Cretaceous-Tertiary Events and the Caribbean Caper

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ABSTRACT

Over the past year or so a number of impact sites have been proposed in the Caribbean region with ages approximating that of the Cretaceous-Tertiary boundary. Assuming that the paleontological record can also be accounted for, the presence of a large crater could be taken as lending credence to the argument that extinctions and impacts may be related. However, the available geologic information suggests that all sites proposed thus far for a K-T impact lack merit.

INTRODUCTION


"Inevitably, with most subjects there is also the silly season, usually of unpredictable duration and of an intensity correlated with the acceptance of the new idea. ... It included the proposal of ideas even more far-out than the original one.

The impact theory as a cause for extinctions of organisms, including the dinosaurs, at the K-T boundary was based on the reasonable interpretation of an excess of iridium at the K-T boundary as extraterrestrial (Alvarez et al., 1980). The original model proposed a giant dust cloud that blocked the Sun, stopping photosynthesis. This model was followed by others suggesting that an asteroid impact on a carbonate terrain vaporized the limestone, leading to a flux of carbon dioxide to the atmosphere and global warming (O'Keefe and Ahrens, 1988); that a comet traversing the atmosphere created nitrogen oxides, leading to acid rain (Prinn and Fegely, 1987); that the larger animals died in response to heat stress following cometary impact, while calcareous plankton were done in by cyanide poisoning (Hsu, 1980, 1981); and that trace elements in the asteroid led to cyanide poisoning of the biological food chain (Erickson and Dickson, 1987; Hsu et al., 1982). The paleontological record does not appear to support a single short-term event as measured in human terms of either terrestrial or extraterrestrial origin, a flaw shared by these corollaries as well as by the original hypothesis.

The relatively small number of dinosaur specimens in the geologic record complicates determination of the time of their extinction. Dinosaur species in western North America showed a rapid decline in number of species over the past 500 million years of the Late Cretaceous (Van Valen and Sloan, 1977), but detailed studies in Montana and North Dakota conclude that the record is not incompatible with a final, abrupt extinction event (Sheehan et al., 1991). Other nonmarine vertebrates in western North America show a geologically rapid but noncatastrophic change during the Late Cretaceous (Archibald and Bryant, 1990). Five extinction events in the fossil record of western Canada have been discovered under several metres of section both predating and postdating the K-T boundary as defined by the iridium anomaly (Sweat et al., 1990).

In a shallow-water marine K-T section in Antarctica, the large extinction occurred over a 30-50 m interval and preceded the planktonic extinctions (Zimmerman et al., 1989). In Tunisia and Texas planktonic foraminiferal extinctions occurred in a stepwise fashion over 1-4 m, or about 200,000 yr (Keller, 1989; Maclod and Keller, 1991). Benthic foraminifera are less affected than surface foraminifera, and nanofossilss show a longer period of transition than do the foraminifera.

In a seldom cited, generally overlooked, paper, Jaeger (1986) has made the most complete study of K-T extinctions known to us. Jaeger reasoned in painstaking detail all species of ammonites, belemnites, mollusks, bryozoans, brachiopods, echinoderms, microplankton, nanoplankton, ichthyosaurs, mesosaurs, pterosaurs, and dinosaurs. The tetrapods show a gradual stepwise pattern of extinctions, with few species remaining at the K-T boundary, most of them having become extinct well before the boundary. Many of the marine biotas passed through the K-T boundary intact, in many cases with more than 50% of the taxa of each family. Though the record does not appear to support instantaneous extinctions, iridium anomalies and quartz grains with microscopic dynamic deformation features suggest to some workers that there was, nevertheless, an asteroid impact at K-T boundary time that has been considered diagnostic of an impact, but recent studies have shown that iridium anomalies can be associated with present-day volcanic eruptions and that shocked minerals are associated with structures of terrestrial origin. Iridium enrichment comparable to that in K-T sections has been found in Hawaii (Zoller et al., 1983; Olsson et al., 1986), in the Antarctic (Koeberl, 1989), in Kamchatka (Pellissy and Vaganson, 1988), and on Rügen Island (Losin, 1989). The only iridium anomaly associated with known impact craters is from the Precambrian Acraman structure, South Australia (Goslin et al., 1989). Furthermore, microscopic dynamic deformation features in quartz grains are associated with terrestrial structures of volcanic, internal explosive, and high-strain-rate tectonic origin (Officer and Carter, 1999; Sage, 1978; Curie, 1969; Tona, 1985; Pagel et al., 1985; Carter, 1968; Steiner, 1972; Hopps and Dryden, 1958; Bunch, 1966; Carter et al., 1986, 1990; Heuberger et al., 1988; Maasch et al., 1981; Kramm et al., 1977; Storzer et al., 1971; Gratz and Kurat, 1988). Some of these structures have been presumed to be impact origin because of the presence of shocked minerals, although their structure is not compatible with that of known craters (Halls and Grieve, 1976; Hartung and Anderson, 1988).

Summing up, iridium anomalies are associated with present-day volcanic activity but are lacking in known impact structures (with one possible exception). Shock features are found in terrestrial structures of nonimpact or enigmatic origin. This suggests that impacts are not required to produce these features unless one makes the circular assumption that they are diagnostic of impacts.

Cretaceous-Tertiary Geologic Sections in the Caribbean

The search for the site of the proposed K-T asteroid impact has continued since the hypothesis was first proposed in 1980. Over the past year or so, particular attention has been placed on the Caribbean region. At least four possible Caribbean sites have been suggested, including the Colombian Basin, the Yucatan Peninsula, western Caribbean, and Haiti. A fifth site that has been suggested is the Manson structure in Iowa, some 200 km to the north. The geologic evidence that stimulated these various conjectures has

Caribbean Caper continued on p. 70
Cretaceous-Tertiary Events and the Caribbean Caper... 69

GeoVentures 1992... 71
GSA Forum... 75
Schiffries Appointed Advocate for Geosciences... 76
GSA Scholarships... 77
Call for Papers... 77
CSA Update... 85
Memorial Prerints... 86
Book Review... 87
Needed: Geological Books... 87
International Division
Sponsors GEOPALAS Program... 87
Meetings Calendar... 90
GSA Meetings... 90
Bulletin and Geology Contents... 90
Classifieds... 91

Caribbean Caper continued from p. 69

come from two sections, one in Cuba and the other in Haiti.

Western Cuba Section

Bolhor and Setz (1980) suggested that these layers represent a "impact blanket" which has been reported before, one is at considerable liberty to hypothesize what the impactor looked like. The "impact blanket" is a hard, weakly bedded, steeply inclined carbonate facies that weathers into the boulders to be of local or in situ weathering origin, represent an exfoliation process, a conclusion confirmed by other investigators (Dietz and McIlvaine, 1990; Robin Brett, Carl Bowin, personal communications; extensive field work by Meyerhoff). Haiti Section

The boundary layer in Haiti is characterized by palagonite alteration products, including brown glasses. Some of the black glass particles are solid glass particles that appear unaltered. The layer or, more appropriately, layers are not in an original depositional sequence and have a similar sequence of turbidity-current or gravity-flow origin. An analysis of 1-2 pb was reported for the cm layer, as well as a comparable anomaly in a mud layer above the layer (Maurazeau et al., 1985). Quartz grains amount to less than 0.01% of the total sample, but about half of them have microscopic dynamic deformation features in the form of single and multiple intersecting sets of planar elements (Iezzi et al., 1990; Lyons and Office, 1992).

These sections were originally interpreted as volcaniclastic sediments (Maurazeau et al., 1985) but have recently been interpreted as impact-generated deposits, the black glass particles being called tektites and the brown glasses being referred to as "clay altered tektites" (Hildebrand and Boynton, 1990; Iezzi et al., 1990; Iezzi, 1991; Kring and Boynton, 1991). Volcanic glass is known to be metasomatic, although unaltered volcanic glasses of Cretaceous (Byerly and Sinton, 1986; Gluskov and Halls, 1989), Triassic (Brew and Muffler, 1966), Carboniferous (Schmincke and Prittchard, 1978), and Jurassic (Hanitsch and Halls, 1989) age have been found. Over 95% of the Haitian section consists of palagonite and the red and yellow-orange clay and siltstone (Phillips and Lyon, 1992), characteristic volcanic glass decomposition products (Knutson, 1981; Helken and Wolhuet, 1985).

A striking characteristic of tektite and mudstone is that they are in their metabolic to an alteration (Izawa, 1979; O'Keefe, 1976; Glass, 1984). Even for the oldest alteration products, extending back for 35 Ma, the H2O content of the MOs are less than 0.02% (Glass, 1984).

Black glasses from brown glasses have two compositional types—siderophues with low CaO (0.95%) and high SiO2 (66.94%) and lighter plagioclase with high CaO (5.36%) and low SiO2 (62.13%) (Lyons and Office, 1992). Some of the brown glasses that nest inside others and are clearly diagenetic; others are hollon, probably because of dissolution of less transparent minerals in the presence of hydrothermal ground-water environment. An example of some brown glasses is contained in the In the brown glass, the evidence that these represent pseudo-morphs of tektites (Hildebrand and Boynton, 1990; Iezzi et al., 1990; Iezzi, 1991), despite the resistance of tektites to alteration. The unaltered black glasses, represent 19%-5% of the total deposit, are vesicular. Volcanic glasses are quite varied (Knutson, 1981; Wolhuet, 1985); tektites are not. With a few exceptions, such as the large globules of bubbles and vesicles; bubbles and vesicles typically amount to only 0.1% of mass of tektites (1985). The boulders are of an anedetic-dacitic composition with an average SiO2 content of 62.6%-62.9% (Iezzi et al., 1990; Iezzi, 1991; 1992; Iezzi et al., 1991; Iezzi et al., 1991) and xenoliths typical of the other 1985. Clasts of black glasses also occur within accretionary lapilli, as do hydrated white clasts and shards, which have a composition different from that of the black glasses (Lyons and Office, 1992). An example of such a particle is shown in Figure 2. There is no counter to such features in the literature on tektites; on the other hand, volcanic glass and xenoliths with an accretionary lapilli texture can be associated with volcanic eruptions (Ray et al., 1979).

Rare vesicular yellow glasses particles averaging 230-240% CaO (1981; Lyon, 1992; Office, 1992) constitute less than 0.1% of the total sample and less than 3% of the glass fraction. These glasses have a holomorphic- matrix and have a distinctive flow pattern comparable to that in the abundant brown glass clasts (Lyons and Office, 1992). Tektites are usually devoid of crystals except for occasional refractory minerals, such as spinel (Iezzi et al., 1991). All of these features are typical of the yellow and black glasses represent mixing from an impactor, a remnant, or an impactor overlying a crust of agglutinative compositional, deagglomeration of the matrix and remelting of a melt formed by the magmatic alteration. If so, why should more than 99% of the mixture have the chemistry of dactyl or anhydrite, why do the yellow glasses have SiO2 contents clustering close to 48%, and why is there a sharp local gap in the range of 39%-57% SiO2 where one might expect strong mixing?

Few clasts are known to be metasomatic, although unaltered volcanic glasses of Cretaceous (Byerly and Sinton, 1986; Gluskov and Halls, 1989), Triassic (Brew and Muffler, 1966), Carboniferous (Schmincke and Prittchard, 1978), and Jurassic (Hanitsch and Halls, 1989) age have been found. Over 95% of the Haitian section consists of palagonite and the red and yellow-orange clasts (Phillips and Lyon, 1992), characteristic volcanic glass decomposition products (Knutson, 1981; Helken and Wolhuet, 1985).

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Tertiary transition occurs between the Mender Formation and the overlying Velasco Formation and that of the Laramide orogeny. The well-stratified geologic sections along the Brazos River, Texas (Keller, 1989) and at Bragg, Alabama (Jones et al., 1987) are similar to the Chichulub structure, although no such volcanogenic-tektite sequence of K-T impact origin has been described. It is generally agreed that bentonite is the result of alteration of a glassy, igneous rock, usually a tuff. Explanation of the bentonitic nodules which are characteristic of the bentonite formation and bentonite lenses is that their origin is secondary, being the result of some process of solution and subsequent deposition of their components in alkaline or carbonated waters. The fact that coniferalen minerals are found embedded in these nodules and have been coated by the same calcareous materials which compose the nodules points toward a secondary origin.4

On a regional scale the Paleocene formations around the Gulf of Mexico record widespread evidence of the Laramide orogeny. In eastern and southern Mexico, within and east of the present-day Sierra Madre ranges, the Paleocene common is represented by a thick, discontinuous, terrigenous, carbonate turbidite sequence referred to as the Chicontecpec Formation (Bussch and Arriola, 1978; Carri-Chapa, 1985). It consists of alternate beds of sandstones and shales with minor conglomeratic beds. In places the Chicontecpec Formation was deposited in deep paleocanyons along the flanks of which strata ranging in age from Tertiary to late Paleocene is known to have been deposited in the Chicontecpec Formation. The paleocanyons had depths of more than 300 m in some places. Away from the paleo-

Caribbean Sea 

As early as the middle Eocene time, uplift of the Sierra Madre ranges continued, with a new cycle of canyon cutting across the Sierra Madre Oriental. In one of these paleocanyons, middle Eocene sandstone and shale were found (from Tithonian through Paleocene (Carri-Chapa, 1985). The Chicontecpec Formation, like the Sabinas Formation, is also calcareous and has been studied widely.5

Colombian Basin, Caribbean Sea

The Colombian Basin of the western part of the Caribbean Sea was suggested as a possible impact site by Hildebrand and Boynton (1990). As shown in Figure 4, the basin topography has a semicircular aspect, and they suggested that it continues to the northwest to form a basin whose topographic feature of about 300 km diameter. Magnetic anomalies do not indicate a circular feature as is suggested by the east-west anomaly trend (Christofferson, 1977, 1976). Seismic reflection and refraction data show that the basement surface continues to deepen on approach to the South American continent (Kolla et al., 1984; Bowlden and Rosencrantz, 1986; Kolla et al., 1986). At nearby DDSF Sites 151, 152, and 153, the Sea Ridge there are several rows of magnetic mounds, of Upper Cretaceous sedimentary strata overlying the basement (Edgar et al., 1975). The free mode can be explained as a combination of seismic horizons to the western part of the Colombian Basin (Moore and Fahrig, 1976; Ludwig et al., 1975; Stofa et al., 1981; Bowlden and Rosencrantz, 1986; Kolla et al., 1986; and Hamilton et al., 1975, from Las Dortber-Doherty Geological Observatory). With conformable seismic horizons of Upper Cretaceous age overlying the basement, it is a stratigraphic possibility for the topography of the underying basement itself to have been formed by a later event of K-T age.

Chichulub Structure, Yucatan Peninsula

The Chichulub structure on the northwestern coast of the Yucatan Peninsula has also been suggested as an impact site (Hildebrand and Boynton, 1990). The Chichulub structure is a circular structure about 200 km in diameter, defined by magnetic and unestablished seismic anomalies suggestive of igneous materials at depth. A central zone 60 km in diameter, with short-wave-length magnetic anomalies approaching 1000 gammas, and a gravity high of 10-20 mgal, is surrounded by an outer zone 200 km in diameter, with low gravity anomalies of -50 gammas and a gravity low in turn surrounded by a weaker gravity high of 30-50 mgal, and then a gravity low that can be explained as a combination of seismic horizons to the western part of the Yucatan Peninsula. In particular, the Tizimin gravity anomaly 150 km west of Mérida and the Puerto Juárez magnetic anomaly on the northeastern coast (Lobo-Ramos, 1975).

Drilling has shown that the anomalies at Chichulub are related to an ane-
estatic body at a depth of 1200-2000 m. Well data (Fig. 4) across this part of the Yucatan Peninsula show a continuous sequence of Cretaceous limestones and dolomites (Lobo-Ramos, 1975; Weidle et al., 1980). The Yucatan No. 6, Chichulub No. 1, and Sacapux No. 1 weles, on the Chichulub structure, have Upper Cretaceous sedimentary strata overlying the anesite and the Yucatan No. 6 well penetrated the anesite and bottomed in Cretaceous limestone, dolomite, and anhydrite. Yucatan No. 2, 120 km southeast of the center of the Chichulub structure, shows a similar sequence of Upper Cretaceous sediments continuing from Maas-

Figure 3. Outline of presumed impact crater in the Colombian Basin from Hildebrand and Boynton (1990). Also shown are Deep Sea Drilling Project Sites 131, 152, and 133; seismic reflection profiles A (Moore and Fahrig, 1976), B (Ludwig et al., 1975), C (Stofa et al., 1981), D (Kolla et al., 1986), and E (unpublished profiles from Lamont-Doherty Geological Observatory). Bottom contour interval is 10 km.

Figure 4. Inferred correlations from well control along an east-west section in the northern part of the Yucatan Peninsula. The Chichulub structure is in left in the diagram. From Lobo-Ramos (1975).

60 km in diameter, with short-wave-length magnetic anomalies approaching 1000 gammas, and a gravity high of 10-20 mgal, is surrounded by an outer zone 200 km in diameter, with low gravity anomalies of -50 gammas and a gravity low in turn surrounded by a weaker gravity high of 30-50 mgal, and then a gravity low that can be explained as a combination of seismic horizons to the western part of the Yucatan Peninsula. In particular, the Tizimin gravity anomaly 150 km west of Mérida and the Puerto Juárez magnetic anomaly on the northeastern coast (Lobo-Ramos, 1975).
Caribbean Caper continued from p. 73

For an impact creating a crater 200 km in diameter, the excavation depth would be around 10 km (Melosh, 1989). If Chixulub had an impact origin and of K-T age, there would be no conformable sequence of Upper Cretaceous sediments at the bottom of the Yucatan No. 6 well would have been vaporized. There would be a gigantic crater, and the infilling debris would consist primarily of breccia from the underlying base- ment (Sharp et al., 1991).

The foraminiferal examination of a sample at 1000-1003 m depth in the Yucatan No. 6 yielded a dated a K-Paleo- cean age (Hildebrand et al., 1991). A sample of Late Cretaceous age at a depth of 200-300 m in the Yucatan No. 2 well is described as a bentonitic breccia with fragments of calcareous and dolomitic limestone. A sample of the tuff from the Yucatan No. 6 well is described as consisting mainly of igneous grains (clasts). There are also few xenoliths, and quartz grains in two of them have multiple intersecting sets of planes before the whole of the under- lying anhydrite is described as being just that, consisting of plagioclase feldspar, alkaline granite, and felsic intrusive rocks.

The Paleocene eocene determination of the core taken at 1000-1003 m in the Yucatan No. 6 led researchers (Sharp et al., 1991) to question the previous age assignment of marr directly overlying the Yucatan No. 1, Yucatan No. 6 wells and for the dolomite, limestone, and anhydrite strata above the Yucatan No. 6 well. The age of these sedimentary strata is crucial to the impact argument because the Yucatan No. 6 core did not result from an impact at K-T boundary time, these strata must necessarily be Paleocene.

Unfortunately most of the critical samples were destroyed in a warehouse fire; however, one of us (Meyersho) was a consultant to Petroleos Mexicanos (Pemex) at different times between 1965 and 1977 and was closely involved in the biostatigraphic correlation of the Yucatan wells. The aged, depocentres to various units given below are based on examinations of well cuttings and cores obtained from a blowout fire, as well as reports on Villagomez (1953).

In the Chixulub No. 1 well, the top of the Yucatan No. 1 core, which between a depth of about 1270 m and the top of the Cretaceous at 920 m. Thus, the Yucatan No. 1 core, and the conformable upper Cretaceous strata above the anhydrite. The age of the highest- placed unit occurs at the foot of the Yucatan No. 1 well, and the only age assigned before the Yucatan No. 6 is Cretaceous.

In addition to the generation and species listed previously in this paper (Lopez-Ramos, 1973), the following additional planktonic taxa were recovered (none of them range above the Cretaceous):

- Tropicsphaera inornata, C. gigas, Tropiscapha gigantica, S. diaphragna, S. calcarifrons. In addition to the shallow-water carbonates and anhydrite found at the bottom of the well, the layered limestone was found in the anhydrite between 1594 and 1605 m. Volcanic breccia and thin-beded lime- stone, which were recovered above this interval to a depth of approximately 1586 m.

Manson Structure, Iowa

A fifth structure that has been suggested as a possible crater target in the Manson structure in Iowa (Izett et al., 1990).

It is difficult to accept Manson as an impact crater as indicated in Figure 5, the central Manson core of Pre-

 cambrian crystalline rocks has been uplifted through 6000 m of Proterozoic red clastic rock, 670 m of Paleozoic limestone, and 45 m of Cretaceous shale (Hoppin and Dryden, 1958).

Impact origin of the central uplift at Manson calls for excavation by impact of a depth of 6000 m from the basement core, and par- tial infilling of the crater created by impact debris (Hart and Anderson, 1988). But as shown in Figure 5, the region surrounding the central uplift consists of an orderly sequence of Cre- taceous shales underlain by Paleozoic limestone, rather than of mixed debris which would consist mainly of Proterozoic red clastic rock. Furthermore, no shock features are found in the reputed impact debris material surrounding the basement core (Ozier and Carter, 1991).

CONCLUDING REMARKS

Speculations are an important component of science and are to be accept- ed but they must eventually answer to the facts. For these examples, the speculations have far overstepped the facts, and the facts, many of them rather obvious, simply do not support the speculations. The original Alvarez et al. hypothe- sizes, whether right or wrong, has been a burden on the geologic sciences for focussing attention on one of the more basic questions in geology: the cause of mass-extinction and mass events. It has in fact brought a great deal of attention in the scientific literature and in the media because it had "everything going for it and it was for the most part correct," and the royal family. However, it has many problems, and it has not proven correct to eliminate such terminological var- iants as relative sea-level changes, atmospheric climatic and oceanic circulation changes, anoxic events, and large-scale volcanism as contributors to this event. So we struggle, bearing in mind the wisdom of Charles Darwin, who wrote, in Descent of Man, False facts are highly injurious to the progress of science, for they are often exceedingly difficult, but false ideas, if supported by some amount of evidence, are likely to spread for everybody takes a sally pleasure in proving their fallacy; and when this is once got into the road to truth is often at the same time opened.

REFERENCES CITED


ISSUE: How Do We Improve Earth Science Education?

Many of us are aware of, and concerned about, the current crisis in precollege science education, but few of us know what the real problems or potential solutions look like. For this Forum, possible relevance to the K-12 level is provided. Selection of future Forum topics and participants is the responsibility of the Forum Editor. Suggestions for future Forum topics are welcome and should be sent to: Bruce F. Molnia, Forum Editor, U.S. Department of Energy, Energy Research, 917 National Center, Reston, VA 20192, (703) 648-4120, fax 703-648-4227.

PERSPECTIVE 1: Geology Phobia
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Why are teachers afraid to teach geology? It's those boxes of unidentified rocks and minerals the kids bring in that they don't know what to do with. While they might have a clue about; students are not comfortable when they don't have a clue. As an earth scientist I have no trouble teaching earth science, so perhaps you could take one day a year to help teachers with identification of these mysterious rocks. Scared teachers could be more useful in a box, however, unless rocks in the field may be difficult for even trained geologists to easily identify. It would be even more useful if college geology departments would prepare and make available identified collections of local rocks and minerals, so that teachers could teach about the rocks their students would be most likely to find. If these collections could be donated to neighboring school districts to be shared out by the teachers. If the colleges could also offer a mini-course (not a semester course) on local geology, the kits would be even more useful.

Teachers and children also need easy-to-understand, straightforward accuracy guides on geology, similar to the many wonderful volumes available on animals. A geology guide with updates on the latest ideas and discoveries would help keep everyone current. Perhaps there could be a geology book added to one of the scientific/children's magazines, such as The Instructor or Mailbox. A collection of experiments to demonstrate principles of geology written by someone who can be understood by a lay person, but still containing the accurate information, is begging to be written. For example, how do you demonstrate the dynamics of plate tectonics to a group of fourth, eighth, or twelfth graders?

Geological environment is also an important new field that teachers are usually not equipped to cover. Perhaps environmental consultants and engaging geologists could be invited to schools at least once a year to demonstrate the environmental problems that face us. The result would be a great service—education for the future. What could be more important?

PERSPECTIVE 2: Problems and Solutions in Earth Science Education: A Geologist's/Resource-Person's Perspective
Leslie C. Gordon, U.S. Geological Survey (USGS), Menlo Park, California

The two most pressing needs in earth science education today are (1) teacher training, and (2) dissemination and accessibility of existing education, material, and resources. These two needs are related and should be considered together. As a geologist and the education coordinator for the USGS's Western Region, I have almost daily contact with school administrators seeking help with science education, and with teachers (from kindergarten to 12th grade). The concerns and needs they have expressed to me have included increasing the presence of the school district to the next, all across the country. The two most frequent concerns have been requests I get from teachers who contact me at (1) "I'm looking for good hands-on earth science activities to use in the classroom," and (2) "I'm really interested in geology but I don't know anything about the subject matter and have to teach a class on Monday." After ten years of working with teachers, I've come to realize that this second concern is frequently implicit in the first one. No one ever says to me "I have a lot of old, ineffective methods for teaching geology. What is there and improved for me to use?" Asking for activities is sometimes a mask for a lack of subject-matter knowledge. If a teacher can follow a recipe for a well-written classroom activity, then it is chemistry. The teacher is not only looking for background knowledge and that the teacher can learn along with the student. The solution to this approach, even the best activities need content background information. In the absence of this background knowledge, the teacher is lost.

Caribbean Caper continued from p. 74

Caribbean Caper continued from p. 74


