

AWARUITE (JOSEPHINITE), A NEW MINERAL FOR NORWAY

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Native nickel-iron is reported from metamorphic ultrabasites at Feragen, Sør-Trøndelag, Southern Norway.

Physical, optical, chemical, and X-ray data are given. The paragenesis of the nickel-iron is described, and its genesis is discussed.

INTRODUCTION

A natural nickel-iron alloy with about 73-79 weight per cent of nickel, 26-21 weight per cent of iron and 1 weight per cent of cobalt has been found at Feragen, Sør-Trøndelag, Southern Norway (Fig. 1), in chromite rich metamorphic dunite-lherzolite rocks of early Caledonian age. The Feragen metamorphic ultrabasites occur intercalated between Eocambrian rocks (augen gneisses) and metamorphic Cambro-Silurian sediments of the Trondheim area. This is the first reported occurrence of such a native alloy in Norway.

Terrestrial nickel-iron has been found, described, and named from a number of localities previously. The first was awaruite, described by Skey in 1885 from Awarua, New-Zealand. Similar material from Oregon was named josephinite by Melville in 1892, from British Columbia, souesite by Hoffman in 1902 and from Brokovka river in U.S.S.R. brokovkite by Wysozky in 1913.



Fig. 1 . Key map (of Norway). The ring indicates the location.

The compositions of natural nickel-irons found to date, vary between 65 and 75 per cent nickel and 25 and 35 per cent iron, sometimes with minor amounts of impurities such as hydrogen, carbon monoxide, and serpentine. They all belong to the same phase and possess identical crystal structures.

Awaruite was the first name applied to material of this composition, and therefore this name should take precedence.

The nickel-iron alloy occurs commonly in metamorphic ultrabasites. It seems evident that the alloy is formed penecontemporaneously with the hydrothermal alteration of the country rocks in an environment deficient in sulphur, but it is difficult to explain why the nickel and iron should occur in metallic state rather than entering the lattice of serpentine minerals.

In view of the world wide occurrence of the natural alloy, there cannot be anything highly abnormal or specialized about the conditions of formation.

PARAGENESIS

The mineral was formed in antigorite, talc, and kämmererite pseudomorphs after chrysolite and pyroxene within the metamorphic ultrabasites. It shows a notable concentration in the most intensively metamorphosed parts of the country rocks. The mineral occurs in euhedral to anhedral crystals, the latter often exhibiting rounded and embayed margins (Fig. 2). The grains are about 0.05 mm in diameter and are often associated with, or surrounded by, secondary magnetite. Apparent equilibrium relationships between magnetite and awaruite have also been noted by Nickel (1959), who, on the basis of thermodynamic calculation, assigned 750° C as the upper limit for such equilibrium. On the other hand, Challis & Long (1964), on the basis of their investigation of awaruite, serpentine, and wairauite, are of the opinion that awaruite was formed below 475° C. Unlike the occurrences described by Nickel and by Challis & Long, there is in the Feragen occurrence a notable concentration of the mineral in the neighbourhood of chromite areas, particularly where

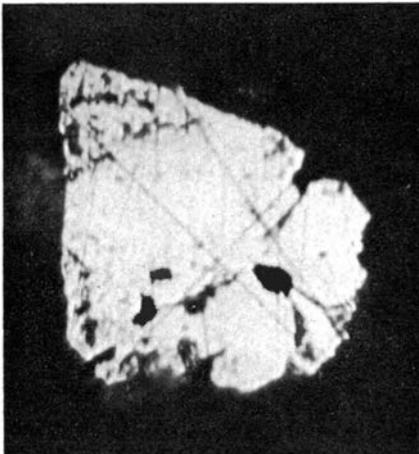


Fig. 2. Porous awaruite with rounded and embayed outlines. Oil immersion. $\times 700$.

the chromite shows extensive hydrothermal alteration to ferrian chromite and chromian magnetite. The alloy is often observed in the pits of ferrian chromite.

The awaruite frequently exhibits a vesicular habit (Fig. 2). Owen & Burns (1939) remarked upon similar porosity in material from Josephine county, Oregon. They proved that their sample contained 30 times its own volume of hydrogen and carbon monoxide and assumed (in view of the high percentage of 'impurities' in their analyses) that it also contained some serpentine.

In the present case, microscopic examination reveals only empty pits, but it must be remembered that any soft minerals present in these cavities could have been ripped out during the preparation of the polished section.

Therefore it is not impossible that the material from Feragen could have similar impurities. The determination of the nature of these impurities would be of great help in the interpretation of the genesis of the mineral.

OPTICAL, PHYSICAL, AND CHEMICAL PROPERTIES

The identity of this mineral was established by the use of ore microscopy, micro-hardness tester, and X-ray powder diffraction methods. Awaruite is yellow white in reflected light. It is slightly harder and has higher reflectivity than pentlandite.

Awaruite from Feragen is magnetic, but because of the small sizes of the grains, it is extremely difficult to measure its magnetic susceptibility.

Twelve measurements of the microhardness of the Feragen material, made on seven different mineral grains, varied within the range 302-424 kg/mm².

The crystal structure of awaruite was first investigated by Owen & Burns (1939) and shown to be isometric, space group $Fm\bar{3}m$. Published data of the lattice-parameters of awaruites all fall within the range of 3.545-3.565 Å.

Samples from three different localities at Feragen gave the following values:

Røtjern mine	3.555 Å
Gjetsjø mine	3.556 Å
Gjetberget mine	3.557 Å

Leech & Sykes (1939) first reported a superlattice in slowly-cooled artificial Ni₃Fe-alloy. Nickel (1959) has described a terrestrial nickel-iron alloy with a cell size 3.555 Å and an approximate composition Ni₃Fe which showed a superlattice that corresponded to the superlattice reported by Leech & Sykes. In view of the similarity in cell size of the Feragen material, it was checked to see if a corresponding superlattice also occurs here. The powder diagram of the Feragen material contains faint lines in addition to those characteristic of a face-centered isometric structure for which the values of N for the first four lines are 3, 4, 8 and 11. The faint lines were measured, but they do not fit into the values of N given by Leech & Sykes. The extra lines observed must therefore belong to impurities such as antigorite, talc, and kämmerite.

According to previous studies of artificial Ni-Fe alloys, it appears that a solid solution series exists over the range 0-100 atomic percent iron, with a near linear relationship between iron content and cell size over the range 0-60 atomic per cent iron and with a maximum lattice-parameter 3.5967 Å at 39 atomic per cent nickel (Owen, Yates and Sully 1937).

The compositions of terrestrial nickel-irons found to date, range from 65-75 weight per cent nickel and 25 to 35 weight per cent iron.

Brandenberger (1939) assumed that the synthetic curve can be used to determine the approximate chemical composition of the terrestrial alloy when its cell size is known, and in two cases where both chemical analyses and cell sizes are available for terrestrial material (Owen & Burns 1939; Nickel 1959) this assumption seems to be justified (Cf. Fig. 3, which is a plot of chemistry, and cell size of synthetic and terrestrial materials).

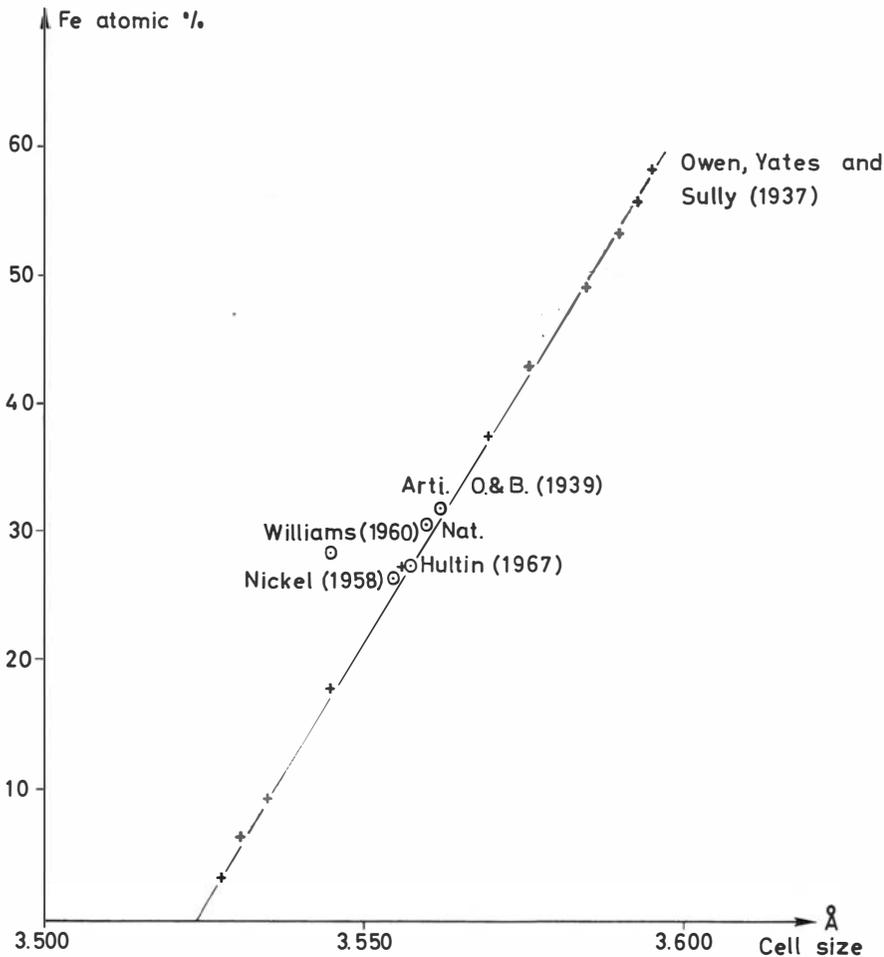


Fig. 3

However, Williams (1960) obtained anomalous results for material from the type locality and warned that considerable error might be involved in such a calculation.

A chemical analysis of awaruites from the locality of Gjetberget has been carried out on an X-ray Microprobe Analyser, type Cambridge Microscan MKII, at the Central Institute for Industrial Research, Oslo.

Pure metals were used as standards, and the methods of Philibert & Castaing were used for correcting the absorptions and fluorescence, respectively. Two samples were run.

Corrected values are listed beneath (in weight per cent).

	I	II
Fe	26.4 %	20.9 %
Ni	72.6 %	78.7 %
Co	1.0 %	0.3 %

There is a considerable difference in the compositions of the two awaruites. The composition of sample I corresponds closely to the awaruite reported by Nickel (1959), which had a cell size of 3.555 Å, while the nickel and iron contents of sample II disagree strongly with the earlier reported terrestrial awaruites. Because of this great disagreement, it would have been of great interest to determine the cell content of sample II, but it was impossible to identify this mineral grain in the specimen with certainty.

Plotting the chemistry and the cell size of sample I in Fig. 3, it is thus apparent that the cell sizes of terrestrial nickel-irons give an approximation of their chemical compositions.

GENESIS

Previous workers, Ramdohr (1950), Nickel (1959), Challis & Long (1964) and others, all agree that awaruite was formed during the hydrothermal metamorphism of the ultrabasities.

Further, Challis & Long (1964) think, as a result of their investigations of the association serpentine, awaruite, and wairauite (Co-Fe alloy), that awaruite was formed below 475° C. Chamberlain et al. (1965) have described the formation of native Ni-Fe and Co-Fe alloys from pentlandite and other minerals by a process of desulphidization during the serpentinization of the Muskox layered complex.

Primary Ni-Fe sulphides have not been found in the Feragen metamorphic ultrabasites, and it seems that the source of Ni and Fe must be the primary silicates and oxides minerals (olivine and chromite).

The awaruite is never found as inclusions in the primary minerals, only in association with their secondary products. There seems, moreover, to be a direct relationship, firstly between the concentration of ferrian chromite and chromian magnetite and that of awaruite, and secondly between the degree of hydrothermal alteration of the primary minerals and the concentration of awaruite.

Optical-spectrographic investigations of the primary minerals revealed a Ni-content of 0.03-0.06 weight per cent in the silicates and 0.05-0.20 weight per cent in the chromites. This evidence points to the conclusion that the hydrothermal alteration of the primary minerals has released nickel and iron which, under strong reducing conditions, formed awaruite rather than Ni and Fe bearing serpentines.

The ultrabasites in the locality showing very advanced hydrothermal alteration (serpentinites) have apparently, in addition, been subjected to sulphur mesomatism, since awaruite is in places replaced by secondary pentlandite.

In trying to account for the existence of strong reducing conditions at an early stage of a hydrothermal alteration, the results of Shipko & Douglas (1956) and Linnenbom (1958) are of great interest. They state that $\text{Fe}(\text{OH})_2$ may form magnetite, hydrogen, and water,



in the absence of oxygen at temperatures higher than 100°C , but this reaction also takes place below 100°C in the presence of $\text{Ni}(\text{OH})_2$. Hahn-Weinheimer & Rost (1961) state that during the hydrothermal alteration of olivine and during the formation of secondary magnetite, the ions of Mg^{+2} , Fe^{+2} , Fe^{+3} , and Ni^{+2} are more or less hydrated and that the formation of $\text{Fe}(\text{OH})_2$ and $\text{Ni}(\text{OH})_2$ occurs in the absence of new supply of acids. Furthermore, these authors state that the newly-formed hydrogen reduces Ni^{+2} to a metallic state, and that the partial pressure of hydrogen is sufficient also to reduce some FeO, and that this metallic iron is stabilized in awaruite



which takes place between 250° and 400°C . (Shipko Douglas 1956). The newly-formed hydrogen could have been partially trapped within the awaruite of Feragen, thus causing its porosity.

According to Hahn-Weinheimer & Rost, the content of iron in the awaruites depends on the partial pressure of the hydrogen in the rocks. In this case it seems as if a variable, partial pressure of the hydrogen accounts for the different Fe-content in the two awaruites of Gjetberget locality.

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