LOVINA, A NEW ATAXITE: EXAMINATION BY µXRD, PETROGRAPHY, SEM AND INAA.

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Introduction: The football-sized 8.2 kg Lovina ataxite was found by Dan Richer on a beach in Bali, Indonesia, in January 1981. Its unusual appearance and strong weathering have, over the years, precluded its being identified as a meteorite. Remarkable features include cm-sized pyramidal projections, or ziggurats, with mm-spaced ribs on its top surface (orientation as discovered) and deep vugs throughout (Fig. 1).

Fig 1. Lovina Ataxite (field of view ~ 30 cm).

The finder brought Lovina to The University of Western Ontario for micro X-ray diffraction (µXRD) analysis [1]. This provides non-destructive *in situ* mineralogical analysis of whole-rock specimens at the 500 to 50 µm scale and using crystal lattice parameters (d-spacings) for mineral identification (Fig. 2).

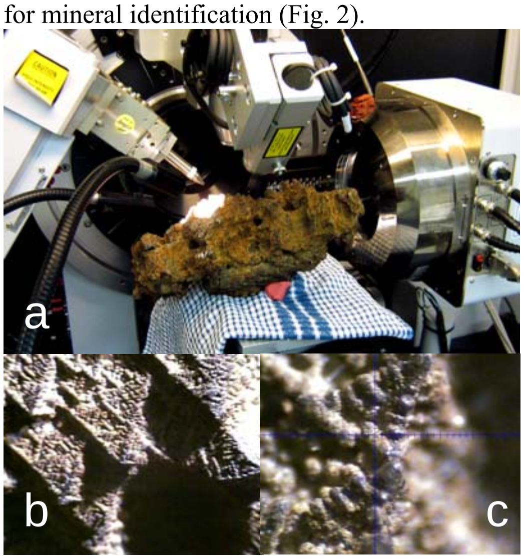

Fig 2. Lovina Ataxite a) on the Bruker D8 Discover µXRD, b) close-up image of ziggurat structures as seen through instrument microscope (fov = 9 mm). c) Same location as b) but taken at maximum magnification (fov = 2 mm).

Micro X-ray Diffraction (µXRD) analysis: The µXRD data were collected with a Bruker D8 Discover diffractometer (theta-theta geometry), operating with Cu Kα radiation (λ = 1.5418 Å) at 40 kV and 40 mA. The incident beam diameter was 500 µm. Positions on the meteorite were analyzed using a remote-controlled XYZ sample stage combined with a microscope-laser unit and CCD camera. Two-dimensional (2D) diffraction data were collected using a General Area Detector Diffraction System (GADDS; Fig 2a). Minerals were identified by comparison with the International Centre for Diffraction Data (ICDD) database.

Weathered surface – ziggurat structures: The ziggurats exhibited by Lovina were associated with two iron alloys: Ni-rich taenite and very Ni-rich awaruite, as identified by µXRD (Fig 3). Although this texture is reminiscent of Widmanstätten pattern, kamacite was not observed. Magnetite was frequently observed in association with awaruite (Fig. 3), indicating very intense weathering. This ziggurat structure is attributed to differential weathering within a taenite microstructure.

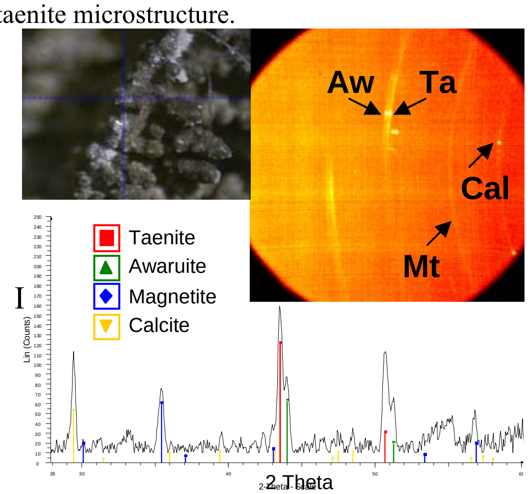

Fig 3. Paired context image and GADDS image of one location on the weathered ziggurats atop Lovina ataxite, and plot of intensity vs. 2 Theta. Taenite, and awaruite are easily discriminated by peak position. (Note: calcite is terrestrial).

Fresh Surface: primarily taenite with troilite. µXRD of several locations on a freshly polished surface of Lovina, free of weathering, revealed primarily taenite with minor troilite (Fig. 4). This suggested that Lovina was an ataxite, as was confirmed by petrographic and INAA analysis.

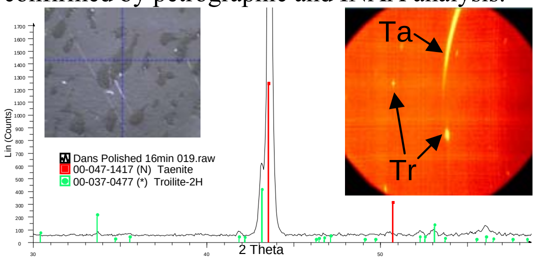

Fig 4. Context image of polished section shows taenite matrix and troilite blebs. The GADDS image reveals additional textural discrimination of the two minerals: Troilite exhibits spots (single crystal), while taenite shows partial Debye rings (strained). µXRD trace shows both.

Petrographic analysis: A polished thin section of Lovina was prepared for petrographic and SEM observations which confirmed its meteoritic origin. Petrographic observations indicated the taenite to be massive, lacking exsolved kamacite spindles, daubreelite and Neumann bands, which are commonly present in ataxites. Abundant globular troilite nodules up to 0.8 mm in diameter are present (Fig. 4). Many of the nodules are partially or totally oxidized to Fe oxides and display Ni-enriched rims of awaruite.

SEM information is correlated to µXRD: Crystal lattice data from µXRD was correlated to elemental data from X-ray maps collected by SEM at Surface Science Western (Fig. 5). Magnetite was confirmed to contain Fe and O, troilite contained Fe and S, massive taenite contained Fe and Ni, with Ni enrichment (awaruite) seen in the alloy surrounding magnetite in severely weathered areas (Fig. 5).

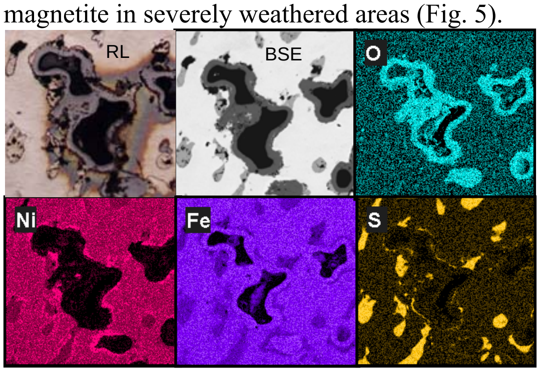

Fig 5. Lovina polished section. RL = Reflected light (after slight etching); BSE = backscattered electron image; O, Ni, Fe, and S are elemental X-ray maps. (SEM was done prior to etching).

Geochemical Analysis by INAA: Polished blocks (3.2 mm thickness; 0.4 to 0.7g) of Lovina and reference standards Odessa and Standard steel NBS 809B were prepared for INAA analysis at Activation Laboratories Ltd., Ancaster, Ontario using the protocol of Wasson et al. [2]. The steel provided the standard for As, Au, Co, Cr, Co, Ga, Ni, Pt, Sb and W whereas the Odessa meteorite was the standard for Ge, Ir and Re. Except for the previous three elements, the well-known composition of Odessa served as an internal standard for the 10 other elements [3].

Results: Lovina has composition Ni 345 and Co 8.73 mg/g; As 5.6, Au 0.07, Cr 321, Cu 395, Ga 22, Ge 150, Ir 0.252, Pt <0.5, Re <0.01, Sb 390 and W <10 (all in µg/g). The composition lies outside the range of most grouped ataxites in group IVB, thus, Lovina is an ungrouped ataxite.

Discussion: Grady [4] lists 54 ataxites, of which 12 belong to group IVB, 9 belong to other groups and 33 are ungrouped or unclassified. Lovina resembles other ungrouped ataxites, e.g. N'Goureyma, in its abundance of troilite nodules with a very low abundance of kamacite spindles and daubreelite, but differs in composition [5]. Although the high Ni-content and low Ir-content is similar to that of some other ungrouped ataxites, e.g. Santa Catharina and Twin City, Lovina differs in its relatively high Ge and Ga contents [5].

Conclusions: *In situ* µXRD is a useful rapid reconnaissance tool in meteoritics. The Lovina ataxite demonstrates the ease with which mineralogical and textural information can be obtained by non-destructive *in situ* µXRD, which identified the presence of taenite and troilite – indicators of extraterrestrial origin. However, the use of a suite of techniques together (µXRD, petrography, SEM, INAA) was the key to confirmation of Lovina's origin. The unusual ziggurats on Lovina provide an opportunity to study terrestrial weathering of irons.

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