Reports

Microtektites and Tektites: A Chemical Comparison

Abstract. *Elemental abundance (20 trace elements, 3 major elements) comparisons for Ivory Coast microtektites and Australasian microtektites indicate that there are distinct chemical similarities between microtektites and nearby tektites. Several trace element abundances in microtektites are quite different from those observed in Apollo 11 and Apollo 12 samples.*

Small (< 1 mm) glassy objects have been found in sediment cores near the coast of Australia and Africa (*1*). On the basis of geographical location, age of deposition, physical properties, and abundance trends of major elements, it has been concluded that these objects are microtektites (*2*). We have analyzed two groups of microtektites for 20 trace elements and 3 major elements. Our results confirm that the microtektites are definitely related to the associated tektite-strewn fields. The unique elemental abundances which distinguish Ivory Coast tektites from australites [except the HNa/K group (*3*)] also distinguish the Ivory Coast microtektites from Australasian microtektites.

The identification of microtektites has had an important bearing on hypotheses for tektite origins. The total mass of tektite material in the Australasian-strewn field alone has been revised upward to 10^{10} kg (*2*). The major element compositions of microtektites greatly extend the normal composition range of tektites. For example, the SiO_2 abundance of australites commonly ranges from 64 to 80 percent, whereas the SiO_2 abundance of the Australasian "normal" microtektites extends to 59 percent and that of the "bottle green" microtektites to less than 50 percent. Chapman and Scheiber (*3*) postulated that the small size of microtektites was caused by rapid ablation of low-viscosity, low-silica glass.

Both major and trace element abundances of Apollo 11 lunar rocks differ from those of tektites and microtektites (*2–4*) (Fig. 1). On the basis of major element abundances, O'Keefe (*5*) has concluded that the glassy portion of Apollo 12 lunar sample 12013 satisfies all the chemical criteria for a tektite. Some discrepancies in trace element abundances (Zr, Y) were noted. O'Keefe suggested that the importance of these discrepancies could be clarified by a trace element comparison of sample 12013 and microtektites (*5*). The trace element data obtained in this research make possible such a comparison (Table 1). Despite the preliminary nature of the Apollo 12 data (*6*), it is clear that sample 12013 has some trace element abundances and ratios that are distinctly different from those of the microtektites (for example, Cr, Ba, and Yb).

The samples analyzed were a composite group of Australasian microtektites (five specimens totaling 1.5 mg) and a composite group of Ivory Coast microtektites (ten specimens totaling 1.3 mg). The composites were made up of "normal" microtektites as opposed to the "bottle green" type (*2*).

The analyses were made by instrumental neutron activation analysis (*7*). Gamma-ray spectroscopy with Ge(Li) semiconductor detectors was used to obtain the reported data (Table 1). Several irradiations were made, varying from 30 minutes to 12 hours. An indochinite [T-3991 (*8*)] was assayed independently and then used as a compo-

Table 1. Elemental abundance data. For microtektites Rb, Ba, Nd, Gd, and Tb data are accurate to ± 10 to 20 percent; for all other elements data are accurate to ± 3 to 10 percent; T-3991 data are accurate to ± 1 to 5 percent. A minus sign (—) indicates data not available. An asterisk (*) indicates data graphed in (*3*). Values in parentheses for sample T-3991 are from (*8*) and (*10*). Typical tektite data are from (*3, 8, 10–12*).

Element	Australasian				Ivory Coast		Apollo 12 No. 12013 (*6*)
	Micro-tektites (composite of five)	Tektites			Micro-tektites (composite of ten)	Tektites	
		"Normal" group	Indochinite T-3991	"HNa/K" group			
Na (%)	0.45	0.97– 1.16	1.07 (1.08)	2.04– 2.90	1.68	1.33– 1.52	0.51
K (%)	1.42	1.93– 2.17	2.06 (2.17)	0.75– 0.93	1.66	1.41– 1.58	1.66
Rb (ppm)	66	62 –144	125 (129)	19.7 – 25.4	70	59 – 75	33
Cs (ppm)	2.3	2 – 4	6.0	—	2.9	—	—
Sc (ppm)	11.9	8.2 – 14	10.0	—	15.9	—	21
Cr (ppm)	81	72 –105	71	220 –385	230	175 –375	1050
Mn (ppm)	820	670 –830	735 (700)	710 –890	600	530 –555	950
Fe (%)	3.26	3.54– 3.98	3.41 (3.50)	4.31– 5.35	5.15	4.69– 4.97	7.80
Co (ppm)	9.9	11 – 14	25.2	41 – 68	51	19 – 26	13
Ba (ppm)	530	330 –425	440	300 –395	830	540 –680	2150
La (ppm)	40	37 – 60	37.8	*	28	*	—
Ce (ppm)	93	60 – 88	82.4	*	56	45.2	—
Nd (ppm)	36	22 – 35	37	*	37	24.9	—
Sm (ppm)	7.1	4.1 – 5.6	6.4	*	5.6	4.59	—
Eu (ppm)	1.37	1.1 – 1.5	1.18	*	1.28	1.13	—
Gd (ppm)	5.4	3.9 – 7.7	4.2	*	2.8	3.57	—
Tb (ppm)	0.9	0.6 – 1.0	0.74	*	0.9	*	—
Dy (ppm)	5.1	3.8 – 4.5	5.2	*	3.7	2.76	—
Yb (ppm)	2.2	1.6 – 2.6	2.0	*	1.3	1.68	20
Lu (ppm)	0.45	0.36	0.40	*	0.29	*	—
Zr (ppm)	—	285 –390	—	140 –170	—	120 –150	—
Hf (ppm)	6.4	3.7 – 5.0	7.1	—	3.8	—	—
Ta (ppm)	2.4	—	7.1	—	—	—	—
Th (ppm)	14.5	9.0 – 14.5	13.5	—	3.8	2.9	34.3

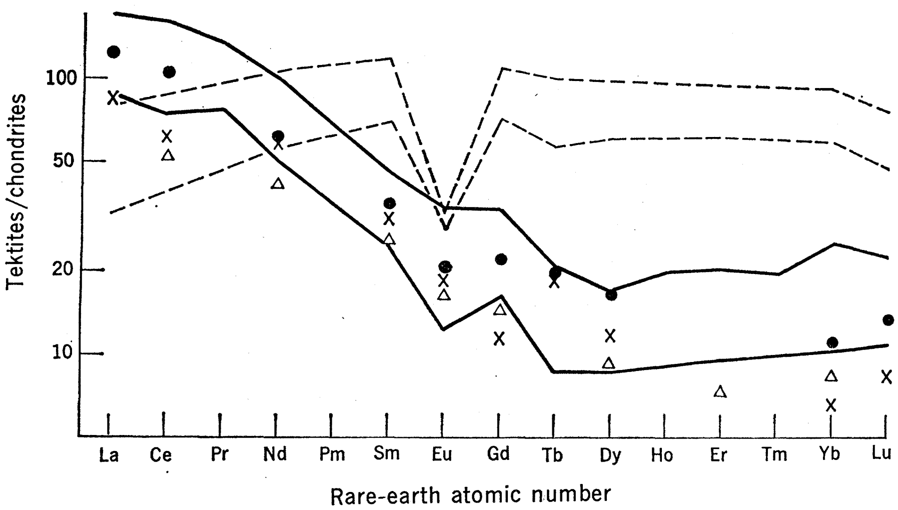

Fig. 1. Tektite and microtektite abundances of rare-earth elements as compared to a chondrite average (*13*). ●, Australasian microtektites; ×, Ivory Coast microtektites; △, Ivory Coast tektites. The solid lines indicate the range of abundances for four indochinites, one bediastite, two philippinites, one moldavite, seven australites, and two unidentified tektites (*10*, *12*, this work). Data for Ivory Coast tektites are from (*11*). Also shown for comparison are dotted lines indicating the normalized average chondrite values for Apollo 11 type A (upper) and type B (lower) rocks (*4*).

sition standard in order to minimize errors resulting from counting geometry. The accuracy of the standardization (± 5 percent) can be seen in Table 1 where our results are compared with literature data for sample T-3991.

A comparison of the neutron activation analyses of the microtektites with earlier electron probe data for Na, K, Fe, and Mn (*2*, *9*) indicates that the composite values differ from the reported averages, but the trends are the same. For example, the Na/K ratio is about 1 for Ivory Coast microtektites and less than 0.5 for the Australasian microtektites. Iron is more abundant in the Ivory Coast microtektites than in the Australasian microtektites. The composite values given in Table 1 are within the range of individual microtektite analyses (*2*).

Several chemical characteristics distinguish Ivory Coast tektites from most Australasian tektites. For example, there are distinct differences in Na/K ratios and in the abundances of Fe, Cr, Th, and Zr (typical tektite abundances are in Table 1). These same differences are seen in the microtektites.

All Ivory Coast samples are distinctly richer in Cr. Cobalt is more abundant (~ factor of 5) in Ivory Coast microtektites than in Australasian microtektites. The Co abundances are not as different for the tektite samples. Chapman and Scheiber (*3*) have recognized an Australasian tektite group (HNa/K) which has some chemical similarities to Ivory Coast tektites. Our data indicate that these similarities extend to Ivory Coast microtektites (for example, Cr). The Co abundance in the Ivory Coast microtektites is in the range observed for the HNa/K tektites.

Zirconium abundances in Ivory Coast tektites have been observed to be ~ 0.5 of the australite Zr abundance (*10*). Similar data are not available for Hf but the microtektite data (Table 1) indicate that Hf abundances are relatively low in the Ivory Coast microtektites. A similar relationship between Zr and Hf is expected since these two elements have similar geochemical characteristics. Ivory Coast tektites are also characterized by low U and Th abundances. This difference for Th is quite marked in the microtektite data.

The abundances of rare-earth elements (atomic number = 57 to 71) in tektites are compared with rare-earth abundances in chondrites in Fig. 1. Except for Ivory Coast samples and HNa/K australites, all tektites analyzed have abundances of rare-earth elements within the narrow range indicated. Considering the wide geographical range of the 17 tektite samples, this is a remarkably narrow abundance range. The abundances of rare-earth elements in the Australasian microtektites are within this range. Ivory Coast tektites have some rare-element abundances that are below the lower limit for other tektites (Fig. 1) (*11*). This is particularly noticeable for the light rare-earth elements (La, Ce) and the heavy rare-earth elements (Yb, Lu). This feature is also observed for the HNa/K australites (*3*). Like the Ivory Coast tektite and the HNa/K australite abundances, the Ivory Coast microtektite abundances fall below the minimum line for La, Ce, Yb, and Lu (Fig. 1). The significance of the chemical similarities of the Australasian HNa/K tektites to the Ivory Coast tektites and microtektites is not yet understood.

The close correspondence of elemental abundances involving elements with different geochemical characteristics indicates that the microtektites are directly related to their adjacent strewn field. Comparison of elemental abundances in microtektites with an Apollo 12 rock of similar SiO_2 abundance (sample 12013) indicates several distinct differences. If the reported Yb abundance for sample 12013 (*6*) is correct, then the rare-earth data are a serious obstacle to the identification of this lunar sample as tektite material.

Note added in proof: Extensive element abundance data have recently been published for Apollo 12 rock 12013 (*14*). Although rock 12013 is quite heterogeneous, the high Ba, Cr, and rare-earth (for example, Yb) abundances shown in Table 1 have been confirmed as primary features of this rock. These abundances plus a Eu depletion indicate that rock 12013 has trace element abundances quite different from those of the microtektites discussed in this report.

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microtektites (ppm): Fe = 62,000; Mn = 770; Na = 14,000; K = 14,600.
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Hyalinea baltica and the Plio-Pleistocene Boundary in the Caribbean Sea

Abstract. *The foraminifer* Hyalinea baltica *is found for the first time in sediments from the western Caribbean Sea. Its relationship to the Plio-Pleistocene boundary and to other criteria used to define this boundary is examined, with the result that a strict adherence to the classical definition is urged.*

Gignoux (*1, 2*) defined his Calabrian stage on the basis of the first appearance of northern marine invertebrates, including the pelecypod *Arctica islandica*, in late Cenozoic sections of southern Italy and Sicily. This stage, assigned by Gignoux to the Pliocene, was reassigned to the Pleistocene by the XVIIIth International Geological Congress (London, 1948). Therefore, the base of the Calabrian is, by definition, the Plio-Pleistocene boundary (*3*). While Gignoux placed the base of the Calabrian at the first appearance of *A. islandica*, Ruggieri and Selli (*4*) subsequently suggested that it be placed at the first appearance of the foraminifera *Hyalinea baltica*, which they found to occur above the first appearance of *A. islandica*. Emiliani *et al.* (*5*) ran paleotemperature analyses on pelagic and benthonic foraminifera and benthic mollusks from the continuous Plio-Pleistocene section at Le Castella, Calabria, southern Italy. In this section, which can be closely correlated with the section at Santa Maria di Cantanzaro (one of Gignoux's type sections) by means of the benthic microfauna, the base of the Pleistocene is clearly marked by the first appearance of *H. baltica*. (Fig. 1).

In other areas, different criteria have been used to define the Plio-Pleistocene boundary. Arrhenius (*6*) defined the boundary on the basis of a sharp increase in calcium carbonate content in cores recovered from the eastern Pacific by the Swedish Deep-Sea Expedition of 1947–1948. Riedel (*7*) correlated the level of extinction of two radiolarians, *Pterocanium prismatium* and *Eucyrtidium elongatum peregrinum*, in tropical Pacific cores with Arrhenius' boundary. Subsequently, Riedel *et al.* (*8*) used only the extinction of *P. prismatium* in defining the boundary. Ericson *et al.* (*9*) defined the Plio-Pleistocene boundary by using the following events in selected Atlantic deep-sea cores; extinction of *Discoaster challengeri, Discoaster pentaradiatus*, and *Discoaster brouweri*; change in coiling direction of *Globorotalia menardii* s.l. from predominantly dextral to predominantly sinistral; appearance of *Globorotalia truncatulinoides* in abundance; extinction of *Globigerinoides fistulosus*; reduction of the *G. menardii* group to a single, relatively uniform race; and an increase in size of *G. menardii*. Later, Ericson *et al.* (*10*) estimated this boundary to be 1.5×10^6 years. This boundary is believed by some to correlate roughly with that of Riedel (*7*) and Riedel *et al.* (*8*). Harrison and Funnel (*11*) related the last occurrence of *P. prismatium* to the Matuyama/Brunhes paleomagnetic reversal, correlated this with the extinction of discoasters in other Pacific cores, and dated it at 0.7×10^6 years.

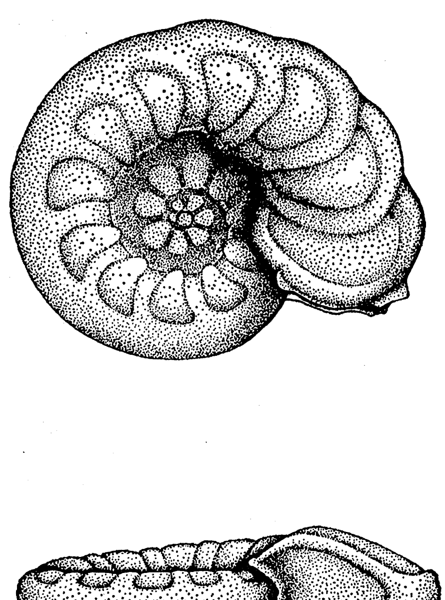

Fig. 1. *Hyalinea baltica* (Schroeter), side view and apertural view (× 150); 2560-cm level in the Submarex core.

Hays (*12*) recognized the boundary between the lower two of four faunal radiolarian zones in deep-sea cores from the Antarctic, marked by a change from red clay below to diatom ooze above, and correlated it with the Plio-Pleistocene boundary of Ericson *et al.* (*9*). Subsequently Opdyke *et al.* (*13*) related the radiolarian zones to paleomagnetic stratigraphy and found the boundary to coincide with the base of the Olduvai Event (1.9×10^6 years).

Berggren *et al.* (*14*) placed the Plio-Pleistocene boundary in a core from the south-central North Atlantic at the first evolutionary appearance of *Globorotalia truncatulinoides* from its immediate ancestor *G. tosaensis*. This boundary was found paleomagnetically to lie within the upper part of the Olduvai Event (1.85×10^6 years), and was correlated with the N21/N22 boundary of Banner and Blow (*15*) from the type Calabrian at Santa Maria di Cantanzaro. Berggren *et al.* (*14*) also suggested that the observed pronounced increase of *Globigerina inflata* and the general decrease and local disappearance of *Pulleniatina obliquiloculata* and *Sphaeroidinella dehiscens* lie within the Jaramillo Normal Event, dated at about 0.9×10^6 years, and correlated these events with the onset of glacial Pleistocene.

Wray and Ellis (*16*) noted that *D. pentaradiatus, D. surculus*, and *"D. variabilis"* (= *D. extensus*) all became extinct at about the same stratigraphic level off the Louisiana coast, while *D. brouweri* persisted longer. Akers (*17*) noted that *D. surculus* and *D. pentaradiatus* became extinct at about the same level as *Globoquadrina altispira*