

AN OCCURRENCE OF VEIN PLYGORSKITE FROM THE NEPHELINE SYENITE AT LILLEBUGT, STJERNØY, NORTHERN NORWAY

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Palygorskite and a montmorillonitic clay mineral occur in mountain leather-like aggregates within fractures cutting nepheline syenite. The veins are part of a late hydrothermal-metamorphic suite but the age of the palygorskite is uncertain. It may have formed as the youngest phase of a hydrothermal assemblage developed under waning conditions of metamorphism or may be completely post-tectonic in origin and related to near-surface ground water circulation.

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In the summer of 1968, one of us (E.C.A.) was enabled, by the kind permission of the directors of Nordkapp Nefelin A/S, to examine the nepheline syenite deposit being mined by this company at Lillebugt, Stjernøy, northern Norway. The nepheline syenite is cut by numerous fractures, a few of which were found to contain a platy, greyish-white, paper-like substance interleaved with cataclastic rock material. Subsequent study of the material by X-ray diffractometry and electron microscopy proved it to be an aggregate of a montmorillonite mixed-layer mineral and palygorskite, material not previously described from this locality. Several lines of evidence point to a very late hydrothermal origin for the mountain leather but a completely post-tectonic origin related to near surface ground water circulation cannot be ruled out.

Geological setting

The Stjernøy nepheline syenite is a stock-like body with a lensoid outcrop plan approximately 1.7 km by 250 m in maximum dimensions. It is emplaced into mafic silicate gneisses on its southern margin and is in turn cut by carbonatite on the north and east and elsewhere around its margins. The geological setting, mineralogy and geochemistry of the nepheline syenite and its associated rocks have been described in detail in a series of papers by Heier (1961, 1964, 1965, 1966). The nepheline syenite is dominantly a nepheline-perthite rock varying in its mafic components: clinopyroxene, amphibole and biotite. In the least recrystallized facies, clinopyroxene is often the only ferromagnesian mineral present but as the rock acquires a foliation, amphibole

and biotite are usually found exclusively. Sturt, Miller & Fitch (1967) obtained two whole rock K-Ar dates on the nepheline syenite of 402 and 404 ± 10 m.y. but believe these to represent a late Silurian thermal overprint on rocks of actual early Ordovician age. They demonstrate that nephelines from nepheline syenite pegmatites elsewhere in the region yield ages of 480 to 491 m.y. and believe this to be the actual age of emplacement. Sturt & Ramsay (1965) and Appleyard (1965) have demonstrated that the alkaline rocks on the neighbouring island of Sørøy were emplaced synorogenically early in the second of two demonstrable episodes of regional folding.

A detailed study of the age and history of deformation of the heavily fractured Stjernøy nepheline syenite has been made by Ramsay & Sturt (1970). A summary of their conclusions is as follows:

1. Emplacement of the nepheline syenite.
2. Metamorphism under amphibolite facies conditions effecting a fairly extensive recrystallization of the nepheline syenite and the imposition of a foliated fabric.
3. Intense fracturing by the application of a localized rapidly applied stress field.
4. Intrusion of the fractured mass by a network of thin basaltic sheets.
5. Synchronous deformation under high temperatures and at low strain rates producing non-systematic shear belts characterized by annealed and recrystallized fabrics.
6. Metamorphism under upper greenschist facies conditions.
7. Late fracturing producing cataclastic zones cutting both nepheline syenite and metabasaltic dykes. These are commonly marked in the nepheline syenite by conspicuous zones of 'hydrothermal' alteration in which nepheline is totally altered and zeolites, clay minerals, scapolite, epidote, cancrinite, muscovite, chlorite, hematite and pyrite are developed.
8. Possible rebound jointing resulting from erosion and mining operations.

The mountain leather material was collected from cataclastic joint surfaces associated with event (7) above.

Sample description and mineralogy

The relevant material was collected from the main mine haulage-way which has the form of a helical spiral rising from the portal near sea-level upwards into the nepheline syenite body within the mountain called Nabberen. Heier (1961: 133) reports the highest elevation of the nepheline syenite on the plateau to be about 700 m. Samples from the centres of hydrothermally altered cataclastic shear zones as well as fresh and partly altered wall rock adjacent to the fractures were collected. Palygorskite occurred in several of the specimens collected from the central portions of the shears. (All specimens used in this

study are deposited in the petrological collections of the Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada.) The specimen (ECA 68-149) which best displays the macroscopic characteristics of the mountain leather is a slab 10 cm by 15 cm and varying from 1 to 2 cm in thickness consisting of a thin layer of white granular cataclastic material enclosed between two flexible, felty, white or greyish-white sheets each several mm in thickness. The latter closely resemble asbestos paper. They are crossed by a series of parallel ridges and grooves, resembling slickensides, but involving microrenulations of the fibrous mountain leather itself.

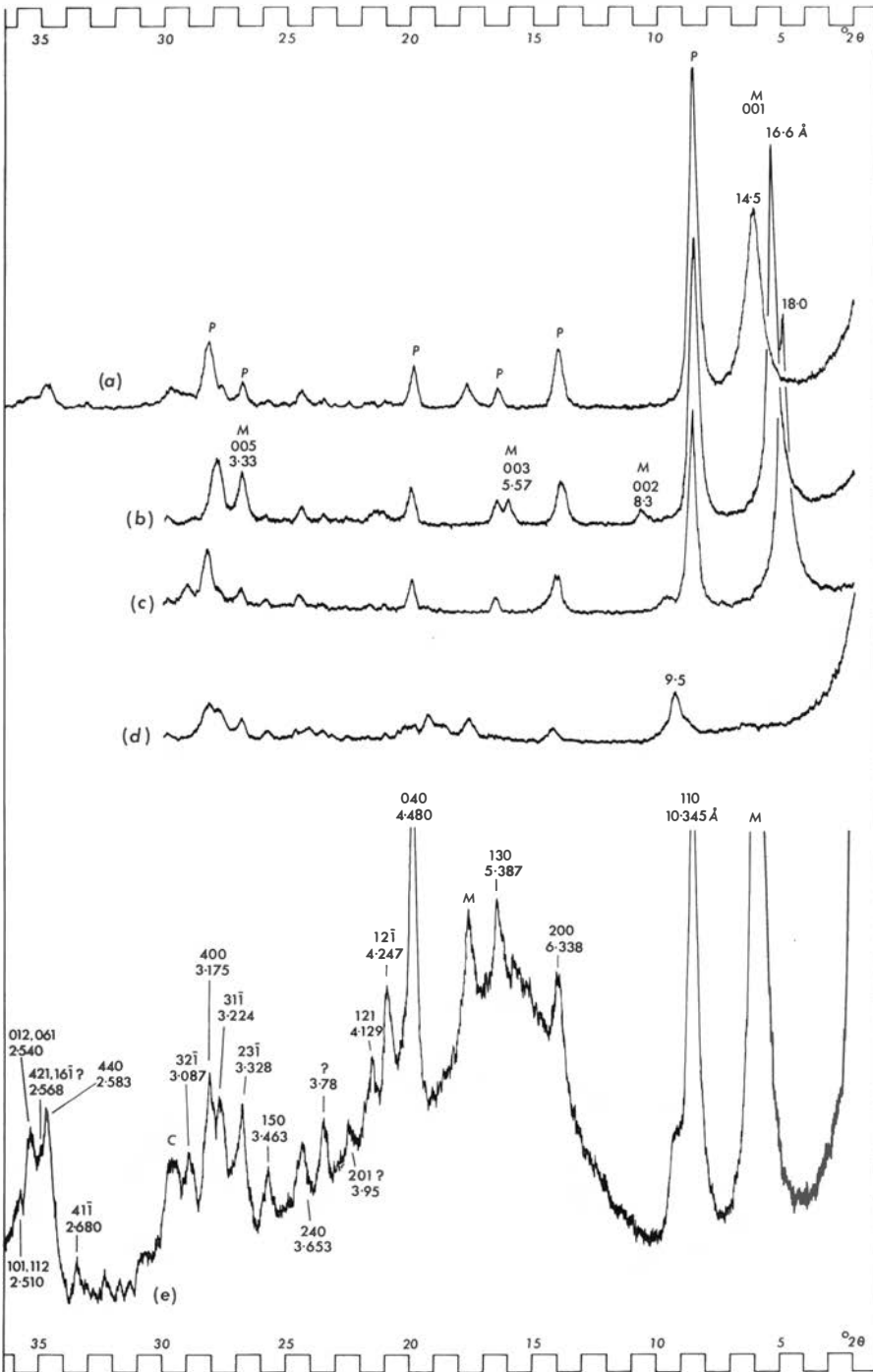
The granular material interleaved in the layered assemblage consists of rounded and angular fragments of the syenite and its feldspathic minerals with a fine-grained white matrix containing fibrous palygorskite visible with a hand lens on a freshly broken surface. This material softens and swells when immersed in water. Sieved particles between 75 and 125 microns consist mainly of well rounded aggregates of cryptocrystalline montmorillonite and relict feldspars. Some euhedral, rhombohedral crystals of calcite, a few mm in length, are scattered in the granular material. Small, fresh stilpnomelane (optical identification) flakes with rounded outlines have also been recovered from this material.

In other samples, the palygorskite occurs as thin, flexible coatings on joint surfaces of altered, hematite-stained nepheline syenite and as thin layers in crustiform, coarsely crystalline calcite vein fillings.

The partly altered wall rock nepheline syenite adjacent to the fractures apparently contains no palygorskite. Nephelines are extensively altered to chalky 'hydronephelite' but X-ray diffractometer traces show only a mixture of montmorillonite and illite, although it is recognized that in such mixtures palygorskite could be present in minor quantities with its chief diffraction peaks obscured by those of illite.

The macroscopic identification of the palygorskite in specimen ECA 68-149 was confirmed by X-ray diffractometry and electron microscopy. The co-existing white granular material was found to consist mainly of an irregularly stratified, mixed-layer mineral, in which the majority of the layers are montmorillonite. This mineral is also present within the paper-like sheets. Diffractograms obtained using a flake of the paper-like material (Fig. 1, diffractogram (a)) gave, in addition to the major peaks of palygorskite, a strong (001) peak of 14.5 Å with a series of weak, non-integral higher order reflections. The sample was dried in an oven at 110°C. Water-saturation of the sample produced a marked shift of the (001) peak corresponding to an expansion to 18.0 Å (diffractogram (c), Fig. 1). Glycolation caused an expansion only to 16.6 Å, though a weak series of integral higher order reflections was produced (diffractogram (b), Fig. 1). Since the treatment with ethylene glycol vapour did not cause expansion to 17 Å which is normal for the (001) peak of montmorillonites, it is concluded that a small proportion of non-expanding layers, probably illitic, are interstratified with about 95% of montmorillonite.

The cation content of the montmorillonite is probably mainly Ca^{++} since



saturation with a calcium chloride solution produced no change in the (001) spacings of the hydrated material, whereas treatment with a Na^+ solution caused a marked decrease in the basal spacing. This is interpreted as indicating that Na^+ cations were not present in any major quantity in the untreated sample.

Complete physical separation of the montmorillonite material from the palygorskite proved impossible, making it difficult to obtain full diffraction data for the latter mineral. Adding to this difficulty, the fibrous habit of the mineral prevents easy achievement of a randomly orientated sample for diffractometry. The best diffraction data for the palygorskite were obtained using a sample prepared by mixing broken-up paper-like material into melted Lakeside resin. When cool, the mixture was pulverized and packed into an aluminium sample holder. The presence of the resin, although contributing to a high background on the diffractogram, theoretically permits the palygorskite fibres to lie randomly orientated within the irregularly shaped particles of resin (Brindley & Kurtossy 1961). The pattern obtained (Fig. 1, diffractogram (e)) gives major peaks which compare well with published data (Christ *et al.* 1969). Indexing the weaker diffraction peaks by comparison with the published data suggests that this palygorskite is the monoclinic form. Separation of the (121, $12\bar{1}$) doublet is seen in the region of $20^\circ 2\theta$, but the (161, $16\bar{1}$) pair in the 35° range is not obvious. The diffractogram compares well with the monoclinic patterns figured by Nathan *et al.* (1970).

A scanning electron micrograph (Fig. 2) of a sample of the paper-like mountain leather shows curved and splitting aggregates of rather thin, lath-like crystals typical of palygorskite (Stephen 1954: plates XIV, XV, Martin Vivaldi & Robertson 1971, van der Wel 1972: plates IA, IB). Associated with the fibrous palygorskite are a few scattered aggregates of anhedral platy crystals of montmorillonite.

Discussion

The genesis of palygorskite is not yet fully understood. Two principal types of occurrences for the mineral are recognized (Caillère & Henin 1961). One type can be classed as sedimentary. The material originally called attapulgitite from Attapulgis, Georgia, U.S.A. (De Lapparent 1935) was a constituent of sedimentary strata and recently published studies describe the mineral from deep sea

Fig. 1. Diffractometer tracings for the paper-like material (Specimen ECA 68-149). (a)–(d) Tracings obtained using a flattened flake as a sample. (a) Sample dried at 110°C . (b) Sample glycolated – heated at 60°C in ethylene glycol vapour for one hour. (c) Sample saturated with water. The tracing was obtained before glycolation. (d) Sample heated at 550°C for 2 hours. (e) Sample prepared by mixing with Lakeside resin, pulverized and packed in an aluminium holder to achieve a random orientation. S-spacings in Ångstrom units and probable indices are indicated. P=palygorskite, M=montmorillonitic mineral, and C=probable calcite peak.



Fig. 2. Scanning electron micrograph of a flake of mountain leather. A tendency for a preferred orientation of the broader aggregates of fibrous crystals is shown. The flexible nature of the thinner palygorskite crystals is displayed by their curvature where they are split away from the larger aggregates, probably as a result of the detachment of the flake from the mass of the specimen.

(Bonatti & Joensuu 1968) and recent marine sediments (Esteoule *et al.* 1970, Blanc Vernet & Chamley 1971). Sedimentary palygorskite is reported also from saline lake sediments and desert soils (Grim 1968). Nathan *et al.* (1970) suggest that palygorskites of this origin may be orthorhombic.

The other type of occurrence is as well-crystallized vein or fissure filling in sedimentary or, more commonly, magmatic rocks. The origin of vein palygorskite has commonly been attributed to hydrothermal action by most authors (Stephen 1954, Nathan *et al.* 1970, van der Wel 1972) but others (Evans & King 1962, Tien 1973) postulate an origin by percolating meteoric water from an overlying erosional surface – in the cases cited, a surface believed to be of Triassic age and involving a desert environment. Nathan *et al.* (1970) suggest that hydrothermal palygorskites may be monoclinic.

It is tempting to consider the vein palygorskite from Stjernøy which appears to be monoclinic as part of the late hydrothermal paragenesis but more information is necessary to support this contention. In favour of such a hypothesis is the fact that the mountain leather is associated intimately with a hydrothermal assemblage of minerals including montmorillonite whose earlier members represent greenschist assemblages and whose later members represent sub-greenschist assemblages. The microcrenulations and/or slickensides exhibited by the mountain leather may have been caused by the last of the movements which generated the cataclastic fractures which the veins occupy. Thin sections of the vein material show bundles of palygorskite with a preferred orientation much like that described by Stephen (1954) but whether this feature is of tectonic origin is unknown.

On the other hand one could argue that very few of the hydrothermal veins appear to have developed palygorskite, which also does not appear to be present in the altered wall rock. This could be the effect of a separate post-hydrothermal chemical or thermal control. Mumpton & Roy (1958) report that sepiolite and palygorskite readily alter to smectites when affected by mild hydrothermal treatment. The palygorskite assemblage is older than the microcrenulations which cross it but the age of these cannot be definitely established. They could be due to post-Caledonian isostatic movements or even to mining operations. A number of the altered cataclastic zones within the mine at the present are seeping water including several of those from which mountain leather was obtained. Our information does not indicate whether these conditions are related.

The source of Mg^{++} necessary for the formation of the palygorskite probably lies in the altered facies of the basaltic dykes. The nepheline syenite itself is exceptionally impoverished in MgO (average $MgO=0.30$; $n=18$). Leaching of MgO from sheared and cataclastic basaltic material occurred during hydrothermal alteration and may be proceeding at present in some of the wet fractures.

In conclusion, vein palygorskite has been described from a variety of igneous rock types including syenite, granite, diorite and low temperature ore veins. These rocks frequently show the effects of hydrothermal alteration to varying degrees but even within such zones palygorskite appears to be an uncommon mineral and is not frequently recognized in such rocks. The problem may reside in recognition and identification difficulties but the mountain leather habit is sufficiently distinctive to attract immediate attention. It appears that further work is desirable to define the P-T-X conditions requisite for the formation of this interesting mineral.

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