Contribution to the mineralogy of Norway, No. 60

HEDLEYITE ($Bi_{14}Te_6$) FROM THE VADDAS-RIEPPE AREA, NORTH TROMS, NORTHERN NORWAY

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Hedleyite is reported for the first time in Norway from four localities in the Vaddas–Rieppe area of northern Norway. The mineral occurs in local metamorphic mobilizates in the Caledonian massive sulphide deposits of the area. The mineral paragenesis in which hedleyite occurs is galena, bismuth, arsenopyrite, fahlore cubanite, chalcopyrite, and sphalerite. Results of microprobe analyses, reflectance-, and microindentation hardness (Vickers) measurements for hedleyite are presented. Some of the values are in disagreement with earlier published data for this mineral, although the chemical composition is in agreement with that of the type material from Hedley, B.C., Canada.

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Hedleyite – $Bi_{14}Te_6$ – was first described as a naturally occurring mineral from the Good Hope Claim, Hedley, B.C., Canada, by Warren & Peacock (1945). The mineral was described as 'a bismuth–tellurium alloy which is essentially a solid solution of bismuth in Bi_2Te_3' (Warren & Peacock 1945: 67). The structure of the lattice was described as having a hexagonal rhombohedral symmetry. Hedleyite was later described by Thompson (1949) from another locality in Canada, in Yukon Territory.

Godovnikov et al. (1966) have studied synthetic bismuth–tellurium alloys, and their conclusion is that the formula of hedleyite is Bi_5Te_3. They further conclude that the composition $Bi_{14}Te_6$ found by Warren & Peacock (1945) on naturally occurring mineral is due to impurities and mechanical admixtures of bismuth in the samples analysed.

Hedleyite was identified in the ores from the Vaddas–Rieppe area (Fig. 1) during work on the mineralogy of the ores. The field work in the Vaddas-Rieppe area was undertaken as part of an exploration programme carried out by A/S Bleikvassli Gruber.

The mineral deposits and the mineral paragenesis

The sulphide deposits in the Vaddas–Rieppe area belong to the northernmost metallogenetic subprovince in the Caledonian mountain belt (Vokes 1958). Mineralizations in this subprovince can be recognized from Signaldal, at the southern end of Lyngenfjord, through the Skibotn and Birtavarre areas, to the Vaddas–Rieppe area, a distance of some 100 kilometres.

The base metal is mainly copper, but in a few localities considerable amounts of zinc occur in addition.

The massive sulphide deposits in the Vaddas–Rieppe area are connected with a greenstone, a submarine basaltic lava eruption in the sequence of Cambro–Silurian sediments (Lindahl 1974). The sedimentary facies was changing rapidly and the thickness of each unit varies greatly over short distances. The rock types are mica schists, quartzites and marbles, also with conglomeratic horizons. The massive sulphide deposits lie stratabound near or on the top of the above-mentioned lava unit. All the ore deposits in this area are predominantly pyrrhotitic with varying amounts of pyrite. They are mainly Cu–Zn ores, except the Rieppe deposit which is a Zn–Cu ore. Copper occurs mainly as chalcopyrite, sometimes as cubanite, while zinc occurs as an iron rich sphalerite (7–11 wt. % Fe).

The deposits in the area are strongly tectonized (durchbewegt), and 'ball textures' (Vokes 1974) can nearly always be recognized. The massive sulphide ores and the sediments in the area are in medium amphibolite facies of regional metamorphism, which has caused a complete recrystallization of the sulphides.

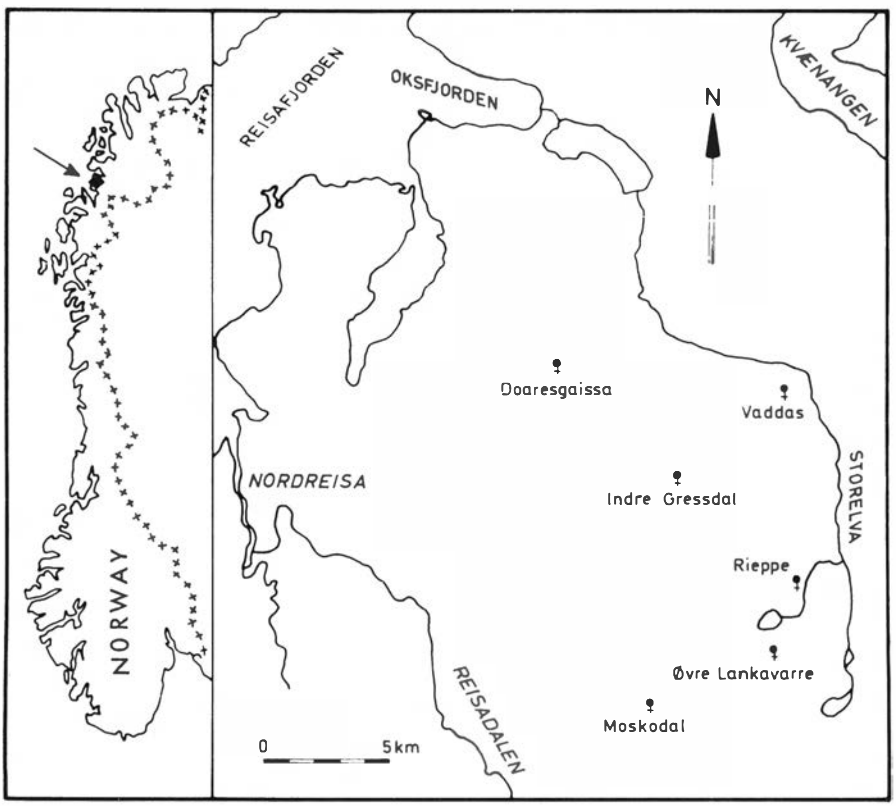

Fig. 1. Location map of the Vaddas–-Rieppe area.

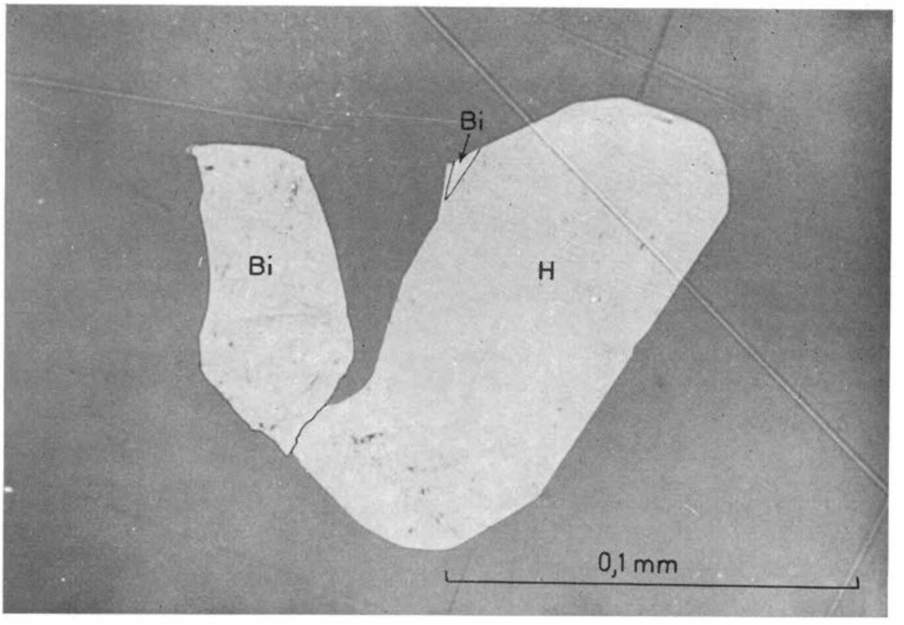

Fig. 2. A composite grain of hedleyite (H) and bismuth (Bi) in galena. Polished section, 1 nicol, oil immersion.

During the regional metamorphism, elements such as Pb, Bi, Te, As, and Sb appear to be easily mobilized (Vokes 1971), and locally to be found concentrated in the ores. The elements occur typically as the paragenesis galena, bismuth, arsenopyrite, fahlore, and hedleyite, together with some of the more common sulphides such as chalcopyrite, cubanite, and small amounts of sphalerite and pyrrhotite. Uytenbogaardt & Burke (1971: 246) and Ramdohr (1969: 436) describe among others galena and arsenopyrite as paragenetic minerals to hedleyite.

The mineral paragenesis containing hedleyite occurs relatively rarely and can be found within the massive ore bodies, towards the wallrock or sometimes in veinlets in the wallrock. Hedleyite is found locally in the ores only in the above-mentioned paragenesis. It is most abundant in the Indre Gressdal deposit, but also occurs at Doaresgaissa, Rieppe, and Øvre Lankavarre (Fig. 1).

Hedleyite

Mode of occurrence

In the sulphide deposits of the Vaddas–Rieppe area the hedleyite most commonly occurs enclosed in galena, but is also sometimes found towards the grain boundaries of the galena. Hedleyite occurs in the first place as rounded allotriomorphic grains (Fig. 2). Composite hedleyite–bismuth grains of the same rounded form also occur in the galena. In these cases the boundary

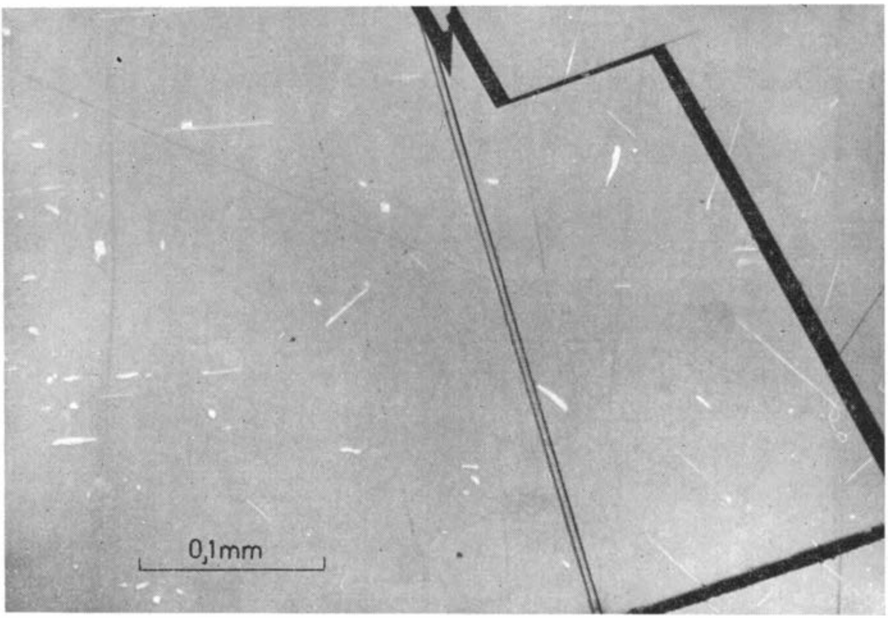

Fig. 3. Thin laths of hedleyite and bismuth (white) crystallographically orientated in galena. The cubic cleavage in the galena can be seen. Polished section, 1 nicol, oil immersion.

between hedleyite and bismuth is often a plane. Thin patches of bismuth are also sometimes found in the hedleyite. In the second place hedleyite occurs as thin lamellae or laths crystallographically orientated in the galena. This is shown in Fig. 3. The lamellae can be seen to be orientated in three directions in the same crystal, all of them different from the visible cubic cleavage. The direction may represent crystal planes in the galena, perhaps octahedral planes. Each lamella can in some cases be a two-phase intergrowth of hedleyite and bismuth, with a bismuth core with an 'overgrowth' of hedleyite. In some cases hedleyite and bismuth each occupy one half of the width of a lamella.

Although bismuth and hedleyite occur intergrown together, the hedleyite can be seen to be a homogeneous mineral phase, even under the greatest magnification. The extremely fine-grained mechanical intergrowths with bismuth in the mineral phases described by Godovnikov et al. (1966) were not observed. This microscopic evidence is supported by the very small deviation in the results of the point analyses carried out on the microprobe.

Optical properties

In the polished sections the hedleyite has a clean white colour with a faint bluish-green tint, especially against bismuth, which has a more yellowish colour. The faint colour of bluish-green is more marked in oil immersion. The bireflectance is weak and the anisotropy is distinct with colours in grey to brown beige.

Warren & Peacock (1945) were of the opinion that the reflectance of hedleyite lies between the reflectance of silver and that of galena. The impression from the polished sections studied by the present author is that the reflectance of hedleyite is relatively close to the reflectance of bismuth; perhaps just a few per cent less. Reflectance values for hedleyite published by Uytenbogaardt & Burke (1971) are 48.0–51.2 % at a wavelength of 546 nm.

Results of the reflectance measurements on hedleyite from the Indre Gressdal deposit are given in Table 1. Because of the big difference in polishing hardness between galena and hedleyite, it proved very difficult to get a perfect polished surface of the hedleyite grains. One had to choose between hedleyite grains with small scratches or with a concave surface having a big relief produced by excessive polishing. Attempts were made to produce as good a surface as possible on the sections, bearing in mind the requirement of perfect polish on the one hand and a plane surface on the other. However, the results of the measurements carried out are considered to be rather too low because of small scratches on the measured hedleyite grains.

Microhardness

The polishing hardness of hedleyite is much less than that of the galena, but slightly higher than that of bismuth. This fits with the relative Vickers Hardness Number (VHN) given by Uytenbogaardt & Burke (1971).

The results of the microindentation hardness measurements from published papers and the new ones are presented in Table 2. A limited number of mineral grains of hedleyite were found to be big enough to allow microindentation hardness measurements to be performed, and a still more restricted number of acceptable impressions were produced. The results agree well with the numbers given by Uytenbogaardt & Burke (1971) from measurements on the naturally occurring hedleyite phase. They do not agree

Table 1. Reflectance measurements on hedleyite.*

Wavelength	$\lambda = 434$ nm		$\lambda = 542$ nm		$\lambda = 587$ nm	
Grain no. \ Reflectance	R_1	R_2	R_1	R_2	R_1	R_2
1	51.5	55.4	55.5	59.9	56.1	60.1
2	51.9	55.1	55.4	58.4	56.3	59.3

* All observations were made at Geologisk Institutt, Norges Tekniske Høgskole, Trondheim, using a Leitz–Ortholuxpol microscope and a Leitz MPV photometer with electronic equipment from Knott Elektronik, Münich. The values given are corrected for secondary glare. The reflectivity standard used is NPL calibrated SiC standard no. 82 issued by the Commission on Ore Microscopy. This standard and the preliminary WC standard provided by courtesy of Dr. N. M. W. Henry, Cambridge University, were used to draw the curve for secondary glare correction. The respective reflectances of the two standards at 542 nm are 20.6 % and 44.5 %.

Table 2. Vickers microindentation hardness for hedleyite.

Indre Gressdal, VHN_{15}*					Uytenbogaardt & Burke (1971)	Godovnikov et al. (1966)
Impression no.						
1	2	3	4	5	VHN_{15}	VHN**
37.6	43.1	39.9	*52.1*	46.7		
29.5	38.4	38.7	46.7	40.5		
29.5 – 52.1					30 – 48	89 ± 3.6

* The measurements were taken at Geologisk Institutt, Norges Tekniske Høgskole, Trondheim, using a Leitz Wetzlar DURIMET instrument.
** Load weight not given.

with the value for the synthetical mineral phase reported by Godovnikov et al. (1966).

Chemical composition

The results of microprobe analyses carried out on the hedleyite from the deposits in the Vaddas–Rieppe area are given in Table 3.

The total sum of bismuth and tellurium in the analyses is rather low. The reason for this is most likely that the bismuth standard used is not quite good enough, as can be seen from the analyses on elementary bismuth grains in the samples examined. These show that the amount of bismuth in the natural occurring metallic bismuth phase is sometimes above one hundred per cent, compared with the standard. The tellurium standard is, on the contrary, of a high quality and it can be seen from Table 3 that the tellurium content shows very small variations.

The analysis seems to lie very close to analysis no. 2 given by Warren & Peacock (1945) except for the generally lower bismuth content (Table 3). During the microprobe analyses a search was also made for the elements As, Sb, Ag, Pb, and S but no detectable amounts were found.

Table 3. Microprobe* analyses of hedleyite.

Element wt. %	Indre Gressdal deposit 1	2	3	4	5	6	Warren & Peacock (1945)** 1	2
Bi	80.95	80.46	80.62	80.47	80.60	81.73	80.60	81.55
Te	17.59	17.55	17.51	17.53	17.49	17.59	18.52	17.60
S				n.d.***			0.12	0.04
Total	98.54	98.01	98.13	98.00	98.09	98.92	99.24	99.19

* The instrument used was an ARL–EMX–SM electron microprobe. The analyses are corrected for absorption, atomic number, and fluorescence (Springer 1967). The standards used are metallic bismuth and metallic tellurium.
** Chemical analyses.
*** n.d. = not detected.

Discussion

It seems that a certain bismuth content is common in the Norwegian Caledonian massive sulphide deposits, especially where lead sulphide occurs in greater or lesser amounts. Elementary bismuth has been reported from the ore deposits at Røros (Jøsang 1964) from Kongsfjell near Bleikvassli (Lindahl 1968) from Moskodal Mine (Kleine-Hering 1973), and from the massive sulphide deposits in the Vaddas–Rieppe area (Lindahl 1974).

Bismuth and tellurium are two elements occurring with a positive correlation in the earth's crust (Oftedal 1959), and minerals containing these two elements are likely more common accessory minerals in the massive sulphide deposits than is now assumed. They will probably be identified with greater frequency as the mineralogies of the deposits are studied in greater detail. Bi–Ag–Te mineral phases have already been reported by Saager (1967), Lindahl (1968), and Kleine-Hering (1973), from the Mofjell area, Kongsfjell near Bleikvassli, and Moskodal in Reisadal, respectively.

It has been reported in this paper that thin laths of bismuth and hedleyite are orientated along certain crystallographic planes in galena, planes which differ from the cubic cleavage planes. The same type of bismuth lamellae or laths in galena have been described by Lindahl (1968) from Kongsfjell near Bleikvassli. Oftedal (1942) concluded that galena may show an octahedral cleavage provided that the lattice bismuth content is above a certain limit. This causes a disorder in the octahedral planes in the galena structure which gives rise to the cleavage. The local mineral paragenesis described from the Vaddas–Rieppe area is extremely rich in bismuth. It seems that most of the bismuth in galena may have migrated to certain lattice planes, which may be former octahedral cleavage planes. They now seem to have been healed by the metallic bismuth and the hedleyite. Exsolution has probably gone so far that the galena no longer contains enough lattice bismuth to give octahedral cleavage, and therefore shows a cubic cleavage.

The reflectance measurements on the hedleyite show that the values lie much higher than the values given by Uytenbogaardt & Burke (1971), which appear to be the only published values available (Table 1). The mineral grains of hedleyite measured in the present study did not have a quite perfect polished surface. The author's opinion, thereffore, is that the real refflectance values for hedleyite are still higher than the values found.

The results of the microindentation hardness measurements fit well with the values reported by Uytenbogaardt & Burke (1971), but do not fit with the values given by Godovnikov et al. (1966). Godovnikov et al. (1966) have not given the weight of the load used, which is essential for the evaluation of microhardness values. The mineral phase studied by Godovnikov et al. (1966) is a product of synthesis, and it has a chemical composition different from that of naturally occurring hedleyite, described by Warren & Peacock (1945), Thompson (1949), and Uytenbogaardt & Burke (1971).

Godovnikov et al. (1966) conclude that the formula of hedleyite should be Bi_5Te_3, and further that the composition $Bi_{14}Te_6$ found by Warren & Peacock (1945) was the result of small impurities of metallic bismuth in the hedleyite phase. The microscopic observations carried out in the present study, even at the greatest magnification, have shown that hedleyite is a homogeneous mineral phase. The microprobe analyses have shown that this homogeneous phase has a composition with the same bismuth–tellurium ratio as found by Warren & Peacock (1945).

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