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'Reichenbach' and 'Brezina' lamellae in meteoritic irons.

(With Plate XIII.)

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[Read January 11, 1951.]

BARON Karl Ludwig von Reichenbach (1788–1869) was born at Stuttgart, ennobled in 1839 by the King of Württemberg, and died at Leipzig. But he spent most of his life in Austria, where he had iron works and estates in Moravia and Galicia and a castle near Vienna. Earning a livelihood as a copyist in the state archives, he was able to obtain a university education, and he started his career as a works chemist. He produced many papers on the distillation products of coal, tar, oil, &c., and was the discoverer of creosote and solid paraffin. He gained considerable notoriety with his ideas and books on what he called 'od' or 'odylic force', a combination of animal magnetism, light, heat, force of crystallization, &c., capable of producing hypnotism. The fall in 1833 of a shower of meteorites, which he witnessed near his works at Blansko in Moravia, fired his intense enthusiasm for the subject of meteorites, on which he wrote 29 scientific papers (1835–65) and many newspaper articles. The well-known names kamacite, taenite, and plessite[1] for the nickel-iron constituents of meteorites are due to him. In 1861 he observed bands of iron sulphide in the Widmanstetter pattern on etched surfaces of three meteoritic irons from Lenarto (Slovakia), Caille (La Caille, France), and Claiborne (now known as

[1] K. L. Reichenbach, Ueber das innere Gefüge der nähern [näheren] Bestandtheile des Meteoreisens. Ann. Phys. Chem. (Poggendorff), 1861, vol. 114, pp. 123, 252, 269, respectively.

Walker County, Alabama).[1] The best example was Claiborne 'das ich im brittischen Museum fand'. His collection of meteorites was bequeathed to the University of Tübingen, making it at that time the best in Germany.[2]

Similar bands of troilite were independently observed by G. Tschermak[3] in 1871 in a meteoritic iron from the Atacama Desert (Ilimaes) and in those from Jewell Hill (Duel Hill, North Carolina) and Victoria West (South Africa). He described them as due to lamellae oriented parallel to cube planes in the octahedral structure, and cutting across the lamellae of kamacite and taenite. A. Brezina[4] in 1880 applied the name *Reichenbach lamellae* (Reichenbach'sche Lamellen) to lamellae of troilite oriented on cube planes, and described other examples in Staunton (Virginia); Trenton (Wisconsin), Juncal (Chile), and Ruff's Mountain (South Carolina).

A. Brezina and E. Cohen in 1887, in their album of photographs,[5] gave a picture of Knoxville (Tazewell, Tennessee) showing bands perpendicular to the edges of equilateral triangles. These were at first thought to represent Reichenbach lamellae of troilite. It was afterwards realized that with such a direction of the bands the lamellae must be parallel to planes of the rhombic dodecahedron and not of the cube. Also it was found that in the centre the bands consisted of schreibersite. In 1898 E. Cohen[6] described the same orientation of schreibersite in Ballinoo (Western Australia). In 1904 A. Brezina[7] completed his account of this

[1] K. L. Reichenbach, loc. cit., 1861, vol. 114, p. 114; 1862, vol. 115, p. 630.

[2] F. A. Quenstedt, Die Meteoriten der Tübinger Universitätsammlung. Geschenk des Freiherrn v. Reichenbach, 1871, 4 pp. S. Blattmann and F. Machatschki, Stand der Tübinger Meteoritensammlung mit Ende 1937. Neues Jahrb. Min., Abt. A, vol. 74, pp. 279–292. [M.A. 7-265.]

[3] G. Tschermak (1836–1927), Ein Meteoreisen aus der Wüste Atacama. Anzeiger Akad. Wiss., Math.-naturwiss. Cl., Wien, 1871, vol. 8, p. 28 (abstract); the full paper in the Denkschriften, 1872, vol. 31, pt. 1, pp. 187–196, 4 pls. Meteoreisen von Victoria West. Min. Mitt., 1872, Jahrgang 1871, p. 109; also in Jahrb. Geol. Reichsanstalt, Wien, 1872, vol. 21 (for 1871).

[4] A. Brezina, Über die Reichenbach'schen Lamellen in Meteoreisen. Anzeiger, Wien, 1880, vol. 17, pp. 177 178 (abstract); the full paper in the Denkschriften, 1882, vol. 43, pt. 2, pp. 13–16, 4 pls. Preprints, pp. 1-4, 4 pls., dated 1880.

[5] A. Brezina and E. Cohen, Die Struktur und Zusammensetzung der Meteoreisen, erläutert durch photographische Abbildungen geätzter Schnittflächen. Stuttgart, 1887, parts II III, pls. X and XI.

[6] E. Cohen, Über ein neues Meteoreisen von Ballinoo am Murchisonfluss, Australien. Sitz.-ber. Akad. Wiss. Berlin, Phys.-math., Cl., 1898, no. II, pp. 19–22.

[7] A. Brezina, Über dodekaedrische Lamellen in Oktaedriten. Sitz.-ber. Akad. Wiss. Wien, Math.-naturwiss. Kl., 1904, vol. 113, Abt. I, pp. 577-583, 1 pl.

structure, giving additional examples in Narraburra (New South Wales),[1] Augustinovka (Ukraine), and Joe Wright (Joe Wright Mountain, Arkansas). Finally, in 1905, E. Cohen[2] proposed the term *Brezina lamellae* (Brezina'sche Lamellen) for lamellae of schreibersite oriented on planes of the rhombic dodecahedron.[3]

Reichenbach and Brezina lamellae have since been mentioned in several other meteoritic irons. They show a scattered and irregular distribution on the etched surfaces. Only exceptionally are the full number of cube and dodecahedral planes represented. The bands are 1–3½ cm. long and 0·1–1 mm. wide, and are usually not very conspicuous, especially in published reproductions of photographs of the etched surfaces. They cut across the bands of kamacite and taenite of the Widmanstetter pattern causing no distortion; and it has been suggested that they crystallized before the nickel-iron. A disconnected network of lamellae could, however, scarcely have controlled the subsequent orientation of the nickel-iron. More likely they crystallized out together as regular intergrowths.

The term Shepard lamellae (Shepard's lamellae)[4] has been applied to lamellae of schreibersite ($(Fe,Ni)_3P$) on (111) [possibly (100)]. Other orientations of schreibersite on (100), (210), (211), or (221) have been described by G. F. Kunz and E. Weinschenk, 1892; O. B. Bøggild, 1927 [M.A. **3**–535]; F. Heide, E. Herschkowitsch, and E. Preuss, 1932 [M.A. **5**–300]; W. Borchert and J. E. Ehlers, 1934 [M.A. **6**–11]; R. F. Mehl, C. S. Barrett, and H. S. Jerabek, 1934, in manufactured iron [Min. Mag. **26**–163]. Troilite (FeS) on (110) has been described by F. Rinne, 1910. Cohenite (Fe_3C) on (111) by E. Weinschenk, 1889; and on (110) by C. W. Beck, L. LaPaz, and L. H. Goldsmith (Min. Mag., 1951, vol. 29, p. 531). A search of the literature would no doubt yield other examples.

The question now arises whether the term 'Reichenbach' lamellae should still be retained for troilite oriented on the cube, and 'Brezina' lamellae for schreibersite oriented on the dodecahedron, or whether the terms should apply to a particular mineral or to a particular orientation.

[1] A. Liversidge, The Narraburra meteorite. Journ. Roy. Soc. New South Wales, 1904, vol. 37, pp. 234–242, 12 pls. The prominent bands are figured, and the high phosphorus shown in the analysis suggested schreibersite.

[2] E. Cohen (1842–1905) Meteoritenkunde, Heft III. Stuttgart, 1905, p. 252.

[3] Dr. Maria Aristides Brezina (1849–1909) had charge of the collections of minerals and meteorites in the Natural History Museum at Vienna. [Min. Mag. **15**–442.]

[4] J. D. Buddhue, Meteoritic iron phosphide. Popular Astronomy, 1938, vol. 46, pp. 282–285; Contr. Soc. Res. Meteorites, [1939], vol. 2, no. 1 (for 1938), pp. 40–43. [M.A. **7**–172.]

Three minerals and six orientations, mentioned in the last paragraph, would give eighteen possible combinations. To introduce a special name for each of these would be quite unnecessary and most undesirable. The orientation of troilite on cube planes has never been rigidly proved, but its orientation on dodecahedral planes is demonstrated by the examples to be described below and illustrated in pl. XIII.

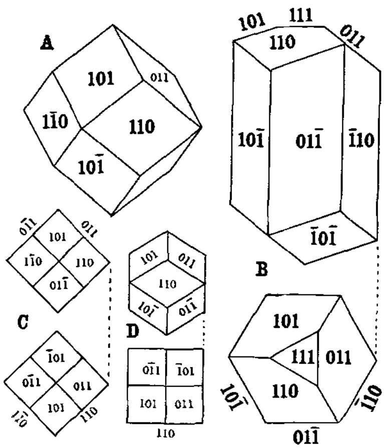


FIG. 1.

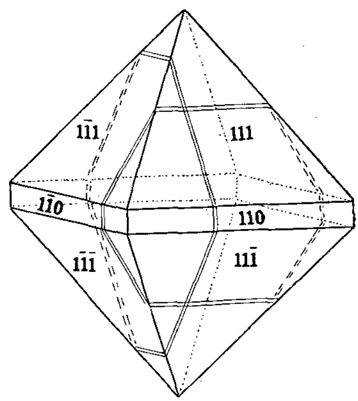


FIG. 2.

FIG. 1. Rhombic dodecahedron. A, clinographic projection. B–D, orthographic projections (plans and elevations); B with a triad axis vertical and elongated along this axis; C and D with a tetrad axis vertical.

FIG. 2. Octahedron with enclosed lamellae parallel to two faces of the rhombic dodecahedron.

It is strange that Tschermak made no mention of Reichenbach and that neither of them made any mention of Schreibers,[1] who briefly described and figured these lamellae as early as 1820, but wisely without guessing at the mineral or the orientation. Lamellae of any mineral in any orientation might appropriately be called Schreibers lamellae. But,

[1] Carl von Schreibers (1775–1852), Beyträge zur Geschichte und Kenntniss meteorischer Stein- und Metall-Massen . . . Wien, 1820, p. 76, pl. VIII. The lamellae are shown on an etched slice from the 39 kg. mass which fell in 1751 at Hraschina near Agram (= Zagreb) in Croatia, and preserved in the Vienna Museum. Mention of this was made by A. Brezina in his 1885 catalogue (p. iv) of the Vienna collection of meteorites; that is, five years after he had proposed the name Reichenbach lamellae. He mentions troilite oriented on the cube, but gives no fresh description. E. Cohen (Meteoritenkunde, 1894, I, p. 189) refers doubtfully to Schreibers's observation.

as now shown, 'Reichenbach' lamellae of troilite have the orientation that was allotted to schreibersite in 'Brezina' lamellae. The best course now would be to retain the term Reichenbach and reject all others.

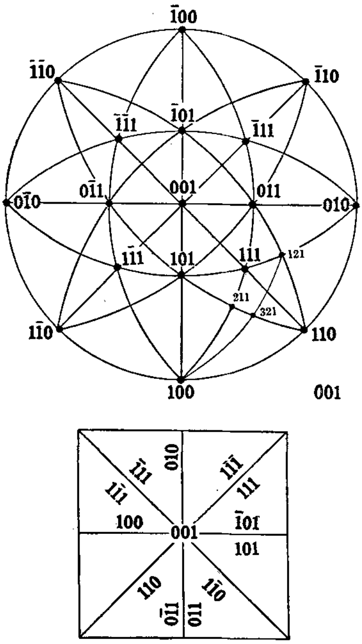


FIG. 3.

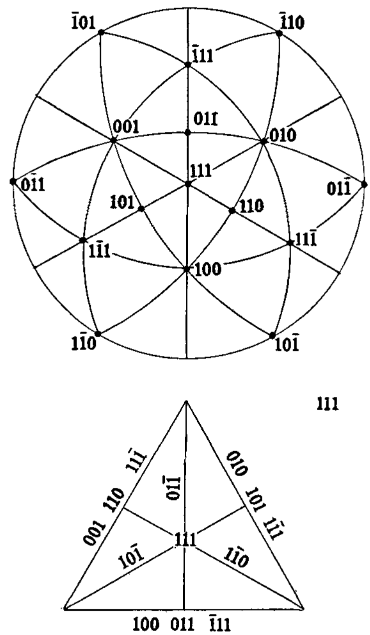


FIG. 4.

FIGS. 3 and 4. Stereographic and orthographic projections on (001) and (111).

When the bands shown on an etched surface are at right angles it has frequently been assumed that they represent lamellae parallel to cube planes. This is not necessarily the case, and on a section parallel to an octahedral plane it is only possible when the lamellae are parallel to planes of the rhombic dodecahedron.

The usual clinographic drawing (fig. 1A) of a rhombic dodecahedron gives some idea of the general shape, but when drawn in other positions it presents quite different aspects (figs. 1B–D). This polyhedron is bounded by four hexagonal zones, each perpendicular to an octahedral face. In fig. 1B one of these hexagonal zones is emphasized by elongation along a triad axis; and it is clear from the plan that intersections on the octahedral face are parallel and perpendicular to octahedral edges. The same effect is illustrated in fig. 2, showing lamellae parallel to (110) and (1$\bar{1}$0) enclosed in an octahedron.

On any chance section of a meteoritic iron the directions of these lamellae in relation to the Widmanstetter pattern may be very puzzling.

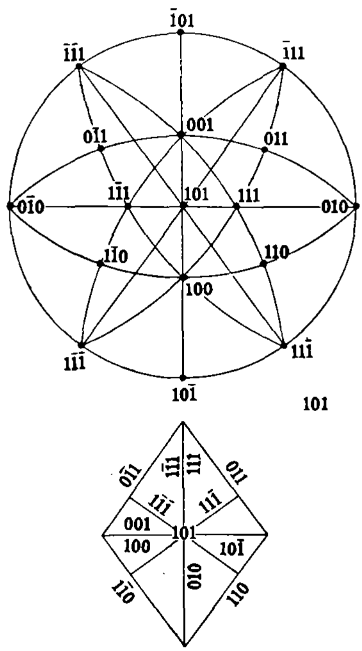


FIG. 5.

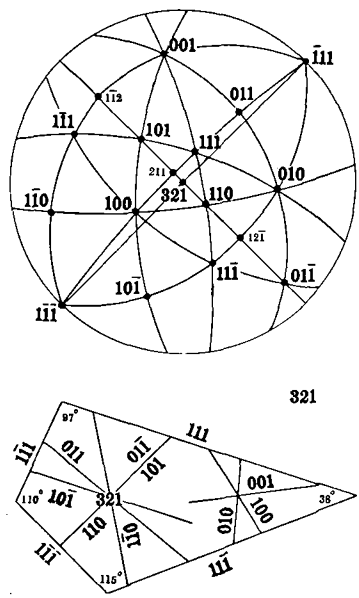


FIG. 6.

FIGS. 5 and 6. Stereographic and orthographic projections on (101) and (321).

The Widmanstetter pattern itself is symmetrical only when the section plane is perpendicular to an axis of symmetry or parallel to a plane of symmetry. But we may continue our lesson in elementary crystallography if we limit ourselves to the principal planes (100), (111), and (110). Figs. 3–5 show in stereographic and orthographic projections the several combinations with these three crystal-forms as section planes. The general case for any chance section not lying in a plane of symmetry yields thirteen directions of intersection with (100), (111), and (110). The example shown in fig. 6 with (321) as the section plane yields only eleven directions, because this face falls in a hexagonal zone with three faces of the rhombic dodecahedron.

In fig. 7 the directions have been sorted out for each crystal-form, with the addition of those for the icositetrahedron (211). This form has been mentioned as a possible orientation of lamellae, and it is of importance in giving the directions of Neumann lines in kamacite. Figures for these

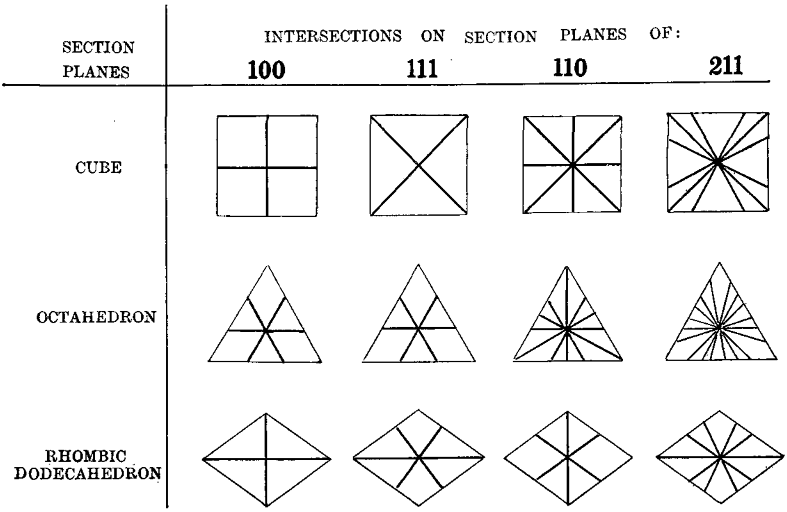


FIG. 7. Intersections of (100), (111), (110), and (211) lamellae on section planes (100), (111), and (110).

have previously been given in this Magazine.[1] On the cube face there are six directions of intersection, on the octahedron nine, and on the rhombic dodecahedron five. For any chance section not lying in a symmetry zone the number is twelve. The general form (*hkl*) would give 24 directions on a chance section plane.

In addition to the right angles shown in fig. 7, there is an infinite number of sections of the octahedron that give this angle. Demonstrating with templets ('jigs'), my grandson Benjamin Barman has pointed out to me that a templet of 90° can be applied to adjacent faces of an octahedron in two ways. (1) It can slide down the edge, while keeping parallel to a cube face, all the way to the adjacent cube pole, the limbs of the templet then coinciding with dodecahedral edges or axes of symmetry.

[1] L. J. Spencer, A new meteoric iron from Piedade do Bagre, Minas Geraes, Brazil. Min. Mag., 1930, vol. 22, pp. 271–282, 2 pls. Under fig. 4 *b*, p. 277, the number of intersections on a cube face is there incorrectly given as ten; the figure actually shows four parallel pairs, thus reducing the number to six.

This gives the square Widmanstetter pattern shown on a section parallel to a cube face. (2) Contact can also be obtained by rotating the templet as it moves along the edge. Starting from a cube pole with the templet parallel to a cube face (and inclined at 45° to the edge) it will, when half way down the edge, be parallel to an octahedron face. With a clockwise rotation the limb on the right-hand face, after moving 30° over that face, is parallel to the edge; while that on the left-hand face, after moving 60°, is perpendicular to the edge (compare fig. 2). An anti-clockwise rotation reverses these angles and directions. Now turn the templet over and travel down the lower half of the edge. There will be a repetition of the same performance, but in reversed order, and ending up parallel to the cube face of the adjacent pole. The half-way position along the edge marks the passage over a dodecahedral plane of symmetry and over a dyad axis of symmetry.

Between the cube and octahedron faces the templet (representing the section plane of the meteorite) has not been travelling perpendicularly to a dodecahedral plane of symmetry, but along a path of hexakisoctahedra with high indices and not in a zone. In fig. 6 I found graphically an angle of 97° for the face (321). An irregular four-sided templet with one angle of 90° and others of 40°, 112°, and 118° was found to fit on the octahedron. Brezina[1] in a table of calculated angles between kamacite bands in the Widmanstetter pattern on section planes of an octahedrite gives for (421) an angle of 90°. Planes deviating but slightly on either side of this position show a departure from this angle: for (454.200.100) he gives 91·7°, and for (742) 87·2°, on either side of (421). He also gives angles of 90° for (64.8.1), (16.4.1), (931), (964), (25.20.6), and (121.110.100), some of which may perhaps fall in this field. Avoiding elaborate calculations, I have assumed when drawing fig. 8A a gradual deviation of the section planes from the dodecahedral planes of symmetry along curved paths (represented by small circles on the stereographic projection), choosing for the maximum deviation a point mid-way between (100) and (111): for (421), angle to (100) 29° $14\frac{1}{4}'$, to (111) 28° $6\frac{1}{2}'$, and angle (421) : (412) 17° $45\frac{1}{4}'$. One curve from (100) passes through (421), turns at (111), and through (241) reaches (010); the other through (412), (111), and (214) to (001). At the limiting position (111), corresponding with the critical point half way down the octahedral

[1] A. Brezina, Meteoritenstudien II. Über die Orientirung der Schnittflächen an Eisenmeteoriten mittelst Widmannstädten'schen Figuren. Denkschr. Math.-naturwiss. Cl. Akad. Wiss. Wien, 1882, vol. 44, pp. 121–158, 5 pls. Preprints, pp. 1–38, 5 pls.. dated 1881.

edge, the (*hkl*) faces coalesce with (111), and the section plane then gives the triangular Widmanstetter pattern. At the opposite limit they coalesce with cube faces, giving the square pattern.

Fig. 8B gives the directions of intersection of octahedral planes on a section plane (421). These directions and angles can be arranged in

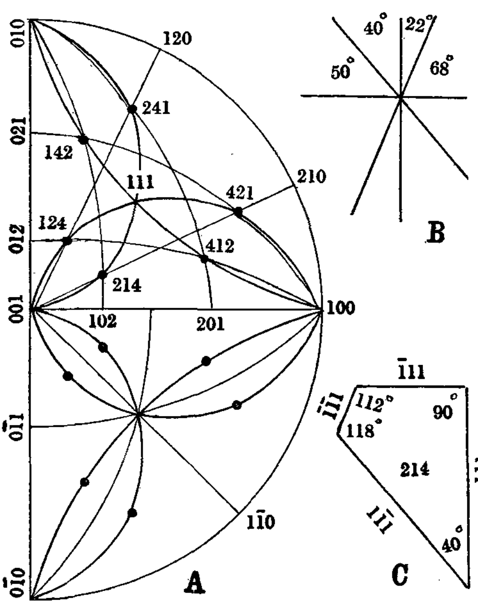


FIG. 8

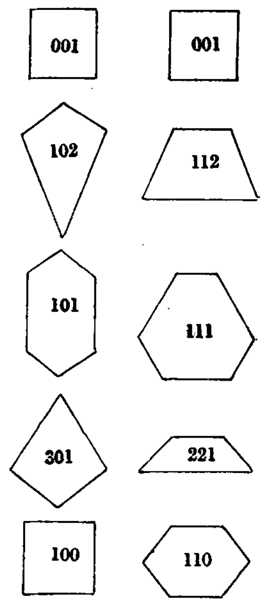


FIG. 9

FIG. 8. A, Loci of oblique section planes of an octahedron giving angles of 90°. B, Directions of intersection of octahedral planes on (421), with an angle of 90°. C, Shape of section plane of an octahedron by (421).

FIG. 9. Series of sections of an octahedron by planes perpendicular to cubic and dodecahedral planes of symmetry.

several ways to give closed polyhedra of different shapes (see Min. Mag., 1941, vol. 26, p. 29, fig. 5). One of them (fig. 8C) cut as a templet can be fitted over each of the six apices of the octahedron in two positions (with reversal of the templet).

Another form of templet devised by B. Barman consists of two hinged right angles. A modification of this in the form of a deltoid with angles 90°, 90°, 45°, 135° (or an octagon with angles 135°) fits to the rhombic dodecahedron and cubo-octahedron, but not to the octahedron. This gives the cubo-octahedral [or dodecahedral] pattern (pl. XIII, fig. 3) of F. Rinne.[1] Deltoidal templets with angles 90°, 90°, 30°, 150° and 90°, 90°, 60°, 120° were cut in an attempt to solve the new type of pattern presented by the La Porte meteorite.[2] But these do not fit the dodecahedron, octahedron, or spinel twin. The hinged templet of two right angles gave no further result, except parallel to cube faces.

Still more templets were cut to represent sections of the octahedron by section planes perpendicular to the cubic and dodecahedral planes of symmetry in positions ranging from (001) to (100) and (001) to (110). The shapes of these sections are represented in fig. 9.

Actual specimens of meteorites showing really good examples of these lamellae, and giving conclusive evidence of the orientation, are quite rare. A preliminary search of the literature for photographic reproductions has also given but few good examples. With the scattered and usual absence of the full number of bands it is not always possible to distinguish between orientations on the cube and the dodecahedron. On a cube section bands at 45° to the kamacite bands may be due to either; but bands at 0° (or 90°) and 45° can be due only to the dodecahedron (pl. XIII, figs. 1 and 3). On an octahedral section bands at 0° may be due to the cube, octahedron, or dodecahedron; but bands at 0° and 90° are due only to the dodecahedron (pl. XIII, figs. 2 and 5). I have not yet found an example giving conclusive evidence of orientation on cube faces.

Plate XIII, fig. 1 shows a section parallel to a cube face of a siderite from the meteorite craters of Henbury in Central Australia. There can be no mistake here about the section being parallel to a cube face, for on the same specimen sections have been cut also parallel to octahedron and dodecahedron faces. The figure is reproduced from this Magazine,[3] and it is only now that the two stray bands of troilite have been specially noticed. One is parallel and perpendicular to kamacite bands, and the other at 45°. As shown by text-figs. 3 and 7 such an arrangement is only possible for lamellae parallel to the rhombic dodecahedron; and it does not conform with the original definition of Reichenbach lamellae of troilite on (100). The complete pattern should show four directions at

[1] F. Rinne, Ein Meteoreisen mit Oktaeder- und Würfelbau (Tessera-Oktaedrit). Neues Jahrb. Min., 1910, vol. i, pp. 115–117, 2 pls.

[2] S. K. Roy and R. K. Wyant, The La Porte meteorite, Geol. Ser. Field Museum Nat. Hist. Chicago, 1950, vol. 7, no. 10, pp. 135–144. [M.A. **11**–271.]

[3] L. J. Spencer, Meteoric iron and silica-glass from the meteorite craters of Henbury (Central Australia) and Wabar (Arabia). Min. Mag., 1933, vol. 23, pp. 387–403, 8 pls.

45° and 90°. The two bands are not connected and they do not disturb the kamacite bands, suggesting that the troilite must have crystallized at the same time as the nickel-iron.

Fig. 3, pl. XIII, shows a section parallel to a cube face of a 404 kg. mass from Goamus farm,[1] of the Gibeon shower of meteorites in South-West Africa.[2] It shows three smaller bands of troilite parallel to kamacite bands and three larger bands at 45° to the same set of kamacite; all of them again isolated and not disturbing the kamacite. The larger troilite bands enclose white specks of schreibersite. This specimen is a rare example in which all four possible directions of troilite lamellae oriented on the dodecahedron are represented. It is also remarkable in showing four directions of the kamacite bands: two long (vertical) bands with associated shorter (horizontal) bands are shown in the upper part of the figure. Rinne regarded one set to be parallel to the cube and the other parallel to the octahedron, and he applied the name 'Tessera-Oktaedrit' (cubo-octahedrite) to this new type of meteorite. But taking the two sets together they represent lamellae parallel to the rhombic dodecahedron, and the type might better be named dodecahedrite.

Fig. 4, showing another section parallel to a cube face with kamacite bands in two directions at right angles, is reproduced from G. Tschermak's figure (loc. cit., 1871) of the Ilimaes (Atacama) meteorite. This shows five troilite bands in one direction (NE.–SW. in fig. 4) but only one in the other direction (NW.–SE.). It may be that other bands (parallel to the dodecahedron) also happen to be missing. There is in fact a small black line (at the left-hand side of the figure) parallel to kamacite bands. If this is troilite then the orientation must be dodecahedral and not cubic.

The remaining two figures on plate XIII are of sections approximately parallel to an octahedron face, with kamacite bands forming triangles almost equilateral. The Breece (New Mexico) meteorite, described in the last number of this Magazine,[3] shows bands of cohenite parallel and perpendicular to kamacite bands, and therefore representing lamellae oriented on the rhombic dodecahedron. They had at first been thought to be Reichenbach lamellae oriented on the cube. Fig. 2 is a reproduc-

[1] F. Rinne, 1910, loc. cit., pl. XV. Other figures show the cubo-octahedral structure more clearly with higher magnification, but no troilite bands.

[2] L. J. Spencer, The Gibeon shower of meteorites in South-West Africa. Min. Mag., 1941, vol. 26, pp. 19–35, 2 pls.

[3] C. W. Beck, L. LaPaz, and L. H. Goldsmith, The Breece, New Mexico, meteoritic iron. Min. Mag., 1951, vol. 29, pp. 531–537.

tion of a clearer figure given earlier by S. H. Perry,[1] who described the bands as Reichenbach lamellae of troilite (loc. cit., p. 17) oriented on the cube. Here the bands are much longer than usual, and it is one of the very few examples where they are in contact, forming a network; but only two of the six possible directions are represented.

Fig. 5 is a reproduction of a portion of one of the several figures given by A. Liversidge[2] of the Narraburra (New South Wales) meteorite. It shows large bands of schreibersite perpendicular and short ones parallel to octahedral edges. His analysis of the iron showed an unusually high percentage of phosphorus, but he only suggested the presence of schreibersite (3·61 %). It was E. Cohen (loc. cit., 1904) who determined the bands to be schreibersite and described them as 'Brezina' lamellae oriented on the dodecahedron.

The remarkable specimen of Walker County, Alabama, which Baron Reichenbach in 1861 'found in the British Museum', weighs 22 kg. = 48½ lb.; it was purchased under the name of Claiborne from Henry Heuland in 1843. The baron promptly acquired the main mass of 40¾ kg. (38·338 kg. now in the Tübingen museum). A preliminary, long-delayed examination of the British Museum specimen shows a complex pattern of troilite bands in at least a dozen directions, suggesting an orientation on (211) and inviting further study.

[1] S. H. Perry, The metallography of meteoric iron. Bull. U.S. Nat. Mus., 1944, no. 184, vii+206 pp., 78 pls. (Fig. 4 on pl. 47, p. 167.) [M.A. **9**–290.]

[2] A. Liversidge, The Narraburra meteorite. Journ. Roy. Soc. New South Wales, 1904, vol. 37, pp. 234–242, 12 pls. (Portion of pl. XXII.)

Explanation of Plate XIII.

Sections of meteoritic irons showing 'Reichenbach' and 'Brezina' lamellae.

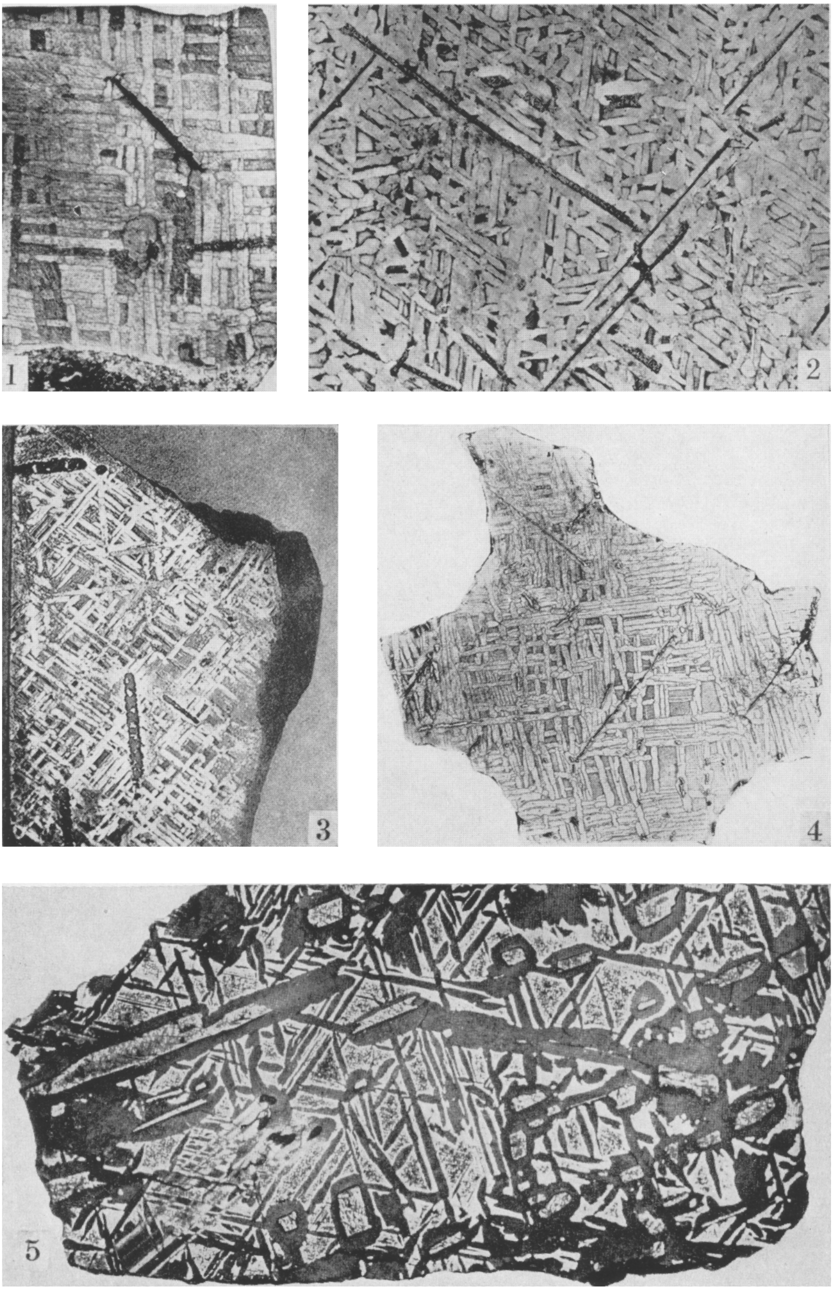
Fig. 1. Henbury, Central Australia. Section parallel to a cube face; bands of troilite oriented on rhombic dodecahedron. ×1·15. (L. J. Spencer, 1933.)

Fig. 2. Breece, New Mexico. Section parallel to an octahedron face; bands of cohenite oriented on rhombic dodecahedron. ×1·3. (S. H. Perry, 1944.)

Fig. 3. Goamus farm, Gibeon, South-West Africa. Section parallel to a cube face; bands of troilite and kamacite oriented on rhombic dodecahedron. ×¾. (F. Rinne, 1910.)

Fig. 4. Ilimaes, Atacama, Chile. Section plane parallel to a cube face; bands of troilite oriented on cube [or possibly rhombic dodecahedron]. ×⅔. (G. Tschermak, 1871.)

Fig. 5. Narraburra, New South Wales. Section plane parallel to an octahedron face; bands of schreibersite oriented on rhombic dodecahedron. ×2. (A. Liversidge, 1904.)



L. J. SPENCER: 'REICHENBACH' LAMELLAE IN METEORITIC IRONS