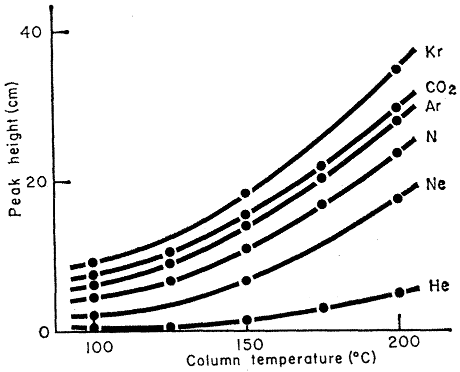

Fig. 1. Peak-height sensitivity plotted against column temperature, showing the effect of carrier-gas thermal conductivity on the response of the flame ionization detector. Column, 122 cm by 0.3 cm; activated alumina. Sample, *n*-butane (gas). All instrumental parameters held constant. The thermal conductivities [10^5 cal cm^{-1} sec^{-1} $(°C)^{-1}$] at 0°C are Kr, 2.0; CO_2, 3.5; Ar, 4.0; N, 5.8; Ne, 10.9; and He, 34.8.

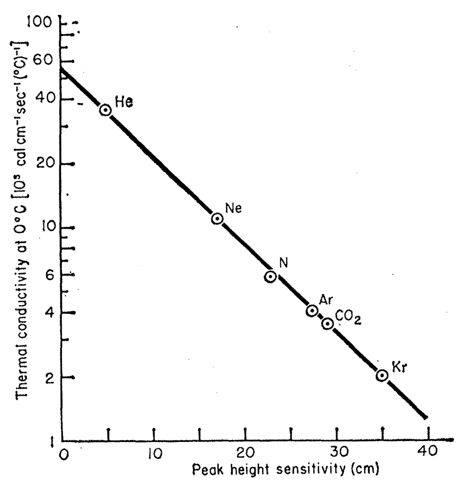

Fig. 2. Peak-height sensitivity plotted against logarithm of carrier-gas thermal conductivity for a column, operated isothermally at 200°C.

detector and with He for the thermal-conductivity detector provides more versatile equipment and allows operation of each detector at its maximum sensitivity.

R. L. HOFFMANN
C. D. EVANS
Northern Regional Research Laboratory, Peoria, Illinois*

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* A laboratory of the Northern Utilization Research and Development Division, Agricultural Research Service, U.S. Department of Agriculture.

4 March 1966

Oxygen Isotope Studies of Ivory Coast Tektites and Impactite Glass from the Bosumtwi Crater, Ghana

Abstract. *Oxygen isotope analyses were obtained for six Ivory Coast tektites, two samples of Bosumtwi Crater glass, and two new moldavites. The Ivory Coast tektites are 2 to 5 per mil richer in oxygen-18 than other known tektites, and they are similar in oxygen-18 content to the impactite glass from the nearby Bosumtwi Crater. These data are compatible with a terrestrial origin for the Ivory Coast tektites.*

The ratios of O^{18} to O^{16} of six Ivory Coast tektite specimens are appreciably different from those of other known tektites. Values are given in Table 1 in the familiar δ-notation:

$$\delta = \left[\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1\right] 1000$$

where R_{standard} is the ratio of O^{18} to O^{16} of standard mean ocean water. The δ-values of Ivory Coast tektites are 12.8 to 14.6 per mil higher than the ocean-water mean, making them 2 to 5 per mil richer in O^{18} than other tektites (*1*, *2*). These data raise the question of whether the Ivory Coast tektites have the same origin as the other tektite-strewn fields; the latter are much larger in area than the Ivory Coast field, and they are more uniform in O^{18} content.

Included in Table 1 are oxygen isotope analyses of two impactite glasses from the Bosumtwi Crater in Ghana. This crater has been suggested by Cohen (*3*) as the site of ejection of the Ivory Coast tektites, presumably by shock melting during the meteorite impact associated with the origin of the Bosumtwi Crater (*4*). Geochemical data now support such an hypothesis. The K-Ar age determinations of Ivory Coast tektites (*5*) and of Bosumtwi Crater glass (*6*) are identical within experimental error at 1.3×10^6 years; this value is also supported by fission-track dating (*7*) as indicating the time of melting of the impactite glass and the Ivory Coast tektites. Schnetzler *et al.* (*8*) and Lippolt and Wasserburg (*9*) have also shown that these tektites, the crater glass, and the igneous and metamorphic rocks exposed in the area of the Bosumtwi Crater all lie on the same Rb-Sr isochron, suggesting that they were derived from rocks with an age of about 2.0×10^9 years. Many chemical similarities also have been found between Ivory Coast tektites and Bosumtwi Crater glass (*6*, *8*).

The impactite glass samples from Bosumtwi Crater show a range of δO^{18} (12.0 to 14.8) that is practically identical to the range of O^{18} in Ivory Coast tektites (12.8 to 14.6), although only two samples of the impactite glass have been analyzed. The variations of O^{18}/O^{16} in the glass could be reasonably attributed to variations in the parent rock types exposed in the Bosumtwi Crater area, although none of these has been analyzed. The δ-values obtained are typical for gneisses and metamorphosed sedimentary rocks (*1*, *10*, *11*); the δ-value of 14.8, in particular, is representative of the argillaceous sedimentary and metasedimentary rocks. Some of the variation in O^{18} content of the glass could be a result of the impact process itself, as oxygen isotope changes generally take place in rocks during melting and dehydration (*2*).

Two new analyses of tektites from the moldavite-strewn field also were made, and are included in Table 1. With these results, we now have a statistically significant amount of data from the four known tektite-strewn fields. The principal features of the existing oxygen isotope data on tektites and impactite glasses (Fig. 1) are (i) the great similarity in the ratios of O^{18} to O^{16} in tektites from the three major strewn fields in Australasia, North America, and Czechoslovakia; (ii) the marked difference between the Ivory Coast tektites and the other types; (iii) the great variability of O^{18}/O^{16} in the impactite glasses, whose ratios range from 7.9 to 14.8 and hence cover most of the range (7 to 19 per mil) shown by the common rocks rich in SiO_2 (excluding cherts) exposed at the Earth's surface; and (iv) the similarity of O^{18}/O^{16} in the Bosumtwi Crater glass and the Ivory Coast tektites.

The Ivory Coast tektites appear to be true tektites in terms of their internal structures, major element chemical composition, and external morphology (*12*); they have, however, slightly lower SiO_2 contents (and higher indices of refraction) than the other tektites. The only known features which clearly distinguish the Ivory Coast tektites from other tektites are their ratios O^{18}/O^{16} and Rb/Sr. A rough isochron, 400×10^6 year, can be drawn through the average values of Rb^{87}/Sr^{86} and $Sr^{87}/$

Sr^{86} of the three major tektite groups (*13*), and the values for Ivory Coast tektites plot nowhere near this isochron (*8, 9*). It should be pointed out that systematic oxygen isotope variations may exist in the Ivory Coast strewn field, as the first three samples we analyzed are distinctly richer in O^{18} than the three specimens recently provided us by Shoemaker (Table 1).

Strong arguments have been presented to the effect that tektites are impact-melted glasses of some type (*14*), but there has long been a controversy as to their terrestrial or extraterrestrial origin. In view of the convincing case that has now been made for a terrestrial origin for the Ivory Coast tektites, it is important to examine the implications this may have to the origin of the other tektite occurrences. If the Ivory Coast tektites are just a special type of terrestrial impactite glass that has been ejected 250 to 300 km from its point of origin, this need not imply that the other tektite fields are terrestrial. If the Ivory Coast tektites were identical to other tektites in all respects, a terrestrial origin would probably be indicated for all. However, this is not true for O^{18}/O^{16} or Rb/Sr, and other factors may be found which will serve to distinguish these objects from the "true" tektites.

If it is accepted that the Ivory Coast tektites do come from the Bosumtwi Crater, this is of importance in demonstrating that tektite-like objects can be formed on the Earth and can travel an appreciable distance in a molten or semimolten state without being broken up into myriads of tiny droplets through wind resistance. This is in disagreement with the conclusions of Chapman and Larson (*15*) concerning this phenomenon and suggests that the objects travel through a partial vacuum produced behind the impacting body, or perhaps that the objects move in a gaseous envelope that is traveling at a velocity similar to that of the objects themselves. Thus, one of the major arguments that has been used against a terrestrial origin for the other tektite-strewn fields would be negated.

Some of the best arguments for an extraterrestrial origin for the major tektite-strewn fields have been the striking similarity in chemical and isotopic compositions of all the tektites. These arguments remain in force, inasmuch as the removal of Ivory Coast tektites from this grouping does not alter the difficulties of producing such similar objects from the widely heterogeneous rock types exposed at the Earth's surface. Even as few as three random impacts would not be expected to produce materials that are so similar to one another, unless large-scale homogenization of the melted rock occurs at the impacting site. No doubt a terrestrial origin for all tektites has been strengthened by the recent data from the Ivory Coast and Ghana (*5–9*), but at the present stage of knowledge one cannot disregard previous studies that have led to postulates of an extraterrestrial (presumably lunar) source for tektites.

In summary, the existing oxygen isotopes data obtained on tektites suggest the following.

1) The Ivory Coast tektites could represent terrestrial impactite glass formed from metasedimentary rocks, soils, or perhaps very deeply weathered granitic rocks; such rock types are exposed in the area of Bosumtwi Crater. They cannot have been formed from unweathered terrestrial igneous rocks, unless exceedingly large O^{18}/O^{16} changes occur during the melting process.

2) It is highly unlikely that the other groups of tektites could have formed from soils or argillaceous sedimentary or metasedimentary rocks (*2*). If these tektites are terrestrial they very likely formed from igneous rocks or high-rank metamorphic gneisses of granitic composition. Of the common SiO_2-rich rocks only the plutonic granites, granitic gneisses, and rhyolites have relatively uniform O^{18}/O^{16} ratios in the

Table 1. Ratios of O^{18} to O^{16} in tektites and impactite glases.

Sample	$\delta O^{18}/O^{16}$ (per mil)	Deviation (av.)	Runs (No.)
Ivory Coast tektites			
IVC-3-64*	14.1	0.2	3
IVC-7-64*	14.6	.2	4
No. 2202 Paris Museum†	14.5	.1	3
No. 3‡	12.8	.1	2
No. 6‡	13.3	.1	2
No. 3.55g‡	13.0	.1	2
Bosumtwi Crater impactite glass			
Buonim Creek§	14.8	0.0	2
Ata Creek§	12.0	.3	4
Moldavites			
Lheninceǁ	11.3	0.1	2
Kocoseky-Vrabceǁ	10.8	.1	3

* From E. C. T. Chao. † From C. C. Schnetzler. ‡ From E. M. Shoemaker. § From H. J. Lippolt. ǁ Czechoslovakia, sample from H. Suess.

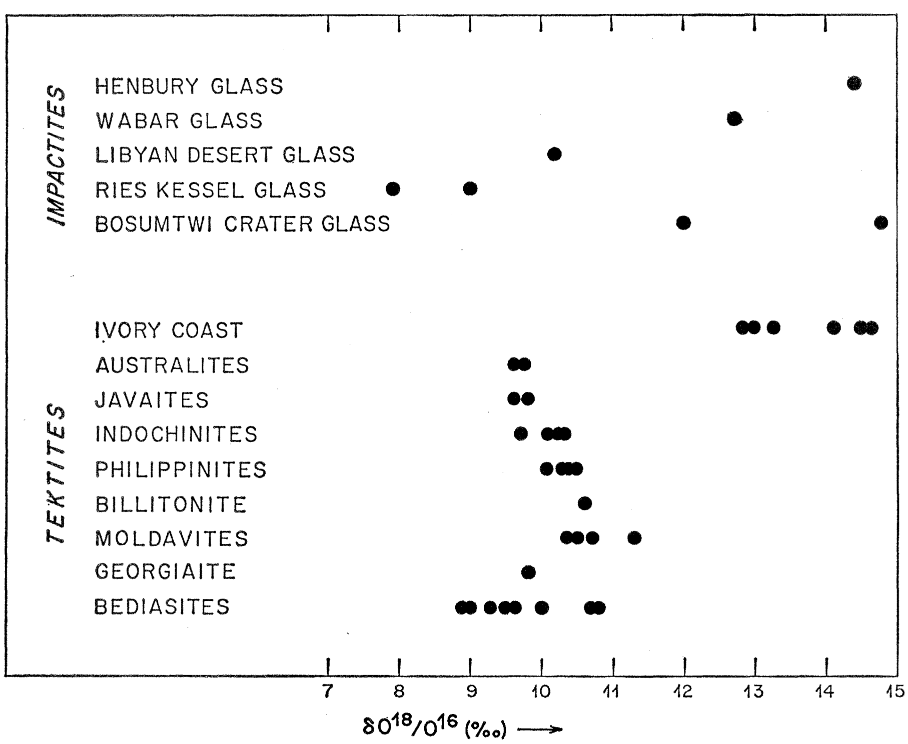

Fig. 1. Comparison of all existing oxygen isotope analyses of tektites from the four known strewn fields and of impactite glasses from several localities. These data are from Silverman (*10*), from Taylor and Epstein (*1, 2*), and from our present study. The Ries Kessel has been suggested as the site of origin of the moldavites and the Bosumtwi Crater has been suggested as the place where the Ivory Coast tektites were formed.

range of $\delta = 8$ to 11 per mil. This implies that their chemical compositions were changed by volatilization of certain elements during the impact melting process.

3) The Ivory Coast tektites come from the smallest known strewn field and presumably represent the smallest impact event of any of the occurrences. One might a priori expect them to be richer in O^{18} because surficial rocks (soils and sediments) are high in O^{18}. Other strewn fields must represent impact events of much greater size, and these would be expected to penetrate more deeply into Precambrian basement terranes where plutonic granites and high-rank metamorphic gneisses are common. In this connection it may be suggestive that the next smallest strewn field is that of the moldavites, and these definitely tend to be slightly richer in O^{18} than the other tektites from North America or Australasia (Fig. 1).

4) If the moon has a granitic or rhyolitic crust it conceivably could have an oxygen isotopic composition similar to that of terrestrial granites. Therefore, it could serve equally well as parent material for the three major tektite occurrences. It is very unlikely that the Ivory Coast tektites could have been derived from the lunar crust, unless very peculiar oxygen isotopic fractionations have occurred there. Granitic igneous rock types on the Earth do not have such high ratios of O^{18} to O^{16}.

HUGH P. TAYLOR, JR.
SAMUEL EPSTEIN
Division of Geological Sciences, California Institute of Technology, Pasadena

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Olfactory Discrimination in the Rabbit Olfactory Glomerulus

Abstract. *Slow potentials evoked by odor stimulation were recorded from individual glomeruli in the olfactory bulb. Systematic analysis of responses to nine different, arbitrarily selected stimuli strongly suggests a certain amount of discrimination. This fact seems to reflect in the first synapse of the olfactory tract the type of discrimination that was recently demonstrated within olfactory neuroepithelium.*

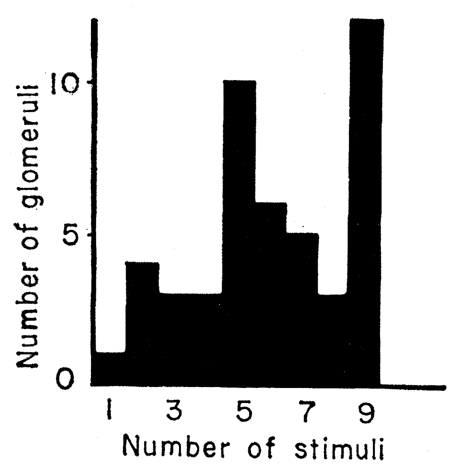
A unipolar microelectrode located in the olfactory bulb near the glomerular layer records, at the same time as Adrian's "induced waves" (*1*), a slow potential evoked by stimulation by odor. The glomerular origin of the potential is attested by inversion of its electrical sign as the electrode is lowered through the glomerular layer (*2*).

The histological structure of olfactory glomerulus, a very dense agglomeration of synaptic connections, and especially the fact demonstrated by de Lorenzo (*3*) that a given olfactory fiber is connected to several mitral cells, suggest that it works as an integrator giving a unique global response to many afferent impulses.

Single-glomerulus responses were recorded through a bipolar system: the shanks of two micropipettes were closely assembled parallel with each other with araldite glue; the tip of one micropipette was 150 μm ahead of the other. Each electrode, filled with $3M$ KCl, had a tip diameter of 0.5 μm and a resistance ranging between 8 and 12 Mohm.

The experiments were performed on young rabbits. After tracheotomy under light barbituric anesthesia, the animal was curarized and connected to a respiratory pump. It was essential to await complete recovery from the anesthesia before recording glomerular potentials; no local anesthetic was used. The chorial side of the dorsal olfactory neuroepithelium and the dorsal side of the homolateral olfactory bulb were exposed.

Electrophysiological recording was then undertaken on two points simultaneously: (i) unipolar recording on the olfactory epithelium through a single microelectrode (indifferent electrode under cranial skin), giving the electro-olfactogram (EOG) (*4*) according to the method of Mac Leod (*5*); and (ii) bipolar recording in the olfactory bulb through the dual microelectrode. This electrode was so devised that the size of its reception field corresponded to the mean vol-



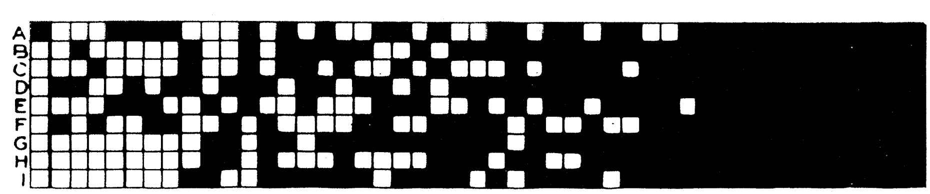


Fig. 1. Distribution of responses of 47 glomeruli explored. (Top) Histogram of the number of glomeruli actually responding (ordinates) plotted against the number of effective stimuli (abscissae). (Bottom) Distribution of the responses of each glomerulus (vertical columns) to each stimulus (horizontal columns). White squares, no response; black squares, response to these odorous stimuli: citral (*A*), propanol (*B*), *n*-butanol (*C*), amylacetate (*D*), ethyl acetylacetate (*E*), benzene (*F*), benzaldehyde (*G*), alpha-ionone (*H*), and beta-ionone (*I*). Apart from the 12 nonselective glomeruli, only these three pairs exhibited the same response spectra: Nos. 23 and 27, 28 and 29, and 33 and 34.