ARE THE „AMERICANITES" TEKTITES?

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In 1914 the moldavites, australites and billitonites had already been known for many years and the queenstownites had just been discovered and recognised as tektites. In this year A. EPPLER communicated that he had received a sphere of obsidian, ± 17 mm in diameter from South America, the place of origin not being known. Both according to his opinion and to that of Professor WEINSCHENK, it should be ascribed to the tektites. He arrived at this conclusion mainly by the external appearance of the pebble, that showed the same sculpture and lustre as that of most tektites. Otherwise, however, it had a marked resemblance to the terrestrial obsidian. EPPLER compared his tektite to South American obsidians and found them to possess the same brownish grey colour in transmitted light, the same refractive index and practically the same specific gravity (the tektite 2.352, the obsidian 2.346).

In 1921 LLERAS described similar spheres of glass from Columbia; he also considered them to be tektites. Later, however, (1925) in a detailed publication he defended the view of a terrestrial, volcanic origin of these rocks. After the appearance of STUTZER's paper LLERAS (1929) was again converted to the opinion, that they were tektites.

In the mean time, in 1924, LINCK had described a tektite from Paucartambo in Peru. On account of the chemical composition and the small, but clearly visible crystals it contained, he supposed that the tektites, more especially that from Paucartambo, originated from a satellite of a celestial body such as the earth, probably, therefore, the satellite of the earth itself — the moon. In 1925 he gave a detailed description of the tektite. It is a stone of 520 grams weight, spherical in shape but flattened on one side and consisting of brownish, light green glass, containing a great number of small crystals, principally of andalusite, sillimanite, wollastonite, scapolite, orthoclase, oligoclase-andesine and zircon, and many small inclusions of a different kind of glass. The refractive index of the glass is 1.4855, the specific gravity 2.3595. The surface is covered with different kinds of pits and grooves of very variable depth, viz.: the very small, shallow pits, that are met with both on the original surface and on fracture surfaces formed at a later period, and worm-shaped grooves and very deep, narrow and perfectly straight incisions, that only occur on the original surface.

Shortly after the paper by LINCK, the first by STUTZER on the tektites of Columbia was published (1926). On the strength of the descriptions by LLERAS (see above) and of his own investigations, he concludes that the following obsidians, formerly described from Columbia, must be included in the tektites:

1. The pear-shaped and spherical pieces of obsidian, that are found in the neighbourhood of Los Serillos, Uvales and Palacé around the volcano Sotará near Popayan (VON HUMBOLDT, 1823). These consist of glass of all shades of colour, from black (in reflected light) to colourless, transparent, and they occur together with pieces of devitrified, white glass (so called porcelain of Réaumur). Their surface in described as "tuberculeux".

2 [1]. Obsidian from Los Ubalos (= Uvales?) and Pisojé near Popayan (ŽUJOVIČ, 1884). The former contains microlites of pyroxene and crystals of sanidine; the latter is highly porous and contains amongst others many crystals of sanidine and orthoclase.

3. Chips of obsidian from the Tetilla near Popayan (KÜCH, 1892, p. 109). These are composed of bottle-green glass, with practically no devitrification products.

4 [2]. Small spheres of obsidian enclosed in a vitrous tuff on the banks of the Río Quilcacé near Popayan (KÜCH, 1892, p. 117). The colour is grey to smoky-grey, sometimes more glassy, sometimes more like enamel and they contain microlites of quartz, sanidine and biotite. There is also a pumice-variety of this glass.

5. Chips of obsidian from the valley of the Río Cauca from Cartago to Popayan and also from further south, as far as Pasto; also, very light and transparent chips from Ensolvado near Buenos Aires, and from the road to the Páramo de Sotará (BERGT, 1899, p. 102). Those from Ensolvado (l. c., p. 117) consist of light grey transparent glass with local glass inclusions or streaks of devitrification products, that are identical with those of the obsidian from the Río Quilcacé.

6. A boulder of obsidian from Poblazón near Popayan (BERGT, 1899, p. 177) with dimensions of 178 × 127 × 75 mm, the surface of which shows minute pits and a rather small number of long, curved, shallow grooves. Petrographically the glass is similar to that of the chips from Ensolvado.

7. Spheres of obsidian from Cali (MERRILL, 1911) of 20 and 30 mm in diam., weighing respectively 12 and 30 grams. These pieces are round, flattened on one side, the surface shows many shallow pits and a few narrow, deep grooves, and is further entirely covered with very small pits; on the flat side only the latter occur. The glass is reddish brown and contains few microlites.

8. Spheres of obsidian from the Hoya del Páez in the province Tolima (LLERAS, 1925, p. 36; 1929, p. 9). The surface shows shallow pits and crescentic grooves and sometimes, parallel lines. The glass is

[1]) STUTZER cited this publication, but was not aquainted with the contents.

[2]) STUTZER, himself, believes these to be terrestrial obsidian, and points out the difficulty in distinguishing between terrestrial and celestial glass in these parts.

reddish brown with a violet tinge and does not appear to contain devitrification products or bubbles.

9. Two spheres of obsidian, probably from Cali (LLERAS, 1925, p. 36), of 14 and 12 grams in weight respectively. On their surface they show shallow pits, crescentic and elliptical grooves (in my opinion possibly identical with the crescentic grooves); furthermore, on the old fracture surfaces there are very small pits and parallel lines. The glass is grey with a violet tinge and contains a few very small bubbles.

10. Spheres of obsidian from Tuluá (LLERAS, 1925, p. 89; 1929, p. 9) from a few milligrams to 15 grams in weight. The colour and surface are the same as those of the other tektites from Columbia.

In connection with these, STUTZER then describes spheres of obsidian, that he saw himself near Buenos Aires and Cali. A tektite from the Loma de Cristalles near Cali was 42 × 40 × 23 mm and rounded with one flattened surface. Except on the flat side the entire surface is covered with shallow grooves both straight and curved; further one sees very small pits over the entire surface, including the flat side. The glass is light brownish smoky-grey with a violet tinge and contains no devitrification products. On the Teta near Buenos Aires and between Popayan and Timbío chips of obsidian of the same colour occur.

Later (1928) STUTZER also described chips of obsidian of the same colour from the Tetilla near Popayan. They are composed of glass of alternately higher and lower refractive indices, and, in a few cases, contain microlites in fluxion arrangement.

The latest tektites which have been described from Columbia are chips of grey transparent glass from the region between the Huila and the Páramo de Santo Domingo (LLERAS, 1929). LLERAS also includes in the tektites a pyroxene andesite bomb from Bordo (S.W. of Popayan) described by BERGT (1899, p. 177) and certain pebbles of obsidian from North America and Mexico.

The principal reasons that led STUTZER and LLERAS to consider the above mentioned obsidian from Columbia as tektites are the following:

1. The sculpture of the surface.
2. The distribution over a very wide area, which fact cannot be explained by river transportation since they are mostly found on the tops of hills. Cartago and Pasto are situated more than 400 km apart. Between these in the valley of the Cauca are situated from north to south: Tuluá, Cali, Buenos Aires and Popayan; the Huila and the Hoya del Páez lie more than 50 km to the east of Buenos Aires.
3. No volcanoes are known in Columbia, from which the glass could have originated. On the Sotará, for instance, obsidian has never been found as bedrock, although the americanites occur in large amounts in the neighbourhood. Neither is obsidian known as bedrock from anywhere else in Columbia.
4. The gases contained in the tektites from Columbia are CO_2, CO and H_2 as in the other tektites; chlorine and sulphur gases do not occur.

LINCK calls attention to the exceptional chemical composition of the tektite from Paucartambo, the curious association of minerals, the surface and the included gases (also CO_2 and CO) (see LINCK, 1927, p. 229).

The chemical position of the tektite from Paucartambo and of two tektites from Columbia are given in the schedule under the numbers 1, 2 and 3. It should further be noted that melting experiments have shown that the tektite from Paucartambo froths up to a mass like pumice at 1000°, and one from the Tetilla near Popayan between 905° and 950° C, while both melted entirely at 1200°.

TABLE.

Analyses	1	2	3	4	5	6
SiO_2	70.56	75.87	76.37	76.20	75.23	75.08
TiO_2		trace	0.11	trace		0.03
Al_2O_3	20.54	14.35	12.59	13.17	12.36	13.63
Fe_2O_3		0.22	0.26	0.34	0.96	1.35
FeO	0.96 (FeO + MnO)		0.48	0.73	1.24	0.28
MnO			0.14	0.10		trace
MgO	0.11	0.29	0.17	0.19	0.01	0.17
CaO	0.78	0.00	0.79	0.42	1.00	1.22
Na_2O	3.42	3.96	3.36	4.31	4.00	3.79
K_2O	3.41	4.65	4.67	4.46	4.62	4.22
H_2O	0.83[1])	0.33	0.97	0.33	0.73	
P_2O_5			0.02		0.27	0.06
SO_2		0.23	0.13[2])			
Sb_2O_3			0.07			
Sum	100.61	99.90	100.13	100.25	100.42	100.06
density	2.360		2.310	2.352		2.354

1. Paucartambo, Peru. LINCK 1925, p. 159 and 1934, p. 14.
2. Cali, Columbia. MERRILL 1911, p. 484.
3. Tetilla, Columbia. DÖRING-STUTZER 1928, p. 35 and 38, an. I.
4. Obsidian Hill, Tewan Mounts, New Mexico, U. S. A. OSANN-ROSENBUSCH Elemente der Gesteinslehre, 4 Aufl., 1923, p. 359, an. 1.
5. Cerro de las Navajas, Mexico. OSANN-ROSENBUSCH p. 359, an. 2.
6. Laguna de Maricunga, Chili. OSANN-ROSENBUSCH p. 359, an. 3.

[1]) combined water.
[2]) SO_3.

From the above it follows clearly that the americanites differ from the other tektites in many respects. The tektites form a clear petrological series: billitonite - australite - moldavite - queenstownite; the americanites do not fit into this series. This may be clearly seen by comparing the NIGGLI-values with those of the other tektites that show a si-number of 350—500.

	si	al	fm	c	alk
Tektites	350—500	33—47	36—28	21—8	11—18
Paucartambo	364.9	62.6	4.7	4.3	28.4
Cali	478.3	53.3	3.8	0.0	42.9
Tetilla	493.6	48.0	6.2	5.5	40.3

In comparison with the other tektites, the americanites contain an abnormally large amount of Al_2O_3; very little FeO, MgO and CaO and a very high alkali content. The k-value is much lower than for the other tektites with si 350—500 (0.40—0.48 respectively 0.45—0.88), also the mg-value (0.18—0.26 [1]) respectively 0.38—0.55), while the o-value is higher (0.20—0.28 [2]) respectively 0.02—0.09).

The difference between the americanites and the other tektites can also be expressed by noting that the americanites have about the same composition as the acid members of the series basalt-liparite (isofaly at si = ± 200) (only the tektite from Paucartambo differs through its abnormally high percentage of Al_2O_3), while the other tektites show isofaly at si = ± 400 and, curiously enough, do not show a further increase of alk, nor a decrease of fm in the further course of their differentiation series (al and c behave fairly normally).

The gases contained in the americanites are the same as those in the other tektites (CO_2, CO and H_2). However, while they occur under very low pressure in the other tektites (as was discovered on cutting through a few hollow billitonites), they appear to be enclosed in the americanites under normal pressure. Thus the americanites froth up on being melted with the production of gas, contrary to the behaviour of the other tektites.

In transmitted light the colour of the tektites is generally green, but that of the americanites is mostly grey; only that of Paucartambo and, according to KÜCH, that of the Tetilla also, are green (STUTZER, however, only describes grey chips of obsidian from the Tetilla).

While, in general, the tektites do not contain devitrification products, or at the most a rare, minute and indeterminable crystal, nearly all americanites show microlites and crystals in varying quantities and sizes.

Various kinds of pits and grooves, that are found on the surface of the tektites are also observed on the americanites, but the latter also show worm-shaped, crescentic or elliptical grooves; otherwise up to the

[1]) The proportion of FeO in the tektite from Cali has not been determined, so that the mg-value seems to be abnormally high, viz. 0.72.

[2]) The proportion of Fe_2O_3 in the tektite of Paucartambo has not been determined.

present these had only been found on terrestrial obsidian from Clifton (Arizona, U.S.A.), High Rock Canyon (Nevada, U.S.A.) and Myvatn (Iceland) (see MERRILL, 1911) and on the pseudo-tektite from Patagonia [1]).

The differences between the americanites and the other tektites are apt to suggest that the americanites might be terrestrial obsidian in spite of all the arguments put forward by LINCK, STUTZER and LLERAS, as was already pointed out by FRIEDLÄNDER in 1927. One of the arguments they present is the sculpture of the surface of these rocks; it has been sufficiently shown how little value can be attached to this reasoning [1]). On the contrary, the sculpture could be used with more effect to demonstrate their terrestrial origin: the very small pits, that are always found along the fractures also, the deeper round pits, and the narrow and deep, generally straight or slightly curved grooves are not only found on tektites and americanites, but also on terrestrial pebbles of obsidian; the worm-shaped and similar grooves, however, are only found on the americanites and on terrestrial obsidian. The fact that the sculpture of the surface is not an argument for celestial origin has far reaching consequences in connection with the americanites. For now we can leave out of account all the rocks ascribed to this group, for which there are no other arguments than the surface for not considering them to be terrestrial obsidian. These are in the first place the tektite of EPPLER, the pyroxene andesite bomb from Bordo mentioned by LLERAS and the pebbles of obsidian from North America and Mexico. It is further difficult to imagine that the large block of obsidian from Poblazón, that must weigh at least 2 kg, is of celestial origin: neither among the tektites, nor among the other americanites, of which the heaviest is that from Paucartambo (520 grams), have such large pieces ever been found.

VON HUMBOLDT's description of the occurrence of glass of all shades of colour from black to colourless, together with pieces of porcelain of Réaumur on the fields around the Sotará and ŽUJOVIČ's petrographic description of the same glass, together strongly recall the small spheres of obsidian, enamel and pumice, that were described from a vitric tuff along the Río Quilcacé by KÜCH which are doubtless of volcanic origin. The resemblance appears to be too great to be a mere coincidence; moreover the places of origin are not far apart. The occurrence of small spheres of obsidian of all sizes to that of a nut, in the vitric tuff along the Río Quilcacé, proves that these have been ejected as lapilli by the volcano Sotará. STUTZER's argument against the volcanic origin of the obsidians described by VON HUMBOLDT and ŽUJOVIČ, namely that no obsidian is known as *bedrock* from the Sotará, is thus refuted. In our opinion it is highly probable, that *all the spheres and chips of obsidian from Los Serillos, Uvales, Palacé Pisojé, the Río Quilcacé, the Páramo de Sotará, Poblazón and Popayan — Timbío have been derived*

[1]) See the forthcoming article by B. G. ESCHER in the Leidsche Geologische Mededeelingen on pseudo-tektites.

from the volcano Sotará. Before a definite conclusion can be arrived at, however, a comparison will have to be made between all the obsidians from these regions with that from the Río Quilcacé, the terrestrial origin of which is beyond doubt.

The resemblance between the glass of the obsidian chips from Ensolvado and that of the obsidian from the Río Quilcacé and from Poblazón is a strong argument in favour of these chips and those from the Teta having been ejected by the volcano Teta.

There now still remain to be considered the tektite from Paucartambo and those from the Tetilla, the Loma de Cristalles near Cali, the Huila and surroundings (Hoya de Páez en Páramo de Santo Domingo) and Tuluá. Except the tektite from Paucartambo they all differ from those just described by their very low content in microlites and gasbubbles.

These are chips (Tetilla, P. de S. Domingo) or spheres; the latter frequently presenting one flattened surface (Paucartambo, Cali), as if they had fallen in a semi-plastic condition. The thermal conductivity of glass is too small to allow for explanation of the semi-plastic state of the spheres by the heat of friction generated during the passage through the atmosphere. This forces one to assume that when these americanites entered into the atmosphere they were already in a semi-plastic state. This means a fundamental difference as compared with the other tektites. The rim of many australites proves that the latter entered the atmosphere in the form of solid glass. In my opinion the rim can only have been formed through melting of the thin outer layer of glass in front by friction with the air during the passage through the atmosphere, and the spreading of this molten part around the solid rear parts. If the glass of the tektites had been formed in consequence of the passage of the atmosphere, as LACROIX (1932) assumes, they would have had to be heated (formation of the glass), then cooled and subsequently reheated locally (formation of the rim of the australites), all during the four seconds in which they passed through the atmosphere. This seems improbable, so I assume that the tektites entered the atmosphere as solid glass. In interstellar space outside the atmosphere they must have been exposed to a temperature far below freezing point; the americanites on the other hand were brought into the atmosphere in semi-plastic condition and therefore cannot have passed through interstellar space. But if it is assumed that they were ejected as semi-plastic or liquid bombs by a terrestrial volcano, the explanation of the shape offers no further difficulties. In other words, *the shape of the americanites from Paucartambo and Cali is an argument in favour more of terrestrial than of cosmic origin.*

In connection with the differences in chemical composition between the americanites and the other tektites it has already been pointed out, that the former show a striking similarity to the acid, terrestrial effusive rocks. It is not hard to discover an analysis of liparite-obsidian, that corresponds exactly to that of the americanites of Cali and the Tetilla (analyses 4, 5 and 6). On the one hand therefore one finds a marked difference from the tektites, on the other a striking resemblance to terrestrial obsidian. From this it may be concluded that *the chemical com-*

position of the americanites from the Tetilla and Cali can only be used as an argument for their terrestrial origin. The tektite from Paucartambo (analysis 1) differs from the other americanites by its abnormally high percentage of Al_2O_3 (al-surplus about 30!) and the small quantities of Fe and Ca it contains; to which should be added the peculiar association of minerals described by LINCK. As in all other respects the tektite from Paucartambo resembles the other americanites, I do not consider the chemical composition sufficient reason for separating them.

There are not sufficient data at hand concerning the americanites from Taluá and the neighbourhood of the Huila to enable one to decide whether they too present properties that point to a terrestrial, rather than to a celestial origin.

In conclusion it may be pointed out that only the following arguments remain for a celestial origin of the americanites:

1. Their distribution, if it is found impossible to prove that they represent lapilli, bombs or chips of obsidian, ejected by known volcanoes of the Andes.
2. The gases they contain (CO_2, CO and H_2).
3. The fact that they occur on the same great circle on which the moldavites, billitonites, australites and queenstownites have also been found.
4. In the case of the tektite of Paucartambo, the chemical composition and the crystalline inclusions.

On the other hand the following arguments are in favour of the terrestrial origin:

1. The chemical composition of the Columbian americanites.
2. Their behaviour on heating (frothing up at 900°—1000°).
3. Their colour, that (except for the tektite of Paucartambo) is identical to that of most obsidians.
4. The microlites and crystals they contain.
5. The greater resemblance of the etching marks on their surface to those of terrestrial obsidian than to that of other tektites.
6. The marked resemblance of the americanites from the fields around the Sotará and from Ensolvado with the spheres of obsidian from the Río Quilcacé, that are certainly terrestrial.
7. The flat surface occurring on the americanites from Paucartambo and Cali.

We are thus able to demonstrate that most available data appear to show that the americanites are bombs, lapilli and chips of obsidian ejected by volcanoes of the Andes, together with other materials, as pumice, enamel and vitric tuff (Sotará, Río Quilcacé). A less extensive investigation led FRIEDLÄNDER to practically the same conclusion (1927).

Before it is possible, however, to separate the americanites definitely from the tektites, a detailed field examination is required and also a minute determination of the chemical composition of the americanites and of the indubitable volcanic rocks from the neighbourhood.

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