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SILICATE-BEARING INCLUSIONS IN IRON METEORITES CADDO COUNTY AND ZAGORA

BY

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ABSTRACT

Silicate-bearing inclusions in iron meteorites Caddo County and Zagora. - Our mineralogical and chemical studies of silicate-bearing inclusions, in the two IAB iron meteorites Caddo County and Zagora, suggest their classification as Odessa type. Mineral and chemical composition of the inclusions in both meteorites is very similar. Silicates show little chemical heterogeneity. The inclusions differ, however, in shape, accessory mineralogy and texture.

Key-words: Iron meteorites, silicate inclusion, IAB chemical group, Widmanstätten structure.

INTRODUCTION

Several IAB iron meteorites contain polymineralic silicate-bearing inclusions. Such inclusions are of great interest; they could provide chemical and mineralogical clues to genetic relationships between irons and other meteorites (Dodd, 1981).

Various processes may be responsible for the formation of this enigmatic metal-silicate assemblage. Different models attempt to elucidate the problem of mixing silicates into the metallic magma. Wasserburg *et al.* (1965), Burnett & Wasserburg (1967) and Bogard *et al.* (1968) concluded that the iron meteorite host and the inclusions are congenetic. An alternative model (Bunch *et al.*, 1970) suggests that the inclusions represent old material trapped by a younger nickel-iron melt and preserved through a rapid cooling.

Large number of observations on silicate-bearing inclusions is necessary for the understanding of their origin and evolution. The results of our present study of silicate-bearing inclusions from iron meteorites Caddo County and Zagora contribute to the data on these complex objects.

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ANALYTICAL TECHNIQUES

The polished surfaces of the hand samples were examined visually and with low-power stereomicroscope. We selected for detailed examination inclusion-rich areas. Polished thin sections were examined optically in transmitted and reflected light. Chemical analyses were carried out with CAMECA SX 50 microprobe equipped with five wavelength dispersive X-ray spectrometers. Analyses were performed with focused beam, at 15 kV accelerating voltage and 10-15 nA beam current. Raw data have been corrected using the PAP (improved ZAF) correction programme.

RESULTS

Caddo County

Description. Caddo County, iron meteorite found 1987 in Oklahoma, USA, was previously classified, from oxygen isotopic data, as a member of IAB chemical group (Graham, 1989). Its polished and etched section shows medium Widmanstätten structure with kamacite lamellae with width 0.5-1.2 mm. Nickel content of metal phase is about 7% (Takeda *et al*., 1993). Metallic matrix contains dark rounded or elongated inclusions, the largest of which is 20 x 25 mm (Fig. 1). A few small millimetre-sized (<1-3 mm) aggregates are also visible. Microscopic examination shows that inclusions

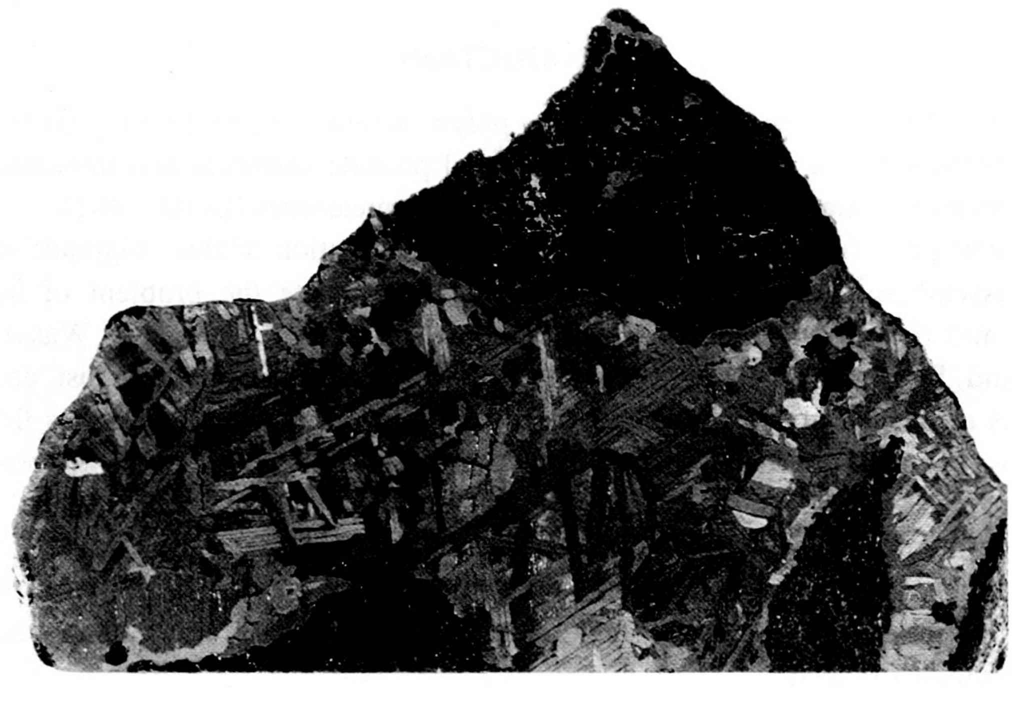

FIG. 1.

Hand sample of Caddo County meteorite with silicate bearing inclusions (dark). The field of view is ~ 7 cm wide.

consist of pyroxenes, plagioclase, olivine, accessory apatite and rutile with interstitial metallic FeNi, troilite and schreibersite. BSE images reveals in troilite fine exsolutions of daubreelite and minute grains of alabandite. The inclusions have coarse qranoblastic texture: majority of crystals vary in size from 0.25-1.0 mm (some grains are as large as 2.0 mm). Pyroxenes are typically anhedral. Large grains have often rims, composed also of pyroxene in form of small (0.015-0.15 mm) commonly oriented crystals. Plagioclase tabular crystals are an-, sub- and euhedral, polysynthetically twinned. Olivine forms anhedral grains, mostly rounded or subrounded. Opaque phases, present inside inclusions, form irregular, amoeboid concentrations up to 2.0 mm. Metallic FeNi is the most abundant, following by troilite. Schreibersite is less common and usually situated within troilite. All silicates contain disseminated tiny (<0.005-0.15 mm) droplets of metallic FeNi and troilite. Both main opaque phases fill spaces between silicate grains. In places eutectic intergrowths of silicates and opaque minerals are visible. Rare silicate grains are corroded, by metal, at their borders.

Mineral chemistry. Microprobe analyses show small compositional variations of silicates. *Orthopyroxene* has compositional range of $En_{90.0-96.2}Fs_{3.0-7.1}Wo_{0.5-2.0}$ with mean of $En_{92.3}Fs_{6.0}Wo_{1.7}$. *Clinopyroxene* is a chromian diopside. It has fairly uniform composition with mean value of $En_{52.1}Fs_{2.7}Wo_{45.2}$ and mean Cr_2O_3 content of 1.20 wt.%. *Plagioclase* is a Na-rich variety, slightly varying in composition from $Ab_{78-83}An_{14-19}Or_{3.0-3.2}$ with mean corresponding to $Ab_{80}An_{17}Or_{3.0}$. *Olivine* is strongly forsteritic: $Fa_{1.5-2.0}$, with mean of $Fa_{1.75}$. Analysis of apatite show the composition of a pure end-member *Cl-apatite*.

Shock-deformations. Olivine crystals are strongly fractured. Both irregular and planar fractures are present. Mosaic extinction is rare. Plagioclase is slightly deformed by fractures, but some grains show undulatory extinction and distinct isotropic spots. These shock effects in plagioclase indicate that silicate-bearing inclusions in Caddo County were deformed by moderate shock pressure of 30-35 GPa (shock stage S4), according to the Stöffler *et al.* (1991) classification scheme.

Zagora

Description. Similarly as Caddo County, Zagora meteorite (found 1987 in Ouarzazate, Morocco) belongs to IAB chemical group. It was classified on the basis of oxygen isotopic data (Graham, 1989). The polished and etched section of Zagora shows coarse Widmanstätten structure with kamacite lamellae with width 1.2-3.0 mm. Nickel content of metal phase is 9.8% (Wasson *et al.*, 1989). Dark brown inclusions are distinct in metallic matrix. They form elongated, angular clusters, the largest of which is 3 x 12 mm (Fig. 2). Like in Caddo County small, subrounded inclusions <1-3 mm are also present. Inclusions contain pyroxenes, olivine, plagioclase, whitlockite intergrown with metallic FeNi, troilite, schreibersite, minor chromite and graphite. Inclusions have crystalline texture: most of the grains range in size from 0.02-0.5 mm (a few grains are as large as 1.0 mm). The Zagora inclusions exhibit distinctly finer texture, than analogous

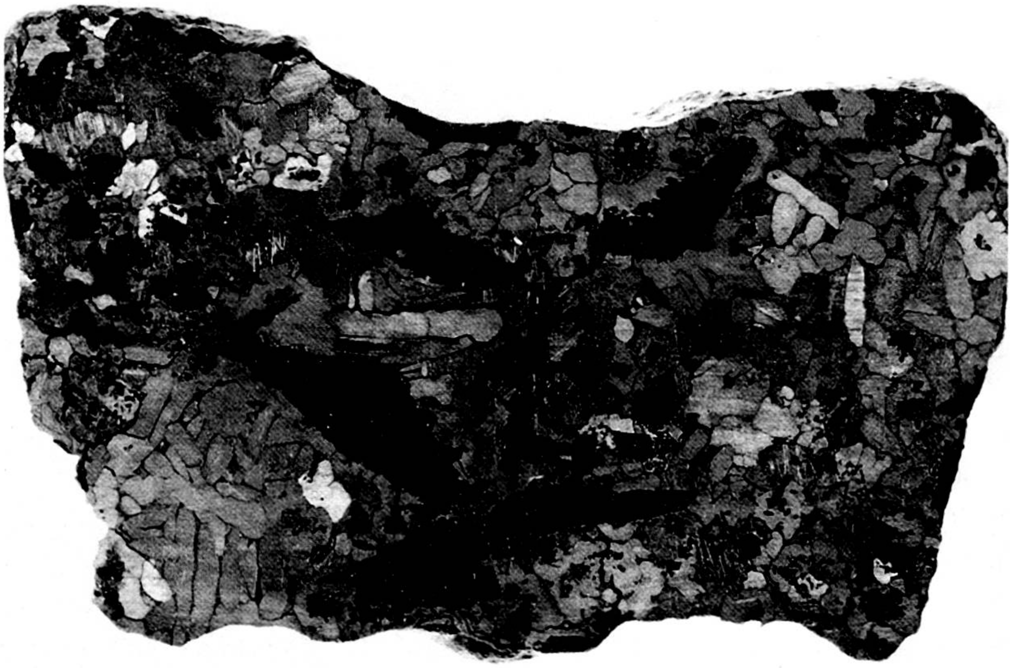

FIG. 2.

Hand sample of Zagora iron meteorite. Dark silicate bearing inclusions are elongated, angular. The field of view is ~6 cm wide.

forms in Caddo County. Pyroxenes occur as sub- and anhedral crystals, some with tabular shape. Olivine forms typically anhedral, isometric grains. Plagioclase is present as prismatic crystals with perfect polysynthetical twinning. Whitlockite is relatively abundant in Zagora inclusions and occurs as angular grains up to 0.15 mm in size (Fig. 3). Silicates and phosphate are associated with the metallic FeNi, troilite and schreibersite up to 4.0 mm. Metallic FeNi predominates among the opaque phases in the inclusions. Troilite, which is the second opaque mineral, interrupts some silicate concentrations. Daubreelite occurs as fine exsolution lamellae in troilite. Schreibersite is more abundant, than in Caddo County inclusions, forming large concentrations up to 1.5 mm. Some of them are cut by intruding silicate-troilite assemblage. Graphite and chromite are accessory and present as grains up to 0.2 mm.

Mineral chemistry. The mineral components of the inclusions show very little chemical heterogeneity. *Orthopyroxene* has a narrow compositional range of $En_{91.5-92.5}Fs_{6.0-7.0}Wo_{1.5}$, with mean value corresponding to $En_{92.0}Fs_{6.5}Wo_{1.5}$. *Clinopyroxene* (chromian diopside) ranges from $En_{51.6-52.1}Fs_{2.6-2.7}Wo_{45.3-45.8}$, with an average of $En_{51.8}Fs_{2.6}Wo_{45.6}$ and mean Cr_2O_3 content of 0.78 wt.%. *Olivine* is highly forsteritic: $Fa_{4.0-4.5}$ with mean of $Fa_{4.3}$. It is slightly more ferrous than olivine in Caddo County. *Plagioglase* is more sodic, than in Caddo County and has smaller compositional variations: $Ab_{83.0-84.2}An_{11.6-13.2}Or_{3.8-4.2}$ with an average of $An_{83.6}An_{12.4}Or_{4.0}$. *Whitlockite* contains on average 2.72 wt.% Na_2O and 3.66 wt.% MgO.

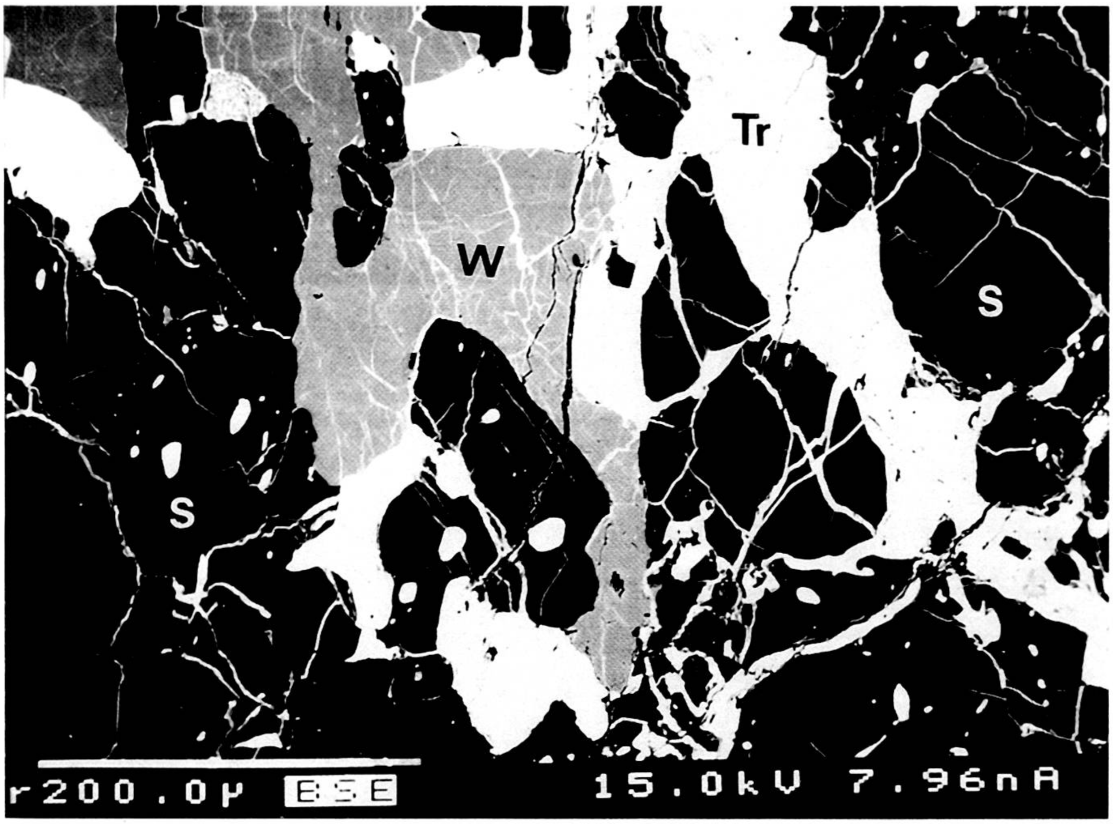

FIG. 3.

Backscattered electron image of an inclusion in Zagora meteorite. S-silicates (black) are pyroxene, plagioclase and olivine. W-whitlockite (grey) is visible in the centre and upper left side. Tr-troilite (white) occurs as large crystals, veinlets and small droplets.

Shock effects. Silicates in Zagora meteorite are severely fractured. The whole inclusions are cut by numerous, irregular fractures. Some olivine grains also show planar fractures. Both olivine and plagioclase display occasionally undulatory extinction. The presence of planar fractures in olivine is the prime criterion for shock stage S3 and indicates that silicate inclusions from Zagora belong to weakly shocked category (shock pressure 15-20 GPa). Heavy fracturing promoted oxidation process of the metal FeNi and troilite. Fractures are commonly filled with iron hydroxides, products of terrestrial weathering.

DISCUSSION

Bunch *et al.* (1970) classified the silicate-bearing inclusions of IAB iron meteorites as Odessa and Copiapo types. Mineral compositions in the Odessa and Copiapo types are very similar. The inclusions differ slightly in accessory mineralogy, texture and shape. The results of present study indicate that Caddo County inclusions are of Odessa type. Their rounded shapes, coarse granoblastic texture and mineral assemblage are the classification basis for this type of inclusions. Caddo County inclusions are similar to well known analogous forms from Toluca and Odessa meteorites (Buchwald, 1975). Takeda *et al.* (1993) studied another inclusion (7.5 x 5.5 mm in size) from Caddo County. The inclusion has mineral composition and chemistry nearly identical to the inclusions in our sample. This suggests that all inclusions in Caddo County have the same character and show very little mineralogical and chemical heterogeneity. The designation of the Zagora inclusions is less straightforward. Their angular shape may suggest the Copiapo type classification. Though their complex mineral assemblage, distinct association of silicates with troilite and relatively abundant schreibersite indicate rather Odessa type affinity. Thus we classified the Zagora inclusions as Odessa type, similar to those known from Linwood meteorite and some fragments of the Campo del Cielo (El Taco mass).

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RÉSUMÉ

Cette publication décrit des inclusions riches en silicates, présentes dans les météorites de fer Caddo County et Zagora, appartenant toutes deux au groupe chimique IAB. Les résultats des analyses minéralogiques et chimiques ont permis de classer ces inclusions comme "Odessa-type". La composition minérale et chimique des inclusions, dans les deux météorites, est très proche. Cependant leurs formes, textures et certains minéraux accessoires sont différents.

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