(as well as limited chemical) analyses have indicated that this buried structure may in fact be of impact origin [8]. The impact origin was recently confirmed by the discovery of unambiguous evidence for shock metamorphism, e.g., shocked quartz and feldspar [9]. The stratigraphy of the crater and the exact succession and age of rocks are not entirely clear at this time, largely because the structure is now buried under about 1 km of Tertiary sediments, mainly limestone, and because of limited sample availability due to the destruction of core samples in a fire. The sedimentary sequence (composed mainly of carbonates and evaporites) overlies a basement at 3–6 km depth that is inferred to be composed of metamorphic rocks. If Chicxulub was formed by impact at a time at or before the end of the Cretaceous, the preimpact surface consisted largely of rocks for the carbonate-evaporite sedimentary sequence, probably releasing large quantities of CO_2 and SO_2 into the atmosphere.

Chicxulub contains abundant carbonate, limestone, and evaporite rocks, and the presence of andesitic rocks has been reported (which would make it a candidate for the source of the Haiti glasses), although it is not clear if the "andesite" is a real andesitic bedrock, or makes up the proposed melt sheet. There are some problems with Chicxulub being the source for the Haiti impact glasses (and therefore for parts of the claystones at some K/T boundaries). For this discussion, we need to review the origin of tektites and impact glasses. Rb-Sr and Sm-Nd isotopic systematics of tektites show that the source material was Precambrian crustal terrane (from Nd model ages), and that the sediments that were later melted to form tektites were weathered and deposited at (for the Australasian tektites, for example) about 167 Ma ago and probably comprised Jurassic sediments. Further evidence for a sedimentary precursor comes from the study of cosmogenic radionuclides. Pal et al. [10] first reported that the ^{10}Be content of Australasian tektites cannot have originated from direct cosmic ray irradiation in space or on Earth, but can only have been introduced from sediments that have absorbed ^{10}Be that was produced in the terrestrial atmosphere. This is an extremely important observation. The recent discovery of Glass and Wu [11], that impact debris is present in the same deep sea core layers as microtektites, gives further proof of an impact event leading to the production of tektites.

For Chicxulub, a major problem is the production of impact glasses (or "tektite-like" glasses), which originate, as I have just mentioned, from the surface layers of the target area. However, any "andesitic" rock or other basement rocks at Chicxulub were obviously covered by carbonates and evaporites of up to several kilometers thickness. We therefore cannot conclude, at least not with the data presently available, that Chicxulub is the most logical source for the Haiti glasses. Although the "andesite" present at Chicxulub is similar in composition to the black glasses [8], other rocks that will be mixed in upon impact have trace-element signatures that are not compatible with any glass composition. Another problem is the obvious lack of quartz-bearing rocks at Chicxulub, which poses problems for the explanation of the abundance of shocked quartz at almost all K/T boundaries. This has led some researchers [e.g., 12] to propose that two impacts, involving Chicxulub and Manson, might be responsible for the K/T event. In view of the preliminary nature of some data we refrain from speculating on such an origin. Other proposed impact locations, such as near Kara Crater, which was suggested by Russian scientists to be of K/T age, have not been confirmed. Precise Ar-Ar ages of Kara show that it is most probably too old to be associated with the K/T boundary, and it is also situated on the wrong side of the Earth, as it was inferred (see above) that the impact crater(s) are most likely near the North American continent. At present we can conclude that the Manson crater is the only confirmed crater of K/T age, but Chicxulub is becoming a strong contender; however, detailed geochemical, geochronological, and isotopic data are necessary to provide definitive evidence.

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TEKTITE ORIGIN BY HYPERVELOCITY ASTEROIDAL OR COMETARY IMPACT: THE QUEST FOR THE SOURCE CRATERS. Christian Koeberl, Institute of Geochemistry, University of Vienna, Dr.-Karl-Lueger-Ring 1, A-1010 Vienna, Austria.

Impact Origin of Tektites: Tektites are natural glasses that are chemically homogeneous, often spherically symmetrical objects several centimeters in size, and occur in four known strewn fields on the surface of the Earth: the North American, moldavite (or Central European), Ivory Coast, and Australasian strewn fields. Tektites found within such strewn fields are related to each other with respect to their petrological, physical, and chemical properties as well as their age. A theory of tektite origin needs to explain the similarity of tektites in respect to age and certain aspects of isotopic and chemical composition within one strewn field, as well as the variety of tektite materials present in each strewn field.

In addition to tektites on land, microtektites (which are generally less than 1 mm in diameter) have been found in deep-sea cores. Tektites are classified into three groups: (1) normal or splash-form tektites, (2) aerodynamically shaped tektites, and (3) Muong Nong-type tektites (sometimes also called layered tektites). The aerodynamic ablation results from partial remelting of glass during atmospheric passage after it was ejected outside the terrestrial atmosphere and quenched from a hot liquid. Aerodynamically shaped tektites are known mainly from the Australasian strewn field where they occur as flanged-button australites. The shapes of splash-form tektites (spheres, droplets, teardrops, dumbbells, etc., or fragments thereof) are the result of the solidification of rotating liquids in the air or vacuum.

Mainly due to chemical studies, it is now commonly accepted that tektites are the product of melting and quenching of terrestrial rocks during hypervelocity impact on the Earth. The chemistry of tektites is in many respects identical to the composition of upper crustal material [1,2]. Trace elements are very useful for source rock comparisons: the ratios of, e.g., Ba/Rb, K/U, Th/Sm, Sm/Sc, Th/Sc, K vs. K/U in tektites are indistinguishable from upper crustal rocks. The chondrite-normalized REE patterns of tektites are very similar to shales or loess, and have the characteristic shape and total abundances of the post-Archean upper crust. The determination of the exact source rocks of tektites is complicated because a variety of inhomogeneous target rocks were sampled by the impact. Muong Nong-type tektites are similar to impact glasses and because of their size and shape it is assumed that they have not traveled far from their location of origin, and may therefore provide information about the crater location.

The discovery of the tektite locations at Barbados and DSDP Site 612 in the North American strewn field is important because microtektites and tektites (tektite fragments) as well as shocked minerals are found in the same layer. A very important observation has recently been made by Glass and Wu [3], who showed that several microtektite-bearing layers in cores from the Australasian and North American strewn field contain shocked minerals (quartz and feldspar), vesicular impact glass, coesite, and possibly even stishovite. This discovery provides an immediate link of tektites with an impact event.

Shaw and Wasserburg [4] have shown that the crustal material that weathered to form the parent sediments for the Australasian tektites have Nd model ages of about 1.15 Ga, and that Rb-Sr data point to a final sedimentation of their parent material around 250 Ma ago. Recently, Blum et al. [5] have studied the Rb-Sr and Sm-Nd isotopic systematic of Muong Nong-type and splash-form tektites, and found that the source material was Precambrian crustal terrane (from Nd model ages), and that the sediments that were later melted to form tektites were weathered and deposited about 167 Ma ago and probably comprised Jurassic sediments, which are not uncommon throughout Indochina. Further evidence for a sedimentary precursor comes from the study of cosmogenic radionuclides. Pal et al. [6] first reported that the ^{10}Be content of Australasian tektites cannot have originated from direct cosmic ray irradiation in space or on Earth, but can only have been introduced from sediments that have absorbed ^{10}Be that was produced in the terrestrial atmosphere.

Where are the Source Craters? During the past half-century, numerous suggestions and educated guesses have been made regarding the location of the possible source craters for the tektite strewn fields. Relatively reliable links between a crater and the respective tektite strewn field have been established between the Bosumtwi (Ghana) and the Ries (Germany) Craters and the Ivory Coast and the Central European (moldavite) fields, respectively. However, no large crater of the required ages are known for the Australasian and North American strewn fields. For the Australasian field, many proposals for possible craters were made and later discounted (including source craters in Antarctica, or the Elgygytgyn or Zhamanshin Craters).

Wasson [7] suggests that the tektites in the Australasian field may have originated in a multitude of small craters scattered over all of Indochina. There are numerous objections, including (1) small craters produce small to negligible quantities of relatively inhomogeneous impact glasses, as is well known from many impact craters; (2) small impact events are unable to provide the energy to launch the (associated) splash-form and aerodynamically shaped tektites; (3) the isotopic data do not seem to be in agreement with the multitude of different source rocks that are required by a multiple impact theory; (4) the crater problem has been multiplied—instead of one missing crater, there is a multitude of missing craters. In agreement with most other studies I therefore prefer a single large impact crater.

Stauffer [8] analyzed the distribution of Australasian tektites and microtektites and found that they do not show a homogeneous distribution. There are radial and concentric patterns and zones that do not contain microtektite-bearing deep sea cores. Stauffer suggested a crater that may be concealed beneath alluvial deposits of the lower Mekong Valley area. A similar analysis was done by Koeberl [9] for the North American strewn field, where I suggested that tektites show a raylike distribution, not unlike lunar crater ejecta. A possible off-shore impact location (about 175 km to the east of the Vietnam seashore) was suggested by Schnetzler et al. [10] from satellite gravity data. Underwater craters must exist on Earth but, with one exception, have not yet been found. Hartung [11] proposed that the lake Tonle Sap (100 km long and up to 35 km wide) in Cambodia is the result of the Australasian tektite source crater. The dimensions are probably minimum values as the structure is almost completely filled with alluvium. Tonle Sap would be in agreement with chemical and isotopic data for tektites, but more detailed studies are necessary. The new discovery [3] of impact debris (shocked minerals) in deep-sea cores near the Indochina coast, as well as the fact that the quantity of both impact debris and microtektites in the cores increases toward Indochina, is in support of a crater in this area. Similarly, Koeberl [9] suggested that the North American tektite source crater is in the area of eastern coast of the North American continent, maybe underwater. This was also supported by the findings of Glass and Wu [3].

The exact mechanism of tektite production during the impact is still not known in detail, but obviously the production of tektites requires special conditions because otherwise more than just four tektite strewn fields would be associated with the known impact craters. Oblique impact seems a possibility because of the asymmetric distribution of tektites within a strewn field. Furthermore, in the two cases where craters are known to be associated with tektite fields, the craters are never in the center of the strewn field. Jetting might contribute to impact melts, but it seems that material originating from jetting may be composed predominantly of projectile material, and projectile signatures in tektites are not well pronounced, excluding a major projectile component. An initial melting phase during the compression stage, before the formation of the crater in the excavation stage, is most likely responsible for the tektite production. Tektites have to originate from target rock layers close to the surface because otherwise it is not possible to explain their ^{10}Be content. The expanding vapor plume after the impact may be important in distributing the tektite material (which is on the order of 10^9 t for the two larger strewn fields).

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