# ON THE STRATIGRAPHIC POSITION OF KAOLIN IN VÄYRYLÄNKYLÄ, SOUTH PUOLANKA AREA, FINLAND

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Drilling data on the stratigraphic position of recently discovered clay occurrences containing kaolinite are given. Preliminary information on the clay minerals involved is included. The weathering undergone by the Precambrian rocks underlying the clays is described briefly. Secondary enrichment of iron caused by weathering in iron formations as revealed by partial ore analyses is presented.

The clays lie between strongly folded Karelidic rocks and Quaternary deposits, and are thus Preglacial in age. Owing to the varying kaolinite content (0-60 %) and the thick Quaternary overburden the clays are not economically exploitable.

The kaolin of Pihlajavaara, which some authors have considered to be of Karelian age, is correlated by the present author with Preglacial clays.

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### Introduction

In 1973 the Geological Survey of Finland carried out drilling operations in some small Precambrian iron formations in the vicinity of the Pääkkö farm at Väyrylänkylä, South Puolanka area, NE Finland (Fig. 1). The sedimentary material overlying the bedrock was drilled with special caution in order to obtain samples also from probable soft ores. Between the Quaternary deposits and the strongly folded Precambrian (Karelidic) rocks clays were detected whose stratigraphic position indicates that they form part of the Preglacial weathering crust.

The previously known kaolin deposit of Pihlajavaara, which has played a key role in discussions of the stratigraphy of the Karelidic rock sequence in Finland, lies only some 6 km NNE of the Pääkkö farm. In the 1920s the age and genesis of the Pihlajavaara and other kaolin occurrences in Puolanka were the subject of a lengthy debate between Väyrynen and Frosterus. Väyrynen (1922, 1924, 1928, 1929) explained the kaolinite to be a primary product of Archean weathering of the subjacent rocks and included the kaolin deposits in the lowermost parts of his





Fig. 1. Preglacial clays and associated weathered zones of the Precambrian rocks plotted on the geological map of the environment of the Pääkkö farm. Quaternary deposits omitted. 1) Prekarelidic basement gneisses. 2-8) Karelidic rocks; 2 =arkosite and feldspar- and/ or sericite-bearing quartzite. 3= quartzite and orthoquartzite. 4 = conglomeratic mica schist.5 = phyllite, black schist and mica schist. 6 = iron formation. 7 = dolomite and marl. 8 =metavolcanics and/or metadiabase. 9) Partially weathered Precambrian rocks. 10) Clay occurrences. 11) Geological contact. 12) Fault and tectonic contact. 13) Drill hole and number. The location of the South Puolanka area is shown on the index map (left-hand upper corner).

Kainuan Quartzite Formation (also known as the Sericite Quartzite Formation). Frosterus (1928), however, doubted that kaolinite could be preserved in sediments that had undergone intensive orogenesis and stated that the kaolin must be much younger, perhaps of Paleozoic or Mesozoic origin. Untill recently Väyrynen's concepts seem to have gained currency in Finland (see, *e.g.* Eskola 1963; Simonen 1971).

When remapping the South Puolanka area I did not detect a single primary Precambrian kaolin horizon (Laajoki 1973, p. 49) nor did I posses data to rectify Väyrynen's concept of the age of the kaolin in Puolanka. The aim of this paper is to present some field and laboratory data on the recently discovered kaolin deposits and some other clay occurrences in the South Puolanka area and to resume the discussion of the stratigraphic position of the kaolin clays.

# Preglacial clay occurrences and associated weathering in the vicinity of the Pääkkö farm

Bedrock: The geology of the Precambrian bedrock in the South Puolanka area has been described recently (Laajoki 1973). The rockstratigraphic units and tectonic terms employed in the present paper are those defined in the previous paper. A simplified geological map of the exposed part of the bedrock in the vicinity of the Pääkkö farm is presented in Figure 1. The bedrock in the area of present study is composed mainly of quartzites, dolomites, phyllites, black schists, iron formations, metavolcanics and metadiabases of the Marine Jatulian and Jatulian Groups of the Karelidic sequence. Structurally these rocks belong to the eastern flank of the Salmijärvi synclinorium. East of the Pääkkö farm an allochthonous unit occurs that has been called the Väyrylänkylä basement wedge. This unit consists of Prekarelidic basement gneisses rimmed by arkosites and feldspar-and/or sericitebearing quartzites of the Jatulian Arkosite

Formation. The wedge separates the rocks of the Salmijärvi synclinorium from the western flank of the Hietajärvi anticlinorium.

The Karelidic rocks are intensely folded. The prevailing bedding of the metasediments and the axial plane of the regional folds of the first deformational stage is about 25°, 70—80°W. In the Pääkkö area, minor folds of the second deformational stage are also visible. The plunge is about 50—80°, 220—240°. Closely associated with these folds are N—S striking fractures, whose genetical connection with the N—S faults so typical of the areas south of Pääkkö (see, Laajoki and Ojanperä 1973) is most probable.

Distribution of the Preglacial clays and weathering: Drilling revealed that in the areas characterized by negative gravity anomalies beds of varying thickness of autochthonous clay occur regularly and are associated with weathered Precambrian rocks (Fig. 2). The probable distribution of these deposits, buried under the Quaternary overburden, is shown on the geological map on Figure 1. The clays and weathered rocks seem to be concentrated along three main zones trending approximately NNE: 1) The Pääkkö zone, which follows the eastern contact of the dolomite west of the Pääkkö farm, is from 50 to 100 m wide and at least 2 km long. In the east it is bounded by a Precambrian iron formation. The underlying bedrock is composed mainly of quartzites and phyllites. Only at its northern end does the zone extend onto the dolomite and iron formation. 2) The Vuorijärvi zone, including its basement, has been encountered only in three drill holes (Nos. 349, 352 and 353). The length of this zone is about 3 km and its width is from 100 to 200 m. 3) A winding zone north of Iso Vuorijärvi, which begins from drill hole No. 345 in the south and runs by drill holes Nos. 361 and 362 to drill hole No. 363 in the north, crosses phyllites as well as an iron formation and metadiabase. It is relatively narrow, being only some 50 m wide. On the basis of the gravity maps, this zone extends in the south beyond the map area in Figure 1; west of Iso Salmijärvi it seems to be about 200 to



Fig. 2. Surface projections of the drilling observations of the Preglacial clay occurrences and associated weathered zones of the Precambrian rocks in the environment of the Pääkkö farm plotted on a gravity map made by the Exploration Department of the Geological Survey of Finland. The contour interval of relative Bouguer values is 0.1 milligal. 1) Clay occurrence. 2) Weathered Precambrain rocks.

250 m wide. The total length of the zone would thus be at least 7 km. It is also possible that the Pääkkö zone extends as far as Iso Salmijärvi.

Thus, in the vicinity of the Pääkkö farm, Preglacial clays and associated weathered Precambrian rocks are encountered in a belt roughly 700 m wide and at least 4 km if not 7 km long, which follows the main trend of the Precambrian metasediments and is located just west of the western contact of the Väyrylänkylä basement wedge.

The relation of the Preglacial clays to the Precambrian basement: It is evident from drilling that the fresh Precambrian rocks pass through a transition zone of more or less weathered rocks into pure clay (Figs. 3 and 4). This is well examplified in the eastern and northern part of the Pääkkö zone (Fig. 1). Thus the formation of the clays has evidently taken place after the folding of the Precambrian rocks. Partial weathering has been detected in the study area in the following Karelidic rocks: quartzites, phyllites, black schists, dolomites, metadiabase and iron formations, which occur as relict beds or wedges among the clays (Fig. 4). The partially weathered quartzites are rust-coloured and porous owing to the leaching of carbonates and other easily soluble minerals. The weathered phyllites are likewise rust-coloured and often contain limonitic matter. Black schists seem to have been relatively resistant to weathering and it is visible in them only as the leaching of iron sulphides and cavities partly filled by limonite. Partially weathered quartz-magnetite-banded rocks of the iron formations are characterized by brown limonite bands. In these rocks the total iron content has risen only slightly, but that of iron soluble in hydrochloridic acid shows a marked increase over that of fresh rock (Table 1). The contents of phosphorus and sulphur have not changed in the weathering process. In the iron formation originally rich in iron-silicates the quartz seems to have been most readily leached and hence the rock has altered into a dark- or rust-coloured iron-silicate-magnetite rock. Also



Fig. 3. Profile of drill holes Nos. 346 and 354 southwest of the Pääkkö farm showing a typical transition zone between Precambrian rocks and Preglacial clays. Note the depth of the clay beds and the Preglacial weathering.
1) Quarternary deposits; sand and gravel.
2) Preglacial clays; (a = blue, b = grey, c = red, d = yellow clay).
3) Partially weathered Karelian rocks (a = phyllite, b = black schist, c = quartzite).
4) Fresh Karelian rocks; (a = phyllite, b = black schist, c = quartzite, d = iron formation). The numbers 1--6 of drill hole No. 346 refer to the sample numbers in TABLE 2.

#### TABLE 1

Average iron, phosphorus and sulphur contents (Wt- $\frac{9}{0}$ ) of fresh (1) and slightly weathered (2) rocks of oxide facies from the Pääkkö iron formation, South Puolanka area, Finland. The analyses were made in the Ore Laboratory of the Geological Survey of Finland

	1	2
Fe <sub>tot</sub>	27.26	29.36
Fehci	20.30	28.15
Fetot—FeHCl	6.96	1.21
Р	1.10	1.23
S	1.99	1.13

<sup>1</sup>) Quartz-magnetite-banded rock. Total length of the core analysed was 388.60 m.

<sup>2</sup>) Quartz-magnetite-limonite-banded rock.

Total length of the core analysed was 8.80 m.

in this case the secondary enrichment of iron was slight.

The verified depth of the Preglacial weathering locally exceeds 113 m. Clay beds have been encountered down to a depth of 85 m (drill hole No. 346 in Fig. 3). At this depth the clay beds are some decimetres, sometimes a few metres thick. The profile in Fig. 3 indicates that both the clays and the weathered rocks may reach, at least in places, even deeper levels.

*Preglacial clays:* The colour, primary rock and mineralogical composition of different types of clays are listed in Table 2. The primary rock was determined by the author macroscopically from the core material. The clay minerals and the kaolinite contents in the clays were determined by J. Hyyppä.

The dominant clays are greyish or red in colour (Nos. 2—6 in Table 2). In some cases at least, it can be concluded that the colour of the clays depends on the primary rock. Thus, clays derived from light-coloured rocks (sericite quartzite) are paler than those from darker rocks

(dolomite and metadiabase). Also the mineralogical composition of the clays depends on the primary rock. Thus, vermiculite and various mixed-layer minerals seem to be characteristic of the clays derived from dolomites and metadiabases. Quartzites and different kinds of schists are clearly more liable to kaolinization than are dolomites and metadiabases.

The clays, especially those close to the weathered Precambrian rocks, often show relict shistosity.

The relation of Preglacial clays to the Quaternary overburden: The contact between the clays and the overlying Quaternary deposits is poorly known, no core samples of the latter having been obtained. However, the onset of the clay core or the rock core indicates that the thickness of the Quaternary overburden in the vicinity of the Pääkkö farm varies between 2 and 33 m. The deposits overlying the Pääkkö zone and the bedrock west of it consist mainly of sand and gravel. East of the zone the dominant Quaternary deposit is till.

TABLE 2

Diagnostic data on Preglacial clays in the vicinity of the Pääkkö farm, South Puolanka area. X-ray identifications of minerals and TGA-determinations of kaolinite contents were performed by J. Hyyppä. Uncertain primary rocks are followed by question marks

Sample No.	Drill hole/depth	Primary rock	Colour of the clays	Content of kaolinite (%)	Other minerals
1	346/43.30	Schist (?)	Pale grey	tr.	Quartz (much), mica
2	» /50.65	*	Grey with whitish		
			and yellowish parts	c. 50	Quartz, dioctahedral mica
3	» /55.00	>>	White	c. 50-60	Quartz
4	» /57.30	»	Blueish white	c. 50	Quartz
5	» /72.75	Mica-bearing schist (?)	Brick-red	c. 10—20	Hydrobiotite, quartz, dioctahedral mica
6	» /77.70	Mica-bearing schist (?)	Red	c. 15	Hydrobiotite, quartz
7	352/56.00	Schist	Yellow	c. 10—15	Sericite
8	» /62.70	Sericite quartzite	Clear white	c. 10-15	Quartz (much), sericite
9	356/18.00	Dolomite	Reddish brown	tr.	Mixed layer mineral (chlorite-vermiculite?)
10	» /44.20	Black dolomite (?)	Black	tr.	Mica, vermiculite
11	362/29.50	Metadiabase	Green	c. 30	Mixed-layer mineral of vermiculite and illite
12	» /36.50	Metadiabase	Pale green	—	Chlorite, mixed-layer minerals of
					chlorite-vermiculite and
				chlorite-montmorillonite	



Fig. 4. Profile of drill hole No. 352 between the lakes of Iso and Pieni Vuorijärvi showing the grading of the Precambrian fresh rock through a partially weathered rock into pure clay. 1) Quaternary deposits; sand and gravel 2) Preglacial clay occurrences (a = grey, b = red, c = white, d = yellow clay). 3) Partially weathered Karelian rocks (a = quartzite, b = phyllite, c = black schist).
4) Fresh Karelian quartzite. Numbers 7 and 8 refer to the sample numbers in TABLE 2.

# Re-evaluation of the kaolin deposit in Pihlajavaara

Because the kaolin quarry at Pihlajavaara has totally mouldered my main concern in this chapter is to revise the facts published in the literature by Väyrynen (1922, 1924, 1928, 1929, 1954), Enkovaara *et al.* (1953) and Frosterus (1928, 1929).

Bedrock: Väyrynen (1924, p. 396) gives the following stratigraphic description of his Kainuan Quartzite Formation: 1) Coarse, macroclastic basal formation, 2) sericite schist with kaolin deposits, and, on the top 3) pure, finegrained quartzite. These rocks overlie the gran-12 7352-75 itic basement. The folding of the Kainuan Formation was so intense that there are now three folds per kilometre (*op. cit.*, p. 396).

These Kainuan rocks in the immediate vicinity of the Pihlajavaara quarry have recently been correlated with the rocks of the Arkosite Formation; they were interpreted as allochthonous and strongly tectonized (Laajoki 1973, p. 17, 42). Structurally they belong to the Väyrylänkylä basement wedge.

Distribution of kaolin: At Pihlajavaara kaolinite has been detected in a zone trending approximately N—S, and which is about 40 to 80 metres wide and some 500 metres long.

The relation of the Pihlajavaara kaolin to the Precambrian bedrock: The relationship between the kaolin and the bedrock at Pihlajavaara was the greatest subject of contention between Väyrynen and Frosterus.

As mentioned on p. 83, Väyrynen considered the kaolin as a primary product of Archean weathering. He rejected the possibility of weathering younger than the folding by referring to the fact that kaolinite had not been found in other rocks as liable to kaolinization as the Pihlajavaara rocks and to the bedding and breccia structures present in the kaolin (Väyrynen 1922). His view (Väyrynen 1924, p. 403) that the kaolin was formed at the same time as the rocks of the Kainuan Quartzite Formation (or the Sericite Quartzite Formation) were deposited was based on the information that all kaolin occurrences in Puolanka were lying on the sericite quartzite of this formation and that they had not been met with overlying granites and mica schists.

Väyrynen (1929, p. 150; cf. also 1933; p. 64, 1938, p. 78; 1939, p. 38) was of the opinion that the sericite schists closely associated with kaolin were formed from primary kaolin deposits through metamorphism.

Frosterus (1929, p. 163, cf. also Väyrynen 1929, p. 130) stated that at both its contacts the kaolin passes into non-weathered mica-rich quartzite and that the schistosity observed in the kaolin indicates a primary phyllitic rock. He considered the kaolin deposits to have formed on a faulted bedrock.

Kaolin in Pihlajavaara: The kaolin deposits in Pihlajavaara are composed of beds of different colour. The white and grey beds contain about 43 to 55 % kaolinite and the red beds up to 65 %kaolinite (Enkovaara *et al.* 1953, Table 3). The other essential mineral is quartz, whose content in clay varies from 30 % to 57 %. Other minerals identified are sericite, magnesian mica and feldspar.

The relation of the Pihlajavaara kaolin to the Quaternary deposits: The Pihlajavaara kaolin is overlain by till beds only a few metres thick. The till contains interbeds rich in kaolinite, indicating that the deposit is at least Preglacial in age (Väyrynen 1924, p. 400).

## Regional distribution of kaolin in Puolanka

Of the kaolin occurrences in Puolanka known by Väyrynen (1929, Enkovaara et al. 1953), those of Pihlajavaara, Leppälä and Pahkavaara are close to the eastern tectonic contact of the Väyrylänkylä basement wedge or lie on the wedge itself. The deposits near the Pääkkö farm lie near the western contact of the same wedge. The occurrence at Honkavaara lies about 20 km NNE of Väyrylänkylä. Stereoscopic interpretation of air-photo maps suggests that Honkavaara belongs to the same N-S striking fault zone as the Pihlajavaara, Leppälä and Pahkavaara deposits. The other kaolin occurrences listed in the papers referred to (Kerkkä, Holstinvaara, Latvajoki and Soikka) are associated with another N-S striking fault zone some 10 km east of Väyrylänkylä. Moreover, small amounts of kaolinite are encountered on a thrust plane near Äylö, northern Puolanka, about 25 km north of Väyrylänkylä (Väyrynen 1954, p. 162).

In addition to the occurrences mentioned above, I have detected kaolinite-bearing till at the bottom of a dike in Leipivaara, about 15 km north of Väyrylänkylä, c. 5 km west of the Honkavaara-Pahkavaara fault zone. According to information given by people in the district kaolinite is also found at Törmänmäki, about 20 km south of Väyrylänkylä.

Thus, kaolin is known to occur in Puolanka in an area embracing some 700 km<sup>2</sup>. The main kaolin occurrences are, however, clearly associated with the strongly faulted zones in the Precambrian bedrock. The areas of the N—S striking fault zones in particular seem to be promising sites for new kaolin deposits. The rocks associated with these faults in Väyrylänkylä have been described previously (Laajoki & Ojanperä 1973).

#### Discussion

The observations on drill cores from the Pääkkö area clearly show that the kaolinite clays are younger than the Precambrian bedrock. These deposits and the deposit of Pihlajavaara lie so close to each other, and their stratigraphic position and relationships with the rocks of the Precambrian are so similiar that they can be correlated with each other. Thus, Frosterus was correct when he assigned a relatively young age to the Pihlajavaara kaolin. Most probably the kaolin occurrences in Puolanka are correlative with the Preglacial weathering clays recently discovered in Kittilä (Yletyinen & Nenonen 1972, unpublished report M 19/2 734/-72/1/10 in the archives of the Geological Survey of Finland) and at Jauratsi and Sokli (Nuutilainen & Mäkelä 1973), in Finnish Lapland, and even with the Preglacial clay at Tyrvää, SW Finland (Härme 1949).

The close association of the Preglacial clays with zones showing signs of strong faulting suggests that these strongly tectonized zones were favourable sites in the bedrock for Preglacial surface weathering down to considerable depth, and hence it was at places such as these that the weathering products were most likely to escape total abrasion by glacial action during the Ice Age (*cf.* Frosterus 1929; Härme 1949). Acknowledgements — The author is indebted to the following staff members of the Geological Survey of Finland: to Mr. Jussi Hyyppä, Phil. Lic., for the mineralogical determination, to Mrs. Marjo-Riitta KujalaTammi and Miss Lea Leiponen for drawing the figures and to Drs. Mauno Härme and Marjatta Okko for critically reading the paper and making valuable suggestions.

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