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The Tatum, New Mexico, Chondrite and its Silica Inclusion

Der Tatum, Neu Mexiko, Chondrit und sein SiO_2-Einschluß

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With 3 figures

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Abstract

We have studied the poorly-described Tatum meteorite and an unusual silica-pyroxene inclusion within it. Tatum is an H4(S2)W4 ordinary chondrite. It is somewhat unusual in that it contains unequilibrated pyroxenes. A mm-sized inclusion consisting of a nearly-pure SiO_2 core surrounded by a corona of low- and high-Ca pyroxene probably did not form by crystallization from a melt, either in a large magma pool on a parent body or within a chondrule. Instead, it probably formed by incorporation of an SiO_2 inclusion into Tatum prior to metamorphism, and reaction of this inclusion with the chondritic host during metamorphic reheating to form the pyroxene corona. The detailed nature of this reaction, including the temperature at which it occurred, is uncertain.

Zusammenfassung

Wir haben den bisher wenig beschriebenen Meteoriten Tatum sowie einen ungewöhnlichen SiO_2-Pyroxen-Einschluß in diesem Meteoriten untersucht. Wir haben Tatum als eine H4(S2)W4 gewöhnlichen Chondrit klassifiziert. Es ist bemerkenswert, daß dieser Chondrit unequilibrierte Pyroxene enthält. Der millimetergroße Einschluß besteht aus einem nahezu reinem SiO_2-Kern, der von einer Korona von Ca-armem und Ca-reichem Pyroxen umgeben ist. Der Einschluß ist sehr wahrscheinlich nicht durch Kristallisation einer Schmelze, weder in einem größeren Magmenreservoir noch in einer Chondre entstanden. Unsere Untersuchungen weisen darauf hin, daß während der Akkretion und vor der Metamorphose des Tatum Chondriten, ein SiO_2-Bruchstück in das Gestein eingeschlossen wurde. Dieser Einschluß reagierte dann während der Metamorphose mit dem umgebenden Gestein, wodurch die Pyroxenkorona entstand. Die Einzelheiten dieser Reaktion bleiben aber vorläufig unbekannt.

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Introduction

This paper is the seventh in a series on poorly described ordinary chondrites from the Oscar Monnig meteorite collection in the Department of Geology, Texas Christian University, Fort Worth, Texas. These studies have not only provided documentation of a number of poorly-known meteorites, but have also revealed a number of unusual meteorites and clasts. This work focuses on the Tatum, New Mexico chondrite and, in particular, on an unusual, silica-rich inclusion within this chondrite.

Tatum chondrite

The 1.787 kg Tatum specimen was obtained by Mr. O. E. Monnig in April, 1938, from Mr. R. E. Franklin of Tatum, Lea County, New Mexico, who stated that he "found the meteorite lying loose on the ground in a field of cotton in the southeast quarter of Section 31, Township 12 South, Range 36 East, 8 miles from Tatum". However, the range listed by the finder is probably incorrect and should be in the southeast quarter of Section 31, Township 12 South, Range 35 East, since this location is 8 miles from Tatum. The approximate coordinates for this location are 33° 14´ N, 103° 26´ 30´´ W. These coordinates differ slightly from those listed in GRAHAM et al. (1985), which appear to be those of the town of Tatum. the original report of Tatum, given by NININGER (1939), did not give coordinates. Tatum is not paired with any other meteorite. The closest locality of a meteorite of similar type (H4) is Hobbs, which is ~60 km from Tatum.

Two polished thin sections (UNM 684 and an unnumbered TCU section) were studied to classify Tatum. The TCU section has largely detached from the glass slide, and most of the work reported here was therefore conducted on PTS UNM 684. Electron microprobe analyses were made with an ARL EMX-SM and a Cameca Camebax instrument using standard procedures. The meteorite was classified into chemical group (GOMES and KEIL, 1980), petrologic type (VAN SCHMUS and WOOD, 1967; SCOTT et al., 1986), shock stage (STÖFFLER et al., 1991) and weathering degree (WLOTZKA, 1993). No evidence of post-accretionary brecciation was found. Tatum is classified as an H4(S2)W4 chondrite.

Classification as an H chondrite is indicated by the mean compositions of olivines ($Fa_{18.4\pm0.4}$, N = 26) and low-Ca pyroxenes ($Fs_{15.4\pm3.1}$, range $Fs_{3.8\pm19.5}$, $Wo_{1.0\pm0.5}$, N = 25). Our mean olivine composition is essentially identical to that of MASON (1963) (Fa_{18}). Feldspar compositions ($An_{11.9}Ab_{82.1}Or_{6.0}$, N = 13) confirm H classification (VAN SCHMUS and RIBBE, 1968). Fe, Ni and FeS abundances are not useful for group classification, due to extreme weathering.

Well-defined chondrule boundaries, abundant striated pyroxene, microcrystalline textures of the chondrule mesostases and Wo content of low-Ca pyroxene ($Wo_{1.0}$) indicate classification as petrologic type 4. Severe weathering prevents determination of the degree of recrystallization of the matrix. Tatum is one of a small number of type 4 chondrites with equilibrated olivines and unequilibrated pyroxenes. Other examples include Bo Xian ($Fs_{3.4-22.9}$; MCCOY et al., 1991) and TIL 91700 (Fs_{15-25}; MASON, 1993). The co-existence of equilibrated olivines and unequilibrated pyroxenes is consistent with the faster diffusion rates for olivine relative to low-Ca pyroxene.

Classification as shock stage S2 is indicated by the undulatory extinction and random fracturing of large olivines. The hand specimen is severely weathered, with both the exterior and a cut surface exhibiting an orange-brown coloration. Extremely rare metallic Fe, Ni and troilite grains are visible in thin section, but were not encountered during modal analyses. Weathering pigments stain many grains. Veins and patches of hydrated iron oxides occur throughout the sections and account for 19.9 vol.% of the meteorite, based on modal analyses of 1100 points in UNM 684 and the TCU section. Classification as weathering stage W4 reflects nearly complete oxidation of opaques.

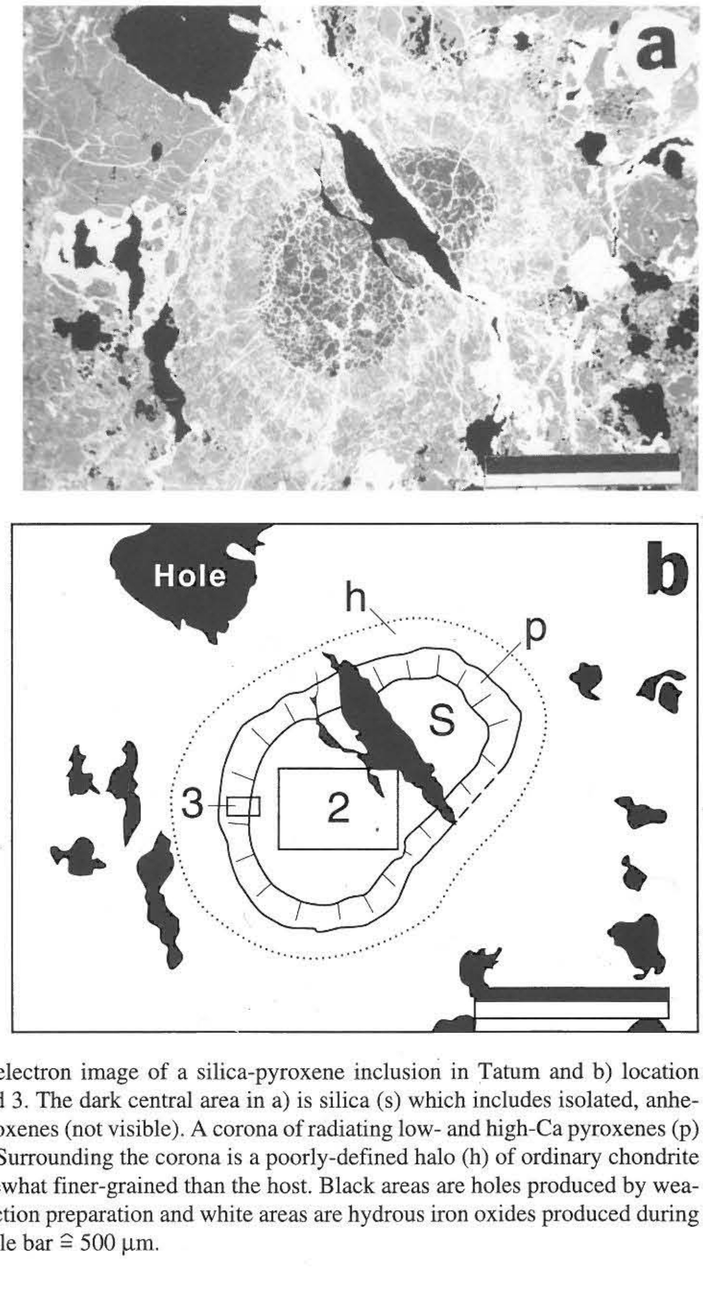

Fig. 1. a) Backscattered electron image of a silica-pyroxene inclusion in Tatum and b) location sketch map for Figs. 2 and 3. The dark central area in a) is silica (s) which includes isolated, anhedral low- and high-Ca pyroxenes (not visible). A corona of radiating low- and high-Ca pyroxenes (p) surrounds the silica core. Surrounding the corona is a poorly-defined halo (h) of ordinary chondrite mineralogy which is somewhat finer-grained than the host. Black areas are holes produced by weathering and during thin section preparation and white areas are hydrous iron oxides produced during terrestrial weathering. Scale bar ≙ 500 μm.

Table 1. Representative microprobe analyses of minerals in the silica inclusion in Tatum. Silica is from the core of the inclusion and high- and low-Ca pyroxenes from the corona of the inclusion.

Oxide	Silica	High-Ca Px		Low-Ca Px	
Na_2O	b.d.	0.39	0.39	b.d.	b.d.
MgO	b.d.	17.1	19.4	30.8	31.0
Al_2O_3	b.d.	0.20	0.34	0.06	0.03
SiO_2	101.7	53.9	54.3	57.9	56.1
CaO	b.d.	22.0	17.5	1.84	0.85
TiO_2	b.d.	0.05	0.11	b.d.	b.d.
Cr_2O_3	b.d.	0.62	0.49	0.05	0.06
MnO	b.d.	0.22	0.20	0.47	0.51
FeO	0.27	5.80	7.40	10.4	11.7
Total	101.97	100.28	100.13	101.52	100.85
En	–	9.0	11.5	15.4	16.9
Wo	–	43.7	34.8	3.5	1.6

b.d. below detection

Silica inclusion

While studying the Tatum chondrite, a conspicuous silica inclusion with a well-developed pyroxene corona was discovered (Fig. 1). Parts of this inclusion are present in both polished thin section UNM 684 and in the TCU section, which were made from adjacent cuts through the meteorite. After discovery of the clast in thin section, five additional sections, now in the Monnig collection, were made from other pieces of Tatum but non contain silica inclusions.

Description

The core of the inclusion measures 870 by 630 μm and is largely composed of nearly pure silica which contains only minor FeO (Table 1). The specific polymorph of silica (e.g., cristobalite, tridymite) was not determined, due to lack of material for X-ray diffraction studies. The core has experienced extensive fracturing during terrestrial residence and hydrated iron oxides fill these fractures. Most of the core fragments are less than 50 μm in diameter (Fig. 1) and have low birefringence. Several show parallel twinning and one mosaic patch shows two parallel twin directions at 90°. Adjacent fragments up to 200 μm in diameter often show optical continuity. Included within the silica core are small (up to 75 μm long), isolated, anhedral patches of both high- and low-Ca pyroxene, which constitute less than 5% of the silica core volume (Fig. 2). In one case, high-Ca pyroxene is observed rimming low-Ca pyroxene. In the TCU section, two veins of pyroxene up to 500 μm in length and 2–10 μm in width are observed cross-cutting the silica core and connecting on at least one end with the pyroxene corona. The detachment of the TCU section from the glass slide made it impossible to study these veins in detail, and they are not observed in PTS UNM 684.

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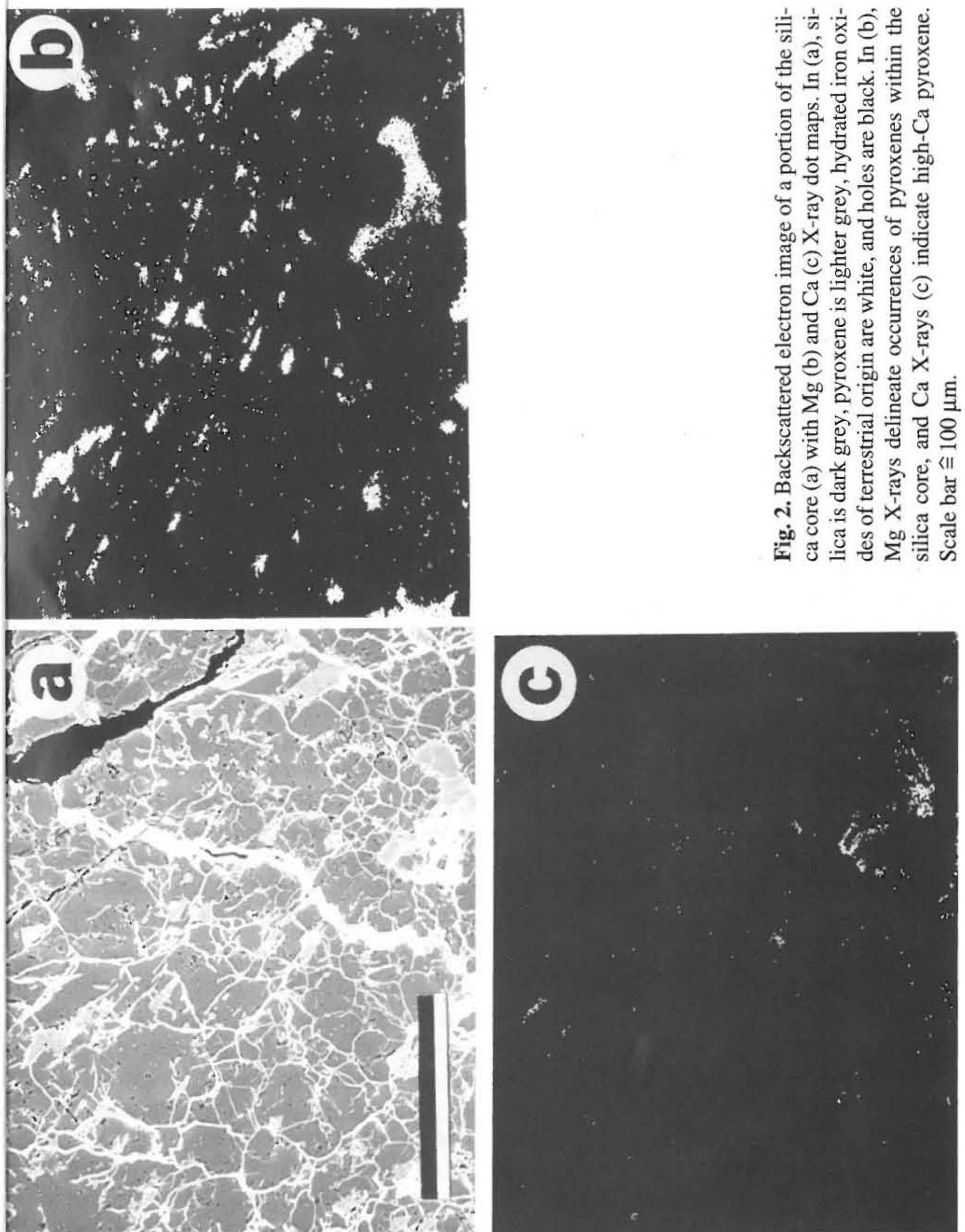

Fig. 2. Backscattered electron image of a portion of the silica core (a) with Mg (b) and Ca (c) X-ray dot maps. In (a), silica is dark grey, pyroxene is lighter grey, hydrated iron oxides of terrestrial origin are white, and holes are black. In (b), Mg X-rays delineate occurrences of pyroxenes within the silica core, and Ca X-rays (c) indicate high-Ca pyroxene. Scale bar ≙ 100 µm.

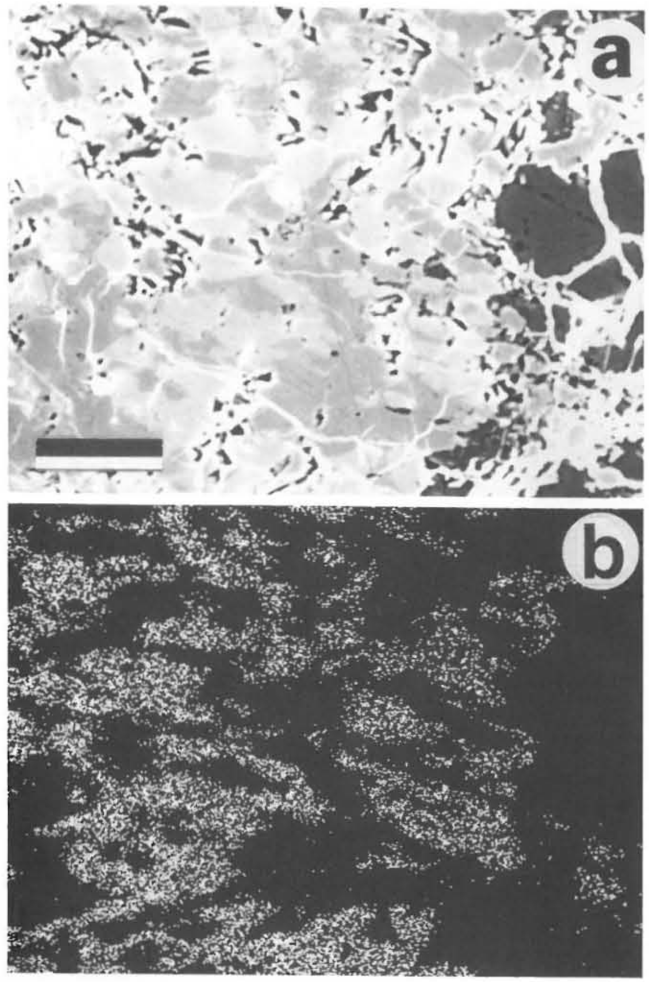

Fig. 3. Backscattered electron image of the pyroxene corona (a). Light grey is high-Ca pyroxene, medium grey is low-Ca is pyroxene, and dark grey at the right edge of the image is silica within the core of the inclusion. Weathering veins (white) and holes (black) are also visible. High- and low-Ca pyroxenes are intergrown in an irregular pattern. No pyroxenes of intermediate composition (e.g., pigeonite) are visible. High- and low-Ca pyroxene are readily distinguished in a Ca X-ray dot map (b). Scale bar ≘ 20 μm.

The boundary between the silica core and the pyroxene corona is irregular. Numerous embayments of pyroxene into the silica are present, and it is possible that some of the isolated pyroxenes in the core volume are embayments in the third dimension or cross-sections of pyroxene veins. The corona is composed of radially oriented pyroxene crystals and averages 70 μm in width (Fig. 1). Imaging of the corona in back-scattered electrons and Ca X-rays (Fig. 3) reveals that low- and high-Ca pyroxenes are intergrown in irregular patches, suggesting that the two phases did not form by exsolution from a pigeonite precursor. The sharp outlines of the high-Ca pyroxene grains indicate that the corona does not contain pyroxenes of intermediate Ca content (e.g., pigeonite). We estimate that low- and high-Ca pyroxene are present in subequal amounts. Microprobe analyses of randomly selected spots in the pyroxene corona range from approximately $Fs_5En_{50}Wo_{45}$ to $Fs_{18}En_{82}Wo_1$; representative analyses of high- and low-Ca pyroxene are given in Table 1. Low-Ca pyroxenes in the coronae have compositions within the range of those reported for the host. Fe, Ni metal and troilite are not present in the inclusion, although extensive terrestrial weathering is indicated by pockets and veins of hydrated iron oxides, as well as numerous pits.

Surrounding the radial pyroxene corona is a poorly defined halo of randomly oriented crystals of pyroxene and olivine (Fig. 1), whose compositions are similar to those in other parts of the•Tatum host. Although there is a generally smaller grain size within the zone, in contrast to the larger grain size in the surrounding host, this distinction is not everywhere defined. Certainly no distinct boundary is observable.

Origin

Silica-bearing objects have now been documented in a number of ordinary chondrites (e.g., Brigham et al., 1986; Ehlmann et al., 1988; Ivanova et al., 1993). The origin of these inclusions has become a subject of increasing controversy, due in large part to the presence of free SiO_2 within olivine-normative rocks. Large grains of Si_2O with pyroxene coronae have been reported in several ordinary chondrites, including Nadiabondi (H5; Michel-Levy and Curien, 1965), Farmington (L5; Binns, 1967), Knyahinya (L5) and Lissa (L6; Brandstätter and Kurat, 1985), and ALH A76003 (L6; Olsen et al., 1981). One occurrence from within a chondrule was noted by Wlotzka and Fredriksson (1980). Models to explain the formation of free SiO_2 include nebular fractionation (Brigham et al., 1986; Krot and Wasson, 1994), oxidation of highly-reduced assemblages (Brandstätter and Kurat, 1985), liquid segregation within chondrules (Wlotzka and Fredriksson, 1980), and fractionation within a large magma body on a chondritic asteroid (Ruzicka and Boynton, 1992a, b). We shall consider three possible origins for the silica inclusion in Tatum.

Igneous processes on the parent body: Ruzicka and Boynton (1992b) argue that a variety of silica-rich objects could have originated by fractionation of a chondritic melt. Crystallization of a pyroxene-SiO_2 assemblage could occur on the pyroxene-SiO_2 cotetic in the olivine-plagioclase-SiO_2 ternary system. However, several lines of evidence suggest that the Tatum inclusion did not form by this mechanism. Fractionation of this type would require a lerge magma volume and, thus, the Tatum inclusion would have to be a fragment of a solidified, differentiated magma body. However, there is no evidence that the Tatum inclusion is a clast that was incorporated into the Tatum host as a fragment during impact gardening of the parent body. Furthermore, if the inclusion represented a fragment that had formed in a magma chamber by fractional crystallization of a chondritic melt, then associated differentiation products such as dunites and orthopyroxenites would be expected to occur; these have not been observed. Most importantly, the structure of the Tatum inclusion, as well as the mineralogy of the various layers, appear to rule out crystallization from a melt. Pyroxene and SiO_2 are not intimately intergrown in subequal proportions, as would be expected. Instead, the core of the inclusion in nearly pure SiO_2, with only minor (<5%) pyroxene. The corona is composed of low- and high-Ca pyroxene, with no SiO_2. For these reasons, we reject this model for the origin of the Tatum inclusion.

Origin of the entire inclusion in the nebula: A second possibility is that the entire inclusion formed in the solar nebula like a chondrule, with subsequent equilibration between pyroxenes in the corona of the inclusion and in the host meteorite having taken place on the parent body. However, many of the points made against an origin in a parent body magma chamber also argue against a solar nebula origin. A liquid of the inclusion bulk composition should, at some point in its history, co-crystallize SiO_2 and pyroxene. However, as pointed out above, such textures are not observed either in the core or the corona of the inclusion. Further, no distinct boundary is visible, as would be expected if the inclusion were some kind of a chondrule. Thus, we also reject the idea that the entire inclusion formed in the nebula.

Reaction of a nebaular, SiO_2-rich particle with the chondrite host on the H chondrite parent body: OLSEN et al. (1981) argue, on the basis of petrologic and oxygen isotopic evidence, that a silica-pyroxene inclusion in ALH A76003 formed by incorporation of an SiO_2-CaO-rich glass particle of unknown origin. During metamorphism, the SiO_2-rich particle is thought to have crystallized to cristobalite, and CaO diffused from the particle. Reaction between SiO_2, CaO and the host olivine formed the low- and high-Ca pyroxene in the corona. The appearance of the corona in Tatum, including the embayment of pyroxene into the SiO_2 core, are reminiscent of a reaction rim and support an origin of the inclusion by processes similar to the ones envoked by OLSEN et al. (1981), although significant deviations from their model are noted. It seems unlikely, for example, that the Tatum inclusion was originally a SiO_2-CaO-rich glass. As noted by OLSEN et al. (1981), all SiO_2-CaO-rich glasses in meteorites are also highly aluminous. Yet, Al_2O_3 is not a major component of either the SiO_2 core or the pyroxene corona of the Tatum inclusion. Furthermore, BRIGHAM et al. (1986) noted that SiO_2-rich objects in unequilibrated ordinary chondrites, which could be similar to the precursor of the Taum inclusion, are poor in CaO. Finally, the texture of the Tatum inclusion does not suggest that it formed by devitrification.

We therefore propose that the original inclusion that formed in the nebula and was incorporated into the Tatum host during accretion and prior to peak metamorphism, consisted of nearly pure SiO_2. During metamorphis, the SiO_2 inclusion reacted with the host to form the pyroxene corona. Apparently, FeO, MgO and CaO were derived from the host. FeO and MgO can be readily supplied by the abundant olivine in the host meteorite, but the source of the CaO is less certain, as that oxide is always associated with Al_2O_3 in plagioclase. Thus, the detailed nature of the reaction between silica and the host chondrite remains uncertain.

An additional problem is related to the temperature at which a reaction between silica and olivine to form the pyroxene corona would take place. The similar inclusion described by OLSEN et al. (1981) occurs in ALH A76003 which is a petrologic type 6 L chondrite. Type 6 chondrites are though to have been heated to peak metamorphic temperatures of ~800–950 °C (Dodd, 1981), at which the proposed reactions should proceed readily. However, Tatum is a petrologic type 4 chondrite, contains unequilibrated (heterogeneous) pyroxenes and was probably heated to only ~600 °C (Dodd, 1981). It is unclear whether the reactions between silica and the host chondrite would take place at these relatively low temperatures. However, Brigham et al. (1986) suggest that these reactions take place at relatively low temperatures: they note that simila reactions occurred in the L3.7 chondrite

Mezö-Madaras which was heated to <600 °C. The high-Ca pyroxenes in this meteorite occur at the edge of the inclusions, similar to the pyroxene corona in Tatum, suggesting that the reaction proceeds predominantly at the SiO_2-host interface. One could, of course, argue that the Tatum inclusion is a foreign clast which experienced a more severe thermal history in another environment, after which it was incorporated into Tatum, for example, by impact processes on the parent body. However, there is no supporting evidence of brecciation and we consider this an *ad hoc* explanation.

Acknowledgements

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Buchbesprechung

GEYER, O. F.: Die Südalpen zwischen Gardasee und Friaul. Trentino, Veronese, Vicento, Bellunese. „Sammlung geologischer Führer, Bd. 86". 576 Seiten, 175 Abbildungen, 4 Tabellen. Gebrüder Borntröger, Berlin-Stuttgart 1993. Preis: Broschur 76 DM. ISBN 3-443-15060-8

Die traditionsreiche Reihe der geologischen Führer wird fortgesetzt. Der von O. F. Geyer vorgelegte Band beschreibt einen Teil der Alpen, der wohl mit zu den schönsten zu zählen ist; das Gebiet zwischen Gardasee im Westen, Belluno im Osten sowie Bozen im Norden und Verona im Süden.

Nach einer Einführung in die Landschaften wird der Geologische Rahmen abgesteckt. Ein dritter großer Abschnitt behandelt die geologische Geschichte vom Permo-Mesozoikum bis zu den jüngsten Ablagerungen des Holozäns.

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Jedem Studierenden und geologisch Interessierten, der in diesem Gebiet arbeitet oder es bereist, wird dieser Führer eine lehrreiche Lektüre sein.

N. ILLNER, Jena