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Bitburg—a group-IB iron meteorite with silicate inclusions

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SUMMARY. Chemical and mineralogical investigations show that the Bitburg meteorite is not a pallasite, but a group-IB iron meteorite. Like other members of this group it contains chondritic silicates.

THE Bitburg meteorite is the largest meteorite discovered in Europe. It was brought to scientific attention by Gibbs (1814), an American army officer who had seen it in 1805. He removed some material from the surface of the meteorite, and some time later an unsuccessful attempt was made to smelt the 1·6 t mass. Most of the smelted material was thrown into the local mill channel, but of the order of 15 kg are preserved in meteorite collections around the world; 55 kg in the Geologische Landesanstalt in Berlin were lost during the 1939–45 war (G. Hoppe, *priv. comm.*). Very little unsmelted material is known. Brauns (1920) carried out a thorough search for the unsmelted material, and reported that it could be found as individual specimens in the Tübingen, Berlin, and Vienna collections, the aggregate mass being only about 34 g. He observed that some unsmelted portions were remarkably different from others, and it now appears that at least one of these (the Tübingen specimen) has been smelted.

Bitburg is classified as a pallasite in Hey (1966). This classification goes back to Rose (1863) and is apparently based on the identification of the silicates as olivine. Brezina (1885) created a special Albacher group of brecciated pallasites in which he placed Bitburg (under the synonymous name of Albacher Mühle) and Brenham.

During a survey of the Ni, Ga, Ge, and Ir contents of metal-rich meteorites, we noted that the composition of a smelted Bitburg sample (Smithsonian Institution specimen NMNH 445) was distinctly different from that of any known pallasite, and relatively similar to that of the group-IB iron meteorites with silicate inclusions Woodbine and Pitts (group-IB consists of all meteorites listed as I-An2 in Wasson (1970) that have Ge concentrations lower than 190 ppm). The data are shown in Table I, together with those for Woodbine and Pitts and for the two most similar pallasites, Brenham and Eagle Station. The analytical techniques used are the same as those reported in Wasson (1970).

Although Ge is normally one of the most useful elements for the classification of metal-rich meteorites, it is also an element that is enriched in carbonaceous samples of

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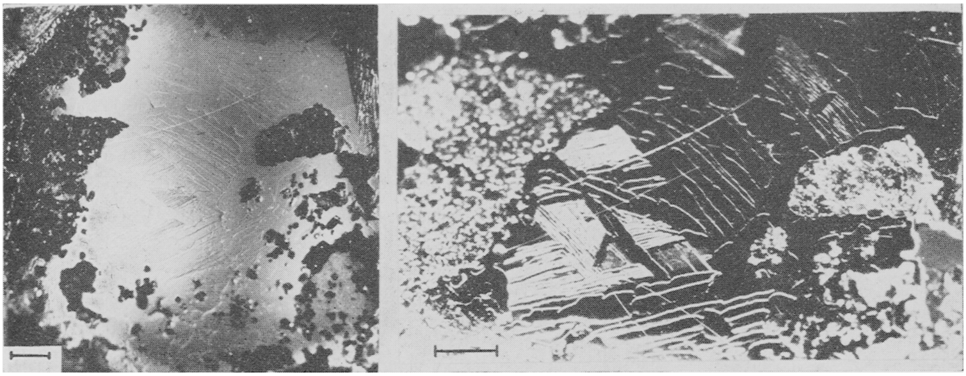
botanic origin. Since plant charcoal was probably present in the furnace where Bitburg was smelted, the Ge concentration reported in Table I may be high by an unknown amount. The other three elements are less easy to contaminate by terrestrial materials at the concentration levels observed. Inspection of Table I shows that their concentrations in Bitburg are much more similar to those in the group-IB meteorites than to those in the pallasites. Eagle Station is listed in Table I as an anomalous pallasite because it (and the very similar Itzawisis meteorite) has Ni and Ir concentrations and a Ge/Ga ratio much higher than those observed in other pallasites. The concentration of Ga in Bitburg is substantially higher than the 14 to 27 ppm range observed in normal pallasites.

TABLE I. *A comparison of the composition of the metallic fraction of the Bitburg meteorite with those of two pallasites and two group-IB meteorites*

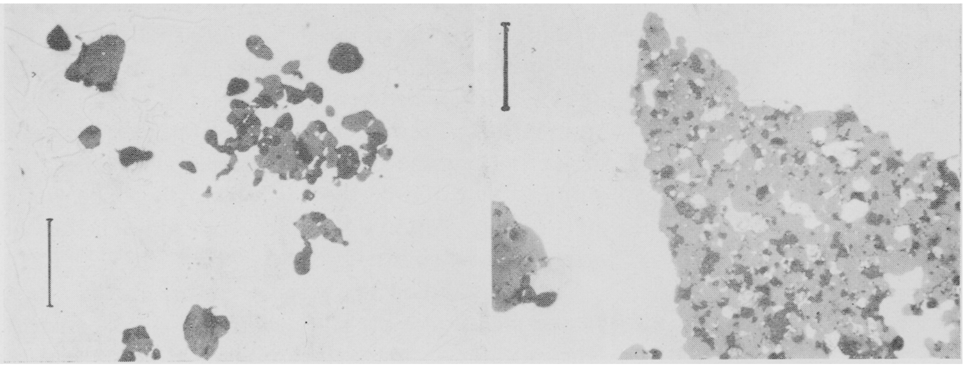
Meteorite	*Class*	Ni	Ga	Ge	Ir
Woodbine	IB	10·6 %	37·3 ppm	114 ppm	1·4 ppm
Pitts	IB	12·8	33·7	94·2	0·86
Bitburg	IB	12·4	34·8	140	0·46
Eagle Station	Pal-An	15·4	4·54	75·3	10
Brenham	Pal	11·1	26·2	70·8	0·041

The silicate mineralogy of group-IB iron meteorites with silicate inclusions is distinctly different from that of the pallasites or that of the other large class of silicate-bearing irons, those that resemble Weekeroo Station (Mason, 1967; Bunch *et al.*, 1970). Pallasitic silicates consist exclusively of olivine with fayalite contents ranging from 11 to 21 mole %. In Weekeroo-type meteorites the dominant silicates are orthopyroxene, plagioclase, and augite, with the ferrosilite content of the orthopyroxene ranging from 16 to 22 mole % (Olsen and Jarosewich, 1970; Bunch *et al.*, 1970). In group-IB meteorites (called Copiapo-type meteorites by Bunch *et al.*, 1970) the dominant silicate minerals are orthopyroxene, olivine, and plagioclase (Mason, 1967). The ferrosilite content of the orthopyroxene ranges between 4 and 9 mole %. The plagioclase in Weekeroo-Station-type meteorites contains about twice as much orthoclase and about ten-fold less anorthite than that in group-IB meteorites.

Because of these differences, the best means to confirm the classification of Bitburg appeared to be an investigation of its silicate mineralogy. To this end we have borrowed two of the specimens that, according to Brauns (1920), had not been smelted, and have investigated their mineralogy by microprobe techniques. The Berlin specimen (Museum für Naturkunde No. 1581) proved the more valuable. As shown in fig. 1 it exhibits a fine Widmanstätten pattern with a kamacite band width ranging between 50 and 230 μm, with an average value of 160 μm. Thus it falls into Buchwald's (1974) finest octahedrite structural category. Plessite areas are well developed and amount to about one-third of the metallic area (fig. 2). The silicate inclusions are surrounded by swathing kamacite (figs. 1 and 3).

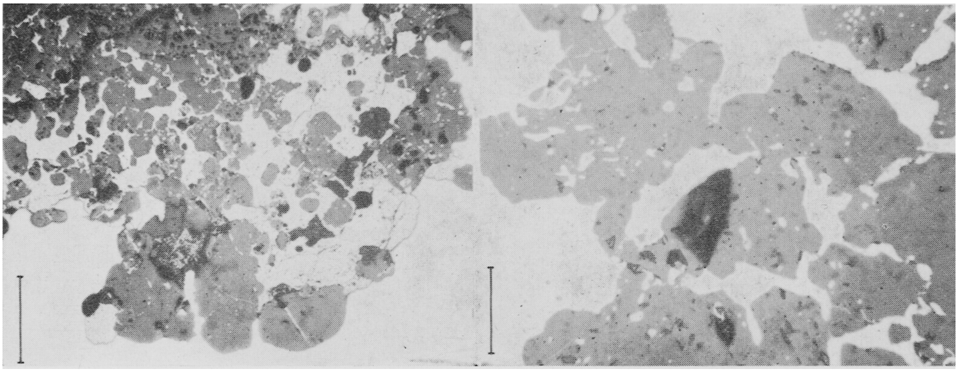


FIGS. 1 and 2: FIG. 1 (left). General view of Bitburg (polished section in reflected light). The Widmanstätten pattern, including plessitic areas, is visible, as well as the swathing kamacite around the silicate inclusions. The different types of inclusions are discussed in the text. Scale bar = 1 mm. FIG. 2 (right). Enlarged portion of Bitburg showing two silicate inclusions of second type (see text). Scale bar = 1 mm.



FIGS. 3 and 4: FIG. 3 (left). Cluster of silicate grains in a kamacite matrix. Scale bar = 450 μm. FIG. 4 (right). Second type silicate inclusion. Note angular shape and interstitial troilite and metal. A plessite area is visible on the left. Scale bar = 450 μm.

Three different types of inclusions can be distinguished in fig. 1: Small, rounded silicate inclusions (in which troilite is notably absent), which are immersed in an iron–nickel matrix; these inclusions are mono- or polymineralic and are generally grouped in clusters (fig. 3). Large angular to subangular silicate inclusions, which contain ortho- and clino-pyroxene, plagioclase, olivine, and minor amounts of metal, troilite, whitlockite, chromite, and graphite; no grain-size gradient or zonal distribution of silicates is observed; fig. 4 shows an enlarged portion of one such inclusion; larger troilite (light grey, cloudy) and metal (white) grains can be easily distinguished, whereas smaller ones are interstitial between silicate grains. Troilite-rich inclusions (upper left and lower right of fig. 1); part of the lower-right inclusion is shown in fig. 5; here silicates and troilite are about equally abundant. Several silicate grains



FIGS. 5 and 6: FIG. 5 (left). Troilite-rich silicate inclusion (visible in lower right of fig. 1). The silicate grains are embedded in troilite, which has intruded along the grain boundaries. Scale bar = 450 μm. FIG. 6 (right). Enlarged portion of fig. 5 showing textural relationships between troilite and silicates, which appear to have been disrupted and brecciated. Scale bar = 88 μm.

are scattered in the troilite matrix, which forms a continuous pattern extending along the silicate grain boundaries. Troilite veins cut through fractured silicate grains. This textural relationship is shown better in fig. 6: troilite (white) has intruded along the boundaries between the brecciated silicate grains (grey). Fig. 7 shows a detail of the upper-left inclusion in fig. 1. Here, the silicate/troilite ratio is smaller than in fig. 5, and silicates seem to be mostly concentrated in the outer portion of the inclusion, while the central part is almost silicate-free.

Notwithstanding the variation in texture and shape of the inclusions, the silicate mineralogy is constant. The silicates in these inclusions are crystalline, as indicated by anisotropic extinction. The dominant silicates are orthopyroxene, plagioclase and olivine; thus the meteorite is not a pallasite.

As noted by Brauns (1920), the 2·5 g Tübingen specimen (University of Tübingen No. 9291008) is quite different. It shows no Widmanstätten pattern, although the ghosts of taenitic areas are discernible in some places. The silicate inclusions consist of a glass of a very uniform, Ca-rich composition. This specimen also is no pallasite. We speculate that the metal structure and the glass are artifacts produced by artificial heating.

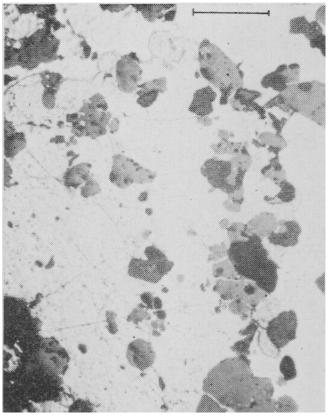


FIG. 7. Detailed view of the troilite-rich inclusion at the upper left of fig. 1. Silicates are concentrated at the border of the inclusion. Scale bar = 450 μm.

In Table II are listed mean Si, Al, Fe, Mg, Ca, Na, and K concentrations measured in clino- and ortho-pyroxene, olivine, and plagioclase inclusions in the Berlin specimen together with the concentration ranges of these elements reported by Bunch *et al.* (1970) for Copiapo-type (IB) silicate inclusions excluding Udei Station and Pine

River; the ranges are much larger if the latter are included. As can be seen, the agreement is quite good. The minerals were analysed by means of a Geoscan electron-probe microanalyser by comparison with standard minerals of known composition.

TABLE II. *Comparison of electron microprobe analyses of silicate minerals from Bitburg with the compositional range observed in Copiapo-type silicate inclusions*

	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Total
Clino-pyroxene								
Bitburg	54·7	0·42	1·8	18·2	23·4	0·67	—	99·1
Range, Copiapo-type	54·0–54·8	0·68–1·17	1·67–2·25	18·0–18·4	21·0–22·4	0·63–1·16	< 0·05–0·12	
Ortho-pyroxene								
Bitburg	57·4	0·20	4·92	35·4	0·70	—	—	98·82
Range, Copiapo-type	57·0–58·5	< 0·03–0·59	4·3–5·2	35·0–35·6	0·58–1·04	< 0·05–0·24	< 0·05	
Olivine								
Bitburg	41·6	—	5·69	53·0	—	—	—	100·29
Range, Copiapo-type	40·5–42·4	< 0·03	4·4–6·3	52·2–52·9	0·02–0·15	< 0·05	—	
Plagioclase								
Bitburg	66·3	20·4	0·54	0·02	2·0	10·9	0·75	100·9
Range, Copiapo-type	63·5–65·7	20·2–22·7	0·10–0·68	—	2·4–4·2	8·9–10·4	0·28–0·71	

The results were corrected for absorption effects according to the method given by Duncumb and Shields (1966). The olivine has a fayalite content of 5·6 mole %, which agrees with the range observed in Copiapo-type inclusions. The ortho-pyroxene has ferrosilite and wollastonite contents of, respectively, 7·1 and 1·3 mole %, which also fall in the range observed for this type of meteorite. The CaO, FeO, and Al_2O_3 contents of the diopside are all in keeping with group IAB (= Copiapo- or Odessa-type) material and different from that expected from Weekeroo-type inclusions.

The Ab, Or, and An values for Bitburg plagioclase are 87·2, 3·9, and 8·8 mole %, while the highest Ab and Or and the lowest An values previously reported for Copiapo-type silicate inclusions are 85·3 (Ab in Woodbine), 3·9, and 11·0 (Or and An in Persimmon Creek). These differences are rather small and may be due to interlaboratory systematic errors. Both sets of values are similar to the compositions observed in ordinary chondrites by Van Schmus and Ribbe (1968). The plagioclase crystals are zoned in several cases, with An decreasing toward the surface of the grains. The highest degree of zoning involved a decrease from 12·4 to 6·8 mole % An. A much smaller range was generally observed.

The K_2O content of plagioclase is much lower than the value expected if the meteorite were a Weekeroo-type iron. A few isolated areas show enrichment in Or of at least a factor of 2 with respect to the average. The highest K_2O found is 1·31 wt %, corresponding to 6·84 mole % Or. There seems to be no relationship between such variation and the zoning of plagioclase, and the two phenomena do not appear to be genetically connected. Van Schmus and Ribbe (1968) made similar observations on chondritic feldspars and suggested that partial ordering of Na and K in the feldspar crystals of chondrites indicates a low cooling rate relative to terrestrial obsidian flows, where Na and K are uniformly distributed in the feldspar.

Bulk chemical analyses of the silicates are available for two group-IAB iron meteorites, IA-iron Campo del Cielo (Jarosewich, quoted in Bunch *et al.*, 1970), and IB-iron Woodbine (Jarosewich, 1967). The silicates are chondritic, and would have a melting range far exceeding that in rocks of magmatic origin. Although our Bitburg section is too small for adequate modal analysis, the fact that its dominant silicates are orthopyroxene, olivine, and plagioclase indicates that the silicates are chondritic, as does the albitic composition of the feldspar. The presence of chondritic silicates in group-IAB irons is one of several pieces of evidence indicating that they have not been molten since their agglomeration and accretion from the solar nebula.

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REFERENCES

BRAUNS (R.), 1920. *Zentr. Min.* 1–9.
BREZINA (A.), 1885. *Jahrb. geol. Reichsanstalt, Wien*, **35**, 151.
BUCHWALD (V. F.), 1974. *Iron Meteorites*, in press, Temple (Arizona State Univ.).
BUNCH (T. E.), KEIL (K.), and OLSEN (E.), 1970. *Contr. Min. Petr.* **25**, 297–340.
DUNCUMB (P.) and SHIELDS (P. K.), 1966. *The Electron Microprobe* (eds. T. D. McKinley, K. F. J. Heinrich and D. B. Wittry), New York (John Wiley), 284–95.
GIBBS (C.), 1814. *Amer. Min. Journ.* **9**, 218.
HEY (M. H.), 1966. *Catalogue of Meteorites*, 3rd edn, London (British Museum).
JAROSEWICH (E.), 1967. *Geochimica Acta*, **31**, 1103–6.
MASON (B.), 1967. *Min. Mag.* **36**, 120–6.
OLSEN (E.) and JAROSEWICH (E.), 1970. *Earth Planet. Sci. Lett.* **8**, 261–6.
ROSE (G.), 1863. *Abhandl. Akad. Wiss., Berlin, Phys.-Math. Kl.*
VAN SCHMUS (W. R.) and RIBBE (P. H.), 1968. *Geochimica Acta*, **32**, 1327–42.
WASSON (J. T.), 1970. *Icarus*, **12**, 407–23.

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