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HAY-SILICA GLASS FROM GNARKEET, WESTERN VICTORIA.

By George Baker, Honorary Associate in Mineralogy, and Alfred A. Baker, Honorary Associate in Palaeontology, National Museum of Victoria.

CONTENTS.

ABSTRACT.

The burning of two adjacent haystacks in the Parish of Gnarkeet, Western Victoria produced approximately 16 tons of hay-silica glass from some 325 tons of pasture plants. The hay-silica glass resulted largely from fusion and melting of the opal phytoliths contained in silica-accumulator species of plants. The opal was fused in the presence of relatively abundant fluxes provided by K_2O, Na_2O, CaO and MgO contained in plant ash.

INTRODUCTION.

Two large stacks of baled hay, 15 feet apart on a property in the Parish of Gnarkeet, near Lismore, Western Victoria, were burnt to the ground on 7th March, 1961.

The haystacks were 4·6 miles in a direction 2° south of east, from Lismore Post Office, and were near the junction of Calvert's Road and the Hamilton Highway. The grid reference is 329.162 on the 1″ = 1 mile Military Survey Map of Lismore (1138 Lismore, 1943).

The two haystacks, only a few feet from the main highway boundary fence (Fig. 1), were constructed of 13,000 wired bales of hay totalling 325 tons in weight. The meadow hay was grown on Newer Basalt soil.

Pasture Plants in the Haystacks.

The principal constituents of the stacks were barley grass (*Hordeum maritimum*), rye grass (*Lolium perenne*), and subterranean clover, with small amounts of oaten straw (*Avena sativa*) and lesser quantities of a few other plants.

Approximate percentages of plant species in the paddock pastures cut and baled during the 1960–1961 season have been estimated by P. Lang, B.Agr.Sc., Ph.D., of Lismore, Victoria as follows:—

TABLE 1.

Approximate proportions of plant species constituting the original meadow hay, Gnarkeet.

Plant Species.	East and West Paddocks (totalling 150 Acres).	North Paddock (12 Acres cut).
	%	%
Subterranean clover	up to 30*	10
Barley grass	50	80
Rye grass	up to 20	5
Spear-thistles	few	..
Oaten straw..	nil	5
Capeweed	nil	trace

* The percentage of clover in the haystacks is likely to have been much lower due to the late date of harvesting (2nd December, 1960) and the habit clover has of wilting away at that time of the year, so that it was beneath the reach of the mower. The haystacks were roughly thatched with oaten straw.

The assemblage of plant species shown in Table 1 constitutes a highly gramineous hay of low nutritive value and high fibre content which is normally concomitant with a relatively high content of plant opal; this is borne out by the large amount of hay-silica glass left in the residues from burning of the haystacks.

Burning of the Haystacks.

Burning of the two haystacks occurred towards the end of the summer season, at 2 o'clock one morning. All combustible constituents were burnt except for small bundles of carbonized plant stalks encased in "rolls" (Plate II.) of sintery and vesicular to scoriaceous hay-silica glass (Plates II., IV.–VII.) up to 2 feet or so in size, which resulted from fusion of the opal phytoliths (plant opal) contained more particularly in species of the gramineae.

The cause of the fire was unknown; the weather conditions at the time were fine and mild, with no wind. Prior to the fire there had been a relatively prolonged, warm to hot, dry period. Between the time mowing commenced on 2nd December, 1960 and the end of stacking on 5th February, 1961, there had been only 0·13″ of rain. No lightning nor meteoritic phenomena were observed, and there had been no burning off nor naturally caused grass fires in the neighbourhood, while no other haystacks in the district were destroyed by auto-combustion.

Residues on the Burnt-out Sites.

The exposed residues on the sites of the burnt-out stacks consisted of abundant loose, fine, powdery, white to grey ash with partially buried cakes and slabs, and protruding pinnacles of hay-silica glass, relatively evenly distributed over the areas of the two adjacent sites (Plate I.). These products rested on thin layers of medium brown and blackened carbonaceous ash that were hidden from view by the overlying bed of lighter coloured ash and hay-silica glass. The soil beneath the residues was derived from Newer Basalt and was blackened in contact with the ash in many places.

Areas of Burnt-out Haystacks.

The sites of the two burnt stacks of baled hay (Plate I.) were near the fence dividing Mr. H. A. Bell's property from the south side of the Cressy–Lismore portion of the Hamilton Highway in the vicinity of Gnarkeet (Fig. 1).

The two sites differed in length and width, the smaller, more northerly of the two, nearest the highway fence, being 99 feet by 35 feet, the larger one, 15 feet away on the southern side being 127 feet by 40 feet. The longer dimensions of each site trended practically east-west. A row of twelve cypress trees (*Cupressus macrocarpa*) 30 feet high were 7 feet from the northern boundary of the smaller northern site, and another row of twelve cypress trees lined the southern boundary of the larger southern site, being 8 feet from its edge. The western edge of the longer southern site extended 28 feet further west than the smaller northern site and was 15 feet distant from a group of sugar gum trees (*Eucalyptus cladocalyx*) up to 60 feet high. The eastern ends of both sites were in line and six feet away from a group of several sugar gum trees and six cypress trees. These measurements were taken to the trunks of the trees, so that their branches were much closer to the original haystacks and could have touched or overhung them in places.

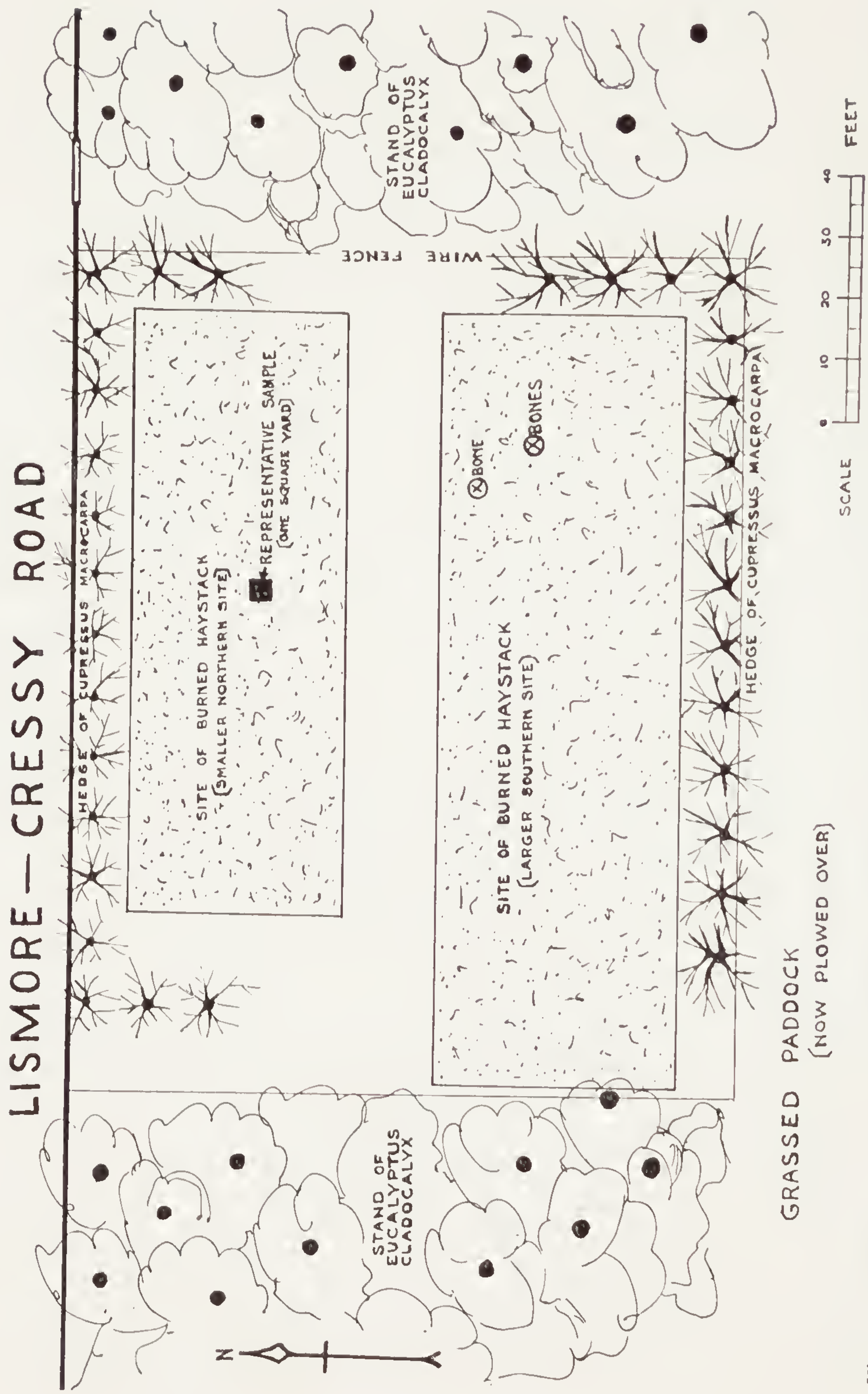

Figure 1.—Sites of burnt-out haystacks relative to surrounding trees and fences. Showing area sampled for analysis and location of calcined bones.

The fire was confined to the actual sites of the two stacks. This is evidenced by (i) the presence of unburnt grass and fence posts all around the perimeter of the sites, and (ii) the fact that the cypress and gum trees were scorched from top to bottom only on their inner sides (i.e., the sides directed towards the sites of the fire). One sugar gum tree situated a little closer to the fire (Plate I., right-hand side) and near the southwest corner of the larger southern site (Fig. 1) was burnt rather more severely than any of the other scorched trees. The bark was incinerated on the side that faced the fire and the surface of the trunk was partially carbonized. The residue of clinker at the base of the trunk of this tree was up to 4 inches thick and vesicular, but much more massive than the bulk of the generally scoriaceous to sinter-like clinker covering the rest of the burnt-out haystack sites. This particular part of the glassy residue occupied an area of some 3 to 4 feet square, and was in direct contact with the base of the tree trunk. It contained fragments of carbonized wood up to 2½ inches by 1 inch in size, these representing remnants of fallen branches that became embedded in the hay-silica glass but were not completely burnt to ash.

A few boulders of brownish-grey vesicular basalt on the sites were partially blackened, but not fused.

Thickness, General Characteristics and Amounts of the Residues.

The principal constituent of greatest interest among the residues from the fire was the hay-silica glass (Plates II. to VIII.).

The associated fine ash was not investigated in any detail because it had been too much affected by the weather at the time of investigation two months after the fire.

The Newer Basalt soil at the sites was overlain by approximately 2 inches of moist, fine, carbonaceous powder and a little blackened soil covered with a layer ⅜ inch thick of medium brown ash. Above this, an uppermost layer of from 8 inches to 12 inches in depth of white to light grey ash and sintery to clinker-like hay-silica glass formed the bulk of the residues. In this rather irregular layer, the fine ash varied from 2 inches to 6 inches in depth according to the irregularity of the layer of glassy residue on which it largely rested.

The total area covered by the residues was 8,545 square feet. An area of 3 feet by 3 feet representing the average spread and thickness of the residues was selected from near the centre of the smaller northern site (see Fig. 1). This was sampled of all its hay-silica glass content for weighing and calculation of the approximate quantity of glass produced by incineration of the two haystacks, assuming that little or none on the sites resulted from the scorching of nearby trees. The glass thus obtained ranged from micro-beads (see attached beads in Plate IV.) of 1 mm. average size to lumps, cakes and " rolls " (Plates II. and III.) up to 2 feet long by 1 ft. 6 in. wide and 1 to 2 inches thick.

The weight of the hay-silica glass residue recovered from this area of 9 square feet (and about 1 foot deep) was 37¼ lb. General inspection revealed a relatively even distribution of glass over the combined areas (8,545 square feet) of the two sites, and it has been estimated that the 325 tons of meadow hay constituting the two stacks yielded 15·8 tons of hay-silica glass. This is equivalent to nearly 4·9 per cent. of the original material forming the stacks.

It was impracticable to determine the quantities of the fine, powdery ash types produced by the fire, because the sites were not sampled until eight weeks after the burning of the haystacks. During this period, wind and a little rain had removed some of the lighter ash components; the glassy residue, however, was evidently unaffected to any noticeable degree by the effects of the weather.

*The Hay-Silica Glass.**

Size and shapes.

The hay-silica glass was formed into various shapes (Plates II. to VIII.). Small micro-beads averaging 1 mm. in diameter occurred both as free entities in the fine powdery ash, and attached to larger pieces of the glass (Plate IV.). Broken pieces of these are very much like the so-called volcanic shards recorded from soils. Several spats, fingers and gobbets ranged in size from under half an inch across to forms three or four inches long, half to one inch wide, and half an inch thick.

Larger cakes, lumps, slabs and " rolls " (Plate II.) showed varying vesicular (Plate VII.A), scoriaceous, ropy, pinnacle, " stalagmitic " and irregular " drip " structures (Plates IV. to VII.). These types ranged in size from a few inches to two or three feet long. Some smaller fragments under ½ inch across and some of the micro-beads of the hay-silica glass were so highly charged with minute bubbles as to be pumiceous and they readily floated in water.

* The specimens of hay-silica glass described herein, and the bulk of the materials constituting the representative sample taken for study from the smaller northern site of the burnt-out haystacks, are all registered together as No. E.2741 in the collections of the National Museum of Victoria.

Alien substances.

The iron wire used in binding the bales of hay was still present, partly embedded in, partly protruding from some of the pieces of hay-silica glass, and sometimes partially rusted. Some of the iron wire had been fused, some acted as the site for accumulation of glass blebs (Plate VIII.) which ran as molten beads down upwardly directed pieces of the wire, and collected into botryoidal and other masses ½ inch to 2 or 3 inches across (Plates VII.B, VIII.).

In one part of the larger southern site, near its eastern end (see Fig. 1), a few calcined animal bones were located amid the residues from the fire (Plate IX.). Some of these bones were incorporated in the powdery ash, some were partially embedded in the hay-silica glass.

Occasional clots of friable soil up to 2 or 3 inches across, with dark brown crusts and lighter brown cores were embedded in parts of the hay-silica glass and the powdery ash. These, however, have evidently contributed little to the composition of the adjacent glass; none were noted in the area of glass sampled for chemical analysis.

The presence of partially fused iron wire and calcined animal bones no doubt means some local contamination of the hay-silica glass. Contamination by iron in close proximity to partly fused iron wire is made evident by reddish, greenish-yellow, and pale bluish-green colourations in localized areas of the glass.

Composition.

The greater part of the glass was formed from the melting and fusion of the numerous, colourless, minute opal phytoliths contained in the barley grass, rye grass and oats (cf. Baker, 1960a; 1960b; 1961) in the presence of fluxes (CaO, MgO, K_2O and Na_2O) contained in plant ash. It is light to dark grey in colour, becoming black in a few places where significant amounts of carbonized plant material are enclosed in the glass.

A chemical analysis (Table 1), reveals that the hay-silica glass is rich in alkalis and alkaline earths which make up approximately 29 per cent. of the constituents present. Silica is the most abundant constituent and there are significant amounts of phosphorus pentoxide and manganese.

The sample analyzed was made as representative as possible. It was selected from the total quantity of glass collected and weighed (37¼ lb.) from the centre of the smaller northern site. Several pieces of the glass taken at random from this field sample were broken up into smaller pieces, quartered, crushed to a powder and again quartered until the requisite quantity was obtained for chemical analysis. The sample so selected showed no obvious nor undue amount of contamination by metals from the iron wire, and was remote from the calcined bones found on the larger southern site.

Other plant-silica glasses, including hay-silica glass, straw-silica glass, grain-silica glass and wood-silica glass are listed in Table 2 for comparison. These are impure silica glasses produced from the burning of vegetation grown on different soils in different localities, where similar species may therefore secrete different quantities of opaline silica.

TABLE 2.

Chemical analyses of impure silica glasses formed from the natural incineration of silica-accumulator plants.

	1. %	2. %	3. %	4. %	5. %	6. %	7. %	8. %	9. %
SiO_2 ..	61·7	58·7	53·1	66·04	57·40	70·11	61·4	81·03	59·3
Al_2O_3 ..	1·16	1·31	1·17	1·55	1·81	0·48	..	2·99	1·3
Fe_2O_3 ..	0·83	0·26	0·37	0·59	0·59	0·72	5·8	0·58	0·3 (with FeO)
FeO ..	0·28	0·03	0·03	..	..	..	..	0·78	
CaO ..	6·77	9·42	10·93	6·00	8·56	4·94	10·3	8·21	8·2
MgO ..	4·88	4·59	5·50	3·80	5·56	3·36	2·9	1·15	4·8
K_2O ..	8·53	12·83	13·00	11·98	13·58	8·76	10·1	2·07	12·0
Na_2O ..	8·73	4·77	7·27	6·88	8·98	7·97	2·4	2·34	7·2
TiO_2 ..	0·19	0·02	0·02	..	..	0·04	..	0·34	0·1
MnO ..	0·30	0·18	0·24	..	..	0·11	..	trace	0·2
H_2O (+) ..	0·20	0·08	0·57	..	..	0·02	..	0·24 (with H_2O (−))	0·2 (with H_2O (−))
H_2O (−) ..	0·12	0·02	0·02	..	..	..	..		
P_2O_5 ..	5·66	7·21	6·67	..	..	1·03	7·2	0·24	6·4
C ..	0·25	0·20	0·30	2·69	3·16	1·88	..	..	0·2
CO_2 ..	none	none	none	..	..	..	..	..	none
SO_3 ..	trace	trace	0·21	..	..	..	..	none	trace
Cl_2 ..	0·08	0·03	0·22	..	..	..	..	trace	0·1
Li_2O ..	none	none	none	..	..	..	..	..	..
Total ..	99·68	99·65	99·62	99·53	99·64	99·42	100·1	99·97	100·3
O	0·02	0·01	0·05	..	..	..	..	..	..
	99·66	99·64	99·57	..	..	..	..	..	..

KEY:

1—Hay-silica glass, Gnarkeet, near Lismore, Western Victoria. Anal. P. J. Sinnott.

2—Hay-silica glass (sample "A"), Dookie Agricultural College, near Shepparton, North-Central Victoria. Anal. P. J. Sinnott.

3—Hay-silica glass (sample "B"), Dookie Agricultural College, near Shepparton, North-Central Victoria. Anal. P. J. Sinnott.

4—Straw-silica glass, O. B. Flat, South Australia. Anal. F. L. Dalwood (see Fenner, 1940).

5—Straw-silica glass, Compton Downs, South Australia. Anal. F. L. Dalwood (see Fenner, 1940).

6—Straw-silica glass, Ramona, California, U.S.A. Anal. N. Davidson (see Milton and Davidson, 1946).

7—Grain-silica glass ("pierres de foudre") resulting from the natural electrical fusion of grain ash (see Velain, 1878).

8—Wood-silica glass, formed from charcoal (boxwood) in the suction gas plant, Stawell, Victoria. Anal. F. F. Field (see Baker and Gaskin, 1946).

9—Generalized average of Australian hay- and straw-silica glasses Nos. 1 to 5.

Although sampling of the Gnarkeet hay-silica glass was so designed as to obtain a representative general sample for chemical analysis (Table 2, column 1), there are obvious macroscopic and microscopic variations from place to place in the glass. This is evident from (i) hand specimen inspection under a x10 pocket lens, (ii) from thin section examination under the higher powers of the petrological microscope, and (iii) from differences in refractive index determinations conducted on the glass from different parts of the burnt-out haystack sites.

Apart from visual colour differences in proximity to iron wire enwrapped by the glass, other parts are whiter due to the incorporation, and/or adherence, of non-volatilized fluxing materials from the plant ash. Thin sections reveal that many crystals of these substances are birefringent under crossed nicols of the petrological microscope, and that there has been variation in the degree of miscibility between them and the constituents of the melt from place to place; it is impracticable to determine how much of the salts of alkalis and alkaline earths, for example, are mechanically entrapped and how much has been absorbed and lies occult in the definitely glassy areas.

Thin sections also reveal variations in carbon content from place to place. Some pieces of the glass contain little or no carbon, others reveal several micro-fragments of carbonized plant remnants enclosed in the glass. On a macro-scale, included carbonized plant fragments are up to 2 or 3 inches across. (Plate VIII.)

Refractive index variations indicate a range in silica content in different specimens selected from various positions among the residues on the burnt-out sites, and sometimes within the compass of one and the same small fragment of the glass.

Some conception of the order of chemical variations within the hay-silica glass from one and the same burnt-out haystack site, is provided by comparison of columns 2 and 3 in Table 2. Here, specimens from different but not widely separated portions of the glass collected from the site of a burnt-out haystack at Dookie Agricultural College, near Shepparton, reveal differences of 5·6 per cent. in the silica content. The sample with less silica contains 2·5 per cent. more Na_2O, 1·5 per cent. more CaO and 1 per cent. more MgO. It also shows a little more K_2O and MnO, but rather less P_2O_5. Such variations are only to be expected across the site of a burnt-out haystack, in which the glass has been formed by non-controlled conditions under circumstances where—

(*a*) different species of plants of different composition become incinerated;

(*b*) the proportions of each species are unlikely to be precisely the same at all locations on the site;

(*c*) the plants present carry different proportions of opal phytoliths and other mineral matter;

(*d*) differential loss of more volatile constituents can arise from place to place;

(*e*) incomplete ignition of some of the plant matter results as a consequence of mechanical entrapment in the carbonized state;

(*f*) complete miscibility in all proportions does not everywhere occur, because of several factors preventing this—such as (i) differing composition of the plant ash which becomes incorporated in already molten glass, and (ii) greater or lesser opportunity to become mixed according to the length of time the plant ash was in contact with or incorporated in the molten glass;

(*g*) different quantities of alien matter became entrapped in different parts of the glass—e.g., such materials as the iron baling wire, small clots of soil, individual adventitious mineral particles from dust mechanically entrained with the hay, occasional animal bones, bird droppings, small pieces of rock fractured by heat from boulders used to anchor down thatching materials or tarpaulin covers and so on;

(*h*) variable refractoriness of substances entrapped in the glass.

Under such variable conditions as this, and because the precise compositions of the several types of plant species added to the haystack are unknown, added to the fact that it is impracticable to effect a mechanical separation of birefringent silicates, non- and partially fused opal phytoliths, and actual glass from one another for separate chemical analyses, it becomes difficult to assess—

(*a*) the quantity of birefringent silicates present;

(*b*) the quantity of actual glass present;

(*c*) the quantity of unfused more refractory substances;

(*d*) the amount of incorporated, incompletely volatilized plant substances remaining;

(*e*) the proportion of alkalis and alkaline earths that lie occult in the glass relative to their proportions occurring as mechanically entrapped non-melted, plant ash.

Hence it has not been practicable to assess the likely quantities of K_2O, Na_2O, CaO, MgO and P_2O_5, that were lost by volatilization under the circumstances of natural, non-controlled burning of haystacks in the field.

It is concluded that these impure silica glasses, arising from the burning of the pasture plants in haystacks, are generally rich in silica, alkalis and alkaline earths, poor in iron, alumina and water, and that they contain significant quantities of P_2O_5 and MnO. These features serve to distinguish them from other types of naturally occurring glasses (cf. Baker and Gaskin, 1946), and there is little doubt that their content of 50 to 60 per cent. and over of silica arises almost entirely from fusion of the opal phytoliths precipitated in silica-accumulator plants.

Refractive index, specific gravity and hardness.

The refractive index was determined by the Immersion Method, using sodium light.

One fragment of the Gnarkeet hay-silica glass gave $n_{Na} = 1{\cdot}520 \pm 0{\cdot}001$, but parts of the same fragment were a little above this value, other parts just below. This was evidently due to incomplete mixing of constituents, for the fragment revealed a partially fused boat-shaped opal phytolith with n_{Na} less than that of both the hay-silica glass and the immersion liquid. In the same refractive index liquid mount containing several fragments crushed from the hay-silica glass were a few freed opal phytoliths, one of which was a serrated rod, one a part of a sharp-pointed opalized plant hair, and one a thin plate of opal with traces of the cell wall structure from the epidermal portion of a gramineous plant fragment. These indicate that all parts of the burning haystacks were not subjected to precisely the same conditions, otherwise these phytoliths should also have fused and melted into the glass.

One crushed micro-bead 2 mm. in diameter gave $n_{Na} = 1 \cdot 510 \pm 0 \cdot 001$, with some of the glass slightly above and some a little below this value; no opal phytoliths or incorporated plant ash constituents were detected as separate entities among the fragments from this micro-bead of hay-silica glass.

Fragments of the glass tested from several vesicular and scoriaceous pieces gave an average n_{Na} of just under 1·510.

The specific gravity of the glass determined in the powdered state in distilled water at T = 21° C. was 2·53. Its hardness on Mohs' Scale of Hardness was determined as between 6·5 and 7.

The lustre of the glass is generally vitreous, varying in places to sub-vitreous.

Micro-structures.

Several pieces of the hay-silica glass were suited to rock sectioning techniques. Thin sections revealed isotropic, vesiculated, impure silica glass (Plate X.) containing birefringent small laths, granules and bunches of minute blade-like crystals of silicates of the alkalis and alkaline earths.

Occasional clusters averaging 0·3 mm. across of birefringent needles and/or sometimes ghost-like skeletal growths and more granular crystals, were commonly situated in the glass bordering some of the larger vesicles. The needles were approximately 0·08 mm. by 0·02 mm. in size. They extinguished at angles of up to 45 degrees under crossed nicols, showed low grey and yellow polarization colours of the first order, and had a higher refractive index than that of the glass in which they were embedded. Clusters of these crystals are shown in Plate X. Elsewhere occurred occasional wisps of carbonized plant remnants and a few partially fused and non-fused opal phytoliths.

The glass forming the walls of the larger vesicles 1 to 10 mm. across often revealed riddling with minute bubble cavities 0·01 mm. to 0·05 mm. in diameter.

The remnants of incompletely fused opal phytoliths were scattered sporadically through the glassy matrix. A few retained the forms possessed originally—more particularly smooth, rod-like types.

Particles of more highly refractory, birefringent mineral species little affected by the fire were uncommon and consisted principally of detrital quartz grains. They were evidently derived particles from the various adventitious substances mechanically entrained in the hay during mowing, raking, binding and stacking.

Parts of the glass were streaky in appearance (Plate X.A), largely from the presence of strung-out, minute particles of carbonaceous matter; such areas were a faint smoky grey-brown in colour compared with surrounding translucent more or less colourless glass.

CONCLUSIONS.

Glass can be generated from the burning of grass, but there are many variants in the circumstances of transition under field conditions. The ultimate composition of the glass will vary according to (i) the species composition of a haystack, (ii) the opal phytolith-flux substances relationships from place to place in one and the same or in different haystacks, and (iii) the opportunities for physical incorporation of non-fused fluxing substances in the silica glass formed by melting of the opal phytoliths. The opal phytolith content of the meadow hay as a whole depends not only upon the availability of silica to the plants from the soil on which they were grown, but also upon the silica-accumulator potentials of the different plant species. Plants grown on the same soil do not all secrete precisely the same quantities of silica in the form of opal phytoliths, neither do the same species of plants grown on different soils in widely separated regions.

Estimates of the amounts of impure silica glass residues formed from the burning of large quantities of stacked meadow hay containing a preponderance of high-silica-accumulator plants (e.g., barley grass) in the Gnarkeet district, show that approximately 5 per cent. of glass containing upwards of 62 per cent. of silica can result from the hay. A further, unassessed, amount of mineral matter remains in the unmelted condition as loose ash (not investigated in detail herein).

Although significant quantities of alkalis and alkaline earths contained in the original hay have been lost to the glass by (*a*) remaining in the non-fused ash, and (*b*) by volatilization, the residual glass is nevertheless rich in such components as K_2O, Na_2O, MgO and CaO, as well as in P_2O_5 and MnO. Little, if any, of these constituents were introduced from more refractory adventitious mineral matter mechanically entrained as dust particles in the original hay, or added from the soil on the sites of the haystacks.

The geological significance of this glass lies in the fact that older pieces of impure silica glass from previously burnt vegetation sometimes become buried for many years, and on exhumation by ploughing operations or by soil deflation, have been occasionally mistaken for (i) acid, vesicular, volcanic glass, (ii) fulgurites ("lightning tubes") and (iii) glassy meteorites (tektites). Their chemical composition serves to discriminate them from volcanic glass, while their form and chemical composition distinguish them from both the fulgarites and the glass bodies (tektites) that fell upon the earth in pre-historic times from an extraterrestrial source. (cf. Baker, 1957.).

One aspect of the significance of pieces of hay-silica glass as soil constituents, is that many of the so-called volcanic shards recorded in soils, are often of microscopic dimensions and hence may have been mistakenly identified. The source of these micro-shards need not necessarily be volcanic in entirety; the small pieces of glass recorded as volcanic shards resemble small fragments from the micro-beads of impure silica glass produced by the fusion of the opal phytoliths and fluxing substances contained in gramineous and other plant species. The distribution of micro-shards in various soils is more consistent with an origin from opal-phytolith fusion during scrub and grass fires, than with origin as micro-ejectamenta from volcanic vents. The further possibility is not overlooked, however, that a few micro-shardlike bodies might have resulted from the fusion of opal phytoliths by natural electrical discharges, especially as it has now been shown by one of us that opal phytoliths are ubiquitous in atmospheric dust.

The significance of the hay-silica glass from the meadow hay aspect is that the quantity of glass formed indicates that the opal phytolith content of plant feed for herbivorous animals can be undesirably increased by man through delaying mowing and stacking. Had the meadow pastures been mown three or four weeks earlier, the content of predominant, high silica-accumulating plant species would have been diluted by more abundant, more nutritious, less opal-bearing medicks and trefoils that had wilted down to such an extent, at the time of mowing, that they were below the reach of the mower.

The results of the various findings set out in this paper make it apparent that the quantity of impure silica glass produced from the burning of any one haystack, is likely to vary from locality to locality, and from time to time, according to the availability of silica from the particular soils on which the pasture plants were grown.

The meadow hay in the Gnarkeet area yielded 15·8 tons of hay-silica glass on burning of the haystacks. This glass was from vegetation grown on 162 acres of newer basalt soil, so that at least one ton of mineral matter that ultimately went to form the glass, was abstracted from each 10¼ acres of this type of soil which is situated in a climatically temperate region. Since the hay-silica glass contains nearly 62 per cent. of silica (SiO_2) by analysis, there has been approximately 135½ lb. per acre of silica abstracted from the Newer Basalt soils during the 1960 pasture growth season. This figure may be rather low in view of the fact that abundant fine, non-fused ash remained on the sites of the haystack fires, and this ash contained some unfused phytoliths as seen under the petrological microscope.

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Plate I.—General view of residues from burnt-out haystacks, near Gnarkeet, Lismore district, Western Victoria. Showing fringing sugar gum and cypress trees scorched on the sides facing the fire.

Plate II. (× 0·4). Close up view of sintery and scoriaceous to ropy "roll" of hay-silica glass encasing mass of carbonized plant fragments (in front of white paper placed at rear of specimen), and protruding above the level of the general crust of hay-silica glass (at point of pencil). Note two blowholes through carbonaceous residue, some of which has been subsequently removed by wind and rainwater.

Plate III. (× 0·4).—" Roll " of scoriaceous hay-silica glass inverted to show enclosed " nest " of carbonized stalks of gramineae, in places lightly attached to the glass. The apparent white colour of some carbonized grass stalks is due to the reflection of light from the surface of highly lustrous carbon containing fused opal.

Plate IV. (× 0·5).—Pinnacle of hay-silica glass showing gas vesicles and several attached micro-beads of the glass. Specimen *in situ* on the larger southern burnt-out site.

Plate V. (×0·5).—Partially collapsed pinnacle of hay-silica glass protruding above general level of the residues from the haystack fire. Note occasional micro-beads, vesicles, and scoriaceous to ropy structures. Specimen *in situ* on the smaller northern burnt-out site.

Plate VI. (× 0·5).—Relatively thin, irregular pinnacle of hay-silica glass with impressions of plant stalks (at left) and numerous, lightly attached remnants of carbonized gramineae stalks. Some minor protuberances are sharp and rough, others are rounded and smoother. Specimen *in situ* on larger southern burnt-out site.

A

B

Plate VII.—A. Section through lump of hay-silica glass showing highly vesicular character. Specimen orientated in position as found on the larger southern burnt-out site (approximately natural size).

B. Sintery to ropy hay-silica glass accumulated around remnants of iron wire used in baling the hay. (× 0·7).

Plate VIII. (× 0·9).—Hay-silica glass from base of sugar gum tree near southwest corner of larger southern burnt-out site. Showing embedded fragment of charcoal (bottom left) and protruding remnants of iron wire with occasional blebs of attached hay-silica glass.

Plate IX. (× 0·5).—Calcined animal bones (white) *in situ* amid residues from larger southern burnt-out haystack. Some of the bones lie in carbonaceous ash, some are embedded in hay-silica glass.

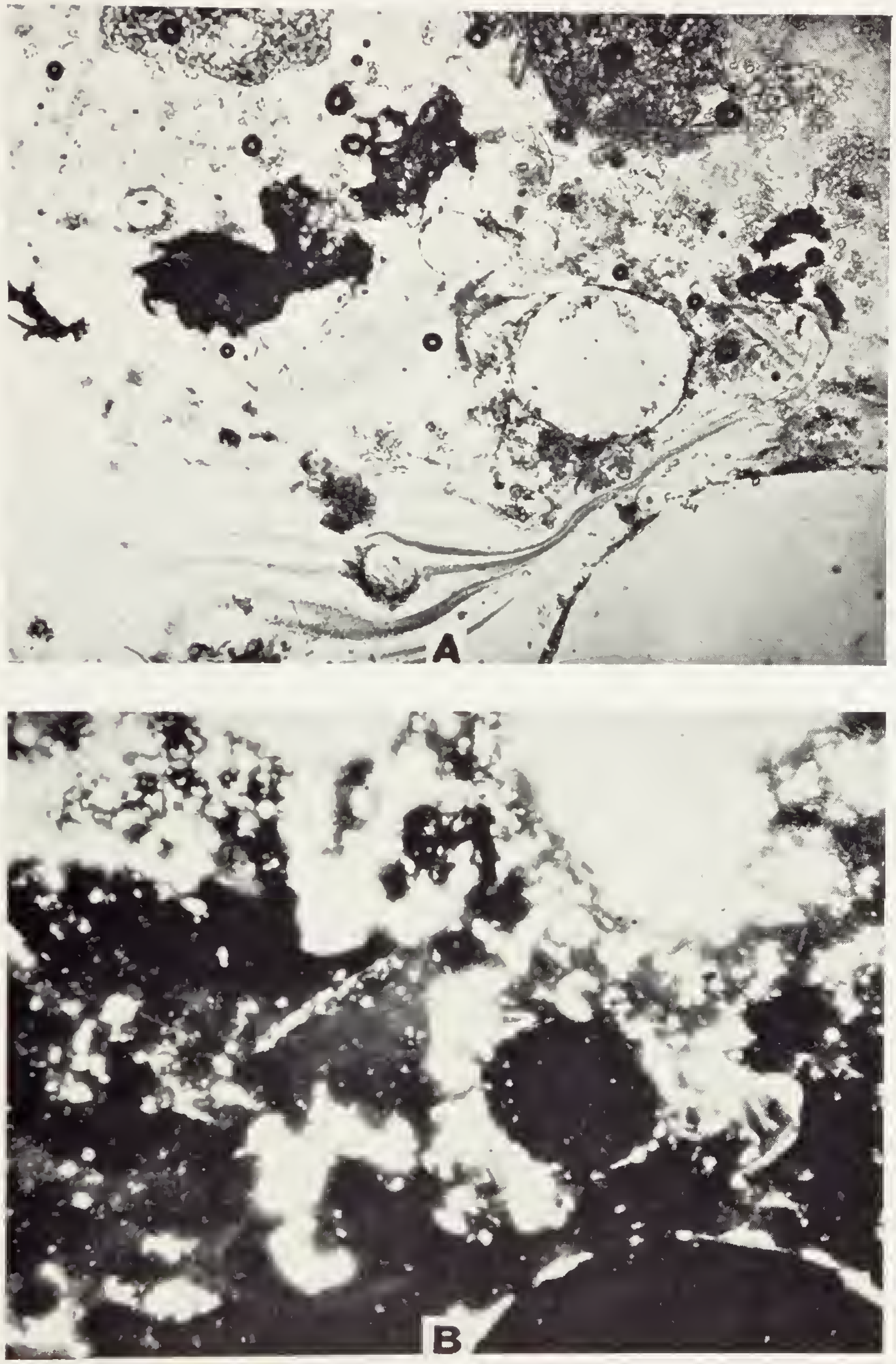

Plate X. (×108).—Thin sections of hay-silica glass.

A = ordinary light;

B = polarized light.

Showing smoky streaks, small and larger bubble cavities, carbonized plant fragments (black in A) and birefringent crystal clusters (white in B).