much less liquid in the underlying peridotite than in the eclogite. The melting interval of hydrous eclogite or peridotite begins to trend almost parallel with the dry melting intervals at higher pressures (Fig. 1), and it is conceivable that at depth, where the temperature gradient is less, the geotherm may pass through the solidus into the subsolidus region.

Where peridotite is present in the upper mantle between 60 and 100 km or deeper, the instability of hornblende and the small proportion of phlogopite permitted by potassium abundances suggest that there may be an interstitial, hydrous pore fluid (Fig. 1). This fluid may contain a high proportion of elements not readily accommodated in the peridotite minerals, including K, U, and Th, the elements important in the thermal budget of the earth. Where eclogite occurs in the upper mantle below 50 km, the same elements may be concentrated in interstitial silicate magma. The quantity, composition, distribution, and migration of such pore fluids and interstitial magmas are important for major geological processes (*20*).

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7 May 1970

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Zircon and Chromite Crystals in a Muong Nong–Type Tektite

Abstract. *Chromite, zircon, and quartz crystals (identified by x-ray diffraction) have been recovered from a 2.07-gram sample of Muong Nong–type tektite. The absence of eskolaite* (Cr_2O_3) *and baddeleyite* (ZrO_2) *supports a previous conclusion that Muong Nong–type tektites were not heated as intensely as other tektite groups. X-ray asterism studies indicate that the crystals are shocked, which supports an impact origin. The presence of chromite and zircon together suggests that the Muong Nong–type tektite was produced from sedimentary material.*

During the investigation of the chemical variation within a Muong Nong–type (layered) tektite from Indochina, several crystalline inclusions, identified as chromite and zircon, were discovered. The discovery was not entirely unexpected, however, since previous work had indicated that the Muong Nong–type tektites were formed at lower temperatures than the splash-form types were and thus provide the logical place to search for minerals included in tektites (*1*). The minerals described in this report are believed to be relict and are therefore of obvious importance in indicating the nature of the parent material from which and the process by which the tektite was formed.

The chromite and zircon inclusions were discovered by crushing and sieving a 5.4-g sample of Muong Nong–type tektite. The fraction consisting of particles 110 to 149 μm in size (2.07 g) was then separated into 14 fractions based on specific gravity by use of heavy liquids (Bromoform and *N,N*-dimethyl formamide). Microscopic examination of each fraction revealed that many of the grains in the heavier fractions (specific gravity, 2.42 to 2.75) contain crystalline inclusions that were identified as zircon and chromite by x-ray diffraction. During further investigations, quartz and possibly coesite were identified by x-ray diffraction in frothy grains from the lightest fractions.

Microprobe analysis of several grains from each specific gravity fraction showed that the tektite has a wide range in composition (approximately 64 to 80 percent SiO_2), but its average composition is similar to that of other previously analyzed Muong Nong–type tektites (*2*). A thin section from the tektite shows highly contorted flow lines and numerous frothy and subangular lechatelierite particles, as well as a layered structure that is also evident in the hand specimen.

All of the mineral inclusions were completely surrounded by glass. Two chromite crystals were recovered; they are opaque and have a bronze color and submetallic luster. One is an octahedral crystal about 75 μm in width (Fig. 1); the other is an irregular grain (56 by 87 μm). These crystals were identified from x-ray diffraction patterns obtained with a Debye-Scherrer camera. Fourteen lines were present and all match lines for chromite. No eskolaite (Cr_2O_3) lines were observed. The composition of one of the chromite crystals was determined by electron microprobe analysis (Table 1). The grain containing the chromite crystal was mounted in epoxy, ground down to expose the crystal, and then polished. Nine chromites of known compositions were used for standards. The silica content of the chromite inclusion is rather high (average, ~ 2 percent) and variable (increasing toward the edges); otherwise the grain was fairly homogeneous, and the chromite-glass interface seemed to be rather sharp. Unfortunately, the grain was lost in an attempt to polish down to the maximum diameter of the chromite crystal; therefore no spectrometer traces or counts across the interface are available.

Approximately 15 zircon crystals were recovered. The largest dimension for each crystal is between 60 and 100 μm. They are generally white and opaque—although one euhedral crystal is partially translucent with an opalescent appearance. They vary in shape from euhedral, doubly terminated crystals to rounded grains and to irregular but rounded grains (Fig. 2). X-ray diffraction patterns were obtained for five different grains. Approximately 25 lines were observed for each pattern;

all of them match zircon lines. No lines for baddeleyite (ZrO_2) were observed.

Elemental scans of two zircon crystals indicated the presence of large amounts of Zr and Si, small amounts of Al, Fe, and Ca, and trace amounts of Ti and Hf. Semiquantitative analyses of three zircons (one euhedral crystal, one rounded grain, and one irregular rounded grain) were performed with the electron microprobe (Table 1). Quartz and zirconia were used as standards to determine the amount of Si and Zr, respectively. Glass standards were used to determine the Al, Fe, and Ca content. The zircons were fairly homogeneous and all three have approximately the same composition.

Scanning electron beam photographs of the zircon crystals also show that the crystals are homogeneous with regard to Zr, Si, Al, and Hf and that the boundaries are sharp (Fig. 2). Spectrometer traces of Zr and Si show that the zircons are fairly homogeneous and that the zircon-glass interface is sharp. Neither the scanning electron beam photographs nor the spectrometer traces show the presence of ZrO_2 (baddeleyite).

One transparent, weakly birefringent area in the thin section was shown by microprobe analysis to be nearly pure SiO_2 and may be a relict quartz grain. Quartz was identified from an x-ray diffraction pattern obtained from some frothy glassy particles separated from the fraction with a specific gravity of less than 2.198. Eleven lines were observed; ten of these lines match those given for quartz (American Society for Testing and Materials 5-0490). However, one line, with a *d*-spacing of 2.76 Å, did not match any line for quartz but does closely match the third most intense line for coesite (2.77 Å). During further examination of the x-ray pattern, a very faint line with a *d*-spacing of 3.08 Å was observed. This is close to the most intense line for coesite (3.098 Å). The second most intense line for coesite (3.432 Å), if present, is masked by the most intense line for quartz (3.43 Å). Therefore, coesite is probably present in the sample, but its identification is not well established. However, coesite has been previously identified in similar particles from other Muong Nong–type tektites (*3*).

Crystalline inclusions in tektites are extremely rare. Metallic spherules [kamacite and iron phosphide (?) of probable meteoritic origin] have been reported in some Australasian tektites (*4*). Magnetite spherules (with associated iron and wüstite) that probably exsolved from the tektite glass, have been reported by Kleinmann (*5*). Coesite has been described by Walter (*3*) in a Muong Nong–type tektite, and baddeleyite has been found in the Martha's Vineyard tektite and a Georgia tektite (*6*). However, prior to this discovery the only apparently relict mineral reported in a tektite was quartz, which was identified in Muong Nong–type tektites by Barnes (*7*) and Walter (*3*).

Clarke and Wosinski (*6*) and King (*6*) consider the presence of baddeleyite in tektites as additional evidence of the impact origin of tektites because of El Goresy's (*8*) work which showed that zircon tends to decompose into baddeleyite and silica as a result of impact. El Goresy states that the presence of baddeleyite in impact glasses is indicative of a very high temperature of fusion of the original rock containing zircon. Experimental work on the system ZrO_2-SiO_2 indicates that zircon breaks down at 1775°C under atmospheric pressure (*9*). Kirby (*10*) reports 1900°C as the breakdown temperature for zircon.

Table 1. Chemical composition of chromite and zircon inclusions as determined by electron microprobe analysis; T, trace; N.D., not detected. Values are expressed in percentages.

Chromite		Zircon*	
Cr_2O_3	57.6	SiO_2	32
FeO	22.5	ZrO_2	59
Al_2O_3	7.0	TiO_2	T
MgO	10.0	Al_2O_3	2
SiO_2	2	FeO	1
TiO_2	0.5	MnO	N.D.
MnO	0.28	MgO	N.D.
		CaO	0.3
		ThO_2	N.D.
		P_2O_5	N.D.
		HfO_2	T
		Y_2O_3	N.D.

* Average of three analyses.

Chromite is a refractory mineral; however, Trojer has shown that chromite can break down to eskolaite (Cr_2O_3) in temperatures as low as 1200°C if heated in a highly acidic siliceous glass medium (see *11*, p. 540).

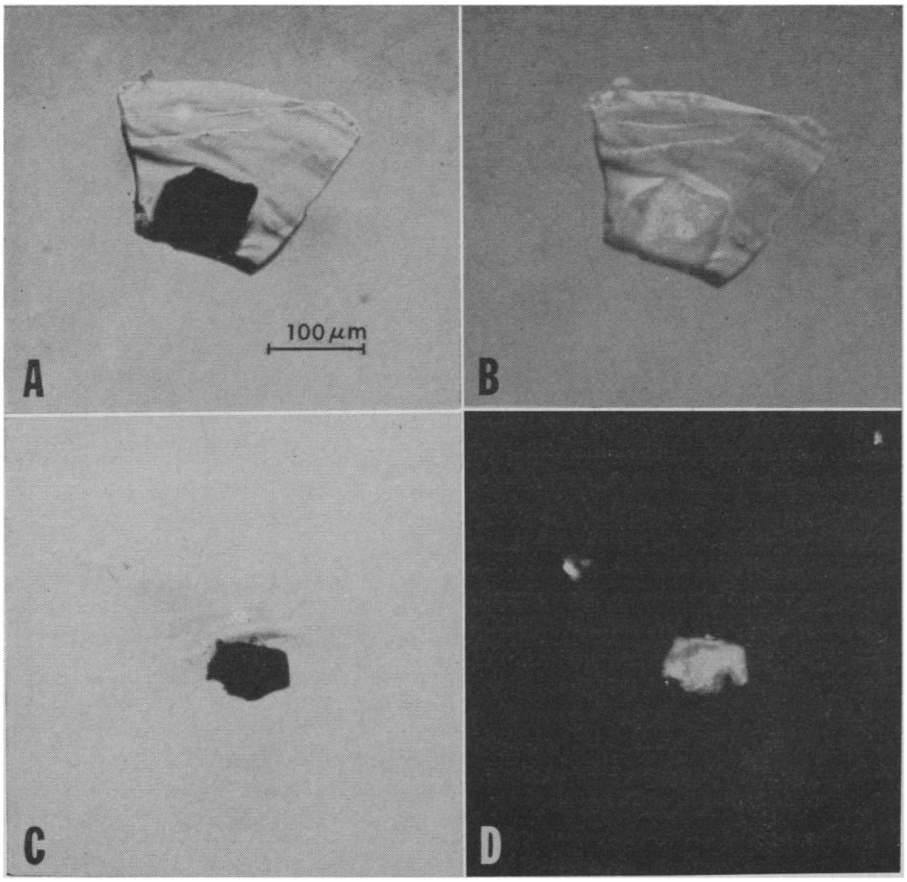

Fig. 1. Photomicrographs of chromite crystals. (A) Euhedral chromite crystal surrounded by tektite glass, in transmitted light. Note flow structure around the chromite crystal (opaque). (B) The same crystal as in (A) in transmitted and reflected light under crossed Nicols. Note octahedral shape of the crystal. (C) Second chromite crystal in transmitted light. (D) The same crystal as in (C) in reflected light and crossed Nicols. Note that a portion of the crystal near the lower right corner is apparently isotropic. The scale is the same for all the photomicrographs.

If baddeleyite described in the Martha's Vineyard and Georgia tektites is a decomposition product of zircon produced during the formation of the tektites, then the presence of zircon and absence of baddeleyite in the Muong Nong–type tektite indicates that this tektite was not heated as intensely as the Martha's Vineyard and Georgia tektites. This supports previous conclusions that the Muong Nong–type tektites were formed at lower temperatures than other tektite groups (*12*).

Nearly all investigators now agree that tektites were produced by impact. X-ray asterism studies of the chromite and zircon grains from the Muong Nong–type tektite support this conclusion. Shock damage can be detected by rotation of single-crystal grains in an x-ray beam (*13*). Shocked crystals produce diffraction patterns that range from spots to streaks to arcs, depending on the degree of shock. Of the mineral inclusions studied, all except one euhedral zircon grain produce continuous diffraction lines similar to those produced by a powder. The euhedral zircon crystal produced a diffraction pattern consisting of elongate spots. Unfortunately, no work has been done which would indicate the shock pressure needed to produce this degree of asterism in chromite and zircon crystals.

The chemical compositions of tektites have been compared to various terrestrial materials. Some investigators maintain that they most closely resemble acid igneous rocks, others note the similarities to sedimentary rocks and soils (*14*), while a third group feels that tektites are not similar to any terrestrial rock type (*15*). Several investigators have suggested a lunar impact origin for tektites (*16*).

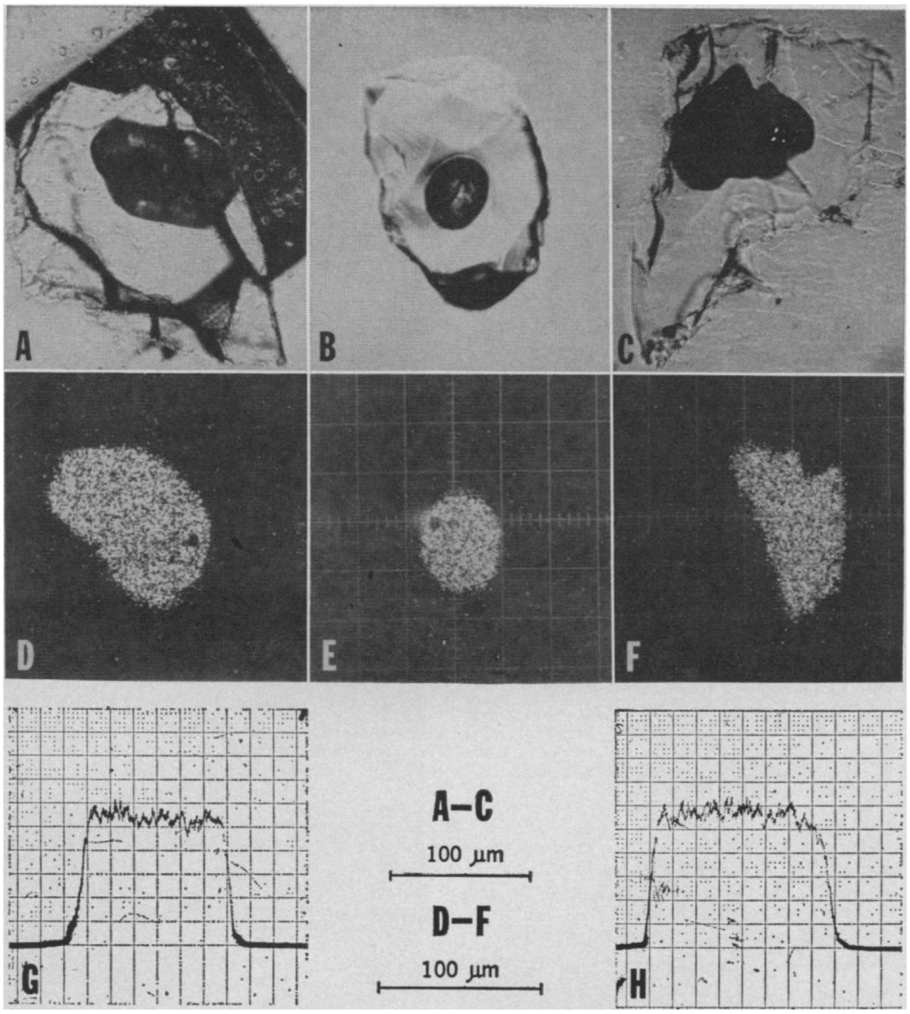

Fig. 2. Photomicrographs (A–C), electron microprobe scanning photographs for Zr (D–F), and Zr spectrometer traces (G and H) of three zircon crystals. (A) Photomicrograph of polished section in transmitted light showing outline of euhedral zircon crystal. The black area outside of the grain is epoxy burned by the electron beam. (B) Muong Nong–type tektite fragment containing a rounded zircon crystal. Transmitted light. (C) Polished section showing an irregular zircon grain. Transmitted light. Zirconium scanning photographs of (D) the euhedral zircon crystal shown in (A); (E) the rounded zircon crystal shown in (B); and (F) the irregular zircon grain shown in (C). Zirconium spectrometer trace (G) across the euhedral crystal shown in (A) and (H) across the irregular grain shown in (C).

The presence of chromite and zircon together indicates a sedimentary source material for the Muong Nong–type tektite. Chromite usually occurs in ultrabasic rocks, such as peridotites and serpentines derived from them. Although zircon has been described in basalts, it is more commonly found as an accessory of acidic igneous rocks such as granite, syenite, diorite, and others (*17*). Thus it seems unlikely that chromite and zircon would form together in a single igneous rock. On the other hand, zircon and chromite are resistant to chemical and mechanical erosion and are stable in sedimentary deposits. (It should be pointed out, however, that chromite does not commonly occur as a constituent of detrital sedimentary deposits.) Therefore, it seems likely that the source material of the Muong Nong–type tektite was a sedimentary material and not an igneous rock. This does not exclude a lunar origin for the tektite, however, since processes forming the lunar regolith tend to mix components from various rock types.

The subangular to rounded shapes of many of the inclusions, especially the zircon crystals shown in Fig. 2B, are also suggestive of a detrital sedimentary deposit. It may also be significant that both the zircon and chromite crystals are approximately the same size (Fig. 1) and have similar specific gravities (4.68 and 4.6, respectively), suggesting that the parent material was gravitationally sorted. This again points to a sedimentary material as the source material for the Muong Nong–type tektites.

A comparison of the chemical composition of the Muong Nong chromite with terrestrial, meteoritic, and lunar (from Apollo 12) chromites shows that it is more similar to terrestrial chromites. The Muong Nong chromite is in fact quite similar in composition to terrestrial chromites but has a higher MgO content than most meteoritic chromites. Although chromite was not found in Apollo 11 samples, it has been described in Apollo 12 samples (*18*). All the Apollo 12 chromites were found to have TiO_2 contents greater than 4 percent, whereas the Muong Nong chromite has a TiO_2 content of approximately 0.5 percent. Additional samples will be required, however, before it can be determined whether the Apollo 12 chromites are typical of lunar chromites.

The discovery of chromite and zircon crystals in a Muong Nong–type tektite increases the number of relict minerals now known to occur in tektites. The absence of any signs of decomposition of zircon or chromite to baddeleyite or eskolaite, respectively, supports previous observations which indicate that the Muong Nong–type tektites were less intensely heated than other tektite groups. X-ray asterism studies of the chromite and zircon crystals support an impact origin for the Muong Nong–type tektite. The presence of chromite and zircon together and the rounding of the crystals, along with evidence of sorting, all indicate that a sedimentary deposit is the source material for the Muong Nong–type tektite.

Note added in proof: After the above investigation was completed, corundum, rutile, and monazite, as well as quartz and zircon, have been tentatively identified by x-ray diffraction in another specimen of Muong Nong–type tektite from Indochina. These inclusions will be discussed in detail in a later publication.

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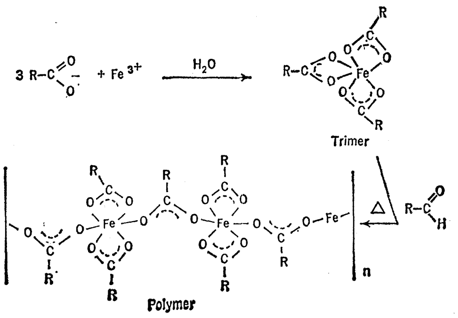
Water-Degradable Polymers for Controlled Release of Herbicides and Other Agents

Abstract. *A new class of polymeric substances that degrade in the presence of water are formed by the reaction of carboxylic acids with metal ions in the presence of an aldehyde catalyst. Possible uses may be found in agricultural chemicals, packaging, and medicine. Important antipollution aspects are present in many of these applications.*

We have found that water-degradable polymers can be formed by the addition of a carboxylic acid and a metal ion in the presence of an aldehyde catalyst. On exposure to water, these polymers depolymerize more or less slowly to release the original carboxylic acid and the hydrous metal oxide gel. The substance whose controlled release is sought may itself be a carboxylic acid, as in the herbicide 2,4-D (*1*), or the substance may be dissolved in a water-degradable polymer formed with any convenient carboxylic acid plus metal. In either case, the desired substance is released on contact with water at a controlled rate which can be varied from days to years.

Water-degradable polymers may have been prepared previously but without an appreciation for the water-degradability. In 1904, for example, Joannis (*2*) prepared a copper benzoate "salt" which did not crystallize well. Purposeful attempts to form polymers incorporating metals have not been very successful. Pitts and Hurley (*3*) have sought unsuccessfully to polymerize bidentate and other ligands with aluminum, cadmium, and nickel. To the best of our knowledge, then, these unique materials are described here for the first time.

The structures and molecular weights of these polymers have not yet been determined. The polymers are thermoplastic and are not cross-linked, as they dissolve wholly in organic solvents such as acetone and methyl ethyl ketone. A proposed structure is:



On heating, the sticky resin is changed into a hard, glassy material which breaks with conchoidal fracture. Metals other than iron which yield these polymers include cobalt, copper, nickel, titanium, manganese, and chromium. The nature of the R-group on the aldehyde is not critical. However, it has been found that if the R-group on the aldehyde is similar to the R-group on the acid, the reaction proceeds more readily.

For example, 2-4-D was polymerized with ion as follows. To an aqueous solution of 3 moles of the amine salt of 2,4-D, sufficient nitric acid was added to lower the *p*H of the solution to about 4. An aqueous solution containing 1 mole of ferric nitrate and 2 ml of concentrated cinnamic aldehyde, in which some nitric acid was included to assist the dissolution of ferric nitrate, was also prepared. The ferric nitrate solution was added to the amine solution quickly after the *p*H of 4 was reached to preclude precipitation of 2,4-D. The addition of the ferric nitrate solution