study area
2. Average of 3 leukogranite samples from the study area
3. Granodiorite; Hirvitarha
4. Granodiorite fragment in the conglomerate; Ilvesvaara Fm.; Hirvitarha
5. Fine-grained matrix of conglomerate; Ilvesvaara Fm.; — » —
6. Phyllite; Urkkavaara Fm., lower siltstone-argillite mb.; Urkkavaara
7. Arkosite; — » — lower graded sandstone mb.; — » —
8. Metasiltstone; — » — upper siltstone-argillite mb.; — » —
9. Arkosite; — » — upper graded sandstone mb.; — » —
10. — » — — » — upper graded sandstone mb.; Verkkõvaara
11. Diamictite; — » — diamictite mb.; Urkkavaara
12. Arkosite; — » — cross-bedded conglomerate mb.; Verkkovaara
13. Diamictite; — » — cross-bedded conglomerate mb.; Kyykkä
14. Metasiltstone intraclast; Urkkavaara Fm., parallel-bedded conglomerate mb.; Verkkovaara

Table 6. Major component XRF-analyses of various rocks in Archean Basement, Hokkalampi Paleosol and in the overlying Vesivaara and Koli Formations. XRF-analyses by Rautaruukki and GSF. Oxides in weight%. See Appendix 2 for location of analyzed samples.

		Hokkalampi Paleosol							Vesivaara Formation						Koli Formation						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
SiO_2	67.98	74.34	69.94	73.50	73.54	80.77	80.29	75.93	87.35	88.09	86.59	67.39	86.44	82.88	91.86	91.88	91.22	96.12	90.05	95.29	89.57
Al_2O_3	16.07	14.13	18.46	16.56	21.13	16.35	15.80	20.53	8.64	7.71	5.30	19.90	9.78	10.02	6.20	3.97	4.55	0.35	5.27	2.01	5.82
TiO_2	0.38	0.20	0.55	0.48	0.32	0.44	0.32	0.49	0.14	0.19	0.36	0.71	0.14	0.29	0.10	0.17	0.11	0.02	0.16	0.04	0.06
Fe_2O_3(t)	4.06	2.54	2.88	2.46	0.30	0.61	0.37	0.30	1.73	1.73	4.59	5.91	1.24	2.08	0.14	0.12	0.58	0.10	0.07	0.05	0.86
Fe_2O_3	1.40	1.31	2.39	0.53	—	—	—	—	1.55	1.56	4.46	5.70	1.16	1.86	—	—	—	—	—	—	—
FeO	2.38	1.12	0.43	1.74	—	—	—	—	0.16	0.15	0.12	0.19	0.07	0.20	—	—	—	—	—	—	—
MgO	1.10	0.90	0.69	0.43	0.00	0.27	0.21	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.00	0.00	0.46
CaO	2.17	1.82	0.55	0.02	0.00	0.10	0.08	0.09	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.14
Na_2O	2.44	0.82	0.39	0.32	0.97	0.20	0.14	0.09	0.13	0.09	0.20	0.42	0.18	0.05	0.04	0.06	0.06	0.23	0.22	0.24	0.00
K_2O	4.06	4.31	5.69	4.11	1.75	0.57	1.04	0.53	0.89	0.73	1.33	3.63	1.77	3.42	0.56	1.10	1.55	0.11	1.43	0.52	1.32
MnO	0.04	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00
P_2O_5	0.18	0.09	0.21	0.02	0.00	0.00	0.05	0.06	0.01	0.03	0.05	0.05	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.03
SUM	98.48	99.20	99.37	97.71	98.16	99.31	98.29	98.21	98.89	98.57	98.38	98.00	99.57	99.13	98.91	97.31	98.30	96.94	97.22	98.16	98.26
CIA	56.6	60.3	70.3	76.7	85.8	93.6	91.3	95.9	88.0	89.2	74.8	81.1	81.4	72.6	90.2	75.5	70.3	—*	73.4	67.7	77.6

* due to low Al2O3 CIA not calculated

1. Granodiorite; Archean Basement Complex Nuutilanvaara
2. Slightly altered granodiorite; Hokkalampi Paleosol, zone 3; Nuutilanvaara
3. Quartz-sericite schist; Hokkalampi Paleosol, zone 2; Nuutilanvaara
4. — » — — » — Sammakkovaara
5. — » — Hokkalampi Paleosol, zone 1; Hirvivaara
6. Quartz-kyanite schist; — » — Sammakkovaara
7. — » — — » — Hokkalampi
8. — » — — » — — » —
9. Conglomeratic quartzite; Vesivaara Fm.; Nuutilanvaara
10. — » — — » —
11. — » — Vesivaara Fm.; Vesivaara
12. Conglomeratic quartzite; Vesivaara Fm.; Vesivaara
13. Quartzite; Vesivaara Fm.; Vesivaara
14. Conglomeratic quartzite; Vesivaara Fm.; Hoikanvaara
15. Quartzite; Koli Fm., quartzite mb.; Nuutilanvaara
16. — » — — » — Kuljunvaara
17. — » — — » — Sikovaara
18. — » — — » — — » —
19. — » — — » — Vesivaara
20. Conglomeratic quartzite; Koli Fm., quartzite mb.; Vesivaara
21. Quartzite; Koli Fm., quartzite mb.; Hoikanvaara

Table 7. Major component XRF-analyses of metasediments in the Jero Formation and Puso Formations. XRF-analyses Rautaruukki and GSF. Oxides in weight%. See Appendix 2 for location of analyzed samples.

	Jero Formation														Puso Formation						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
SiO_2	79.46	87.31	90.04	90.72	73.71	84.75	87.47	89.35	87.66	93.74	85.31	80.40	81.87	91.73	90.96	83.62	95.84	93.69	94.02	96.80	97.67
Al_2O_3	3.92	7.03	5.46	4.90	13.21	7.83	8.15	6.30	8.00	3.49	9.44	10.99	8.46	4.32	4.37	7.20	1.26	1.83	3.19	1.80	1.31
TiO_2	0.03	0.06	0.05	0.09	0.53	0.07	0.15	0.12	0.05	0.06	0.04	0.11	0.07	0.09	0.04	0.07	0.03	0.06	0.04	0.03	0.02
Fe_2O_3(t)	0.95	0.53	0.25	0.39	4.56	0.50	1.35	0.70	0.73	0.71	0.75	0.79	0.52	1.03	0.77	1.54	1.30	0.36	0.74	0.21	0.15
$Fe_2O_3$3	—	—	—	0.21	4.42	—	—	0.63	0.55	—	0.68	—	0.47	0.87	0.50	—	0.86	—	0.60	0.17	—
FeO	—	—	—	0.16	0.13	—	—	0.06	0.16	—	0.06	—	0.04	0.14	0.24	-	0.34	—	0.13	0.04	—
MgO	1.83	0.32	0.00	0.04	1.26	0.26	0.46	0.12	0.23	0.35	0.13	1.08	1.78	0.23	0.96	2.09	1.05	0.22	0.14	0.07	0.06
CaO	7.07	0.01	0.07	0.00	0.02	0.03	0.10	0.00	0.01	0.10	0.00	0.41	1.41	0.00	0.12	0.10	0.03	0.06	0.02	0.05	0.03
Na2O	0.00	0.31	1.86	0.00	0.00	0.39	0.00	0.00	0.01	0.00	0.00	1.02	0.60	0.00	0.00	1.87	0.00	0.72	0.00	0.00	0.00
K_2O	0.87	2.35	0.62	1.63	5.05	4.28	2.06	2.95	3.02	0.66	3.97	3.77	2.57	2.22	1.83	1.87	0.04	0.12	1.36	0.67	0.40
MnO	0.15	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.04	0.08	0.00	0.01	0.04	0.02	0.02	0.01	0.01	0.01
P_2O_5	0.02	0.01	0.02	0.00	0.03	0.03	0.00	0.02	0.01	0.00	0.03	0.07	0.05	0.02	0.02	0.05	0.01	0.04	0.01	0.03	0.00
SUM	94.30	97.94	98.39	97.78	98.38	98.14	99.77	99.56	99.73	99.11	99.68	97.68	97.41	99.64	99.07	98.46	99.58	97.10	99.59	99.66	99.63
CIA	—*	69.6	—**	73.5	70.6	59.5	77.2	65.0	70.8	79.6	68.7	—*	—*	64.3	66.6	—**	—**	—**	67.6	68.8	72.7

* sample contains carbonate, CIA not calculated
** sample contains secondary albite and/or chlorite, CIA not calculated

1. Conglomeratic sericite-quartzite;	Jero Fm., conglomerate mb.;	Sikovaara
2. Quartz-pebble conglomerate;	— » —	— » —
3. Conglomeratic sericite quartzite;	— » —	Eteläpää
4. — » —	— » —	Vesivaara
5. Sericite schist;	— » —	Ylä-Paukkaja
6. Conglomeratic arkosite,	— » —	Eteläpää
7. Quartz-pebble conglomerate;	— » —	Hoikanvaara
8. Conglomeratic arkosite;	— » —	— » —
9. — » —	— » —	— » —
10. Quartzite;	— » —	— » —
11. Arkosite;	— » —	— » —
12. Sericite-arkosite;	Jero Fm., arkosite mb.;	Tammasuo
13. — » —	— » —	Ylä-Paukkaja
14. Subarkosite;	— » —	Rapuvaara
15. — » —	Puso Fm., subarkosite mb.;	Haukilampi
16. — » —	— » —	Heraniemenkoli
17. Quartzite;	— » —	Pukkivaara
18. — » —	— » —	Pusonjärvi
19. — » —	— » —	Pörövaara
20. — » —	— » —	Pusonjärvi
21. — » —	— » —	Pörölampi

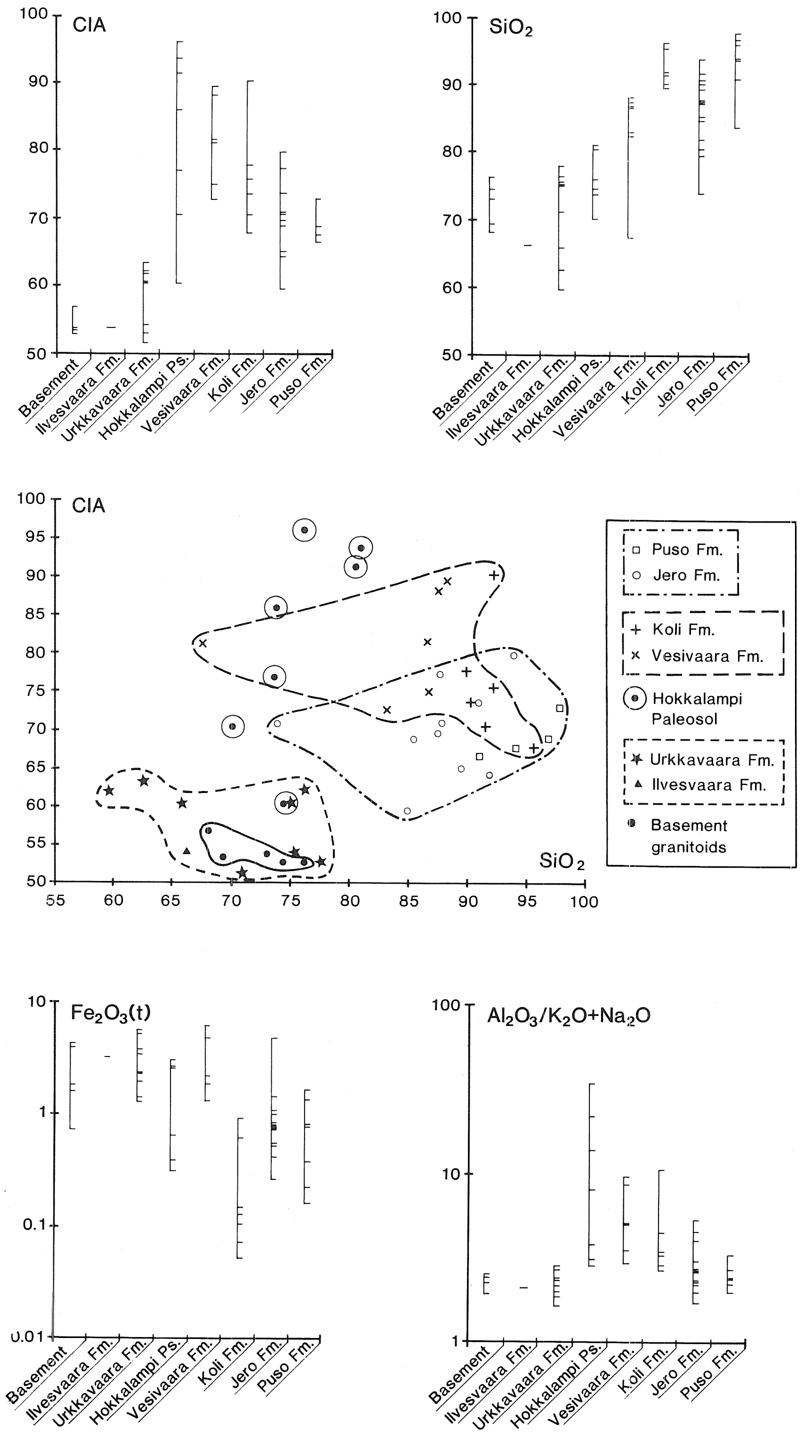

Fig. 33. Variation of CIA, SiO_2, total iron and Al_2O_3/K_2O+Na_2O within the studied formations. CIA versus SiO_2 plot for the same samples is also shown.

Hokkalampi Paleosol, lime, magnesia and sodium are virtually absent in these sediments. Two striking features concerning iron concentration can been seen from Table 6 and Fig. 33: the aluminous rocks of the Vesivaara Formation are clearly enriched in total iron relative to the paleosol but show very low contents of ferrous iron. The Koli Formation is virtually devoid of iron.

Within the lower member of the **Jero Formation** the upward decreasing maturity can also be observed in the chemical composition, in that the ratio of K_2O/Al_2O_3 increases along with the increasing K-feldspar content. The iron contents of the Jero Formation are low for an arkosic rock (cf. Pettijohn et al., 1972). Relative to the sandstones of the Kyykkä Group, both the contents of iron and sodium are lower in the Jero Formation. According to the CIA values obtained (Table 7), the degree of chemical alteration within the formation is generally low to moderate.

The chemical composition of typical **Puso Quartzite** is charactized by a very high SiO_2 content, corresponding to that of true quartz-arenite (Fig. 32). In comparison with the quartzite and sericite-quartzite of the Koli Formation, these rocks also accordingly have slightly lower abundances of alumina (Table 7). Some samples show secondary albite, and in the quartzites of the Puso Formation, alumina, alkali- and alkaline-earth contents are generally close to the limits of analytical detection. Consequently, the low CIA values for these rocks may not be very reliable, but are, however, consistent with the observed mineral composition (K-feldspar).

The variation in some major elements, and parameters calculated from these, for the studied rocks have been plotted in Figure 33. Both CIA values and silica content can be interpreted to reflect maturity characteristics. The samples from the basement and from the metasediments of the Kyykkä Group clearly form a group characterized by their low silica content. On the other hand, the variation in CIA values allows the distinction of two groups, namely that comprising the Kyykkä Group, showing very low to low values and that containing the Herajärvi Group, which shows values comparable to those of the Hokkalampi Paleosol, ranging from low to very high. In addition, the plots for the Herajärvi rocks fall into two fields. The Vesivaara and Koli rocks form the first field, CIA values ranging from moderate to very high, most probably indicating their genetic relationship to the paleosol. The second field is contains data from the Jero and the Puso rocks, characterized by low to moderate values for the index.

PALEOCURRENTS

Paleocurrent directions were determined on outcrops, wherever the geometry of the cross-bed and the strike and dip the horizontal bed could be defined, the total number of measurements gathered being 504. All directions were corrected for tectonic tilt; fold axis correction appears to be unnecessary because the strata are not markedly deformed into plunging folds. The only exception is the sequence located at the eastern limb of the Kolinniemi Syncline (Group 8 in Table 8), where some clockwise rotation is to be expected. All the determinations were assembled according to geographical location and are presented in Figure 34.

Exposure in the study area is controlled by structural lineaments. Therefore, observations made were concentrated along NNW-SSE oriented hillsides. This may induce an apparent bimodality into the current directions perpendicular to the dominant plane of exposure. This possible error especially concerns planar cross-beds, because only those structures deviating from the observation direction can be discerned on a two-dimensional surface.

The number of measurements within the Kyykkä Group is small and there is a large variation (Table 8); consequently, evaluation of data is difficult. Within the Herajärvi Group, measurements in the two lower formations (Vesivaara and the Koli Fms.) indicate a general westward transport. However, in the Koli Formation the variability in paleocurrent direction is rather pro-

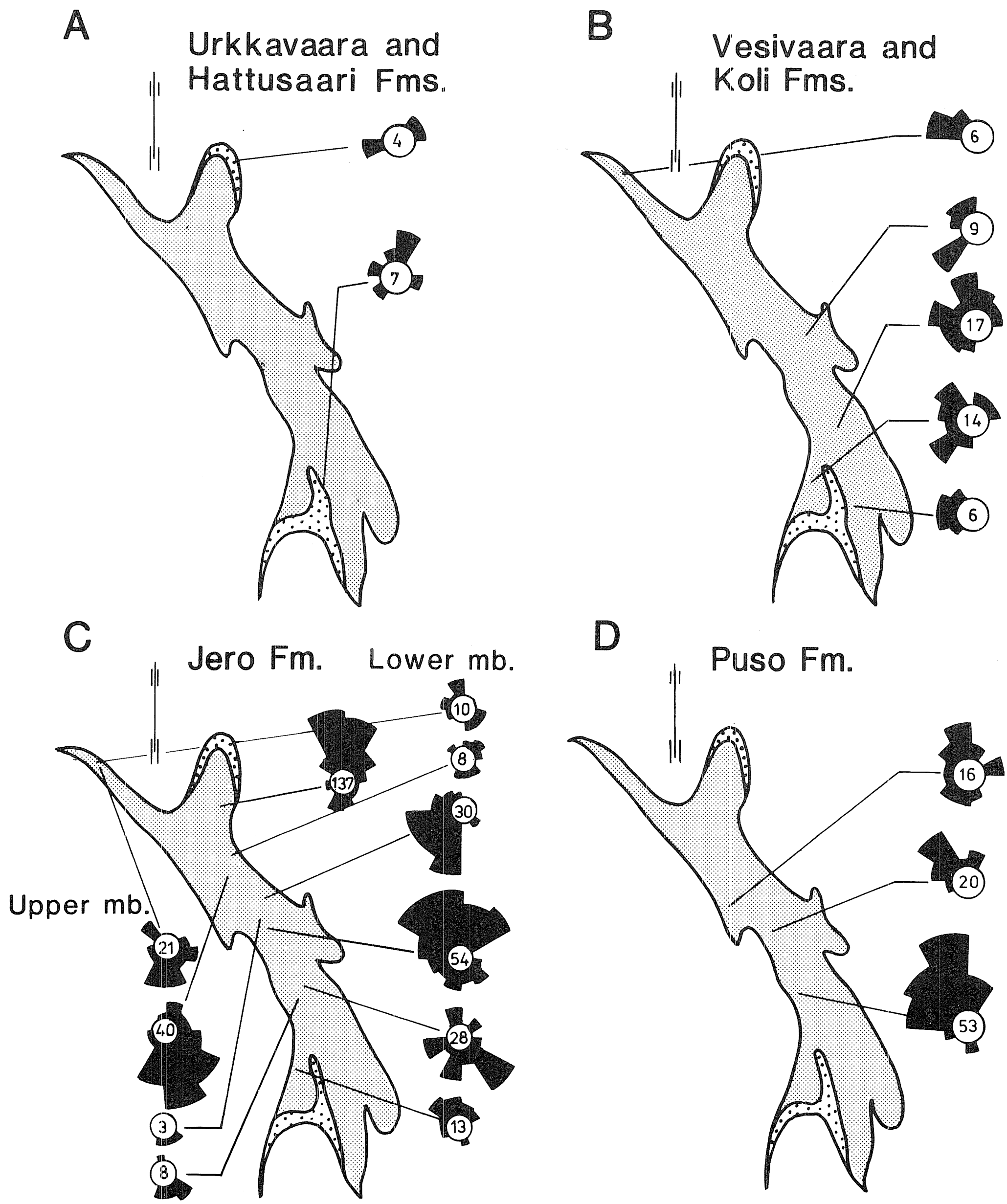

Fig. 34. Paleocurrent rose diagrams representing depositional stages: A — Kyykkä Group, B-D — Herajärvi Group. Observation sites and numbers of measurements are also given.

nounced. Measurements in the Jero Formation clearly indicate that transport directions for the lower conglomerate member and for the upper arkosite member differ considerably. Within the lower member, the paleocurrent directions mostly plot toward the southwest, west or northwest, although variation, again, is considerable. For the upper member, transport of detritus toward the south is undisputably indicated. During the deposition of the thick Puso Formation, the sediment was clearly carried toward the northwest.

Table 8. Paleocurrent statistics for grouped data (see Fig. 34 for groups).

Group	Number of readings	Vectoral mean (bearing in degrees)	Magnitude of resultant vector	Consistency Ratio (%)	Standard Deviation (degrees)	Variance (degrees^2)
1	4	321	0.2	5.4	87	7569
2	7	358	2.7	38.5	60	3583
3	6	286	5.9	98.3	10	93
4	9	282	6.1	67.3	42	1773
5	17	314	8.1	47.7	56	3149
6	14	274	6.6	47.2	57	3257
7	6	278	5.4	89.4	23	506
8	137	3	71.0	51.8	51	2553
9	10	317	3.1	30.6	71	4970
10	8	75	2.7	34.2	64	4064
11	30	234	22.6	75.4	33	1087
12	54	339	20.5	37.9	61	3760
13	28	181	9.4	33.7	66	4342
14	13	332	8.2	62.7	45	2004
15	21	169	11.3	53.7	51	2586
16	40	147	23.1	57.7	47	2236
17	3	164	2.8	94.2	18	312
18	8	147	5.0	63.0	44	1903
19	16	302	4.6	28.6	69	4778
20	20	314	17.3	86.7	24	566
21	53	327	44.9	84.8	26	692

Groups (see also Fig. 34): 1. Hattusaari Fm. map sheets 4313 09, 12, 2. Urkkavaara Fm. map sheets 4224 11, 12, 3. Vesivaara Fm. map sheet 4313 06, 4. Vesivaara and Koli Fms. map sheet 4313 11, 5. Koli Fm. map sheets 4242 03, 4331 01, 6. Koli Fm. map sheet 4224 12, 7. Koli Fm. map sheet 4242 03, 8. Jero Fm., lower mb. map sheet 4313 09, 9. Jero Fm., lower mb. map sheet 4313 06, 10. Jero Fm., lower mb. map sheet 4313 11 B, 11. Jero Fm., lower mb. map sheet 4313 11 C, 12. Jero Fm., lower mb. map sheet 4313 10 C D, 13. Jero Fm., lower mb. map sheet 4313 10 C, 14. Jero Fm., lower mb. map sheet 4224 12, 15. Jero Fm., upper mb. map sheet 4313 06, 16. Jero Fm., upper mb. map sheets 4313 08, 11, 17. Jero Fm., upper mb. map sheet 4313 10 C, 18. Jero Fm., upper mb. sheet 4313 10 C, 19. Puso Fm. map sheets 4313 08, 11, 20. Puso Fm. map sheet 4313 10 B, 21. Puso Fm. map sheets 4224 12, 4313 10.

DEPOSITIONAL SETTING

Detailed environmental interpretations and discussions are beyond the scope of the present paper and can be found in Marmo and Ojakangas (1984), Marmo (1986, 1992), Kohonen (1987) and Marmo et al. (1988). However, some new ideas have recently arisen and as depositional environments and tectonic settings are intimately related, a brief interpretational review is presented.

The immature character of the **Ilvesvaara Formation,** reflecting the composition of the local basement rocks, suggests that mechanical erosion dominated over chemical weathering during deposition. The model preferred by Marmo (1986) is one in which deposition was initiated by the creation of topographic contrasts as a result of high-angle normal faulting. Fracture zones acted as sites of mechanical disintegration. The material remained either in situ or, with the steepening of topographical relief, was transported into valleys. In this model fluvial action further reworked and transported the coarse detritus in topographic lows, resulting in the better sorted gravels and arkosic sands of the upper part of the Ilvesvaara Formation.

An alternative model for interpreting the lowest unit of the formation is to attribute the observed physical disintegration of the gneiss to »ice shattering». The observed features may be attributed to stress generated by a thick, flowing continental ice sheet that broke the gneiss in large fragments. The cavities between the fragments may have been simultaneously injected and filled by glacial rock flour (see Fig 5.). The overlying boulder-dominated conglomerates might thus be interpreted as terrestial tills.

A detailed glacial model invoking repeated advances and retreats has been proposed as the environment of deposition of the **Urkkavaara Formation** by Marmo and Ojakangas (1984) and Marmo (1986). They suggest that the lower part of the formation was deposited near a grounded or floating glacier. In this model, the lower siltstone-argillite facies containing dropstones was deposited in front of the glacier as a silt-clay rhythmite sequence. The graded sandstone facies was deposited closest to the glacier front by turbidity currents during glacial advance. Glacial retreat revived siltstone-argillite deposition followed by the diamictites in a more distal aqueous environment.

Deposition of the upper graded sandstone member on top of the diamictite member is, again, attributed to an advance of the glacier. The considerable thickness (50 to 70 meters) indicates that the ice-front probably remained stable for a considerable span of time. The overlying but transitional parallel-bedded conglomerates are interpreted as products of sedimentation from subaqueous meltwater tunnels during the same stage. Finally, the massive conglomerates and associated cross-bedded pebbly arkoses are considered to have accumulated as proglacial sandur and/or esker deposits laid down in front of the retreating glacier.

The sedimentary rocks of the conglomeratic **Hattusaari Formation** have been interpreted as proximal braided river or alluvial fan deposits (Marmo et al., 1988). Facies associations of the Trollheim type (Miall, 1978) characterize the lower part of the formation, and those of the Scott type are typical of the upper part. The relationship of the Hattusaari Formation to the overlying paleosol and its sedimentary characteristics suggest that the rocks of the formation might be correlative with the upper part of the Urkkavaara Formation.

It has been suggested that the quartz-sericite schist underlying the Herajärvi Group originated as a paleosol (Marmo, 1986, 1992). This interpretation is based on zonal variations in the chemical and mineral composition of its profiles and its association with the overlying aluminous and quartzitic rocks, which were formed during subsequent soil erosion. The chemical maturity and the great thickness of the paleosol and associated metasediments are interpreted to record intense chemical weathering under a warm and humid climate. The interpretation seems valid, although schists rich in aluminium may also result from hydration in shear zones (e.g. Etheridge and Cooper, 1981; Sinha et al., 1986) and the Hokkalampi rocks evidently underwent intensive tectono-metamorphic processes after their formation (e.g. Ward and Kohonen, 1989).

The lower part of the **Vesivaara Formation,** characterized by matrix-rich quartz-pebble conglomerates, has been interpreted (Kohonen, 1987; Marmo et al., 1988) as consisting of mass flow deposits which were initiated in an environment of moderate topographic relief, with an abundance of weathered detritus (soils of the Hokkalampi profiles), and seasonal flash floods. The better sorted and largely cross-stratified upper part of the formation may be interpreted as deposits formed in proximal braided rivers or alluvial fans.

Characterized by well-sorted massive gravels and superimposed upward-fining cycles, the conglomerate member of the **Koli Formation** has been considered (Kohonen, 1987; Marmo et al., 1988) to correspond to the Scott-type braided river sediments of Miall (1978). The environment of deposition was probably a braidplain, where the conglomerates were deposited as bars or channel fills and the sandy interbeds resulted from changes in flow discharge.

Two lithofacies associations (Marmo et al., 1988) are distinguished within the quartzite member of the Koli Formation: the northern coarse sand — fine gravel association and the southern sand-dominated association. The southern association is comparable to the Bijou Creek-type of Miall (1977, 1978), which represents poorly channeled braided stream deposits formed in an ephemeral environment characterized by catastrophic floods. The dominant horizontally laminated sands are interpreted as sheet flood deposits (see McKee et al., 1967; Williams, 1971) having wide areal extent. The presence of desiccation cracks clearly indicates the subaerial environment of deposition.

The northern association is characterized by massive pebble conglomerates and trough cross-bedded sands. It differs from the southern association not only in grain size but also in being better sorted. This association has features common to both the Scott- and Donjek-types of Miall (1977, 1978), associations typical of proximal and distal braided stream deposition, respectively. The most striking features within this association are the thick, crude, upward-fining cycles of high lateral continuity. These are interpreted to have been deposited as bars on a braidplain. The sand-dominated and gravel-dominated associations grade laterally into each other and are interdigitated within several mapping profiles. Consequently, the northern part of the study area may represent a more proximal environment of deposition.

The conglomerate member of the **Jero Formation** begins as an upward-coarsening sequence (Fig. 19) typical of prograding systems (e.g. Steel and Aasheim, 1978; Heward, 1978; Miall, 1982). The lower facies association of the member consists of trough cross-bedded sericite-quartzites with minor gravel lag conglomerates. The relatively thin upward-coarsening cycles are interpreted as products of braided river channel fill or bar deposition. The absence of upward-fining cycles on top of the gravelly facies might reflect partial drying of the bars in a river system featured by rapid falls in water depth during waning flow (cf. Costello and Walker, 1972; Crowley, 1983).

The upper association of the lower member, characterized by upward-fining cycles and cross-bedded gravelly or sandy lithofacies, resembles sediments of the Donjek-type of Miall (1977, 1978), which are interpreted to result from deposition in a cyclic, gravelly braided river. Because substantial sorting and reactivation surfaces are lacking within the unit, deposition is assumed to have occurred from heavily loaded rivers near the margin of a rapidly subsiding basin.

As a whole the conglomerate member reflects an upward increase in the sediment supply and improved channeling. A suggested paleoenvironment is a braidplain, which due to increased rate of subsidence developed into an alluvial plain.

The ubiquitious giant-scale trough cross-bedding within the arkosite member of the Jero Formation appears to be a »key structure» in a model of deposition. According to Miall and Gibling (1978), these structures can be formed in two contrasting environments, either as eolian dunes or as fluvial sandwaves. The coarse grain size and rather poor sorting rule out the former alternative. Large-scale cross-beds form in large deeply channeled rivers (Miall, 1982). The scale and morphology of the cross-beds in the arkosite member closely resemble those formed by the migration of sand waves in the Brahmaputra River (Coleman, 1969).

The **Puso Formation** is enigmatic because of the absence of primary structures or facies associations diagnostic of any specific environment of deposition. Uncertainty also arises because the nature of primary contacts is vague. The dominance of horizontally bedded sands does, however, favour deposition in the upper flow regime. The well rounded and sorted detritus suggests substantial reworking and/or a polycyclic origin. All these features indicate to a near shore environment, and especially a swash zone (Eriksson, 1978; McCubbin, 1981). However, due to its great thickness, the formation cannot have formed during single transgression. Therefore, the formation probably represents the result of protracted filling of an aggradational basin, during which several depositional environments and subenvironments must have existed.

The lower and middle parts, characterized by horizontally bedded and planar cross-bedded sands, represent the best sorted units within the formation. The former are interpreted to have been deposited in high energy conditions within the beach zone. McCubbin (1981) reports a very similar facies association occurring in a barrier island environment, where tangential asymptotic cross-bedded sands are interlayered with horizontally bedded units. The presence of more weakly sorted sericitic quartzites in the middle part of the formation could reflect a fluvial incursion within an otherwise nearshore environment.

In the upper part of the Puso Formation, small-scale cross-beds arranged into cosets predominate. This lithofacies may form in several nearshore, shelf or fluvial environments. Thus, a more detailed interpretation is not yet appropriate. Also the interpretation for the lower part must still be regarded as preliminary and tentative, demanding detailed future fieldwork.

Given that marine processes were involved during the deposition of the Puso quartzite, associated distal fine sediments and carbonates should also have been formed. The north-westerly trending paleocurrents probably indicate the direction of the paleoslope and, consequently, the direction which may be most promising to look for the interdigitation of marine sediments.

PROVENANCE

The conglomerates in the Kyykkä Group provide direct evidence of their provenance. Both the Ilvesvaara Formation and the lower part of the Hattusaari Formation simply reflect the composition of the local basement rocks. The former contains almost exclusively granodioritic to tonalitic fragments while in the latter, the majority of fragments were derived from a source area composed of felsic to ultramafic volcanics, such as occur in the adjacent Archean greenschists. The arkosic upper part of the Hattusaari Formation with abundant K-feldspar suggests a source consisting dominantly of felsic plutonics.

Except for the fine-grained intraformational clasts, the lithic fragments of the Urkkavaara Formation are composed dominantly of coarse to fine-grained granites, granodiorites and tonalites. Sporadic mafic to ultramafic rock fragments (now chlorite schist) have also been observed. Given the glaciogenic origin for the formation, the source area must have been extensive, covering thousands of square kilometers. The low values for the CIA indicate a source area with no significant chemical weathering. Mature rock fragments, such as orthoquartzites, are absent as well. As the diamictites represent an average composition of the source area and as their chemical compositions resemble that of a granodiorite, it may be assumed that the source area consisted of plutonic rocks similar to the Archean basement exposed today to the east of the study area.

Field relationships supported by mineral compositions (no feldspar) and chemical data (high values of CIA) suggest that the Vesivaara and Koli Formations (and perhaps also the sericite-rich lowermost part of the Jero Formation) have a close genetic relationship with the Hokkalampi Paleosol. The primary material within the sediments of the Vesivaara Formation probably consisted of detrital quartz (65 to 80 %) and residual clay (20 to 35 %), now metamorphosed into sericite and aluminosilicates. Low textural maturity indicates a short transport distances with little reworking and thus proximity to the source.

The clast material in the conglomerates of the lower part of the Koli Formation provides direct evidence concerning the composition their source. The ultimate source of the quartz and tourmaline-quartz clasts was presumably veins in the Archean basement complex. Because of their resistance to weathering these clasts were reworked into gravel deposits.

The chert-like clasts in these conglomerates may well have originated in weathering processes through silicification, or else represent true chemical sediments derived from the Archean terrain. The former idea is supported by the presence of tiny rutile needles in these fragments (see Summerfield, 1983). According to Summerfield (1983), silcretes are typically formed in soils of humid climatic conditions and indications of silicification have been reported from the Hokkalampi Profile (Marmo, 1992). Sericitic and aluminous clasts present in the basal part of the conglomerate are interpreted as fragments derived from the paleosol.

The association of relatively high abundances of original clay material, now represented by sericite and aluminosilicates, with rounded quartz clasts is typical of quartzites of the Koli Formation; exceptions however include quartz-cemented »glassy» interbeds and strongly strained, recrystallized quartzite varieties. The preservation of clays during depositional processes that produce rounded quartz clasts is improbable (Folk, 1951) and this kind of »textural inversion» (Pettijohn et al., 1972) is usually interpreted as representing the mixing of already mature sands with clays during the final depositional process. However, the present authors prefer a single-cycle model with a regolith as a source for these feldspar-free quartzites (cf. Akhtar and Ahmad, 1991). The rounded clasts may have been derived from the sediments below the regolith and/or underwent rounding during weathering, as described by Crook (1968) and Koryakin (1971).

The high proportion of sericite (originally clay) and the presence of variably altered feldspar grains at the base of of the Jero Formation reflect the abundance of chemically weathered material in the source area. The upward increase in the feldspar content can be attributed to advanced erosion exposing unaltered basement granitoids or older immature sediments. The rarity of quartzite fragments even in the lowest part of the Jero Formation and the variable degrees of roundness of detrital quartz could be attributed to poor lithification of the Koli quartzite prior to deposition of arkoses (Piirainen et al., 1974). However, observations from the lower contact of the formation support a model in which normal faulting was followed by rapid subsidence and an increased rate of sediment supply. The proximal parts of the rift basin are represented by quartzite block breccias whereas even the basal parts of the formation further from fault zones would be characterized by basement-derived material and consequent absence of quartzite fragments.

The relatively small proportion of lithic fragments in the conglomerate member could indicate that the source terrane mainly consisted of coarse-grained plutonic rocks susceptible to physical breakdown during transport. Fresh microcline clasts, some of which are several centimeters in diameter, may in turn have been derived from Archean porphyric granodiorites of the adjacent basement area, which according to Frosterus and Wilkman (1920), contain large microcline phenocrysts.

The majority of blastoclastic feldspar in the arkosite member of the Jero Formation, in contrast to the lower member, consists of plagioclase (albite-oligoclase). Together with distinctly different paleocurrent directions for the two members, this has been interpreted to reflect the change to a tonalitic-trondhjemitic source area (Marmo et al.. 1988). However, the observed quartz-albite-biotite-muscovite assemblage (with additional chlorite and epidote) is a typical low grade metamorphic mineral paragenesis. The sericitic arkosites are often strongly schistose, in contrast to the quartzites of the study area, and if the abundant sericite represents primary clay matrix, the sediments were originally rich in water. During metamorphic dehydration substantial dissolution of unstable grains and consequently, loss of provenance information may have occurred.

The detritus of the Puso Formation does not offer much information regarding its source. The clastic feldspar in the formation is dominantly K-feldspar, which compared to plagioclase is more resistant to both chemical and physical weathering (Pettijohn et al., 1972). Thus, K-feldspar may have been concentrated through reworking of the underlying arkosite of the Jero Formation.

Alternatively, if the alteration of feldspars into sericite and carbonate in the arkosite member is attributed to premetamorphic in situ chemical weathering and represents the development of a soil horizon, the plagioclase might have decomposed prior to reworking. Detailed studies on these rocks still need to be done, but this interpretation might help in understanding the origin of the thick Puso orthoquartzite.

DISCUSSION

Speculation concerning supracrustal conditions during deposition

The deposition of enormous amounts of quartz sand seems to be a fundamental characteristic of Early Proterozoic platforms (e.g. Salop, 1977, 1983; Long, 1978) and may represent a unique environment not repeated later in geological history. It is widely accepted that the lack of terrestrial vegetation implies that runoff, and probably also climate, were different from present conditions (e.g. Schumm, 1968). However, there is less of a consensus concerning early Proterozoic surface temperatures, pH-Eh-conditions, atmospheric composition and the rheological behaviour of the crust, all of which are important factors controlling the rate of weathering and styles of basin evolution. These uncertainties limit the validity of the interpretations derived from recent anologues. Nevertheless, some general inferences concerning Early Proterozoic conditions, based on the studied sequence, can be presented.

The association of the glaciogenic Urkkavaara Formation and the warm and humid climate Hokkalampi Paleosol attest to a drastic climatic change. Unfortunately, we are unable to estimate the rate of these fluctuations, although recent paleomagnetic studies (Mertanen et al., 1989) suggest that the Fennoscandian Shield drifted several tens of degrees towards equatorial latitudes 2.3 — 1.95 Ga ago. The strong depletion of ferrous iron from the Hokkalampi Paleosol indicates reducing conditions within the soil profile, but on the other hand the abundant hematite, if primary, in the overlying aluminous sediments (Vesivaara Formation) could record oxisol development.

The quartzite sequences of the study area show a paucity of fine sediments and a striking monotony in the sedimentary style. Facies models derived from recent deposits may not be entirely appropriate for the interpretion of all formations in this area. Quartz-rich detritus seems, in contrast to Phanerozoic basins, to be intensively accumulated in every kind of depository, excluding those with very rapid sedimentation. The present authors suggest that during stable platform deposition, the following features were characteristic:

(1) Intense and deep weathering, that according to some isotopic studies (e.g. Karhu and Epstein, 1986), may have taken place at a higher surface temperature than at present. This resulted in the formation of enormous amounts of clay and detrital quartz destined to be reworked into first cycle clayey quartz sands and, by further sorting, into quartz arenites.

(2) Conditions of a kind of an ephemeral macrodesert prevailed with periodic floods governing the style of sedimentation and perhaps precluding the formation of large eolian dunes, sabhkas and other features diagnostic of present sand seas. Sheet flood deposition took place in poorly channeled braided streams over a gentle topography with local escarpments.

Sedimentary sequence and preservation of formations in relation to extensional movements

An important, although often ignored, component of basin modeling is the preservation of a given unit. Principally, both deposition and preservation are controlled by the subsidence-uplift path of the area, but preservation of a certain formation is not necessarily directly related to factors controlling sedimentation of the same unit.

For example, platform-type sequences are, in case of continuously uplifting craton, often subsequently erased but may be locally preserved at the base of a relatively downfaulted block. In general it may be that in cratonic environments potential marker horizons of extensive lateral continuity often have little chance of surviving regionally. In contrast, thick sediment accumulations with high preservation potential occur in certain, rapidly subsiding tectonic regimes (e.g. aulacogens) but these deposits are by their nature less valuable for broad regional correlation. Thus, a basin evolution model must include, in addition to factors controlling the deposition of the formations, consideration of reasons for the burial of deposits with a low preservation potential.

The studied stratigraphic sequence comprises a succession of immature deposits (the Kyykkä Group), supermature deposits indicating subaerial chemical weathering (the Hokkalampi Paleosol, the Vesivaara and Koli Fms.), immature alluvial deposits (the Jero Fm.) and, again, mature sediments (the Puso Fm.).

The sporadic distribution of the Kyykkä Group indicates that these formations were probably deposited in basement-bounded rift basin. In addition, the Kyykkä area in the south seems to have remained a relative topographic low during the development of the Hokkalampi-type soils and related deposition of the supermature sediments. The latter explanation for preservation is based on the presence of the most complete sections of the paleosol within this area, and on the fact that quartz-pebble conglomerates representing the proximal facies of the Koli Formation are nearly absent on top of the paleosol.

Pediment formation, represented by the Hokkalampi Paleosol and associated sediments, may have been continent-wide, and the environment of deposition was probably also rather uniform regionally. However, it is suggested that localized rapid subsidence, indicated by the alluvial sediments of the Jero Formation, was the main factor controlling burial of these deposits: the downfaulted base of the Jero basin provided the opportunity for preservation of the aluminous rock record. The basement derived, proximal-type sediments in the lower parts of Jero Formation indisputably demonstrate that Archean rocks were exposed to erosion outside the marginal faults of the basin. Accordingly, the present distribution of the Vesivaara and Koli Formations and the paleosol seems to have been controlled by the margins of the Jero basin.

The mafic intrusions within the sequence are useful, not only because they indicate a minimum age of the truncated strata, but also in evaluation of the basin model. The mafic intrusions with age about 2.2 Ga (karjalites) have not been observed to cut the uppermost Puso Formation. These intrusions form long, gently dipping sill-like sheets close to and along the Archaen — Proterozoic boundary. The presence of magnetite in part of these differentiated units (Vuollo and Piirainen, 1992) results in distinctive anomalies in airborne magnetic maps showing a pattern with NW-striking, SW-dipping main intrusions linked to steeper perpendicular zones (Fig. 35). Recent studies (Wernicke and Burchfiel, 1982; Lister et

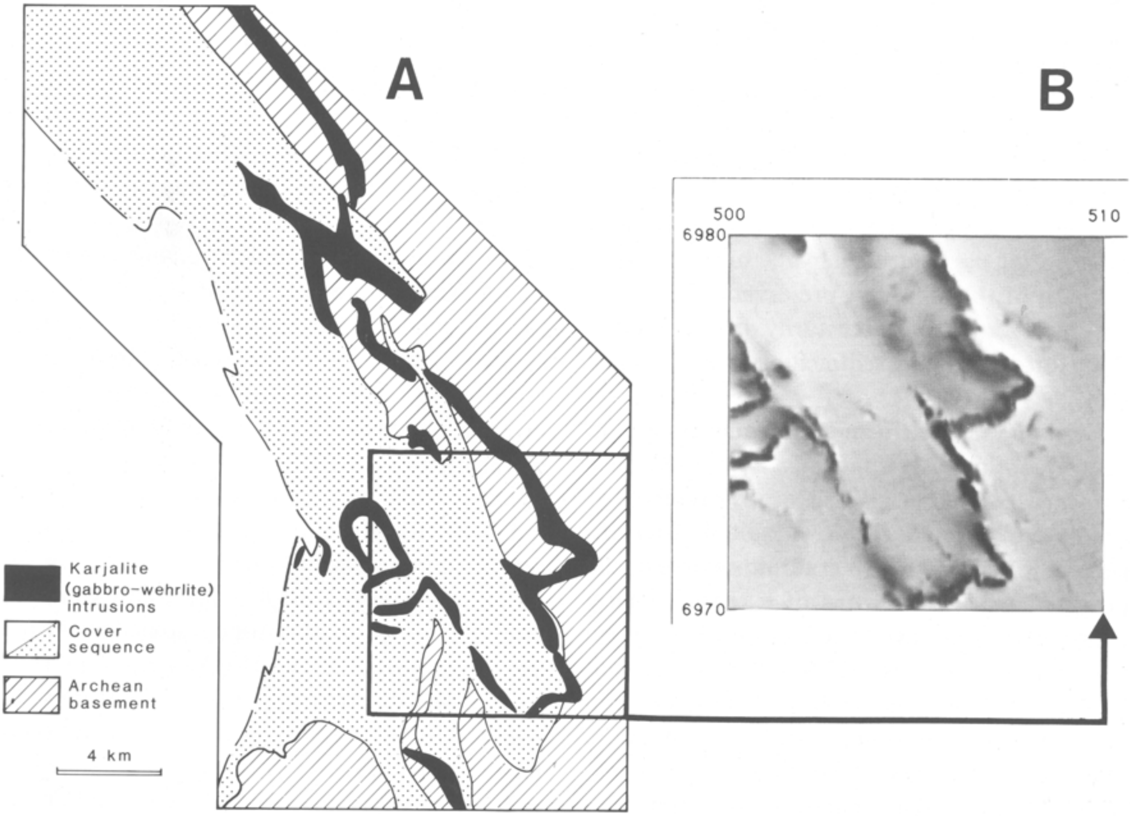

Fig. 35. (A) Distribution pattern of karjalite intrusions in the southern part of study area. Location of the area in airborne magnetic grey tone map (B) is also shown.

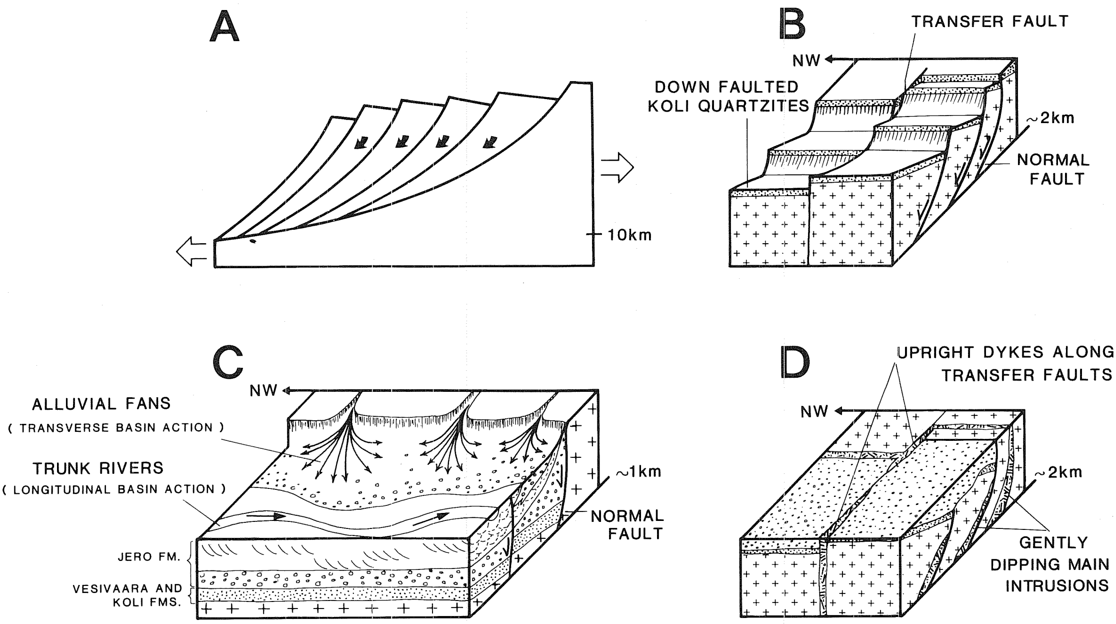

Fig. 36. (A) Schematic model representing listric fault system related to crustal extension. Effects of rifting are illustrated as follows: (B) preservation of pre-existing platform-type strata, (C) deposition of the alluvial Jero formation and (D) intrusion of mafic magma along fault planes.

al., 1986) indicate that crustal extension takes place, in addition to subvertical normal faults, along gentle, curved listric faults. In the upper crust this type of fault surface might offer spaces for intruding magma (Fig. 36).

Within the study area the karjalitic intrusions and the Archean-Proterozoic boundary are spatially closely related (see Fig. 2). However, the occurrence of karjalites most typically within rather homogenous basement granitoid gneisses implies that the basement-cover boundary did not control the emplacement of these intrusions. Instead, it is suggested that the location of the Archean-Proterozoic nonconformity on the present surface of erosion reflects relative downwarping of the block west from the intrusions during the development of the rift structure. Accordingly, the zone of these intrusions marks the approximate edge of the Jero basin and represents a 2200 Ma old escarpment in the basement relief.

Because the basal contact of the Puso Formation has not been observed, the possibility that a hiatus separates it from the underlying sequence cannot be excluded. The quartzites of the formation reflect prolonged stability, but significant subsidence was also necessary in order to accumulate such huge amounts of sediment. This phase was evidently again followed by rifting and associated tholeiitic magmatism, represented by numerous mafic dykes. However, because the upper contact of the Puso formation is also unexposed, the exact nature of the transition from Puso stage sedimentation to mafic magmatism remains vague. It is tentatively assumed that the accelerated subsidence of the developing rifted continental margin, which probably had no direct connection to the Puso deposition, may have caused the final preservation of the studied platformal record.

Regional correlations

The genesis of the studied sequence, and corresponding Karelian systems in general, covers a time span of 250 to 500 million years. At any realistic rate of continuous net sedimentation (cf. Sadler, 1981), deposits tens or even hundreds of kilometers thick should be expected. Furthermore, more than one third of the studied section was presumably deposited in rift basins during a relatively short time interval. Although a much greater period of time is probably recorded in the quartzites and associated units, especially in the paleosol (cf. Kraus and Bown, 1986) even these probably only represent relatively minor intervals with respect to the entire time period. Consequently, the fundamental question in lithostratigraphic correlation cannot be avoided: can it be assumed that the rocks studied and other scattered remnants of Early Proterozoic cover in the eastern part of the Fennoscandian (Baltic) Shield represent coeval deposition? From this point of view, the regional correlation of a certain quartzite formation or its interpretation as a part of a geological evolution paradigm require special care, especially, if relations to the sedimentary sequence as a whole are unknown and/or age data are insufficient. These questions and the underlying concepts involved in correlation within multiply rifted Karelian Domain are discussed in

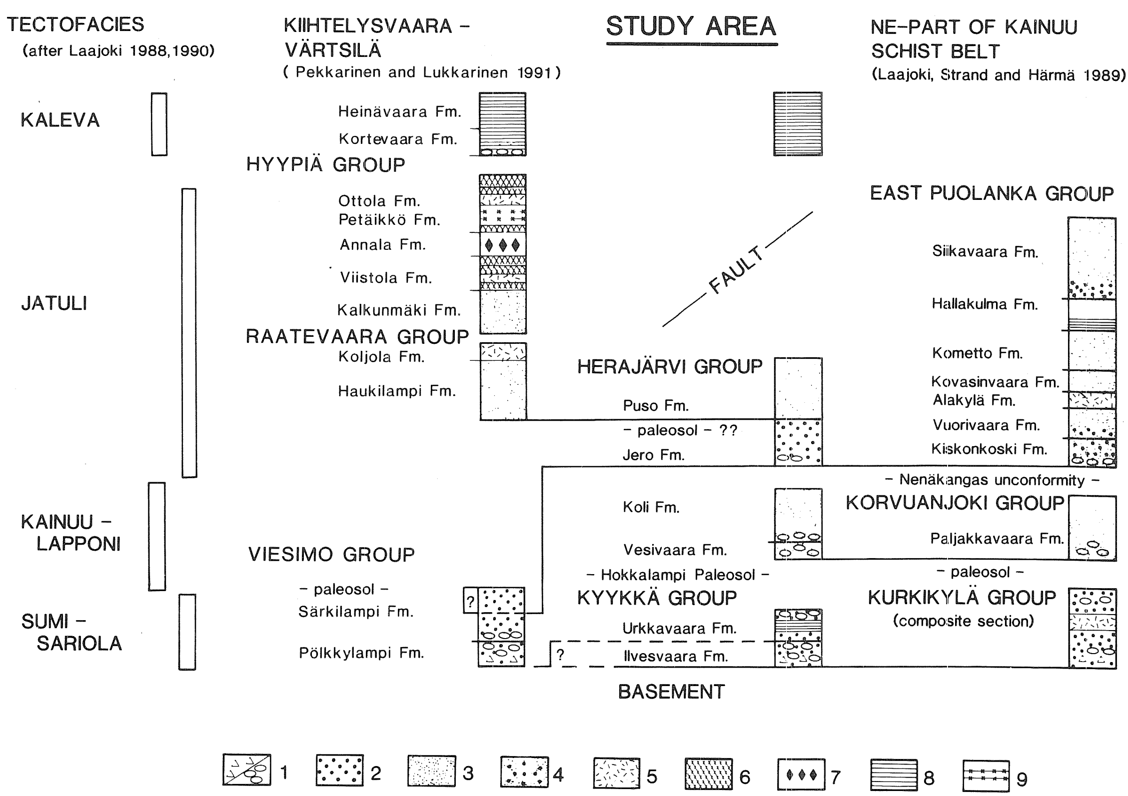

Fig. 37. Lithostratigraphic correlation of the Karelian rocks in the study area with the Kiihtelysvaara-Värtsilä and Kurkikylä-Siikavaara areas. Lithologies and relative thickness of formations are schematic.
1 = breccia-conglomerate/conglomerate; 2 = arkosite; 3 = quartzite; 4 = feldspathic quartzite; 5 = mafic volcanite; 6 = dolomite; 7 = iron formation; 8 = mica schist; 9 = black schist.

more detail by Kohonen and Marmo (in press).

The Kainuu Schist Belt to the northwest of the study area and the Kiihtelysvaara-Värtsilä Area (the southeastern part of the North Karelia Schist Belt) appear to be the most relevant and useful in regional correlation (Fig. 37). In addition, some tentative comparisons with the platform sequence in the adjoining Russian Karelia are presented.

Although the Ilvesvaara Formation is of very limited extent, even within the study area, similar rock types have been reported from the base of Proterozoic sequences in a number of areas in the Fennoscandian Shield. In Kainuu, Sariola-type sediments have been described at several places (Väyrynen, 1954; Laajoki, 1973; Strand, 1985; Laajoki et al., 1989) and basal breccias within the Laanhongikko Formation of the Kurkikylä Group may be correlated with the Ilvesvaara Formation. The Latvalampi Formation of the Saari-Kiekki belt at Kuhmo (Luukkonen, 1989) and perhaps also some basal breccias (e.g., Sääperi) in the Kiihtelysvaara — Värtsilä area (Pekkarinen, 1979) resemble the Ilvesvaara Formation. In the Russian Karelia, Koryakin (1971) also reported analogous deposits. All these occurrences of brecciated Archean basement gneisses and local basement clast conglomerates are interpreted to have resulted mainly from in situ mechanical weathering.

Glaciogenic deposits have recently been reported from Kainuu (upper parts of the Laanhongikko Formation in Kurkikylä area) (Strand, 1988; Laajoki et al., 1989) and their stratigraphic position seems to be approximately the same as that of the Urkkavaara Formation. In the middle part of the Kiihtelysvaara area, at Saralampi, Särkilampi and Viesimo, the basement is overlain by diamictites with basement-derived clasts, arkosic conglomerates with interlayered arkosites, and siltstones containing dropstones (Ojakangas et al., 1989). These diamictites show a sharp, angular unconformable contact with the Archean rocks (Pekkarinen, 1979).

In Russia Karelia, mafic volcanics form an essential part of the Sumi-Sariola sequence. Tillites, glaciolacustrine or glaciomarine beds with dropstones, and glaciofluvial deposits have been reported in both Karelia (the Paanajärvi Formation) and in the Kola Peninsula (Lower Akhmalahti Formation) (Salop, 1983; Ojakangas et al., 1989). If all these occurrences of glaciogenic deposits in eastern Finland and adjacent Russian Karelia are products of the same glaciation, they have significance in intracontinental, or perhaps even in intercontinental (see Ojakangas, 1985, 1988) correlation.

An Early Proterozoic paleosol underlies quartzites in Kainuu (Pekkala, 1982; Strand, 1985; Laajoki, 1986) and a similar association has also been reported also from Russian Karelia (Koryakin, 1971; Sokolov and Heiskanen, 1984). All the paleosols resemble the Hokkalampi paleosol in being essentially composed of quartz-sericite schist, but are generally much thinner. However, the paleosol in Kainuu (Hallavaara, Kurkikylä), 300 km north of the study area, is several tens of metres thick and also contains aluminosilicates (Strand, 1985). Moreover, it developed on a similar sedimentary, glaciogenic protolith. The paleosol clearly has potential as a marker horizon in the regional correlation of the Karelian sequence, since wherever the extraordinary association of glacial deposits and paleosols is present, the likelihood of a valid correlation is much improved.

In the northern part of the Kainuu Schist Belt, the Paljakkavaara and Lukkarinvaara Formations, comprising the Korvuanjoki Group (Laajoki et al., 1989), are representatives of the »Kainuu lithostratigraphic type» (Laajoki, 1986) or »Kainuu tectofacies» (Laajoki, 1988a). Ferruginous and aluminous quartz pebble conglomerates and quartzites, similar to the Vesivaara Formation and overlying a paleosol, have been reported from the lower part of the Paljakkavaara Formation (Strand, 1985; Laajoki et al., 1989). Parts of the Paljakkavaara and Lukkarinvaara Formations are lithologically similar to the Koli Formation. Thus, lithostratigraphic correlation of these units, as suggested by Laajoki et al. (1989) seems tenable.

In northern Kainuu, the Nenäkangas-type conglomerates (Laajoki, 1988b) and the dominantly arkositic Kiskonkoski Formation (Laajoki et al., 1989), in places unconformably overlying the Korvuanjoki Group, can be correlated with the Jero Formation or at least its lower parts (Fig. 37). In the Hyrynsalmi area, both the lowermost Syväjoki Formation and the Iso Tuomivaara Formation (Kontinen, 1986) share some lithological features in common with the Jero Formation, but evidence at present is insufficient to permit definite correlation. Laajoki et al. (1989) nevertheless regard the Syväjoki Fm. as a correlative of the Kiskonkoski Formation.

In the Kiihtelysvaara — Värtsilä area, the Jatuli-type sequence (Raatevaara and Hyypiä Groups) is intepreted to have been deposited in a basin characterized by littoral and shallow water marine conditions. Immature sediments of fluviatile origin are present only in the lowermost Viesimo Group (Pekkarinen, 1979; Pekkarinen and Lukkarinen, 1991).

To assist discussion of correlations between the southern and northern parts of the North Karelia Schist Belt, attention will be drawn to a few focal points regarding the subdivision of stratigraphic units in the Kiihtelysvaara-Värtsilä area.

The contact between the Viesimo and Raatevaara Groups ('pre-Jatulian' and lower part of Jatulian Group of Pekkarinen (1979), respectively) is not exposed but has been intersected by drilling at several localities. The reported upward increase in sericite content of the Särkilampi Formation has been attributed to chemical weathering (Pekkarinen and Lukkarinen, 1991). However, if this paleosol and the overlying quartzite are correlated with the Hokkalampi Paleosol and the Koli quartzite in the present study area, several other problems will arise, as has already been pointed out by Pekkarinen (1979), who based his correlation largely on similarities between Haukilampi Formation (Lower Quartzite Fm. of Pekkarinen, 1979) and the Koli Quartzite. The problems may be listed, as follows:

1. The uniform presence of basal arkosite in the Kiihtelysvaara-Värtsilä (Nykänen, 1968, 1971; Pekkarinen, 1979) area versus the sporadic occurence of the Kyykkä Group in the study area.

2. The absence of a middle arkosite between the two quartzites in the Kiihtelysvaara-Värtsilä area versus the ubiquitous presence of the Jero Arkosite in the study area.

3. The presence of the volcanite horizon on top of the lower quartzite (Haukilampi Fm.) in the southern part of the Kiihtelysvaara-Värtsilä area versus the total absence of volcanics in the present study area.

4. The presence of the 'Marine Jatuli'-type dolomites and black schists of Hyypiä Group in the southern part of the Kiihtelysvaara-Värtsilä area versus their total absence in the present study area.

5. The thickness of the siliciclastic Jatuli-type rocks in Kiihtelysvaara and Värtsilä is much less when compared to the Koli area. Especially, the thickness of the Kalkunmäki Formation (Upper Quartzite Fm. of Pekkarinen, 1979) seems to be only one-sixth of that of the Puso Quartzite.

According to Pekkarinen (1979), the sediments of the Särkilampi Formation are rather variable in character with regard to mineral and chemical compositions and primary features. The lower, unsorted arkosite is in places associated with the breccia-conglomerates of Pölkkylampi Formation which shows glaciogenic features. More reworked arkosites and conglomerates with rounded pebbles and cobbles form the upper part of the formation. At Särkilampi the sediments of the latter type are separated from the breccia-conglomerate by an unconformity (Pekkarinen, 1979).

The upper arkosite (e.g., at Särkilampi) and the conglomerate member of the Jero Formation are very similar, both in sedimentary style and in composition. In addition, the Jero conglomerates and coarse arkosites seem to directly continue from the southern part of the Nunnanlahti-

Koli-Kaltimo area via Mönni to the Kiihtelysvaara area.

It therefore seems justified to correlate of the Jero Formation with the upper part of the Särkilampi Formation. Consequently, only the lowest, sporadic occurrences of conglomerate at Kiihtelysvaara are considered to be correlative with the Kyykkä Group. A corollary of this is that the counterpart of the Koli Formation at Kiihtelysvaara is absent or only sporadically preserved.

Accordingly, the Puso Formation and the Haukilampi Formation at Kiihtelysvaara are correlative with each other. This accounts for the absence of volcanites in the study area and is perhaps supported by the fact that the Koljola Formation (mafic volcanics), the Kalkunmäki Formation ('upper quartzite') and the Hyypiä Group (Marine Jatuli-type association) all wedge out towards the study area in the northern part of the Kiihtelysvaara area. The Puso and Haukilampi quartzites are also quite similar both in lithology (Pekkarinen, 1979; Kohonen, 1987) and in paleocurrent directions (Ojakangas, 1965; Marmo et al., 1988).

The Tottolampi conglomerate (cf. Fig.18) containing quartzite and mafic pebbles and interbedded with partly red-colored quartzite (Kohonen, 1987), is a candidate for correlation with the Kalkunmäki Formation at Kiihtelysvaara. This interpretation is very tentative, but must be kept in mind especially in speculations concerning the character of the western contact of the quartzites.

Tectonic setting

In the Karelian system, discrete mafic magmatic episodes with ages around 2440, 2200, 2100 and 1970 Ma have been reported (Huhma, 1986; Huhma et al., 1990; Vuollo et al., 1992). In North Karelia, the rocks of the Kyykkä Group and correlative formations comprise a purely sedimentary series, whereas in Kainuu (Laajoki et al., 1989) and Russian Karelia (e.g. Salop, 1983), glaciogenic rocks are underlain by a volcanic-sedimentary unit. In Lapland the lowermost Proterozoic unit is dominantly volcanic and the development of the Lower and Middle Lapponi rocks took place prior to 2200 Ma (Lehtonen et al., in press). If the deposition of the Kyykkä Group is related to rifting about 2400 Ma ago, the absence of the corresponding volcanic rocks may indicate that evolution did not proceed to the stage of magmatism in the North Karelia Region.

Metadiabases of various ages are typical of throughout the entire Karelian domain, and one of the most striking features in the geology of North Karelia is the abundance of mafic dykes with ages of 2.2—1.97 Ga cutting the studied platform sequence. According to Fahrig (1987), such extensive cratonic dyke swarms are characteristic of two tectonic environments: failed arm rifts and passive continental margins.

The karjalitic (gabbro-wehrlite) magmatism is interpreted to represent the advanced stage of the same rifting that resulted in the deposition of the immature sediments of the Jero Formation. In a more broad context, this event may be interpreted as representing an intracratonic rupture about 2.2 Ga ago in North Karelia as well as in adjacent areas in Kainuu. The reported Nenäkangas unconformity (Laajoki, 1988b) and the arrangement of intrusions correlative with karjalites (Kontinen, 1987) are in accord with the model presented. It is tentatively assumed that in Lapland more significant crustal extension occurred and that contemporaneous volcanism took place (Fig. 38).

The extensive tholeiitic dykes with ages around 2.1 to 2.0 Ga in eastern Finland form subvertical NW-trending swarms (Aro and Laitakari,

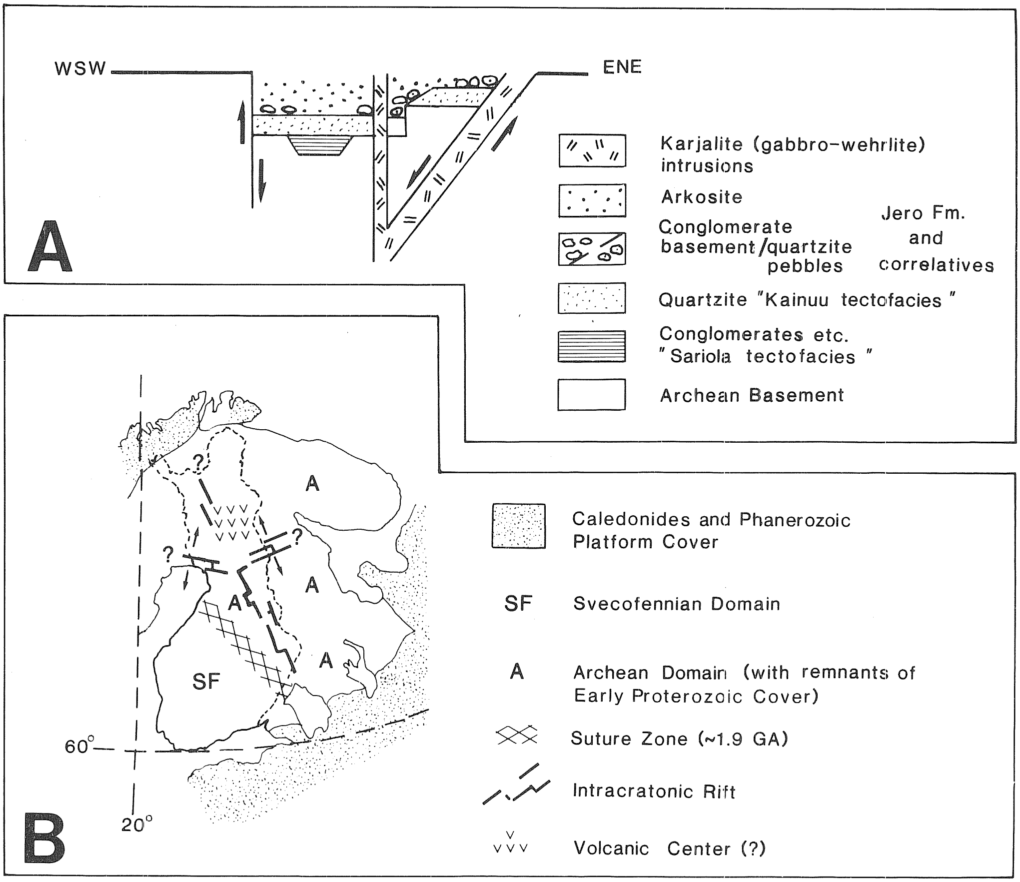

Fig. 38. (A) Schematic section across Jero basin after intrusion of karjalites and (B) tentative reconstruction of corresponding intracontinental rift system about 2.2 Ga ago.

1987). The intrusion of these dykes has been connected by many authors (e.g. Gaal and Gorbatchev, 1987) to breakup of the Karelian continent during the first phase of the Svecofennian (Svecokarelian) Orogeny. The Haukilampi Formation in Kiihtelysvaara is cut by 2.1 Ga mafic dykes (Pekkarinen and Lukkarinen, 1991), and this seems to be the case also with the Puso Formation (Vuollo et al., 1992). Thus, the Puso Formation precedes the major breakup and might, within the plate tectonic framework, represent the fill of an aggradational epicontinental basin related to an initial phase of crustal extensional thinning rather than to development of a passive margin (Fig. 39).

Economic geological considerations

Although economic geology is outside the scope of the present paper, some aspects, and especially those related to supracrustal processes, are considered here. Most mineral deposits within study area have an obvious stratigraphic control and, consequently, we believe that the results of

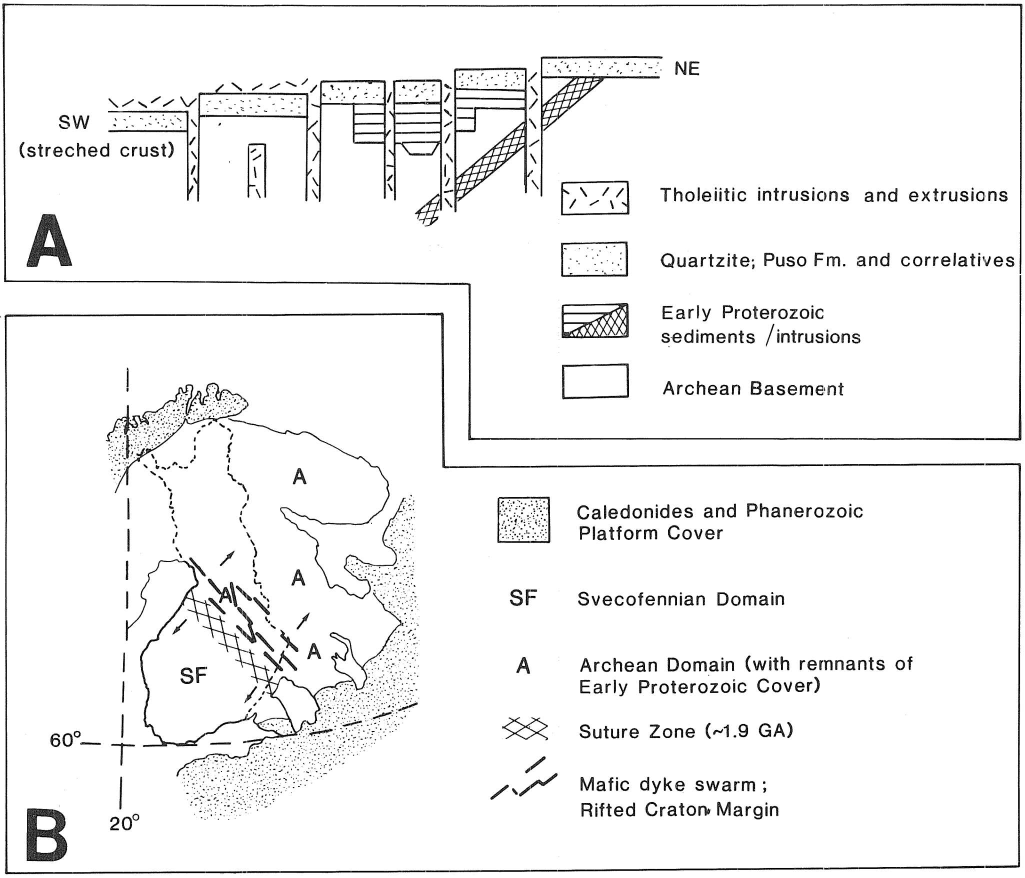

Fig. 39. (A) Schematic section across the depository after intrusion of tholeiitic dykes and (B) approximate location of craton margin after departure of the southwestern Archean block about 2.0 Ga ago.

this study can be utilized in future prospecting.

The study area is well-known for numerous, but small, uranium occurrences. Although stratabound, the deposits are epigenetic in nature (Piirainen, 1968; Äikäs and Sarikkola, 1987), and thus differ from the quartz-pebble uranium deposits of Witwatersrand and Elliot Lake. The uranium mineralizations can be roughly divided into three types, and in all these the Archean granitoids and the associated Proterozoic paleosol are considered to be the most probable source of uranium (Äikäs and Sarikkola, 1987).

The first, and largest, group of deposits consists of uranium and thorium rich lenses along certain horizons within the sequence. Thorium is mostly observed to occur in the Vesivaara formation, whereas uranium has been enriched in parts of the Koli and Jero Formations. Within the Koli Formation, the uraniferous zone is located in the upper, but not uppermost, part of the formation where an exceptionally well sorted, sericite-poor horizon containing local quartz-pebble conglomerates is present. These rocks show, atypically for the formation as a whole, locally patchy, epigenetic red coloring. This probably implies that the zone acted as a permeable passage for the epigenetic fluids carrying the uranium. In places where reductants were present the precipitation of uranium locally occurred. Within the Jero Formation the situation is quite similar, but the host rocks are magnetite bearing grits, quartz-pebble conglomerates and pebbly subarkosites in the lower part of formation (Äikäs and Sarikkola, 1987).

The second type of uranium mineralizations occurs at the contacts between diabases and with the rocks representing lowermost parts of the Herajärvi Group. According to Piirainen (1968), the ferrous iron in the mafic dykes acted as a reducing agent causing the precipitation of uranium. The third mineralization type, represented by the Riutta deposit, occurs as small, rich pockets near the basement-cover interface. This deposit displays features common to the unconformity-type uranium ores (Äikäs, 1989).

The impetus for studying the gold potential of the Koli area was based on the observation that the rocks resemble those described from the famous auriferous conglomerate areas (e.g. Witwatersrand, Jacobina) both in age and composition. However, the results from sampling conducted by sedimentological basis, using analogues from well studied goldfields, were discouraging. Only a few samples from the Vesivaara Formation showed slightly anomalous gold contents (for details, see Marmo, 1988a).

It seems that, if the Witwatersrand-type genetic model and paradigm are taken to be valid, the most probable reasons limiting the gold potential of the study area are the composition of the paleoatmosphere and the provenance. Both the sedimentary sequence studied and the source rocks are about 300 Ma younger than the Witwatersrand counterparts (e.g. Armstrong et al., 1991). It is widely accepted that the nature of the atmosphere changed from reducing to oxidizing in Early Proterozoic times (e.g. Cloud, 1968; Walker et al. 1983). If the oxyatmoinversion had an impact on the behaviour of gold in supracrustal processes, as seems to be the case with detrital uranium minerals in this kind of deposits, the age difference could be critical.

However, during the project the lithological similarity of some rocks of the studied sequence and the rocks hosting paleoplacer-type deposits was vindicated. The Koli Formation in particular and the Upper Witwatersrand Formations (cf. Button and Adams, 1981) are quite similar. Both are dominated by sericite-quartzites, classified as primary quartzwackes, and quartz-pebble conclomerates are common; chemical compositions are alike; both are associated with a paleosol and deposition of both units occurred in fluvial environment. Further, when examining the common characteristics of ancient gold-bearing placers presented by Minter (1991), almost all the criteria regarding sedimentology and tectonic setting are positive in the study area. The only major drawback is the absence of detrital sulphides and uraninite in the study area.

In southern Africa the Archean greenstones have been proposed as the source of the detrital gold (Pretorius, 1981). In contrast, both the conglomerates and detrital heavy minerals (Kohonen, 1987) from the study area indicate a source area consisting mainly of felsic plutonic rocks. This may in fact be the decisive factor decreasing the potential for paleoplacer gold in the study area.

A major aspect of the present study has been the assessment of industrial minerals. Kyanite deposits in the Koli area have been known since the early decades of this century, but the connection between these and the Hokkalampi Paleosol was first recognized by Marmo (1986, 1992). In short, deposits of kyanite, andalusite and iron-poor white mica are formed during low-grade regional metamorphism of a paleosol characterized by enrichment of aluminium and strong depletion of alkalies, alkali-earth elements and iron. The most richest and coarsest-grained pockets are found in places where segregation of quartz veins has locally caused further enrichment of aluminium in the wall rocks.

The base metal indications within the studied sequence are restricted to uneconomic sulphide lenses in quartz-carbonate veins at diabase contacts, and to the epigenetic Zn-Pb mineralization at Rintasenvaara. In the latter case (for details, see Marmo, 1988b) the lower part of the Hattusaari Formation has been albitized and mineralized, and interestingly, some of the fragments in the conglomerate consist of massive sulphide ore.

SUMMARY

The Early Proterozoic formations in the study area are divided litostratigraphically into the Kyykkä and Herajärvi Groups. The lower group comprises the Ilvesvaara, Urkkavaara and Hattusaari Formation, while the Vesivaara, Koli, Jero and Puso Formations constitute the Herajärvi Group. The two groups are separated by the Hokkalampi Paleosol. The lithostratigraphic use of traditional names, Sariola and Jatuli, is not no longer recommended, but they still appear to be useful as 'megacycle' or 'tectofacies' terms.

The stratigraphy of the study area forms a unique platformal sequence within the North Karelia Schist Belt and the closest analogue can be found 300 km to the north, in the northeastern part of the Kainuu Schist Belt. In general, the 'extraordinary' sediments of the glaciogenic unit together with the association of Hokkalampi-type paleosol and ultramature sediments may have potential for regional lithostratigraphic correlation over great distances.

The intrusion of karjalites about 2.2 Ga ago accompanied intracratonic rifting, possibly representing a failed arm related to more significant crustal extension in Lapland. The associated fault zones controlled the preservation of the Vesivaara, Koli and Jero Formations, and the present location of the Archean — Proterozoic boundary within the study area. This event caused local disconformities in sedimentary sequences as indicated by »Nenäkangas-type» conglomerates in the Kainuu area. Given that the ideas presented here concerning the preservation of the pre-Jero sequence are valid, analogous rift basins should also regionally be surrounded by mafic intrusions correlative to karjalites.

As a whole the sequence studied reflects alternating phases of rifting and intermittent stability. These depositional conditions were terminated by the break-up of the continent about 2.1 — 2.0 Ga ago.

It is suggested that Jero and Puso Formations in the study area correlate with the upper arkosite of the Särkilampi Formation and the Haukilampi Formation in the Kiihtelysvaara-Värtsilä area; the sequences preserved the two areas represent partly distinct stratigraphic levels and together form an excellent example of different major cycles, or tectofacies, typical of the Karelian Domain in eastern Finland.

ACKNOWLEDGEMENTS

The authors thank the heads of the Mineral Resources Department of the Geological Survey of Finland, especially Prof. Jouko Talvitie, Dr. Pentti Ervamaa and Dr. Pekka Nurmi. Financial support was also received from the Academy of Finland and from the Jenny and Antti Wihuri Foundation. The leader of the North Karelia Research Project, Professor Tauno Piirainen of University of Oulu provided material collected during the project. Credit is also due to Olli Äikäs, who provided data and many useful comments. Pirkko Kurki drafted the figures and Peter Sorjonen-Ward revised the language of the manuscript. We greatly appreciate reviews by Richard W. Ojakangas and Asko Kontinen, who made for many comments and suggestions for improving the manuscript.

REFERENCES

Äikäs, O., 1989. Selostus uraanitutkimuksista Enon ja Kontiolahden kunnissa valtausalueella Riutta 1, kaivosrek. nro 3495/1. Unpublished internal report M06/4242/-89/1/60. Geological Survey of Finland.

Äikäs, O. & Sarikkola, R., 1987. Uranium in lower Proterozoic conglomerates of the Koli area, eastern Finland. In: Uranium deposits in Proterozoic quartz-pebble conglomerates. IAEA-TECDOC-427, Wien, 189—234.

Akhtar, K. & Ahmad, A.H.M., 1991. Single-cycle cratonic quartzarenites produced by tropical weathering: the Nimar sandstone (Lower Cretaceous), Narmada basin, India. Sediment. Geol., 71, 23—32.

Armstrong, R.A., Compston, W., Retief, E.A., Williams, I.S. & Welke, H.J., 1991. Zircon ion microprobe studies bearing on the age and evolution of the Witwatersrand triad. Precambrian Res. 53, 243—266.

Aro, K. & Laitakari, I. (eds.), 1987. Diabases and other mafic dykes in Finland. Geological Survey of Finland, Report of Investigation 76. 254 p.

Button, A. & Adams, S.S., 1981. Geology and recognition criteria for uranium deposits of the quartz-pebble conglomerate type. U.S. Dept. of Energy, National Uranium Resource Evaluation, Report GJBX-3(81), 390 p.

Cloud, P.G., 1968. Atmospheric and hydrospheric evolution on the primitive earth. Science 160, 729—736.

Coleman, J.M., 1969. Brahmaputra River: channel processes and sedimentation. Sed. Geol., 3, 129—239.

Costello, W.R. & Walker, R.G., 1972. Pleistocene sedimentology, Credit river, Southern Ontario: a new component of the braided river model. Jour. Sed. Petr. 42, 389—400.

Crook, K. A. W., 1968. Weathering and roundness of quartz sand grains. Sedimentology 11, 171—182.

Crowley, K.D., 1983. Large-scale bed configurations (macroforms), Platte River Basin, Colorado and Nebraska: Primary structures and formative processes. Geol. Soc. Am. Bull. 94, 117—133.

Eriksson, K.A., 1978. Alluvial and destructive beach facies from the archean Moodies group, Barberton Mountain Land, South Africa and Swaziland. In: Miall, A.D. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 31, 287—311.

Eskola, P., 1919. Huvuddragen av Onega-Karelens geologi. Meddelanden från Geologiska Föreningen i Helsingfors år 1917 och 1918, p.13.

Etheridge, M.A. & Cooper, J.A., 1981. Rb-Sr isotopic and geochemical evolution of recrystallized shear (mylonite) zone at Broken Hill. Contr. Miner. Petrol. 78, 74—84.

Fahrig, W.F., 1987. The tectonic settings of continental mafic dyke swarms: failed arm and early passive margin. In: Halls, H.C. and Fahrig, W.F. (eds.) Mafic dyke swarms. Geol. Ass. Canada Spec. Paper 34, 331—348.

Folk, R.L., 1951. Stages of textural maturity in sedimentary rocks. Jour. Sed. Petr. 21, 127—130.

Frosterus, B. & Wilkman, W.W., 1920. Vuorilajikartan selitys. Lehti D3, Joensuu. Suomen geologinen yleiskartta, 1 : 400 000.

Gaál, G., 1964. Jatul und karelische Molasse im S-Koligebiet in Nordkarelien und ihre Beziehungen zum Gebirgsbau des präkambrishen Orogens. Bull. Comm. Geol. Finlande 213. 45 p.

Gaál, G. & Gorbatchev, R., 1987. An outline of the Precambrian evolution of the Baltic Shield. Precambrian Res. 35, 15—52.

Hanski, E., 1982. Albiittidiabaasit ja niihin liittyvät ultramafiset kivet Kuhmon ja Kolin alueilla. Arkeeisten alueiden malmiprojekti, Oulun yliopisto. Raportti n:o 6.

Hanski, E., 1984. Geology of the gabro-wehrlite association in the eastern part of the Baltic Shield. Arkeeisten alueiden malmiprojekti, Oulun yliopisto. Raportti n:o 20.

Heward, A.P., 1978. Alluvial fan sequence and megasequence models, with examples from Westphalian D — Stephanian B coalfields, Northern Spain. In: Miall, A.D. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 5, 669—702.

Huhma, H., 1986. Sm-Nd, U-Pb and Pb-Pb isotopic evidence for the origin of the Early Proterozoic Svecokarelian crust in Finland. Geol. Surv. Finland, Bull., 337. 48 p.

Huhma, H., Cliff, R.A., Perttunen, V. & Sakko, M., 1990 Sm-Nd and Pb isotopic study of mafic rocks associated with early Proterozoic continental rifting: the Peräpohja schist belt in northern Finland. Contrib. Mineral. Petrol., 104, 369—379.

Karhu, J. & Epstein, S., 1986. The implication of the oxygen isotope records in coexisting cherts and phosphates. Geochim. Cosmochim. Acta 50, 1745—1756.

Kohonen J., 1987. Jatulimuodostumien paleosedimentologia Herajärven alueella Pohjois-Karjalassa. Pohjois-Karjalan malmiprojekti, Oulun Yliopisto. Raportti n:o 6.

Kohonen, J., Pernu, T. & Mursu, J., 1990. Kvartsiittien (Jatuli) ja kiilleliuskeiden (Kaleva) kontaktivyöhykkeen geologiset ja geofysikaaliset piirteet Kontiolahden — Ahmovaaran — Nunnanlahden jaksolla Pohjois-Karjalassa. Pohjois-Karjalan malmiprojekti, Oulun yliopisto. Raportti n:o 26.

Kohonen, J. & Marmo, J., in press. Stratigraphic correlation concepts within multiple rifted Karelian Domain — an example from eastern Finland. In: Balagansky, V. (ed.) Correlation of Lower Precambrian formations of the

Karelian-Kola region, USSR and Finland: proceedings of the Finnish-Soviet symposium held in Apatity 10th-12th September, 1991.

Kontinen, A., 1986. Early Proterozoic stratigraphy and sedimentation in the Hyrynsalmi area, eastern Finland. In: Sokolov, V.A. and Heiskanen, K.I. (eds.) Early Proterozoic of the Baltic Shield: proceedings of the Finnish-Soviet symposium held in Petrozavodsk 19th-27th august, 1985.

Kontinen, A., 1987. Hyrynsalmen alueen varhaisproterotsooiset mafiset juonikivet. In: Aro, K. and Laitakari, I. (eds.) Diabases and other mafic dykes in Finland. Geological Survey of Finland, Report of Investigation 76, 13—20.

Koryakin, A.S., 1971. Results of a study of Proterozoic weathering crusts in Karelia. Int. Geol. Review 13, 973—980.

Kraus, M.J. & Bown, T.M., 1986. Paleosols and time resolution in alluvial stratigraphy. In: Wright, V.P. (ed.) Paleosols; their recognition and interpretation. Blackwell Scientific Publications, 180—207.

Laajoki, K., 1973. On the geology of the South Puolanka area, Finland. Geol. Surv. Finland, Bull. 263. 54 p.

Laajoki, K., 1986. The Precambrian supracrustal rocks of Finland and their tectono-exogenic evolution. Precambrian Res. 33, 67—85.

Laajoki, K., 1988a. Karjalaisten muodostumien jako tektofasieksiin. In Lappalainen, V. and Papunen, H. (eds.) Tutkimuksia geologian alalta. Annales Universitatis Turkuensis. Ser. C, Tom 68, 21—30.

Laajoki, K., 1988b. Nenäkangas-type conglomerates — an evidence of a major break in the sedimentation of the early Proterozoic (»Jatulian») quartzites in Kainuu. In: Laajoki K. and Paakkola J. (eds.) Sedimentology of the Precambrian formations in eastern and northern Finland. Geol. Surv. Finland, Spec. Paper 5, 91—107.

Laajoki, K., Strand, K. & Härmä, P., 1989. Lithostratigraphy of the early Proterozoic Kainuu Schist Belt in the Kurkikylä — Siikavaara area, northern Finland, with emphasis on the genetic approach. Bull. Geol. Soc. Finland 61, 65—93.

Lehtonen, M.I., Manninen, T., Rastas, P. & Räsänen, J. (in press) On the early Proterozoic metavolcanic rocks in Finnish Central Lapland. In: Balagansky, V. (ed.) Correlation of Lower Precambrian formations of the Karelian-Kola region, USSR and Finland: proceedings of the Finnish-Soviet symposium held in Apatity 10th-12th September, 1991.

Lister, G.S., Etheridge, M.A. & Symons, P.A., 1986. Application of the detachment fault model to the formation of passive continental margins. Geology 14: 246—250.

Long, D.G.F., 1978. Proterozoic stream deposits: Some problems of recognition and interpretation of ancient fluvial systems. In: Miall, A. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 5, 313—341.

Luukkonen, E.J., 1989. The early Proterozoic Saari-Kiekki Greenstone Belt: a representative of the Sariola group at Kuhmo, eastern Finland. Bull. Geol. Soc. Finland 61, 161—187.

Luukkonen, E. & Lukkarinen, H., 1985. Stratigraphic map of Middle Finland 1 : 1 000 000. Geological Survey of Finland.

Mc Cubbin, D.G., 1981. Barrier-island and strand plain facies. In: Scholle, P.A. and Spearing, D. (eds.) Sandstone Depositional Environments. AAPG Memoir 31, 247—279.

Mc Kee, E.D., Crosby, E.J. & Berryhill, H.I. Jr., 1967. Flood deposits, Bijou Creek, Colorado, June 1965. Jour. Sed. Petr. 37, 829—851.

Marmo, J.S., 1986. Sariolan stratigraphy in the Koli — Kaltimo area, North Karelia, eastern Finland. In: Sokolov, V.A. and Heiskanen, K.I. (eds.) Early Proterozoic of the Baltic Shield: proceedings of the Finnish-Soviet symposium held in Petrozavodsk 19th-27th august, 1985.

Marmo, J., 1988a. Kaltimon-Nunnanlahden alueen jatuli- ja sariolasedimenttien sedimenttipetrologiset tutkimukset ja kyseisten muodostumien potentiaali placer-tyyppisten kultaesiintymien suhteen. Unpublished internal report M19/4313/-88/2/10. Geological Survey of Finland.

Marmo, J., 1988b. Sinkki-, kupari- ja kultatutkimukset Lieksan Hattusaarenkylän Rintasenvaarassa vuosina 1986—1987. Unpublished internal report M19/4313/-88/1/10. Geological Survey of Finland.

Marmo, J.S., 1992. The Lower Proterozoic Hokkalampi paleosol in North Karelia, eastern Finland. In: Schidlowski, M., Golubic, S., Kimberley, M.M. and Trudinger, P.A. (eds.) Early Organic Evolution; Implications for Mineral and Energy Deposits. Springer Verlag, 41—66.

Marmo, J.S. & Ojakangas, R.W., 1983. Varhaisproterotsooinen Urkkavaara-muodostuma Kontiolahdella — glasigeeninen metasedimenttisarja Sariola-ryhmän yläosassa. Geologi 35 (1), 3—6.

Marmo, J.S. & Ojakangas, R.W., 1984. Lower Proterozoic glaciogenic deposits, eastern Finland. Geol. Soc. Am. Bull. 95, 1055—1062.

Marmo, J., Kohonen J., Sarapää O. & Äikäs O., 1988. Sedimentology and stratigraphy of the lower Proterozoic Sariola and Jatuli Groups in the Koli-Kaltimo area, eastern Finland. In: Laajoki, K. and Paakkola, J. (eds.) Sedimentology of the Precambrian formations in eastern and northern Finland. Geol. Surv. Finland, Spec. Paper 5, 11—28.

Meriläinen, K., 1980. On the stratigraphy of the Karelian Formations. In: Silvennoinen, A. (ed.) Jatulian geology in the eastern part of the Baltic Shield: proceedings of a Finnish-Soviet Symposium, Finland, 1979, 97—112.

Mertanen, S., Pesonen, L.J., Huhma, H. & Leino, M.A.H., 1989. Paleomagnetism of the Early Proterozoic layered intrusions, northern Finland. Geol. Surv. Finland Bull. 40.

Miall, A.D., 1977. A Review of the braided river depositional environment. Earth Sci. Rev. 13, 1—62.

Miall, A.D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Miall, A. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 5, 597—604.

Miall, A.D., 1982. Analysis of Fluvial Depositional Systems. AAPG Education Course Note Serie.

Miall, A.D. & Gibling, M.R., 1978. The Siluro Devonian clastic wedge of Somerset Island, Arctic Canada, and some regional paleogeographic implications. Sed. Geol. 21, 85—127.

Minter, W.E.L., 1991. Ancient placer gold deposits. In: Foster, R.P. (ed.) Gold Metallogeny and Exploration. Blackie, Glasgow and London, 283—308.

Nesbitt, H.W. & Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites, Nature 299, 715—717.

Nykänen, O., 1968. Kallioperäkartan selitys, Tohmajärvi 4232—4234. Suomen geologinen kartta 1 : 100 000.

Nykänen, O., 1971. Kallioperäkartan selitys, Kiihtelysvaara 4241. Suomen geologinen kartta 1 : 100 000.

Ojakangas, R.W., 1965. Petrography and sedimentation of the Precambrian Jatulian quartzites of Finland. Bull. Comm. Geol. Finlande 214.

Ojakangas, R.W., 1985. Evidence for Early Proterozoic glaciation: the dropstone unit — diamictite association. In: Laajoki, K. and Paakkola, J. (eds.) Proterozoic exogenic processes and related metallogeny. Geol. Surv. Finland, Bull. 331, 51—72.

Ojakangas, R.W., 1988. Glaciation: An Uncommon »Mega-Event» as a Key to Intracontinental and Intercontinental Correlation of Early Proterozoic Basin Fill, North American and Baltic Cratons. In: Kleinspehn, K.L. and Paola, C. (eds.) New Perspectives in Basin Analysis. Springer Verlag, New York, 431—444.

Ojakangas, R.W., Marmo, J.S. & Heiskanen, K.I., 1989. Lower Proterozoic Glaciogenic Deposits; Finland and USSR, Baltic Craton. 28th International Geological Congress, Washington D.C.; Abstracts 2, 542.

Ovenshine, A.T., 1970. Observations of of iceberg raftings in Glacier Bay, Alaska, and the identification of ancient ice-rafted deposits. Geol. Soc. America Bull. 81, 891—894.

Pekkala, Y., 1982. Kyaniitin esiintyminen Suomen kallioperässä. In: Laajoki, K., Paakkola, J. and Tuisku, P. (eds.) Suomen kallioperän ja malmien metamorfoosi ja deformaatio. Res Terrae, Ser.B 5, 179—194.

Pekkarinen, L.J., 1979. The Karelian formations and their depositional basement in the Kiihtelysvaara — Värtsilä area, East Finland. Geol. Surv. Finland Bull. 301. 22 p.

Pekkarinen, L.J. & Lukkarinen, H., 1991. Paleoproterozoic volcanism in the Kiihtelysvaara — Tohmajärvi district, eastern Finland. Geol. Surv. Finland Bull. 357. 30 p.

Pettijohn, F.J., 1975. Sedimentary Rocks. 3rd edition. Harper & Row.

Pettijohn, F.J., Potter, P. & Siever, R., 1972. Sand and Sandstone. Springer-Verlag.

Piirainen, T., 1968. Die Petrologie und die Uranlagerstätten des Koli-Kaltimogebiets im finnischen Nordkarelien. Bull. Comm. Geol. Finlande 237. 99 p.

Piirainen, T., 1969. Initialer magmatismus und seine Erzbildnung in der Beleuchtung des Koli-Kaltimogebiets. Bull. Geol. Soc. Finland 41, 21—45.

Piirainen, T., Honkamo, M. & Rossi, S., 1974. A preliminary report on geology of Koli area Bull. Geol. Soc. Finland 46, 161—166.

Pretorius, D.A., 1981. Gold and uranium in quartz-pebble conglomerates. Inf. Circ. Econ. Geol. Res. Univ. Witwatersrand, Johannesburg 151.

Rossi, S., 1975. Ipatin — Hattusaaren kylän alueen kallioperä Pohjois-Karjalan liuskealueen koillisosassa. Master thesis (unpublished), University of Helsinki.

Sadler, P.M., 1981. Sediment accumulation rates and the completeness of stratigraphic sections. J. Geol. 89, 569—584.

Salop, L.J., 1977. Precambrian of the northern hemisphere and general features of early geological evolution. Elsevier. Amsterdam, Oxford, New York.

Salop, L.J., 1983. Geological evolution of the Earth during the Precambrian. Springer Verlag. Berlin, Heidelberg, New York.

Schumm, S.A., 1968. Speculation Concerning Paleohydrologic Controls of Terrestial Sedimentation. Geol. Soc. Am. Bull. 79, 1573—1588.

Senior, B.R. & Mabbuth, J.A., 1979. A proposed method of defining deeply weathered rock units based on regional mapping in southwestern Queensland. J. Soc. Aust. 26, 237—254.

Simonen, A., 1955. Congr. Geol. Int. Comm. Stratigraphie. Finland. In: Lexique Stratigraphique International, 1, 89—101.

Simonen, A., 1980. The Precambrian in Finland. Geol.Surv. Finland Bull. 304. 58 p.

Simonen, A., 1986. Stratigraphic studies on the Precambrian in Finland. Geol. Surv. Finland Bull. 336, 21—37.

Sinha, A.K., Hewitt, D.A. & Rimstidt, J.D., 1986. Fluid interaction and element mobility in the development of ultramylonites. Geology 14, 883—886.

Sokolov, V.A. & Heiskanen, K.I., 1984. Developmental stages of Precambrian crusts of weathering. Proceedings of the 27th International Geological Congress, VNU Science Press, 5, 73—94.

Steel, R. & Aasheim, S.M. 1978. Alluvial Sand deposition in a rapidly subsiding basin (Devonian, Norway). In: Miall, A.D. (ed.) Fluvial Sedimentology. Can. Soc. Petrol. Geol. Mem. 5, 385—412.

Strand, K. 1985. Alaproterotsooisen Kurkikylän ryhmän ja sen päällä olevien karjalaisten muodostumien litostratigrafia, paleosedimentologia ja rakenne. Res Terrae, Ser. B, 7.

Strand, K. 1988. Alluvial sedimentation and tectonic setting of the early Proterozoic Kurkikylä and Kainuu Groups in northern Finland. In: Laajoki, K. and Paakkola, J. (eds.) Sedimentology of the Precambrian formations in eastern and northern Finland. Geol. Surv. Finland, Spec. Paper 5, 75—90.

Summerfield, M.A., 1983. Geochemistry of weathering profile silcretes, southern Cape Province, South Africa. In: Wilson, R.C.L. (ed.) Residual Deposits: Surface related weathering Processes and Materials. Geol. Soc. London Spec. publ., 167—178. Blackwell Scientific Publications.

Vuollo, J. & Piirainen, T., 1992. The 2.2 Ga old Koli layered sill: The low-Al tholeiitic (karjalitic) magma type and its differentiation in northern Karelia, eastern Finland. Geol. För. Förhand. 114, 131—142.

Vuollo, J., Piirainen, T. & Huhma, H., 1992. Two Early Proterozoic tholeiitic diabase dyke swarms in the Koli-Kaltimo area, eastern Finland — their geological significance. Geol. Surv. Finland, Bull. 363.

Väyrynen, H., 1933. Uber die Stratigraphie der karelischen Formationen. Bull. Comm. Geol. Finlande 101, 54—78.

Väyrynen, H., 1939. On the geology and tectonics of the Outokumpu ore field and region. Bull. Comm. Geol. Finlande 124. 91 p.

Väyrynen, H., 1954. Suomen kallioperä, sen synty ja geologinen kehitys. Otava, Helsinki.

Walker, J.C.G., Klein, C., Schidlowski, M., Schopf, J.W., Stevenson, D.J., & Walter, M,R., 1983. Environmental Evolution of the Archean — Early Proterozoic Earth. In: Schopf, J.W. (ed.) Earth's earliest Biosphere, its Origin and Evolution, 260—290. Princeton University Press.

Ward, P. & Kohonen, J. 1989. Structural provinces and style in the Proterozoic of North Karelia: Preliminary correlations and discussion. In Autio S. (ed.) Geological Survey of Finland Current Research 1988. Geol. Surv. Finland, Spec. Paper 10, 23—29.

Wernicke, B. & Burchfiel, B.C., 1982. Models of extensional tectonics. J. Struct. Geol. 4, 105—115.

Williams, G.E., 1971. Flood deposits of the sand-bed ephemeral streams at Central Australia. Sedimentology 17, 1—40.

Appendix 1. Locations of type localities and reference sections for the established stratigraphic units.

Kyykkä Group; type area: Kyykkä, Kontiolahti

Ilvesvaara Fm.; lower contact: map sheet 4224 11 D, x = 6969.04, y = 4499.25 (Ilvesvaara); map sheet 4224 11B, x = 6965.82, y = 4493.67 (Ahola); type localities: map sheet 4224 11D, x = 6969.11, y = 4499.25; map sheet 4224 11B, x = 6965.82, y = 4493.67 (solitary outcrops in the surroundings of Lake Pesinpyttylampi and at Ahola)

Urkkavaara Fm.; lower contact (nearly exposed): map sheet 4224 11B, x = 6965.27, y = 4499.62

Lower siltstone-argillite Mb.-lower graded sandstone Mb.; type section: map sheet 4224 11D, x = 6969.27, y = 4499.92 to W (270°)

Lower graded sandstone Mb.-upper siltstone-argillite Mb.; type section: map sheet 4224 11D, x = 6969.30, y = 4499.62 to W (270°)

Upper siltstone-argillite Mb.-diamictite Mb.-upper graded sandstone Mb.; type section: map sheet 4224 12C, x = 6670.39, y = 4499.48 to W (270°) (gradual lower contact of the diamictite member 20m W from the starting point)

Upper siltstone-argillite Mb.-upper graded sandstone Mb.-parallel bedded conglomerate Mb.-cross-bedded conglomerate Mb.; type section: map sheet 4224 12C, x = 6971.42, y = 4499.94 to W (270°)

Cross-bedded conglomerate Mb.; type locality: map sheet 4224 12C, x = 6972.00, y = 4499.20 (scattered outcrops at the top of the hill Verkkovaara)

Hattusaari Fm.; lower contact: map sheet 4313 12B, x = 7008.30, y = 4490.83 (Rintasenvaara); type section: map sheet 4313 12B, x = 7008.30, y = 4490.83 to SW (225°), reference section: map sheet 4313 09D, x = 7008.82, y = 4489.75 to S (180°)

Hokkalampi Paleosol; type area: Hokkalampi, Kontiolahti

lower contact: map sheet 4224 12C, x = 6971.17, y = 4498.78 (Mökinpelto); map sheet 4331 01A, x = 6980.65, y = 4501.00 (Paukkajanvaara)

type locality 1: map sheet 4224 12C, x = 6972.65, y = 4497.35 (surroundings of Lake Hokkalampi); type locality 2: map sheet 4313 10D, x = 6987.93, y = 4499.53 (Hirvivaara)

Herajärvi Group; type area: Herajärvi, Eno-Kontiolahti

Vesivaara Fm.; lower contact DH 4313/84/301,302,303 (Nuutilanvaara); type section: map sheet 4313 11C, x = 6990.59, y = 4497.63 to SW (230°), reference section: map sheet 4313 10D, x = 6988.85, y = 4499.42 to SW (250°)

Koli Fm.; lower contact: map sheet 4331 01A, x = 6980.66, y = 4500.96 (Paukkajanvaara); map sheet 4313 11B, x = 6999.33, y = 4490.42 (Koli)

Conglomerate Mb.; type section: map sheet 4331 01A, x = 6980.59, y = 4500.44 to SW (240°)

Quartzite Mb.; type section: map sheet 4331 01A, x = 6980.36, y = 4500.80 to WSW (250°), reference section: map sheet 4313 11B, x = 6995.10, y = 4493.75 to SW (225°)

Jero Fm.; lower contact: map sheet 4331 01A, x = 6980.28, y = 4500.63 (Sikovaara): map sheet 4224 12C, x = 6983.47, y = 4496.68 (Sammakkovaara)

Conglomerate Mb.; type section: map sheet 4313 10C, x = 6984.42, y = 4497.46 to NW (300°), reference section: map sheet 4313 06D, x = 7008.34, y = 4475.94 to SW (230°)

Arkosite Mb.; type localities: map sheet 4313 10C, x = 6984.65, y = 4496.37, x = 6982.42, y = 4497.70, 4313 11 A, x = 6994.63, y = 4490.76, 4313 06D, x = 7007.50, y = 4476.08

Puso Fm.; lower contact: map sheet 4242 03C, x = 6972.45, y = 4505.60 (Kaltimonjärvi)

Subarkosite Mb.; type section: map sheet 4313 10D, x = 6988.32, y = 4495.30 to W (270°)

Quartzite Mb.; type localities: map sheet 4313 10C, x = 6981.14, y = 4496.94, map sheet 4313 10B, x = 6987.96, y = 4494.17; x = 6987.94, y = 4492.88

Appendix 2. Location of samples for XRF-analyses.

	Sample	Map sheet	x	y
Table 5.				
1.	composite			
2.	composite			
3.	JSM-81-175.M3	4224 11B	6965.82	4493.67
4.	JSM-81-175-M1	4224 11B	6965.82	4493.67
5.	JSM-81-175-M2	4224 11B	6965.82	4493.67
6.	JJK-82-7.1	4224 11D	6969.31	4499.90
7.	JJK-82-7.7	4224 11D	6969.28	4499.88
8.	JJK-82-7.M3	4224 11D	6969.27	4499.87
9.	JSM-81-194	4224 12C	6970.40	4499.42
10.	JSM-84-5	4224 12C	6971.77	4499.65
11.	JSM-81-194	4224 12C	6970.40	4499.43
12.	JSM-84-18	4224 12C	6972.67	4498.80
13.	JJK-82-76	4224 12C	6970.13	4497.93
14.	JSM-84-7	4224 12C	6971.83	4497.56
Table 6.				
1.	DH 303/80.2m	4313 11A	6994.13	4494.62
2.	DH 303/74.0—80.0m			
3.	DH 303/65.2—66.8m			
4.	DH 311/61.0—70.0m	4224 12C	6973.95	4497.32
5.	JSM-86-27	4313 10D	6988.10	4498.92
6.	DH 311/0.0—20.0m	4224 12C	6973.95	4497.32
7.	DH 307/53.0—63.0m	4224 12C	6971.88	4497.10
8.	DH 307/10.7—20.7m			
9.	DH 303/42.5—47.4m	4313 11A	6994.13	4494.62
10.	DH 303/31.1—39.6m			
11.	JJK-84-62.2	4313 11B	6990.56	4497.62
12.	JJK-84-62.3	4313 11B	6990.56	4497.62
13.	JJK-84-62.4	4313 11B	6990.56	4497.60
14.	PAH-85-15.1	4313 06D	7008.51	4476.05
15.	DH 303/0.4—12.7m	4313 11A	6994.13	4494.62
16.	JJK-84-2.2	4242 03B	6979.66	4503.58
17.	JJK-84-25.5	4331 01A	6980.35	4500.78
18.	JJK-84-25.8	4331 01A	6980.33	4500.74
19.	JJK-84-63.3	4313 11C	6990.45	4497.57
20.	JJK-84-64.3	4313 11C	6990.36	4497.56
21.	PAH-85-18.1	4313 06D	7008.38	4476.06
Table 7.				
1.	JJK-84-25.12/1	4331 01A	6980.30	4500.62
2.	JJK-84-25.16	4331 01A	6980.30	4500.61
3.	JJK-84-29.1	4313 10C	6982.64	4498.66
4.	JJK-84-68.3	4313 10D	6989.89	4497.24
5.	JJK-84-19.6	4242 03B	6978.93	4501.86
6.	JJK-84-32.3	4313 10C	6982.21	4498.52
7.	PAH-85-30.6	4313 06D	7008.36	4476.03
8.	PAH-85-32.1	4313 06D	7008.30	4475.99
9.	PAH-85-33.1	4313 06D	7008.32	4475.95
10.	PAH-85-33.3	4313 06D	7008.32	4475.93
11.	PAH-85-34.2	4313 06D	7008.34	4475.78
12.	JJK-84-36.2	4313 10C	6982.37	4497.87
13.	JJK-84-18	4242 03B	6978.75	4501.93
14.	PAH-85-37.2	4313 06D	7007.65	4476.15
15.	JJK-84-43.1	4313 10C	6981.69	4497.32
16.	JJK-84-85.1	4313 10D	6988.32	4495.28
17.	JJK-84-46.1	4313 10C	6981.10	4497.02
18.	JJK-84-93.1	4313 10B	6988.15	4494.17
19.	JJK-84-55.16	4224 12D	6969.80	4496.96
20.	JJK-84-100	4313 10B	6987.73	4493.74
21.	JJK-84-52.4	4224 12D	6979.32	4496.02

Tätä julkaisua myy

GEOLOGIAN
TUTKIMUSKESKUS (GTK)
Julkaisumyynti
02150 Espoo
☏ 90-46931
Teleksi: 123 185 geolo sf
Telekopio: 90-462 205

GTK, Väli-Suomen
aluetoimisto
Kirjasto
PL 1237
70101 Kuopio
☏ 971-205 111
Telekopio: 971-205 215

GTK, Pohjois-Suomen
aluetoimisto
Kirjasto
PL 77
96101 Rovaniemi
☏ 960-297 219
Teleksi: 37 295 geolo SF
Telekopio: 960-297 289

Denna publikation säljes av

GEOLOGISKA
FORSKNINGSCENTRALEN (GFC)
Publikationsförsäljning
02150 Esbo
☏ 90-46931
Telex: 123 185 geolo sf
Telefax: 90-462 205

GFC, Mellersta Finlands
distriktsbyrå
Biblioteket
PB 1237
70101 Kuopio
☏ 971-205 111
Telefax: 971-205 215

GFC, Norra Finlands
distriktsbyrå
Biblioteket
PB 77
96101 Rovaniemi
☏ 960-297 219
Telex: 37 295 geolo SF
Telefax: 960-297 289

This publication can be obtained
from

GEOLOGICAL SURVEY
OF FINLAND (GSF)
Publication sales
SF-02150 Espoo, Finland
☏ 90-46931
Telex: 123 185 geolo sf
Telefax: 90-462 205

GSF, Regional office of
Mid-Finland
Library
P.O. Box 1237
SF-70101 Kuopio, Finland
☏ 971-205 111
Telefax: 971-205 215

GSF, Regional office of
Northern Finland
Library
P.O. Box 77
SF-96101 Rovaniemi, Finland
☏ 960-297 219
Telex: 37 295 geolo SF
Telefax: 960-297 289

ISBN 951-690-456-4
ISSN 0367-522X