

**TAMBO QUEMADO: EXTRAORDINARY CONCENTRATIONS OF REE AND REFRACTORY TRACE ELEMENTS CAUSED BY ARTIFICIAL HEATING.** E. Olsen (Geophys.Sci., Univ. of Chicago), I. Hutcheon (Geol. Planet. Sci., Caltech) & C. Moore (Dept. of Chem., Ariz.State U.)

Buchwald [1] examined samples of the IIIB iron Tambo Quemado (TAMQ) cut from the 130 kg main mass. He determined it had been artificially heated, at some time prior to being reported, in an attempt to obtain metal from it. Although the Widmanstätten structure appears relatively unaffected under macroscopic examination, microscopic study of etched sections reveals the effect of the heating. Taenite and plessite area boundaries are indistinct due to high temperature diffusion. Schreibersite, once present in significant amounts, has been melted. Schreibersites in the interior have resolidified in fine-grained eutectic textures surrounded by dark-etching metal rims supersaturated with phosphorus. Buchwald states that phosphate minerals were probably present originally, because graffonite, and its polymorph sarcopside (both essentially  $\text{Fe}_3[\text{PO}_4]_2$ ), are common in irons of the IIIAB groups. Based on his metallographic study Buchwald estimates TAMQ was heated to 1000°C for about one hour.

An interior sample from TAMQ was examined in order to determine what effect this unintended heating "experiment" had upon the phosphate phases. It was considered unlikely that an interior sample within this large a meteorite would have had significant chemical communication with the terrestrial atmosphere during this short a heating time. Oxygen entering the interior would be buffered by metallic iron, and the results should be evident. Any observed changes could provide a baseline for interpreting unusual mineralogical or chemical features in the large number of IIIAB irons currently being studied by the authors of this abstract and their colleagues. An interior sample was collected from Arizona State Univ. sample ASU 605.6. It appeared to be a normal graffonite inclusion,  $\approx 500 \mu\text{m}$  bleb contained in swathing kamacite. Back-scattered electron images of the polished section showed fragments (150 x 400  $\mu\text{m}$  range) of graffonite (Phase 1 in Figs below) with irregular patches, 10 to 40  $\mu\text{m}$ , of Phase 2 strung out in trains running through the length of the graffonite. Also, within the trains were numerous very small irregular grains, generally < 10  $\mu\text{m}$ , of Phase 3, with very high back-scattered electron brightness. Grains of Phase 3 are contained within Phases 1 and 2. Electron microprobe analyses were made:

| Phase                   | 1            | 2            | 3            |  |
|-------------------------|--------------|--------------|--------------|--|
| MgO                     | 0.03         | 0.02         | 0.00         | Phase 1 (Graffonite) $(\text{Fe,Ca,Mg,Al})_3(\text{Si,P})_2\text{O}_8$                                     |
| $\text{Al}_2\text{O}_3$ | 0.02         | 0.47         | 0.71         |  |
| $\text{SiO}_2$          | 0.34         | 10.47        | 1.77         | Phase 2 (Silicophosphate) $\text{Fe}_{10}(\text{Al}_{0.09}\text{P}_{3.93}\text{Si}_{1.95})_6\text{O}_{24}$ |
| $\text{P}_2\text{O}_5$  | 39.91        | 25.00        | 9.78         |  |
| CaO                     | 0.28         | 0.00         | 0.00         | Phase 3 (Phosphoran wüstite) $\approx (\text{Fe,Al,Ti,Si,P})_7\text{O}_8$                                  |
| $\text{TiO}_2$          | 0.00         | 0.00         | 0.12         |  |
| FeO                     | <u>60.02</u> | <u>65.01</u> | <u>89.12</u> |  |
| Total                   | 100.60       | 100.97       | 101.50       |  |

The phase relations in the system Fe-P-O (in the presence of metallic Fe) have been studied [2]. Solid phases 1 and 3 coexist in the subsolidus field below a 940°C eutectic. From the presence of phosphoran wüstite it is clear that a small amount of terrestrial oxygen entered the system during the heating,  $\log P(\text{O}_2) \approx -18$ . Original graffonite in TAMQ melted, oxidized slightly and then recrystallized as graffonite and phosphoran wüstite. Graffonites in IIIAB irons usually contain 0.02 to 0.04 wt%  $\text{SiO}_2$ . During the heating silica appears to have concentrated in the melted graffonite, increasing its silica content by about 10 $\times$ , entering the phosphoran wüstite, and creating a new silicophosphate phase.

The abundances of rare earth elements (REE) and refractory trace elements (RTE) in the three phases in TAMQ were measured with the PANURGE ion microprobe [Figs. 1 & 2]. Phase 1 has a flat REE pattern with 1-2  $\times$  C1 abundances and a negative Eu anomaly. The pattern is similar to those measured in Ca-phosphates in chondrites [3,4] but at much lower REE abundances. The RTE abundances in Phase 1, except for Ti, are depleted relative to C1. Phase 3 has a LREE-enriched pattern with much higher abundances of LREE: La  $\approx 20 \times$  C1 and a C1-normalized La/Lu ratio of 10-20. Eu is strongly enriched at  $\approx 120 \times$  C1. The RTE abundances in Phase 3 are

## TAMBO QUEMADO: Olsen E., Hutcheon, I. and Moore C.

also substantially enhanced relative to Phase 1 and decrease in abundance with increasing refractory character, from Ba  $\approx 400 \times C1$  to Zr  $\approx 3 \times C1$ . The pronounced enrichments of Ba and Eu in phase 3 are accompanied by complementary depletions in Phase 1. Phase 2 contains the lowest REE abundances with a REE pattern very similar to that of Phase 3 but at abundances  $\approx 10$  times lower. It is possible Phase 2 contains essentially no REE and the data reflect very small, undetected inclusions of Phase 3 within Phase 2. The RTE abundance pattern of Phase 2 also mimics that of Phase 3, generally at lower abundances, although V, Sc and Ti levels are approximately equal in both phases. The relatively high abundances of REE and RTE in the TAMQ graffonite inclusion contrast sharply with the abundances of these elements measured in Fe-phosphates in other IIIAB irons. Ion probe analyses of graffonite and several associated phosphate phases have revealed very low REE and RTE concentrations, generally below  $0.1$  to  $0.01 \times C1$ ; those results appear to confirm the argument that phosphates in IIIAB irons formed by oxidation of P dissolved in metal [5] with the phosphates inheriting the absence of lithophile elements in the metal source. High Ba has been found in one occurrence but without a satisfactory explanation.

Compared to phosphates in other IIIAB irons the abundances of the REE and RTE in the three phases of TAMQ are extraordinary. Unfortunately it was not possible to determine a mode to calculate bulk trace element concentrations because the sample chips do not represent the entire original inclusion. If the original inclusion was the same as phosphate inclusions analyzed in other IIIAB irons, *i.e.*, very depleted in both REE and RTE, then it is clear there has been a significant increase in both groups of elements in the graffonite inclusion during the heating "experiment". The source of these elements is a puzzle. One possibility is that temperature gradients in the heated mass caused these elements, in generally undetectable amounts in the original graffonite inclusions, to diffuse from graffonites in hotter volumes to those in cooler volumes. One difficulty with this arises from the manner of occurrence of phosphate inclusions in the metal host. The phosphates are commonly separated by large volumes of intervening metal, requiring diffusion of lithophile trace elements over distances of up to tens of centimeters.

The data from TAMQ, in particular the high and relatively uniform REE abundances in Phase 1 and the complementary distribution of Ba and Eu between Phases 1 and 3, serve as a warning. Natural reheating of a IIIAB iron, even at temperatures of only a few hundred degrees C for longer periods of time than in this "experiment", *i.e.* several hours, may lead to significant mobilization of trace elements. The resulting abundance patterns may strongly resemble those traditionally attributed to single nebular or parent body processes, leading the unwary to invalid conclusions. [Div. Contrib. 5227 (791)]

**REFERENCES:** [1] Buchwald, V.F.(1975) *Handbook of iron meteorites*, v.3, U.Calif. Press. [2] Trömel, G. & Schwerdtfeger, K. (1963) *Arch. Eisenhüttenwissen* 34, 58. [3] Reed, S.J.B. & Smith, D.G.W. (1985) *Earth Planet. Sci. Lett.* 72, 238. [4] Crozaz, G., *et al.* (1989) *Earth Planet. Sci. Lett.* 93, 157. [5] Olsen, E. & Fredriksson, K. (1966) *Geochim. Cosmochim. Acta* 30, 459.

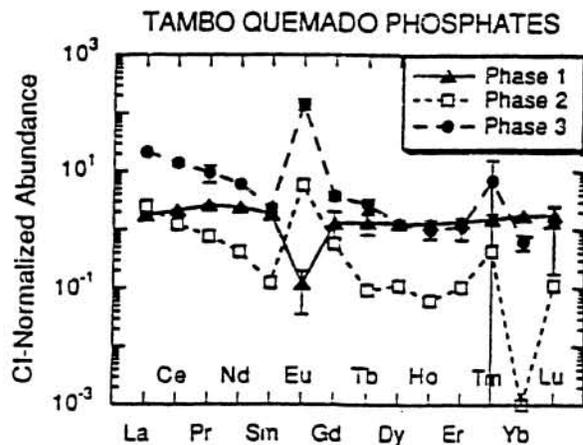


Fig.1

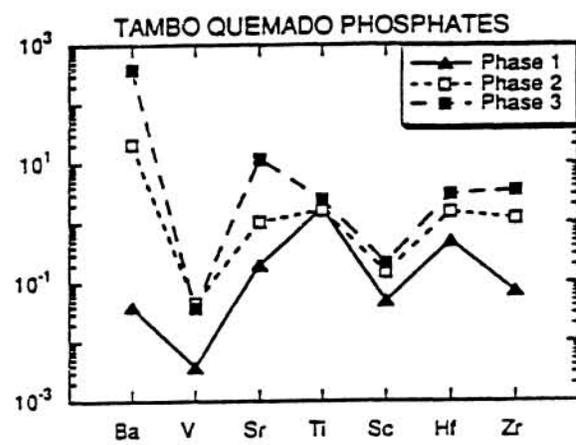


Fig.2