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Tektites and silica-glass.

(With Plates XVI and XVII.)

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THE natural glasses recognized as tektites are characterized by their acidic composition, the silica percentage ranging from 68 to 80. Their origin is still a debatable point. Within this range glasses are known which have undoubtedly been produced by the fusion of siliceous terrestrial materials in the intense heat developed when large iron meteorites have struck the earth's surface; while others of the same origin show silica ranging up to 98 per cent., that is, an almost pure silica-glass.

From a collection of 84 chemical analyses of tektites taken from the literature, only 36 (many of them due to A. Lacroix) give data for the specific gravity and refractive index which presumably were determined on the same sample of material as that analysed. These are reproduced in table I (arranged in order of silica percentages) and plotted in figs. 1 and 2. Corresponding with the range in SiO_2 from 68·00 to 80·73 % there is a nearly uniform decrease in d (2·498–2·339) and n (1·526–1·4867). The specific refractivity, $K = (n-1)/d$, varies from 0·2050 to 0·2107 (0·2258 in the case of no. 29 with the abnormally high n 1·5380).

Table I. Chemical analyses, specific gravity, and refractive indices of tektites (from the literature).

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	Na_2O.	K_2O.	Sp.gr.	n_D.
1.	68·00	16·46	—	6·08	3·38	2·00	1·45	1·84	2·465	1·5178
2.	68·60	15·80	0·18	6·46	2·88	1·40	2·35	1·92	2·487	1·5146
3.	69·32	12·27	0·06	6·81	4·05	3·72	0·77	2·18	2·498	1·526
4.	70·08	13·61	0·15	4·81	2·16	3·48	1·99	2·44	2·443	1·5148
5.	70·28	12·67	0·20	5·28	2·62	3·92	1·71	2·32	2·457	1·5157

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	Na_2O.	K_2O.	Sp.gr.	n_D.
6.	70·40	13·65	0·17	5·13	1·94	3·00	1·57	2·72	2·440	1·5120
7.	70·56	20·54	—	0·96	0·11	0·78	3·47	3·38	2·359	1·4855
8.	70·58	13·23	0·10	5·08	1·92	3·92	1·43	2·59	2·445	1·5146
9.	70·62	12·34	2·25	3·17	3·61	2·99	1·68	1·57	2·442	1·51
10.	70·66	12·08	1·78	4·52	3·65	2·97	1·62	1·69	2·439	(1·51)
11.	70·90	13·50	0·32	5·47	2·45	2·35	1·46	2·17	2·457	1·5097
12.	71·20	13·52	0·59	3·89	2·23	3·40	1·59	1·84	2·436	(1·51)
13.	71·32	12·16	2·03	3·03	2·94	2·95	1·66	1·90	2·431	(1·51)
14.	71·45	12·54	0·51	4·61	2·72	2·82	1·44	2·41	2·442	1·5113
15.	71·64	12·53	—	5·32	2·79	3·42	1·21	2·28	2·447	1·5130
16.	72·08	13·21	0·37	4·47	1·92	2·42	1·61	2·80	2·422	1·5063
17.	72·12	12·88	—	4·99	2·04	3·14	1·45	2·28	2·432	1·5089
18.	72·26	13·18	—	5·32	2·15	2·42	1·42	2·15	2·440	1·5133
19.	72·40	12·68	0·23	3·59	2·34	2·75	1·68	3·16	2·409	1·50
20.	72·48	12·84	—	4·59	2·16	2·78	1·73	2·63	2·429	1·5089
21.	72·62	12·20	—	5·19	2·20	2·28	2·00	2·17	2·421	1·5042
22.	72·78	12·20	—	5·33	2·30	2·52	1·69	2·09	2·414	1·5053
23.	73·14	12·48	—	4·88	2·12	3·34	1·29	1·84	2·429	1·5076
24.	73·30	11·98	—	5·19	2·44	2·28	1·64	2·25	2·429	1·5058
25.	73·73	11·33	0·83	4·46	2·39	2·49	1·15	2·32	2·436	1·5091
26.	74·14	12·73	—	4·93	1·78	2·24	1·03	2·41	2·419	1·5035
27.	74·56	12·34	—	4·66	1·82	2·40	0·92	2·47	2·419	1·5045
28.	74·56	12·60	—	4·98	1·22	1·34	1·81	2·21	2·404	1·4986
29.	74·91	13·80	0·44	3·10	1·66	1·16	0·72	3·76	2·383	1·5380
30.	76·56	11·54	0·17	3·99	3·60	1·62	1·32	0·82	2·4	1·4991
31.	76·64	11·36	0·06	4·39	1·29	1·48	1·56	2·30	2·413	1·4972
32.	77·08	10·66	0·36	1·78	2·20	3·74	0·54	3·33	2·395	1·5033
33.	78·75	10·99	0·54	1·43	1·75	2·38	0·51	3·01	2·352	1·4891
34.	80·00	10·04	—	2·27	1·46	1·76	0·51	3·37	2·339	1·4877
35.	80·52	9·44	—	1·98	1·73	1·84	0·52	3·15	2·341	1·4875
36.	80·73	9·61	—	1·93	1·59	2·13	0·37	3·60	2·343	1·4867

1. Akakoumoekrou, Ivory Coast, West Africa. A. Lacroix, 1934, 1935. Analyst, F. Raoult; also TiO_2 0·80, MnO 0·09, H_2O+ 0·13, H_2O- 0·14; total 100·37.
2. Ouellé, Ivory Coast, West Africa. A. Lacroix, ibid. Analyst, F. Raoult; also TiO_2 0·80, MnO 0·06; total 100·45.
3. Martapoera, Borneo. A. Lacroix, 1932, pp. 193, 203. Analyst, F. Raoult; also TiO_2 1·01, MnO 0·09, H_2O+ 0·14, H_2O- 0·11; total 100·53.
4. Malaya. A. Lacroix, 1929, 1931, 1932. Analyst, F. Raoult; also TiO_2 0·79, MnO 0·15, H_2O- 0·08; total 99·74.
5. Billiton, Dutch East Indies. A. Lacroix, 1929, 1931, 1932. Analyst, F. Raoult; also TiO_2 1·10, MnO 0·19, H_2O- 0·05; total 100·35.
6. Attopeu, Laos, French Indo-China. A. Lacroix, 1930, 1932, 1935. Analyst, F. Raoult; also TiO_2 1·03, MnO 0·15, H_2O- 0·16; total 99·92.
7. Paucartambo, Peru. G. Linck, 1926, 1928. Also, some MnO included with FeO, ign. loss 0·83; total 100·63. Contains various unusual crystallites.
8. Tan-hai island, Kwang-chow-wan, south China. A. Lacroix, 1930, 1932, 1935. Analyst, F. Raoult; also TiO_2 0·99, MnO 0·13, H_2O+ 0·20; total 100·17.
9. Kaliosso, Soerakarta, Java. C. M. Koomans, 1938. Also TiO_2 0·62, MnO 0·10, P_2O_5 0·12, H_2O+ 0·75; total 99·82.
10. 'Rizalite': Philippine Islands. C. M. Koomans, 1938. Also TiO_2 0·63, MnO 0·16, P_2O_5 0·18, H_2O+ 0·15; total 100·09.

11. Tutong, Brunei, British Borneo. F. P. Mueller, 1915. Analyst, Hinden; also TiO_2 1·00 about, MnO trace; total 99·62.
12. Bulakda, Philippine Islands. C. M. Koomans, 1938. Also TiO_2 0·92, MnO 0·08, P_2O_5 0·10, H_2O+ 0·63; total 99·99.
13. Busuanga, Philippine Islands. C. M. Koomans, 1938. Also TiO_2 1·04, MnO 0·11, P_2O_5 0·13, H_2O+ 0·51; total 99·78.
14. Philippine Islands. F. Heide, 1938. Analyst, P. Wagner; also TiO_2 1·02, MnO 0·10, P_2O_5 0·38, H_2O+ 0·24, H_2O- 0·04; total 100·28. Spectroscopic traces of Ni, Cr, Sr, Ba, Zr, V, Cu, Ga.
15. Rosario, prov. Batangas, Philippine Islands. A. Lacroix, 1931, 1932. Analyst, F. Raoult; also TiO_2 0·98, MnO 0·10, H_2O+ 0·19, H_2O- trace; total 100·46.
16. Smach (= Schmach), Cambodia, French Indo-China. A. Lacroix, 1929, 1930, 1932, 1935. Analyst, F. Raoult; also TiO_2 0·78, MnO 0·13, H_2O+ 0·13, H_2O- 0·13; total 100·05; corrections in later publications.
17. Beausite, Pia Coc, Tonkin, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 1·00, MnO 0·13, H_2O+ trace, H_2O- 0·04; total 100·07.
18. Dan-kia, Annam, French Indo-China. A. Lacroix, 1931, 1932, 1935. Analyst, F. Raoult; also TiO_2 0·99, MnO 0·10, H_2O+ 0·14, H_2O- 0·06; total 100·20.
19. Dhupan hill, Siam. C. M. Koomans, 1938. Also TiO_2 0·74, MnO 0·06, P_2O_5 0·14, H_2O+ 0·43; total 100·20.
20. South of Muong Nong, Laos, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 1·01, MnO 0·11, H_2O+ 0·14, H_2O- 0·05; total 100·52.
21. Near Kratié, Cambodia, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·94, Cr_2O_3 0·01, MnO 0·11, H_2O- 0·17; total 99·89.
22. Dalat, Lang Bian, Annam, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·90, Cr_2O_3 0·03, MnO 0·12, H_2O- 0·07; total 100·03.
23. Dong Van, Tonkin, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·95, MnO 0·16, H_2O+ 0·21, H_2O-0·09; total 100·50.
24. Dalat, Lang Bian, Annam, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·99, Cr_2O_3 0·01, MnO 0·32, H_2O+ 0·12, H_2O- 0·14; total 100·46.
25. Solo, central Java. F. Heide, 1939. Analyst, P. Wagner; also TiO_2 0·87, MnO 0·11, P_2O_5 0·19, H_2O+ 0·25, H_2O- 0·06; total 100·18. Also by spectroscopic analysis NiO 0·026, Cr_2O_3 0·047 %.
26. Sim-San, Hai-nan island, south China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·90, MnO 0·11, H_2O+ 0·08; total 100·35.
27. Potao, Kwang-chow-wan, south China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·92, MnO 0·10, H_2O+ 0·07; total 100·26.
28. Samrong, 50 km. SE. of Kratié, Cambodia, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·88, Cr_2O_3 0·01, MnO 0·12, H_2O- 0·14; total 99·87.
29. Moldavite: Senohrady, Moravia. R. Nováček, 1932. Also TiO_2 0·55, MnO 0·02, H_2O+ 0·09, H_2O- 0·03; total 100·24.
30. Akakoumoekrou, Ivory Coast, West Africa. A. Lacroix, 1934, 1935. Analyst, F. Raoult; also TiO_2 0·60, MnO 0·08, H_2O+ 0·22, H_2O- 0·07; total 100·59.
31. Smach (= Schmach), Cambodia, French Indo-China. A. Lacroix, 1935. Analyst, F. Raoult; also TiO_2 0·99, MnO 0·10, H_2O+ 0·22; total 100·39.
32. Moldavite: Něchov, Bohemia. R. Nováček, 1932. Also TiO_2 0·36, MnO 0·07, H_2O+ 0·13, H_2O- 0·04; total 100·29.
33. Moldavite: Dukovany, Moravia. R. Nováček, 1932. Also TiO_2 0·41, MnO 0·07 H_2O- 0·03; total 99·87.
34. Moldavite: Radomilice, Bohemia. A. Lacroix, 1932. Analyst, F. Raoult; also TiO_2 0·74, MnO 0·06, H_2O+ 0·10, H_2O- 0·05; total 100·36.

35. Moldavite: Třebíč (= Trebitsch), Moravia. A. Lacroix, 1932. Analyst, F. Raoult; also TiO_2 0·72, MnO 0·09, H_2O+ 0·11, H_2O- 0·05; total 100·15.
36. Moldavite: Lhenice, Bohemia. R. Nováček, 1932. Also TiO_2 0·32, MnO 0·07, H_2O- 0·02; total 100·37.

For the specially interesting australites complete data are unfortunately lacking. The few published determinations of both specific gravity and refractive index (but without chemical analysis) made on the same sample of material are assembled in table II. These are plotted, together with the values in table I, on fig. 2. Additional determinations of *d* and *n* made on tektites from other regions are also given in table II; but, to avoid overcrowding of the diagram, these have not been plotted. Several published analyses of australites are, however, accompanied by specific gravity determinations. The silica percentages of these, together with those for a few tektites from other regions, are listed in table III (but again not plotted).

TABLE II. Specific gravity and refractive index of australites and of tektites from other regions (from the literature).

Locality.	Sp. gr.	n_{Na}.	*K*.	Reference.
A. Mt. William, Victoria	2·380	1·5002	0·2102	Lacroix, 1929, 1932
B. Australia	2·386	1·4981	0·2088	Ježek & Woldřich
C. Mt. William, Victoria	2·393	1·504	0·2106	Tilley
D. Hamilton, Victoria	2·415	1·5043	0·2088	Lacroix
E. Mt. William, Victoria	2·443	1·520	0·2128	Tilley
F. Australia	2·453	1·519	0·2116	Tilley
G. Charlotte Waters, Central Austr.	2·458	1·5178	0·2107	Lacroix
Other regions.				
Moldavite: Radomilice, Bohemia...	2·342	1·4879	0·2083	A. Lacroix, 1929, p. 288; 1932, p. 203. (See also table I and Ježek & Woldřich, 1910.)
,, Slavice, Moravia ...	2·345	1·4908	0·2093	
,, ,, ,, ...	2·345	1·4928	0·2101	
,, České Budějovice ...	2·350	1·4948	0·2106	
Hai-nan, south China	2·421	1·5065	0·2092	
Cambodia, Indo-China	2·424	1·5079	0·2095	
,, ...	2·425	1·5092	0·2000	
Ban-Don-Phay, Cambodia ...	2·425	1·5081	0·2095	
Smach, Cambodia	2·428	1·5092	0·2097	
Cambodia, Indo-China	2·428	1·5102	0·2101	
Between Kantoum and Dek-Tô, Annam	2·438	1·5102	0·2093	
Mt. Moeriah, Java (black)	2·51	1·5241	0·2088	
,, ,, (white) ...	2·512	1·5305	0·2111	

TABLE III. Silica percentage and specific gravity of australites and of tektites from other regions (from the literature).

Locality.	SiO_2.	Sp. gr.	Reference.
Uralla, New South Wales	68·91	2·459–2·482	J. C. H. Mingaye, 1916
Upper Weld, Tasmania	69·80	2·454	W. H. Twelvetrees, 1906

Locality.	SiO_2.	Sp. gr.	Reference.
Coolgardie, Western Australia	70·62	2·454	E. J. Dunn, 1908
Between Everard Range and Fraser Range, South Australia	71·22	2·433	F. E. Suess, 1900
Mount Elephant, Victoria	71·38	2·44	R. H. Walcott, 1898
Kalgoorlie, Western Australia	71·65	2·47	E. S. Simpson, 1902
Mount Elephant, Victoria	72·39	2·427	H. S. Summers, 1909
Central Australia	73·40	2·47	R. H. Walcott, 1898
Pieman, Tasmania	73·59	2·428	W. H. Twelvetrees, 1906
Wimmera, Victoria	73·70	2·47	Selwyn & Ulrich, 1866
Hamilton, Victoria	76·25	2·398	H. S. Summers, 1909
Charlotte Waters, Central Australia ...	76·94	2·407	J. C. H. Mingaye, 1916
„ „ „ „ ...	77·15	2·395	„ „
Peake Station, Lake Eyre, South Australia	77·72	2·385	H. S. Summers, 1909
Other regions.			
Dendang mine, Billiton	70·30	2·4395	E. Dittler, 1933
Polo, prov. Bulacan, Philippine Islands ...	70·88	2·441–2·448	T. Hodge-Smith, 1932
Trebrung, Dendang, Billiton	70·92	2·447	F. E. Suess, 1900
Lura mine, Dendang, Billiton	71·14	2·43	R. D. M. Verbeek, 1897
Billiton, Dutch East Indies	74·30	2·503	P. van Dijk, 1879
Tetilla, Popayan, Colombia	76·37	2·310	T. Döring & O. Stutzer, 1928
Skreje, Moravia	77·78	2·3667	F. E. Suess, 1914
Kozichowitz, Trebitsch, Moravia	81·21	2·35	F. v. Hauer, 1880

Finally, in table IV are collected together a few data relating to glasses from meteorite craters and from the Libyan Desert. As seen on the plotted diagrams (figs. 1 and 2) these do not fall well in the series with the true tektites. The low specific gravity is here obviously due to the presence of bubbles in the glass, and the high refractive index of the black glass possibly to the richness in iron.

TABLE IV. Data for silica-glass from meteorite craters, Darwin glass, and from the Libyan Desert.

	Locality.	SiO_2.	Sp.gr.	*n*.	*K*.
I.	Black glass: Henbury, Central Australia	68·88	2·31	1·545	0·2359
II.	Darwin glass: Mt. Darwin, Tasmania ...	86·34	2·296	(1·474)	(0·2065)
III.	Black glass: Wabar, Arabia	87·45	2·24	1·500	0·2232
IV.	Darwin glass: Mt. Darwin, Tasmania ...	88·76	2·2921	(1·479)	(0·2088)
V.	„ „ „ „ ...	89·81	2·2845	(1·477)	(0·2087)
VI.	„ „ „ „ ...	—	2·275	1·4790	0·2105
VII.	White glass: Wabar, Arabia	92·88	2·10	1·468	0·2229
VIII.	Silica-glass, Libyan Desert	97·58	2·206	1·4624	0·2094
IX.	Lechatelierite: Meteor Crater, Arizona ...	(98·63)	2·10	1·460	0·2190
X.	Pure silica-glass (artificial)	100	2·203	1·45845	0·2081

I, L. J. Spencer, 1933; analyst, M. H. Hey; also Fe_2O_3 8·46, FeO 7·92, &c. III, ibid.; also Fe_2O_3 0·28, FeO 5·77, &c. II, IV, V, T. W. E. David et al., 1927; the optical values are calculated from the specific refractivity of the normative

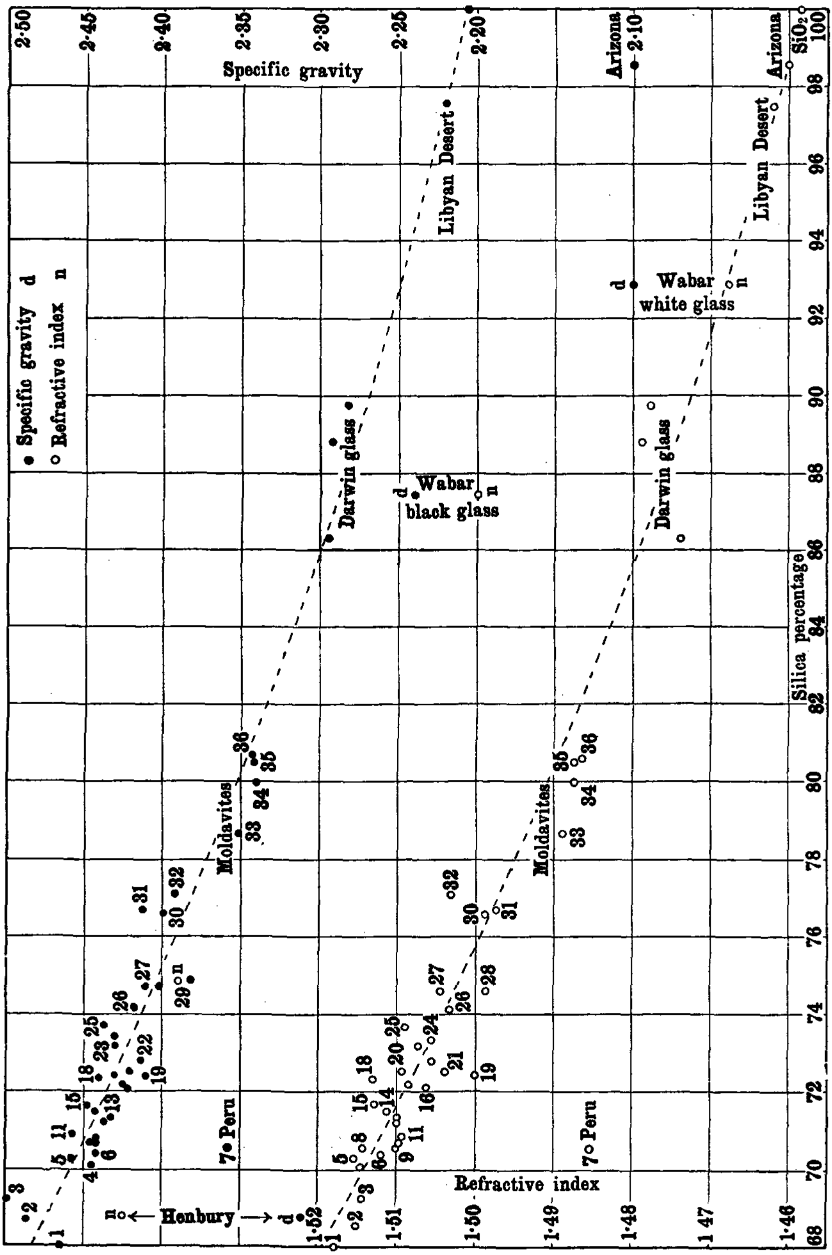

FIG. 1. Plot of specific gravity and refractive index against silica percentage. (Key to numbers on fig. 2.)

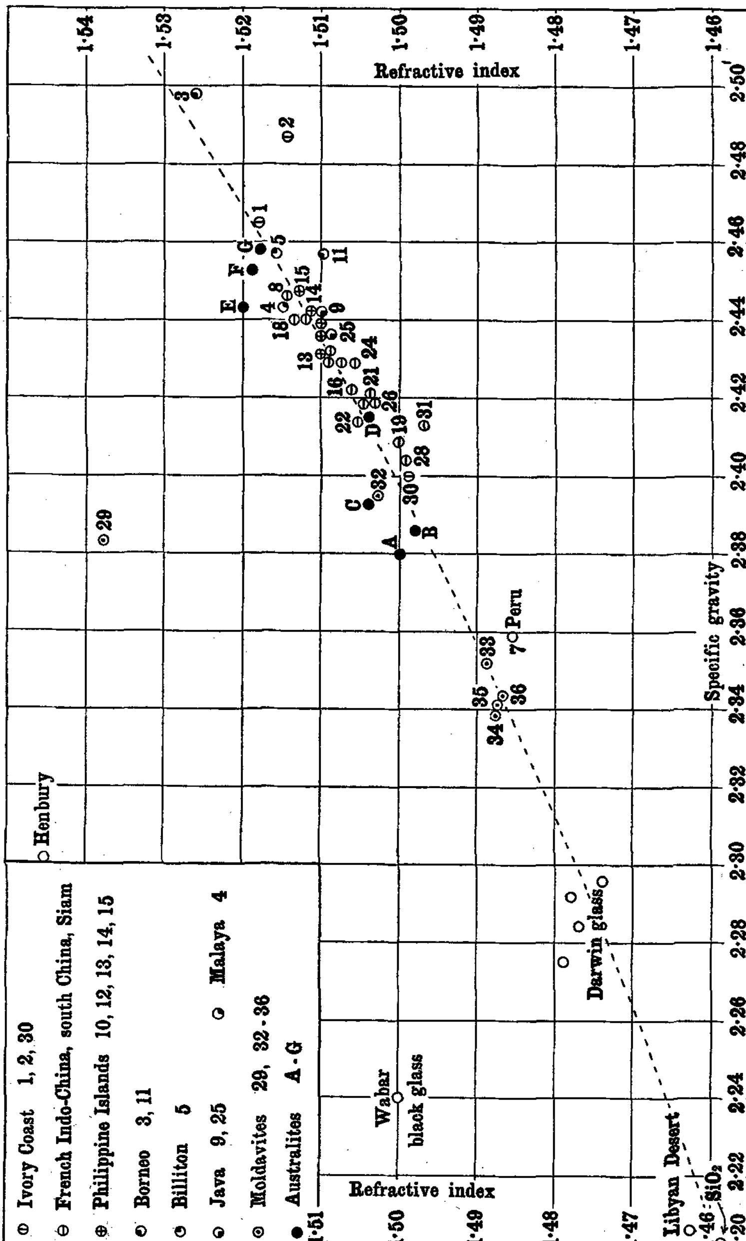

FIG. 2. Plot of specific gravity against refractive index.

Nos. 6, 16, 17, 18, 20–24, 28, 31 from French Indo-China; nos. 8, 26, 27 from south China; no. 19 from Siam. Wabar white glass and Arizona lechatelierite (with low sp. gr. due to bubbles) fall off this diagram.

minerals and the specific gravity. Direct measurements made on two other specimens gave the higher values *n* 1·486 and 1·497. VI, A. Lacroix, 1932, p. 203. VII, L. J. Spencer, 1933. VIII, P. A. Clayton and L. J. Spencer, 1934. IX, A. F. Rogers, 1930; silica percentage from analysis of altered sandstone, G. P. Merrill, 1907. X, R. B. Sosman, International critical tables, 1929, vol. 6, p. 341.

Darwin glass from Tasmania.

Darwin glass from the neighbourhood of Mount Darwin, near Macquarie Harbour, on the west coast of Tasmania, was described by F. E. Suess (1914, p. 98) and placed by him amongst the tektites with the special name 'queenstownite'. It is quite distinct from the tektites (australites) found at several places in the northern part of the island. More recently Suess (1933 a, p. 118; 1933 b, p. 857; 1936, p. 136; footnotes) and H. Michel (1939) have agreed that it should be classed with the silica-glass of meteorite craters. This glass is found only as small, broken, and worn fragments. It occurs abundantly ('thousands of tons', H. Conder, 1934) in glacial deposits and has evidently undergone some transportation. Much of the material is vesicular and slaggy, and has very much the appearance of the abundant silica-glass from the meteorite craters at Wabar in Arabia. Small, clear fragments are sometimes of a greenish-yellow colour, and these closely resemble the silica-glass of the Libyan Desert. David, Summers, and Ampt (1927, p. 173) mention that 'some specimens showed a number of minute black specks'. Such specimens are, however, rare, and the black specks are metallic spheres attracted by a magnet (Spencer, 1933 d). Sandstone, quartzite, and dune sands occur in the vicinity, and we can safely conclude that these 'tektites' at least were produced by the fusion of siliceous terrestrial materials in the intense heat developed when a large iron meteorite struck the earth's surface. No traces of meteorite craters or meteoritic iron have been found (nor specially searched for) at the locality; but these would be easily obliterated by glacial action, while fragments of the resistant silica-glass have survived.

Silica-glass from the Libyan Desert.

The silica-glass of the Libyan Desert differs in many respects from the tektites proper, and like them its origin presents a difficult problem. No clues have been suggested. Since Mr. P. A. Clayton's discovery of the glass in the Sand Sea in December 1932, I was privileged to join a special expedition of the Survey of Egypt to the area in December 1934. The glass was found between latitudes 25° 2′–26° 13′ N. and longitudes 25° 24′–25° 55′ E., in a more or less oval area measuring about 130 km.

N.–S. and 53 km. E.–W. The locality has since been visited and material collected by Mr. W. B. K. Shaw[1] in 1935 and by Major R. A. Bagnold[2] in 1938. Mr. Shaw also showed me a small, wind-worn flake of the glass with chipped surfaces which he had found inside the Gilf Kebir at 23° 2′ 4″ N., 26° 6′ 16″ E., 240 km. S. by E. of the centre of the silica-glass area; and Mr. P. A. Clayton saw a small piece of the glass that had been collected by Count Almásy at Abu Ballas (= Pottery Hill), 24° 26½′ N., 27° 39′ E., 225 km. ESE. of the area. These isolated pieces had no doubt been transported by Arabs or prehistoric man.

An old and long-disused camel track crosses the southern end of the silica-glass area, going from the oasis of Kufara (Italian, Cufra) in Cyrenaica to Abu Mungar in Egypt. Here an old camel bell was found in December 1934. The former sultans of Wadia had often attempted to establish a connexion with the Nile valley. In 1810 a caravan attempting to reach Dakhla perished of thirst. In 1846 another unsuccessful attempt was made under the leadership of one Hadji Huceyn (Hussein), who related to F. Fresnel[3] that in 1846 at two or three days out from Kufara there were seen traces of an ancient route and a great quantity of fragments of glass. P. Borchardt,[4] to whom I am indebted for this reference, has suggested that this material might have been sherds of glazed pottery. No pottery of any kind was found in December 1934 in the silica-glass area, but associated with the broken and flaked pieces of glass there are many quartzite implements, sandstone querns, and broken ostrich shells. These date back long before the Egyptian dynasties; and a search with Mr. A. Lucas in the Cairo Museum of Antiquities showed none of the glass amongst the variety of ornamental stones used by the ancient Egyptians.

The accompanying map (fig. 3) and photographs (pl. XVI) will give some idea of the peculiar configuration of the area. The parallel series of high dunes rests on an appreciably level plain of Nubian sandstone, which is exposed in places and is then usually silicified to a quartzite. But most of the surface in the corridors or 'streets' (2–3 km. wide) between the dunes is covered with gravel and reddish weathered debris, or sometimes a fine white sand, and is very much like a speedway track.

[1] W. B. K. Shaw, Geogr. Journ. London, 1936, vol. 87, p. 208. M. H. Mason, The paradise of fools. London (Hodder & Stoughton), 1936, pp. 231–233.

[2] R. A. Bagnold, Geogr. Journ. London, 1939, vol. 93, pp. 286, 293.

[3] F. Fresnel, Mémoire sur le Waday. Bull. Soc. Géogr. Paris, 1850, ser. 3, vol. 13, pp. 82–83.

[4] P. Borchardt, Petermanns Geogr. Mitt., 1929, vol. 75, p. 304. See also E. Behm, ibid., 1862, Ergänzungsheft no. 8, p. 51.

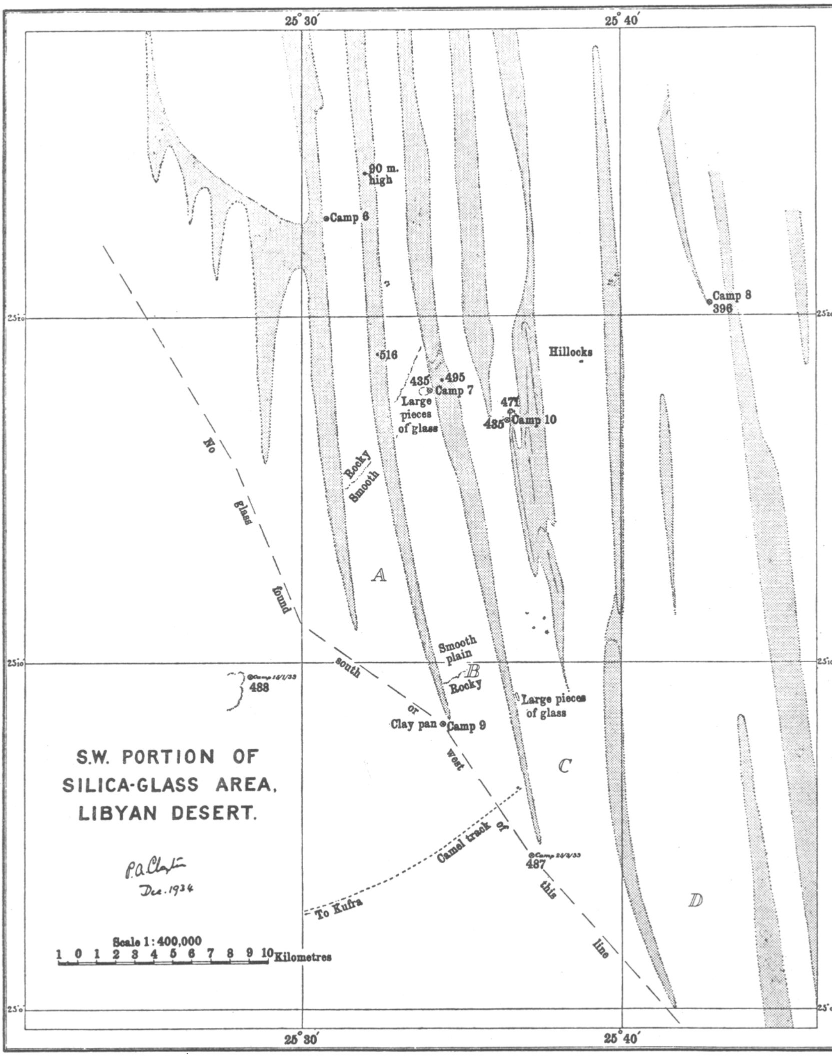

FIG. 3. Map of the SW. portion of the silica-glass area, Libyan Desert. Reduced, with permission of the Director, from the map published in 1935 by the Survey of Egypt. Heights above sea-level in metres.

The yellow sand with rounded grains forming the dunes is not seen in the streets, and the edges of the dunes are perfectly sharp, as if tidied up with a broom. The dunes are up to 300 feet high and they extend from north to south for more than 200 miles. Each dune, on a base 1–2 km. wide, is a complex of ridges with slopes of 28° on the eastern side and not so steep on the western side. Only one or two small pieces of the silica-glass were found on the dunes, and then in company with stone implements, suggesting that they had been transported by prehistoric man. The glass is found in the streets, small pieces loose on the surface and the larger pieces only partly embedded. A pit (pl. XVI, fig. 4), 2 metres in diameter, was dug near camp 7 in reddish sandy loam down to large blocks of Nubian sandstone at a depth of 2·45 m. The excavated material was sieved and only ten quite small pieces of glass, some of them flaked, were found down to a depth of 1·18 m. Small quartz pebbles and fragments of sandstone were abundant.

The glass was found most abundantly in the neighbourhood of camp 7 (25° 17′ 54″ N., 25° 34′ 0″ E.) in street B. A piece weighing 6030 grams (13¼ lb.) was found 5 km. south of camp 7 and is now in the mineral collection of the British Museum. The largest piece, weighing 7¼ kg. (16 lb.), and a clear piece of a dark green colour (5¼ kg.) were found on the west side of street C at 8 km. from the south end of dune B–C (25° 9′ N., 25° 36′ E.) (fig. 6); these are now in the Geological Museum at Cairo. Proceeding outwards from this portion of the area less and less glass is found and the pieces are progressively smaller. The roughly oval area (130 × 53 km.) over which glass has been found reminds one of the two areas in southern Bohemia and western Moravia in which moldavites are found.

At several places many broken pieces of glass were found in small patches (fig. 5); these pieces often had the form of flakes and were accompanied by stone implements and crude 'spear-points' of glass. One such patch with a large stone in the centre presented quite the appearance of a workshop. At another spot, on an area of 2 × 2 yards, 111 broken fragments of glass were counted, but here no distinct flakes. At 24 km. south of camp 8, in street D, sixty quartzite axes up to 10 inches in length and of a palaeolithic type were found lying about with their wind-worn surfaces uppermost.

The lumps of glass are irregular in shape and range in weight from a few grams up to 7¼ kg. Smaller rounded bits are not readily distinguished at sight from small pebbles and grains of clear quartz. All of them, including also flakes and worked implements, are much pitted and wind-worn by sand blasts. Some specimens show deep conical pits which may pass into tubular cavities and sometimes even penetrate the specimen (pl. XVII, fig. 7; and Min. Mag., vol. 23, p. 507, fig. 4).

Similar cavities were seen in limestone on the Cretaceous plateau above Hez in the Bahariya oasis, where they have been formed by the whirling action of sand grains on a pitted surface, in much the same way that pot-holes are formed by pebbles under water.

The clearest pieces of the pale greenish-yellow glass contain a few minute bubbles. As these increase in number the material becomes cloudy to white and opaque in the mass. Larger bubbles are irregular in outline and up to ½ mm. across; smaller ones (down to 1/100 mm.) are round, oval, or pear-shaped (fig. 9). A few slabby pieces show a silvery sheen on the flat surface, due to the presence of flattened bubbles up to 1 mm. across and 1/20 mm. thick (figs. 10 and 11). Several specimens show brown streaks and parallel bands in the paler coloured glass. In thin section these show as a cloud of fine dust, or at times are not at all visible. X-ray photographs of these darker portions taken by Mr. F. A. Bannister yielded only two broad bands characteristic of silica-glass.

Small ($\frac{1}{10}$–$\frac{1}{2}$, the largest 1 mm.) white spherulites are seen in many specimens, usually singly (fig. 8), but sometimes in strings and clusters. These consist of cristobalite (not quartz). They have a specific gravity of 2·35, low birefringence, and index of refraction less than that of Canada balsam, and Mr. Bannister's X-ray photograph showed the cristobalite pattern.

The results of a new chemical analysis made by Dr. M. H. Hey in 1935 on material collected by me in 1934 are given in table V, together with his earlier analysis made in 1933 on material collected by P. A. Clayton.

TABLE V. Chemical analysis of silica-glass from the Libyan Desert. (Analyst, M. H. Hey.)

	I.	II.	Mean.	1933.
SiO_2	97·97	98·44	98·20	97·58
TiO_2	0·21	0·25	0·23	0·21
Al_2O_3	0·91	0·49	0·70	1·54
Fe_2O_3	0·54	0·53	0·53	0·11
FeO	0·24	—	0·24	0·23
NiO	0·032	0·016	0·02	trace
MnO	—	—	—	trace
MgO	0·01	0·01	0·01	trace
CaO	0·05 ?	0·30	0·30	0·38
Na_2O	0·33	—	0·33	0·34
K_2O	0·02	—	0·02	nil
H_2O+(110°) ...	0·03	—	0·03	0·05
H_2O- ...	0·03	—	0·03	0·05
Total	—	—	100·64	100·49

Spectroscopic analyses of the glass have been kindly made by several persons to whom I had supplied material. Professor Alfred Fowler, of London, found Mg and an absence of Al. Professor V. M. Goldschmidt, of Oslo, in work which was not completed before he left Göttingen, found no indications of impurities that might give a clue as to the origin of the material. The late Mr. Hugh Ramage, of Norwich, in the flame spectrum of the 2·3 % residue [no doubt as sulphates], after dissolving the glass in HF and H_2SO_4, identified lines of Fe, weaker lines of Ca, Sr, Mn, Cu, Ag, Li, Na, K, and only just visible lines of Pb, Ni, Ga. Mr. Frank E. Chapman, on leave from the Government Chemical Laboratory at Perth, Western Australia, and working in the Mineral Department of the British Museum, identified Mg, Cu, Al, Ba, Ca, Fe, Pb, Mn, Ag, Si, Li, Zn, Ti, Ni, Cd in the arc spectrum of the residue after dissolving the glass in HF and H_2SO_4. In a spectrogram of the untreated glass many of the lines are masked by the large amount of silica present. Dr. E. Preuss, of Jena (1935, pp. 406, 410), found Cr_2O_3 0·0006 %, and Ni if present must be less than the determinable amount of 0·001 %. This makes (with O and H) a total of 22 chemical elements found in the silica-glass from the Libyan Desert.

The red loamy sand, still adhering to larger specimens of the glass that were found partly buried, was examined by Dr. M. H. Hey, and found to contain much calcium and magnesium carbonates, some gypsum, ferric oxide, and clayey material, together with rounded grains of quartz with a red powdery coating. The fine white sand collected in street A consists of small angular grains of quartz, ¼ mm. and less across.

Another form of silica-glass was found at a few places in the Sand Sea, but this time only on the dunes. This—lightning tubes or fulgurites—has the form of thin-walled tubes, glazed inside and with partly fused grains of quartz adhering to the outside. Blackened sticks projecting about 3 inches above the sand attracted attention because of the total absence of any vegetation. These were often surrounded on the surface of the sand by a number of broken pieces of blackened tube, each also about 3 inches in length, which had evidently been broken off by the wind when sand was removed. One fulgurite was dug out to a depth of 27½ inches without reaching the end, while the broken pieces found around on the surface totalled 6 feet 2 inches in length. A micro-section of the glass shows it to be full of bubbles, mostly round and some elongated. The glass is isotropic and colourless with grey-brown clouds and streaks.

There can be no possible connexion between this form of silica-glass found on the dunes and the lumps of glass found in the streets. A special look-out was kept for meteorites in the desert, but none was found. Any depressions (such as clay pans) were examined in the hopes that they might prove to be meteorite craters. Publication of the above notes has been delayed, now for five years, in the forlorn hope that some clue might turn up to help solve the mystery of the silica-glass of the Libyan Desert.

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EXPLANATION OF PLATES XVI AND XVII.

Silica-glass from the Libyan Desert.

(Photographs (figs. 4–6) by L. J. Spencer; photomicrographs (figs. 8–11) by D. L. Williams, Mineral Department, British Museum.)

FIGS. 1–3 in the text.

PLATE XVI, FIG. 4. Pit dug to bed-rock at camp 7, street B. Dune B–C in the distance.

FIG. 5. Lumps and broken flakes of silica-glass (white), with darker sandstone fragments. Near camp 7, street B.

FIG. 6. Silica-glass and quartzite flakes collected on the west side of street C, 8 km. from the south end of dune B–C.

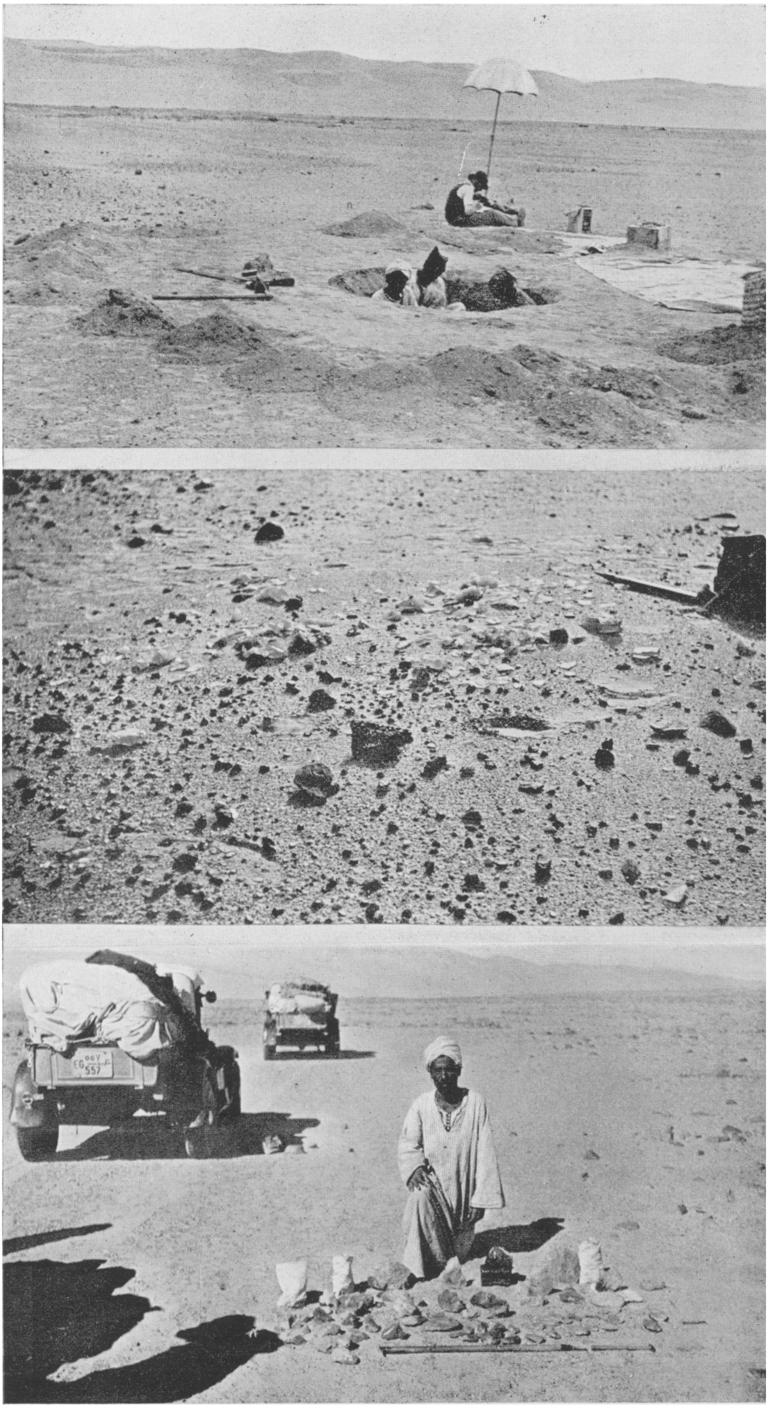
PLATE XVII, FIG. 7. Silica-glass showing tubular cavities with conical end (rod projecting from one). An old break in the direction of the tubes shows the inside of the tubes with a different type of erosion. B.M. 1935,83. $\times \frac{4}{5}$.

FIG. 8. Spherulites of cristobalite in clear glass. B.M. 1935,141. $\times 16$.

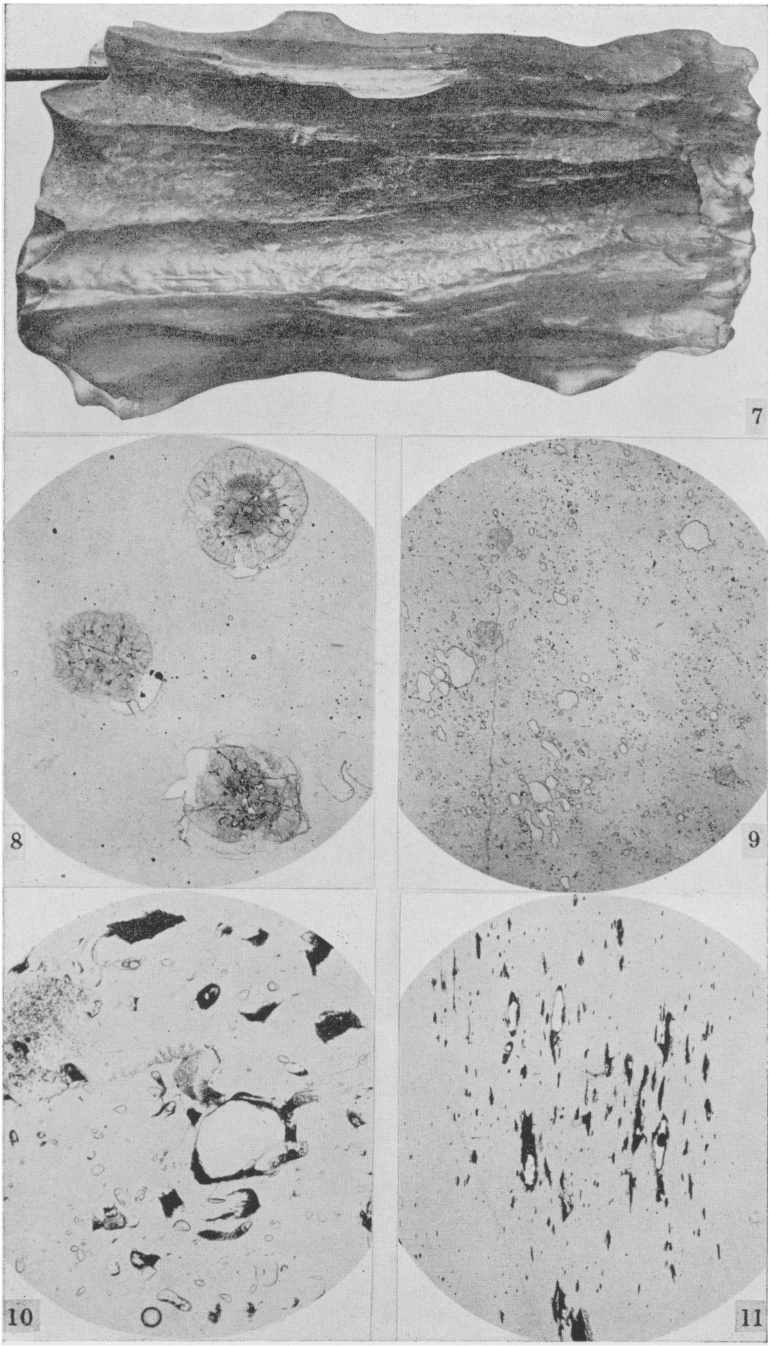
FIG. 9. Abundance of bubbles in cloudy glass, opaque white in the mass. B.M. 1935,145. $\times 16$.

FIG. 10. Flat bubbles in white translucent glass with silvery sheen on slabby surface. Section parallel to this surface. B.M. 1935,147. $\times 16$.

FIG. 11. Ditto. Section perpendicular to this surface. B.M. 1935,147. $\times 16$.



L. J. SPENCER: SILICA-GLASS FROM THE LIBYAN DESERT.



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