indicate a corrosion loss by pitting of the order of kilograms.

Specimen in the U.S. National Museum in Washington:
4,038 g slice (no. 927, 45 x 10 x 1 cm)

Tishomingo, Oklahoma, U.S.A.
34°14'N, 96°40'W

Martensitic ataxite. Anomalous. Coarse, slightly tempered martensite. HV 425±25.

Anomalous. About 32.5% Ni.

HISTORY

A mass of about 164 kg was discovered in 1965 by a 14-year-old boy, Glenn Orr, when he was bird hunting near Tishomingo, Johnston County. The coordinates above are for the town of Tishomingo.

Figure 1741. Tishomingo. The four fragments restored to position in the field where discovered in 1965. The ruler measures 24 inches. S.I. neg. 1470A.

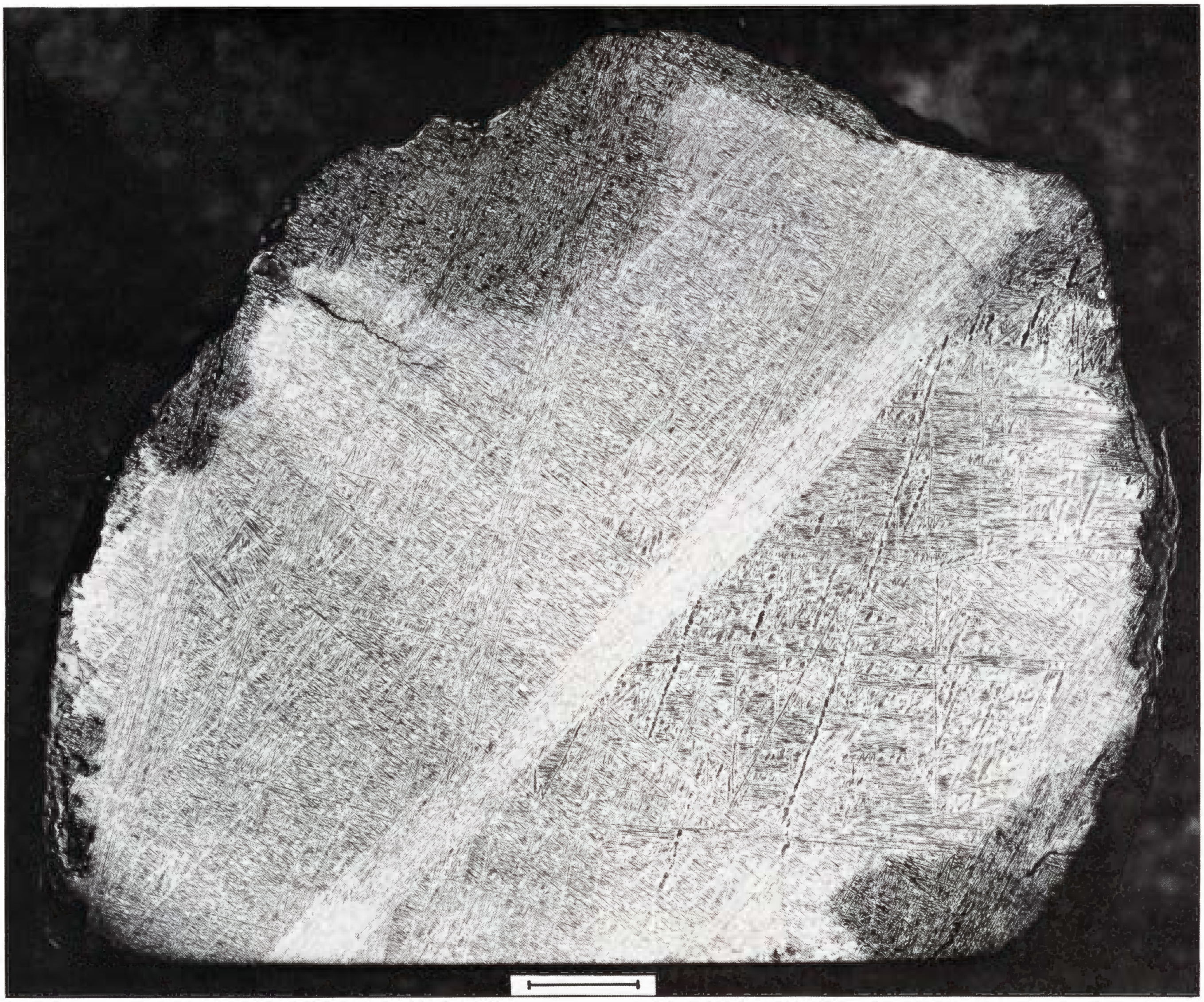

Figure 1742. Tishomingo. A part slice showing the anomalous, coarse martensitic structure. An austenite twin crosses the entire section. Terrestrial corrosion penetrates irregularly from the surface (black patches). Etched. Scale bar approximately 4 mm. S.I. neg. 1470C.

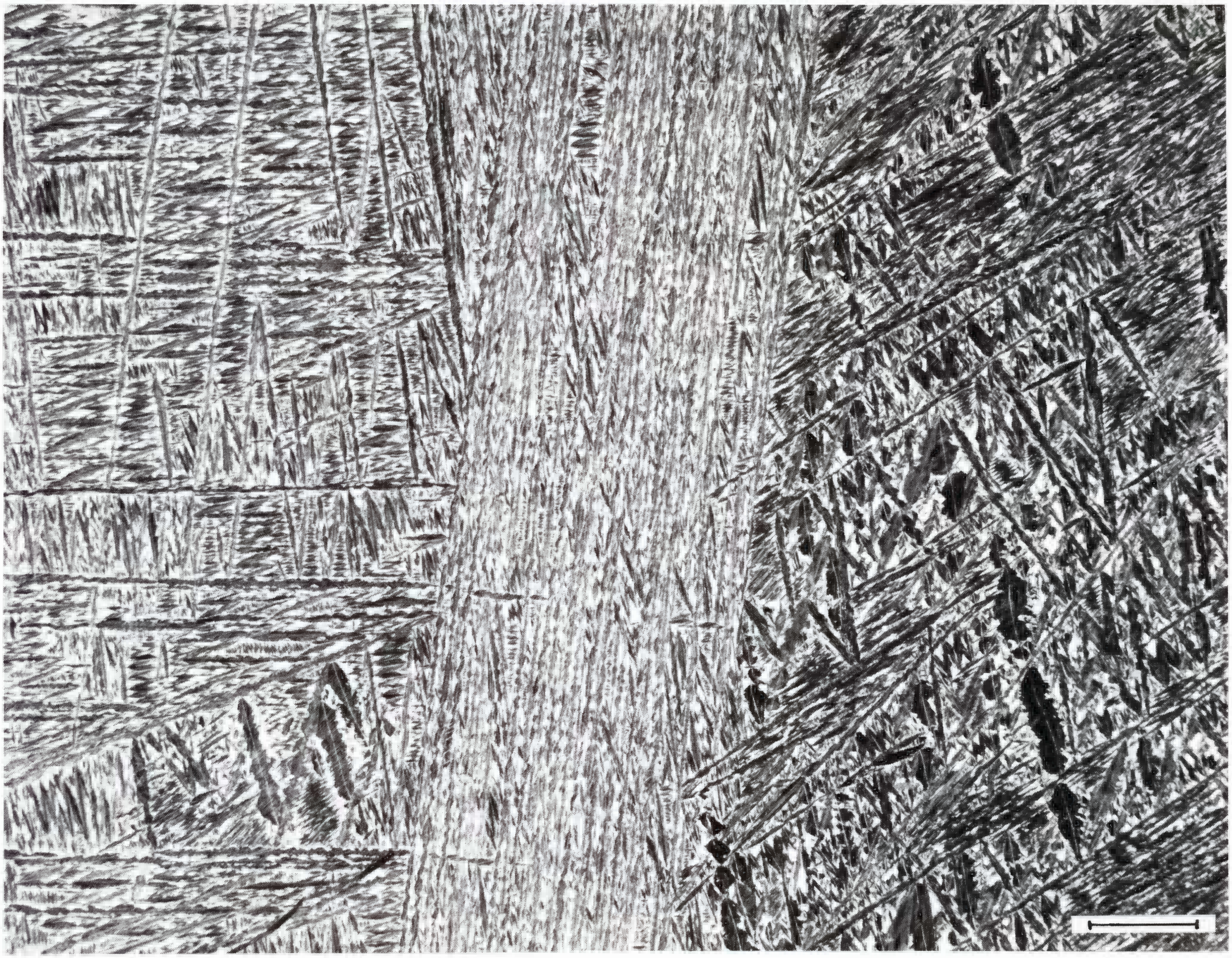

Figure 1743. Tishomingo. Detail of Figure 1742 showing the central austenite twin. The martensitic plates within the twin are parallel to the twin plane and to one of the directions on either side of the twin. Etched. Scale bar 800 μ. S.I. neg 1470B.

The mass was protruding from the ground in a granitic pasture. Subsequent efforts to locate additional pieces revelaed a 97 kg mass and two fragments of 2.5 kg and 1.08 kg. All the pieces were found in juxtaposition in the same depression, and it appeared that they had once formed one piece which separated upon weathering, possibly along certain preexisting fissure zones from the atmospheric flight (Monnig 1967).

A metallographic examination of polished sections from the smallest sample was reported by Buchheit et al. (1967).

COLLECTIONS

The main masses have apparently been retained by the finders. Small samples are on loan to the Smithsonian Institution.

ANALYSIS

A partial analysis by Buchheit et al. (1967) yielded 32.5% Ni.

DESCRIPTION

The dimensions and shapes of the three larger fragments are unknown. The following is based on an examination of the smallest fragment which was loaned to the Smithsonian Institution in 1968 by Mr. O.E. Monnig, Fort Worth. It is an almost square flat mass with the dimensions of 12 x 10 x 3 cm, and a weight of 1.08 kg. Terrestrial shales form a laminated 0.5-2 mm thick crust over a considerable part of the surfaces. According to Monnig, the piece fits together with at least one of the other fragments, so that corrosion has only slightly altered the overall morphology.

The 1.08 kg piece was cut through the middle and several polished sections were prepared. In a few places the original fusion crust is present as a crust up to 100 μ thick. It is composed of 5-10 layers of crossbedded metal which is now severely oxidized. Its presence confirms that the present overall size of the fragments is the same as immediately after the fall.

Etched sections display a coarse martensitic structure; a similar structure is unknown in any other meteorite and is

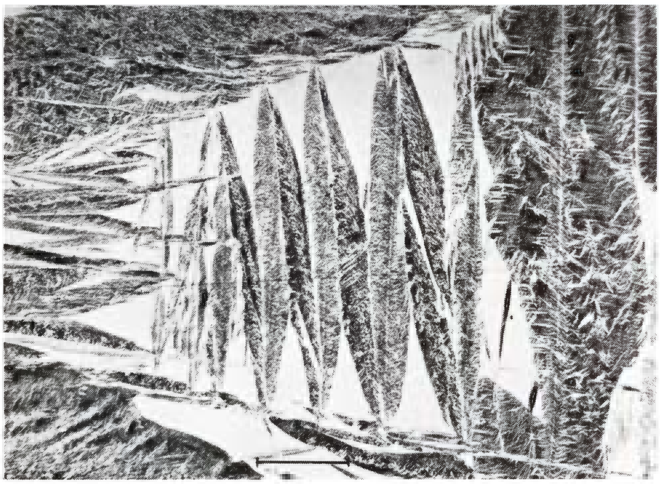

Figure 1744. Tishomingo. A group of martensitic plates in retained austenite (white). Etched. Oil immersion. Scale bar 20 μ.

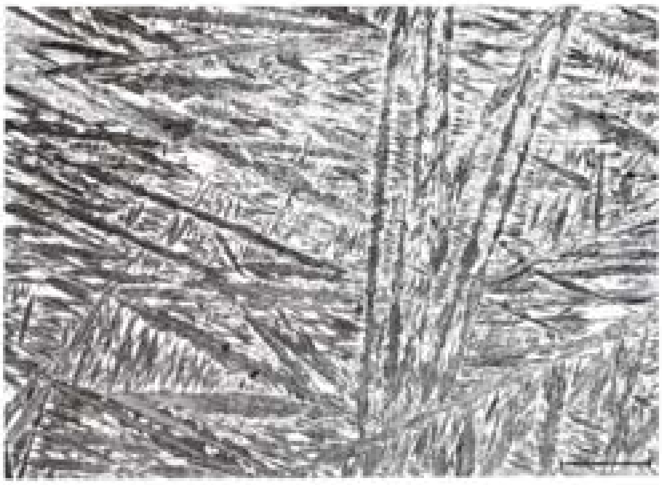

Figure 1745. Tishomingo. Martensite in retained austenite (white). Etched. Scale bar 300 μ.

also much coarser than in any terrestrial alloy. The martensite forms lenticular platelets which are usually 20-50 μ wide. In length they range from about 50 μ to at least 20 mm. However, the longer ones are pinched into segments that are seldom longer than 1-2 mm. Even on the largest section prepared, about 3 x 5 cm in size, all martensite platelets were uniformly arranged, indicating that the parent austenite crystal was at least of that size. In one case an austenite twin, 2 mm wide and 40 mm long, was observed. The martensite platelets all change their directions abruptly when passing the twin boundaries. A majority of those within the band are parallel to the long dimensions of the band, which is presumably parallel to the twin plane $(111)_\gamma$.

The martensitic transformation products constitute about 80% of the volume, while the retained austenite constitutes 20%. The martensite has a hardness of 425±25. The hardness decreases slightly to 385±35, in areas where the martensite platelets are small and visibly intercalated with retained taenite. The retained taenite, which forms irregular wedges, 10-50 μ across, or occasional patches 500 μ across, is structureless and relatively soft, 250±10. However, annealed taenite of this composition is at least 100 units softer, so the retained taenite must be cold-worked.

The individual martensite platelets are so coarse that the midrib and the twin striations are distinctly seen in the optical microscope. The twins run obliquely as dense parallel lines across the platelets. Strong anisotropy is observed when using crossed Nicols on an etched section. However the anisotropy seems to be associated with the etching, since no effects were visible on a polished section. The martensite morphology suggests that the transformation is of the acicular type with an irrational habit plane. It was not examined further in this study, but indications are that the habit plane is close to $\{259\}\ \gamma$, as reported for synthetic Fe-30Ni alloys, with no change in the symmetry of the cubic martensite – but with the martensite being

Figure 1746. Tishomingo. A daubreelite-troilite aggregate in martensite. The troilite is shock-melted while the daubreelite (D) has survived intact. Etched. Scale bar 100 μ.

internally twinned (Kelly & Nutting 1961; Owen et al. 1965; Speich & Swann 1965; Dash & Brown 1966; Patterson & Wayman 1966).

Tishomingo is a very pure iron-nickel alloy. No carbides, phosphides or silicates were identified at all, and graphite is not present. It is estimated that both the carbon and the phosphorus contents are below 0.05%.

Sulfides are present, however. Scattered through the matrix there are numerous (i.e., about 5-10 per cm^2) small blebs of what was previously monocrystalline troilite-daubreelite bars and nodules. They are 20-250 μ across, or occasionally form a straight veinlet 250 x 10 μ in size. They have been remelted – apparently due to shock reheating – and have dissolved part of the adjacent metal. Upon a very rapid cooling, they developed serrated edges against the metal and an internal microcrystalline eutectic, consisting of iron sulfide and nickel-rich austenite blebs in the 1-5 μ range. The original daubreelite bars occur as dispersed subangular fragments, 5-10 μ across, in the eutectic.

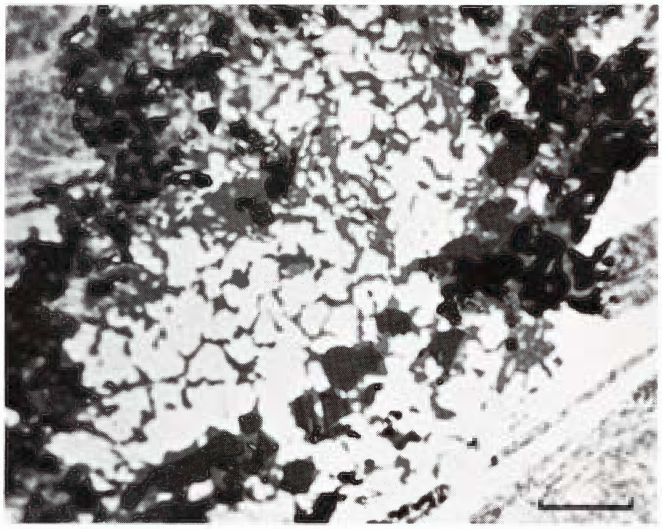

Figure 1747. Tishomingo. Detail of a shock-melted sulfide nodule like that of Figure 1746. Iron sulfide (gray), metal (white) and angular daubreelite fragments (black). Corrosion and pits (dead black). Etched. Scale bar 10 μ.

Tishomingo is rich in nickel but is nevertheless easily etched with 2% nital. It is interesting to note that the meteorite is weathered *below* the immediately visible limonitic crust. The internal oxidation has attacked the martensite in a 1-3 mm wide zone and has etched it naturally to a pattern corresponding to what is produced upon etching with nital. Evidently oxygen has been able to diffuse through the bulk of the Fe-Ni alloy to a depth of 1-3 mm and thereby precipitate submicroscopic iron oxides. The hardness of the internally oxidized layer is 365±35, a decrease of about 60 units relative to the unoxidized interior. Only the strained and disordered martensitic transformation products are attacked, while the retained austenite survives for a long time.

The internal oxidation may appear surprising, since it is unreported (?) in steels. It is, however, quite common in iron meteorites as noted in numerous descriptions in this book. Perhaps the amount of dissolved carbon in the iron meteorites is significantly lower than in technological steels so that any oxygen diffusing into the meteoritic matrix will be available for iron oxide formation, not having been consumed by carbon in solid solution.

Tishomingo is a unique meteorite, unrelated to any other meteorite. Only three others contain more nickel. In its trace-element composition it will probably also be found to be anomalous.

It is the structure, however, that poses the most puzzling problems. It appears that the precursor taenite crystals were large, i.e., above 50 mm in size; but since no large scale sections have been prepared, it is unknown whether Tishomingo was one single crystal or coarsely polycrystalline, as, e.g., Santa Catharina and Twin City.

Tishomingo does not display any structural features which can be referred to γ - α decomposition after the equilibrium Fe-Ni diagram. There are thus no discernible α-platelets and no swathing α-rims around heterogeneous nuclei of troilite. (Or, if they once were there, they are now masked by later alterations.) This is an interesting difference from Twin City (30% Ni) and Santa Catharina (35.3% Ni) and suggests a more rapid primary cooling for Tishomingo.

The cooling may eventually have reached such low temperatures that diffusionless martensitic reactions could occur. According to Kaufman & Cohen (1956) the M_S temperature for synthetic Fe-32.5% Ni alloys is about 180°K; 80% transformation to martensite might be expected if the temperature ever decreased to about 90°K. It is plausible that a portion of Tishomingo's martensite formed this way but probably not until it had been released from its parent body and circled in space as a small, poorly isolated body.

The troilite is present in a micromelted form which is similar to what is present in numerous other meteorites and

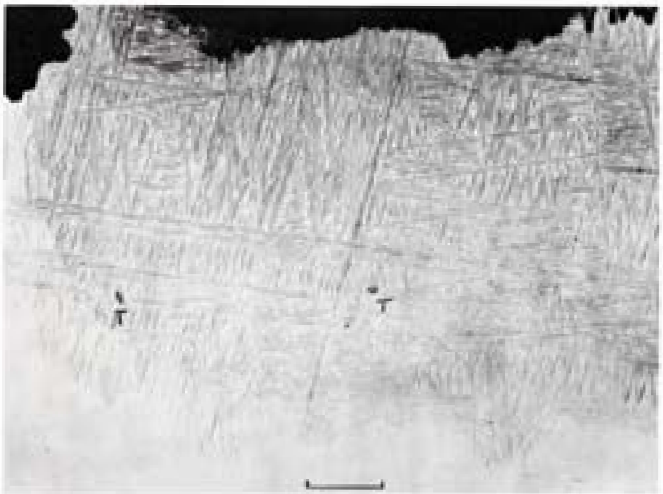

Figure 1748. Tishomingo. A near-surface section showing how terrestrial weathering has penetrated the massive iron and selectively oxidized it so that the martensitic pattern becomes visible on a polished section. Two dots (T) are shock-melted sulfides. Polished. Scale bar 500 μ.

Figure 1749. Tishomingo. Detail of the martensite plates showing a faulted midrib. Etched. Scale bar 100 μ.

Figure 1750. Tishomingo. Martensite plates occur within this field in a large number of directions. Striations indicate internal twinning. The density of twins is particularly high along the midribs of the plates. Etched. Scale bar 100 μ.

has been ascribed to shock pressures with associated relaxation heating. The microhardness values, 425 for martensite and – particularly – 250 for retained austenite, indicate hardening from shock deformation, possibly with slight tempering of the martensite. Scheil (1932), McReynolds (1946) and others have shown that plastic strain induces transformation at temperatures well above the martensite start temperature, M_S. If we accept the fact that the micromelted troilite pools are indicative of intense strain from shock deformation, it must also be considered that part of Tishomingo's martensite can have been formed during the shock. Perhaps future investigations can deduce what relative importance the two possible mechanisms can have played in the case of Tishomingo. Moreover, the problem seems to have general importance for the iron meteorites, since a large number contain martensitic transition zones in the plessite fields, or even wholly martensitic fields. In several cases I have noted martensitic morphologies quite similar to Tishomingo's, albeit on a small scale. So Tishomingo may well be considered only a special case in a general problem.

The final reheating in the Earth's atmosphere was superficial, and the tempering due to the terrestrial climate was very mild. There are no indications of artificial reheating by the discoverer.

Specimens in the U.S. National Museum in Washington:
Polished sections.

Tlacotepec, Puebla, Mexico

Approximately 18°41'N, 97°39'W

Nickel-rich ataxite, D. Duplex $\alpha + \gamma$ with a few 30 μ wide α-spindles. Oriented sheen in Widmanstätten directions. HV 242±8.

Group IVB. 16.20% Ni, 0.71% Co, 0.05% P, about 0.05% S, 0.20 ppm Ga, 0.03 ppm Ge, 24 ppm Ir.

HISTORY

This meteorite was not reported when it was found, but was "discovered" in the Museum of the Institute of Geology, in Mexico City, by Ward (1904a: 25). His information was very insufficient; the sample he saw was estimated to weigh 24 kg and to be an octahedrite from the District of Tecamachalco, State of Puebla. He obtained 40 g of the mass for his own collection. Farrington (1915: 436) and Prior (1923a) could only quote Ward since no more information had become available.

In 1929 when Nininger examined the Mexico collection, he was able to give more detailed information of the weight and nature of the material. The locality was confirmed, but nobody knew about the date of discovery, finder or how the meteorite arrived in Mexico City. Tlacotepec is a village in the state of Puebla, about 70 km southeast of the city of Puebla, on the main road from Puebla to Tehuacan. The corresponding coordinates are given above.

Nininger (1931d) described the meteorite, with an analysis and two photomacrographs. The mass was estimated to weigh 71 kg and to be a coarse octahedrite of an unusual type. It had previously been divided into two halves, one of 34 kg and the other 36.6 kg. Nininger managed to acquire the larger mass by exchange, and this he subdivided and circulated (see, e.g., Ward's Price List No. 342, 1931).

Haro (1931: 79), while reporting on the Mexican meteorites, gave no new information of Tlacotepec. The specimen that remained in Mexico City weighed 32.6 kg and was classified as an octahedrite.

Reeds (1937: 629) also adhered to the classification as a coarse octahedrite. Finally, Perry (1944: plate 23) correctly concluded that Tlacotepec was a nickel-rich ataxite. His two photomicrographs clearly show a fine-grained plessite in which scattered kamacite spindles occur. Reed (1965b) examined the plessite with the microprobe and found an average nickel concentration of 17%, similar to

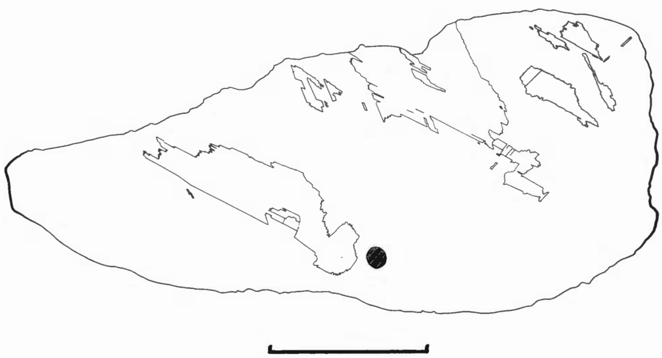

Figure 1751. Tlacotepec (U.S.N.M. no. 872). Sketch of a full slice with a lamellar troilite-daubreelite inclusion. An attempt has been made to delineate areas of different shadings, i.e., different orientation of the $\alpha - \gamma$ intergrowths. Scale bar 10 cm.