II.

THE EXPERIMENTAL PRODUCTION OF THE PHENOMENA DISTINCTIVE OF VITRIFIED FORTS. BY PROFESSOR V. G. CHILDE, D.LITT., D.SC., F.S.A.SCOT., AND WALLACE THORNEYCROFT, F.S.A.SCOT.

Vitrified forts have so often figured in the *Proceedings* that any comprehensive description is now superfluous. We must, however, recall certain features in order to explain the considerations guiding our experiments and to show how far these were successful. We apply the epithet "vitrified" to those forts—in Scotland or abroad—that comprise within their ramparts broken stones fused together to form a solid mass. The extent of such vitrifaction varies enormously from site to site. The most famous Scottish examples, perhaps not more than twenty in all, at least superficially give the impression that a substantial wall of vitrified matter once ran more or less continuously round the whole perimeter of the enclosure or at least extended over substantial strips. In others, on the contrary (*e.g.* Dundeardail, Ord of Kessock, Trudernish Pt., Harelaw), it is necessary to hunt about to find even two or three stones fused together.

In quite a number of instances inspection or excavation reveals built masonry wall-faces inside (Rahoy [1]); outside (Duntroon,[2] Carradale, Torr Duin,[3] Lochan Gour,[4] Dundee Law); or on both sides of the vitrified rampart (Finavon,[5] Dundeardail, Eilean Buidhe,[6] Dunagoil [7]): such faces are frequently so dilapidated and distorted that they are liable to be missed by old-fashioned methods of excavation. The vitrified masses are always heavily undercut. Neither at Finavon nor at Tap o' Noth [8] were they ever found *in situ* resting on bed-rock. In Inverness-shire, according to Col. M'Hardy,[9] there is generally a layer of loose stones on virgin soil below the vitrified masses, and such a layer was observed in some sections at Rahoy and Duntroon. But at Rahoy we

[1] *Proc. Soc. Ant. Scot.*, vol. lxxii. p. 35.
[2] *Ibid.*, vol. xxxix. p. 275.
[3] *Ibid.*, vol. xl. p. 140.
[4] *Ibid.*, vol. xliii. p. 35.
[5] *Ibid.*, vol. lxix. p. 51.
[6] J. Harrison Maxwell in *The Buteman*, February 5, 1937.
[7] *Trans. Bute Nat. Hist. Soc.*, 1925, p. 60.
[8] Jas. Macdonald in *Huntly Field Club, Local Place Names*, 1887, vol. v. p. 25.
[9] *Proc. Soc. Ant. Scot.*, vol. xl. p. 37.

found masses fused on to bed-rock at two points, and at Duntroon "the vitrified massed generally stood on solid rock." In a general way the loose stones in the ramparts of vitrified forts seem to be smaller than the rubble filling between the faces of brochs and dùns. The rocks known to have been vitrified include Old Red Sandstones and the Conglomerates of that series (Finavon, Craig Phadrig, Ord of Kessock, Cnoc Farril), Diorite (Tap o' Noth), Epidiorite (Duntroon), Moine Schist (Goat Isl.) and other varieties of schist—all rocks that contain a relatively high proportion of minerals other than quartz.

In the vitrified forts that have been scientifically excavated and adequately described,[1] a fierce conflagration within the fort is attested both by traces on the sub-soil and by an astonishing number of carbonized logs lying under the debris of the ramparts. At Finavon the charred timbers lay upon and above the hearths and floors of houses built under the shelter of the north rampart; at Rahoy they lay upon the rock floor round hearth H2. The pieces of wood in question cannot therefore have been burned in any vitrifaction process preparatory to the occupation of the fortified enclosure. Moreover, both at Eilean Buidhe and at Rahoy, charred material extended under the foundations of the walls.

In the vitrified masses themselves we regard the following observations as particularly significant: (1) some stones have been completely fused and run in the molten state forming what we term "drops"; (2) we have frequently found casts of pieces of timber enclosed in the vitrified masses and exactly similar casts have been reported in vitrified forts in France [2]; (3) more rarely small pieces of completely carbonized wood are included in the vitrified masses.

We have no intention of traversing here the numerous theories that have been proposed to account for the foregoing phenomena. On the Continent the most authoritative explanation is that of Schuchhardt accepted by Déchelette,[3] and subsequently supported by the masterly excavations of Bersu.[4] These authors maintain that vitrifaction results from the combustion of the wood in a wall composed of stone and timber built in the manner of Cæsar's *murus gallicus* and illustrated in Scotland by the ramparts of Burghead, Castlelaw, Abernethy, and Castlelaw, Forgandenny. This hypothesis not only offers an intrinsically plausible

[1] Duntroon (*Proc. Soc. Ant. Scot.*, vol. xxxix. p. 282), Finavon, Rahoy.

[2] Fort de la Courbe, near Argentan, Orne; Puy de Gaudy, Creuse and Chateau Meignan, Mayenne (*Revue archeol.*, vol. xli. (1881), p. 19; vol. xliii. (1882), p. 275); Camp de Péran, Côtes du Nord (photographs and information kindly supplied by Dr R. E. M. Wheeler, F.S.A.), Gourdon (Déchelette, *Manuel d'archéologie préhistorique*, ii. 2, p. 705).

[3] *Op. cit.*, pp. 707 ff.

[4] *Cf.* especially *Der Breitenburg bei Stregau.*

account of the production of a vitrified rampart, it would also explain some of the specific phenomena noted above, viz., the casts of timbers in the ramparts, the presence of charred material below them, the existence of built wall-faces in an extremely dilapidated state, the relatively high proportion of small stones.[1] One of us [2] has, moreover, drawn attention to a similarity between the relics recovered from *murus gallicus* and vitrified forts in Scotland. The excavation at Rahoy has enhanced the impression of similarity. In any case the fibula from this vitrified fort stands typologically so close to that from the Gallic-walled fort at Abernethy that the two forts must be assigned to the same archæological period. At the same time the character of the broches establishes the use of the *murus gallicus* technique as early as La Tène I. in Scotland and *a fortiori* on the Continent, too, since the Gallic-walled forts at the mouth of the Tay obviously belong to an intrusive complex. This dating removes a difficulty felt by Déchelette, who notes that the Gallic-walled forts of France are essentially La Tène III. while the vitrified forts seem earlier. Incidentally the technique employed in these later examples seems more advanced than that illustrated at Abernethy and Forgandenny where, for instance, the use of iron clamps for the timbers [3] was not observed. It may be due to such technical improvements that Cæsar was unable to set these walls on fire (in La Tène III. times). We, however, entertained doubts whether the combustion of such a wall would generate a temperature between 800° C. and 1100° C. such as we had found necessary to melt the stones employed at Rahoy and Finavon. We accordingly designed experiments to test the theory.

1. At Plean Colliery, Stirlingshire, a model *murus gallicus* 12 feet long by 6 feet wide by 6 feet high was erected to our specifications under the continuous personal supervision of Mr Daniel Wright, then coke-oven manager (fig. 1). Old fireclay bricks were used for the faces and arched bricks were included in the foundation course, needed to level up the slope of the ground, to simulate the vent holes that rock fissures would provide on actual Scottish sites. A raft of closely set transverse timbers (pit-props) of 5 inches diameter was laid down resting on the earth at one end on the foundation course at the other (termed the inner face). The outer face rested on the earth, the inner mainly on the timber raft, in accordance with the arrangement described in the *murus gallicus* fort at Burghead. A layer of pit-props and smaller timbers, parallel to

[1] We were much impressed by the value of small angular rubble in stabilizing the woodwork by preventing logs from rolling.

[2] V. G. Childe, *Prehistory of Scotland*, p. 236.

[3] Déchelette insists on the failure to find such clamps in the French vitrified forts that had been excavated.

the faces, rested directly on the raft. The two faces were tied together with four layers of pit-props set at intervals of 16 inches vertically and horizontally. Each layer of tie-beams carried a layer of longitudinal pit-props and smaller timbers lying parallel to the wall-faces. Especially

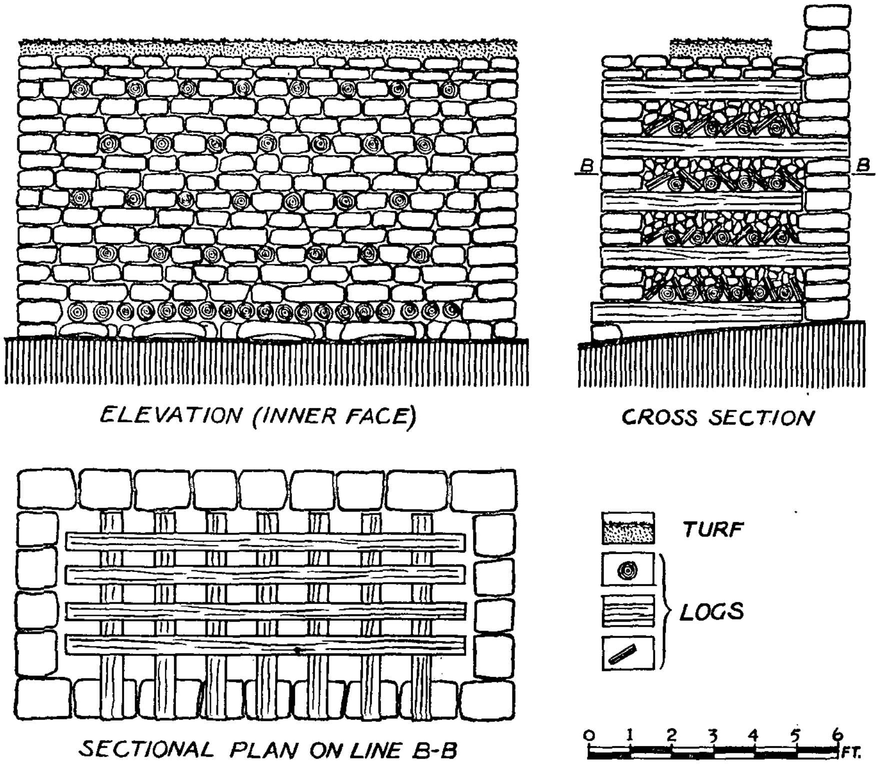

Fig. 1. Plean: The Model Wall.

in the upper layers additional half-round timbers had to be nailed across the longitudinal timbers to stabilize the structure. The space between the faces was filled with basalt (whinstone) rubble, broken to size of 1·5 to 2 inches cube. The mass was covered at the top with a turf blanket that did not, however, come up quite to the edge of either face. The ends were bricked up solidly save for an opening 2 feet square at the base of one end. Care was taken that the fire bricks did not fit more closely than would the flat stones of a dry stone wall. About 1 ton of pit-props, and 6 cwt. scrap timber, both *dry*, were built into the wall, while the rubble weighed 7 tons 7 cwt. (fig. 2).

To ignite the wall, scrap timber and brushwood were heaped around

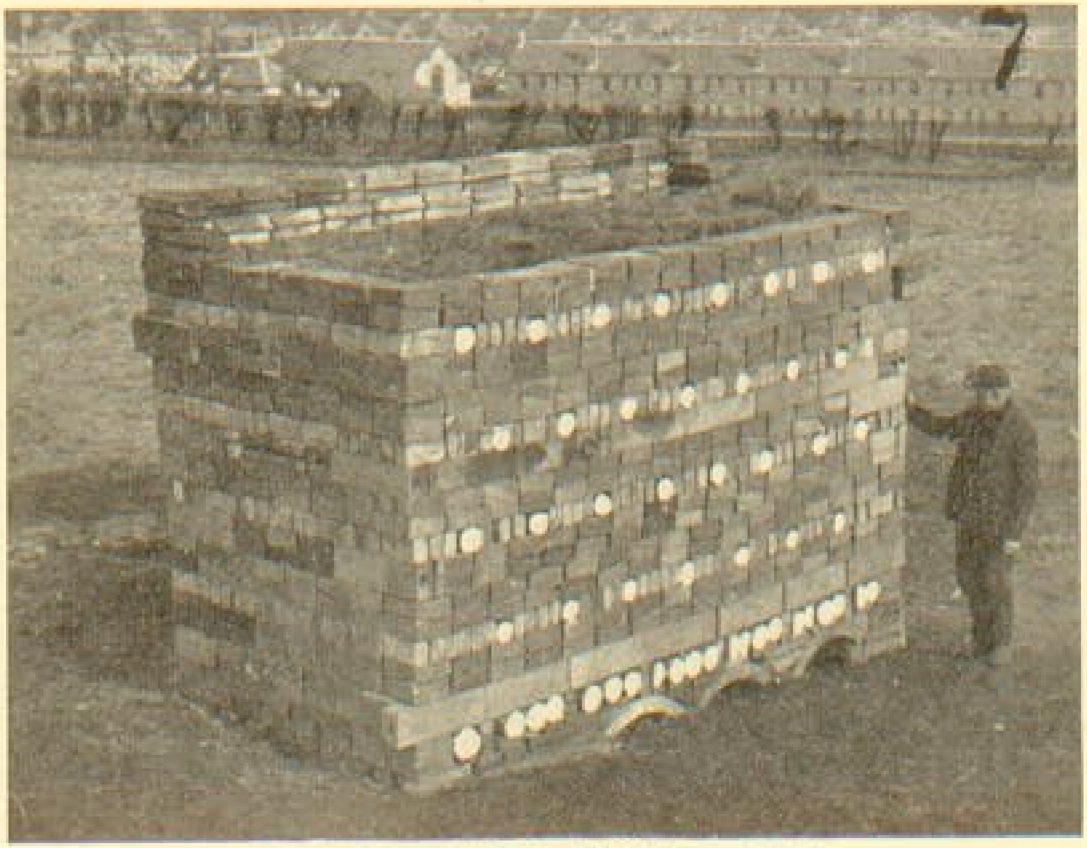

Fig. 2. Plean: The Model Wall completed.

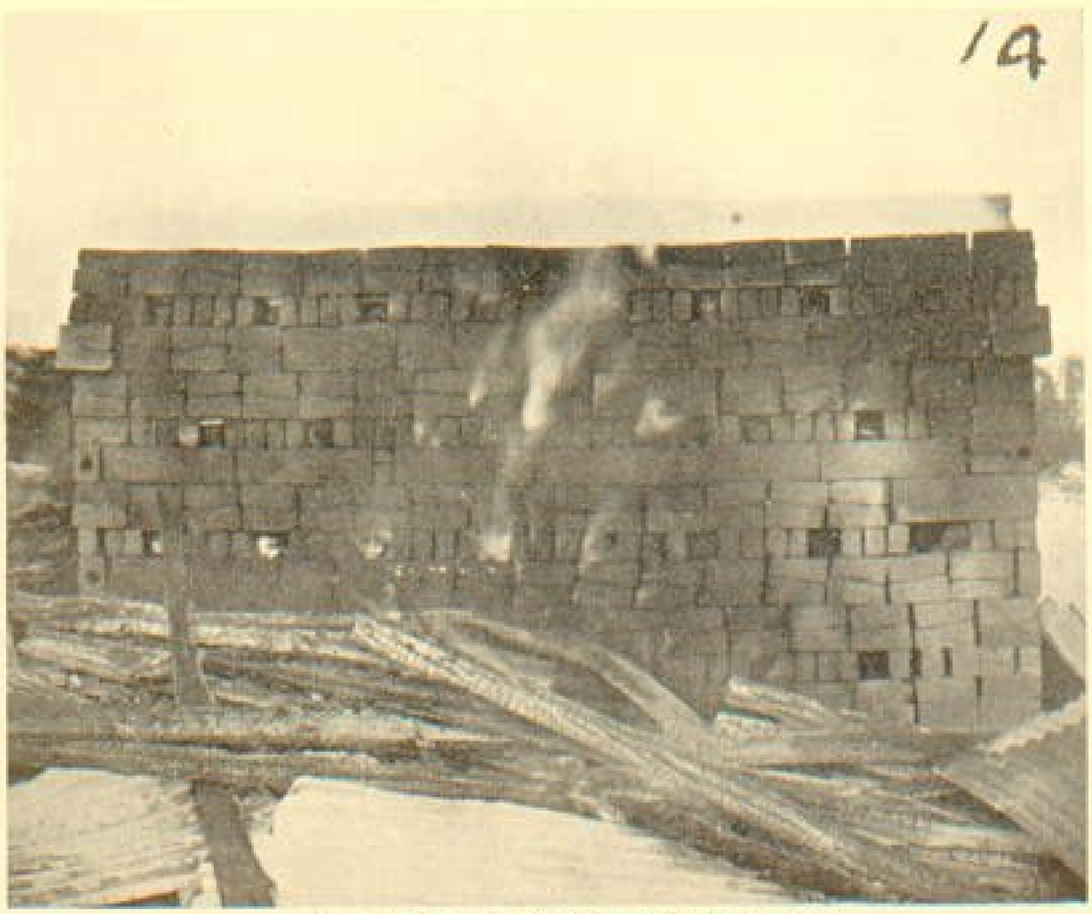

Fig. 3. Plean: The Model Wall burning.

it 6 feet high and 3 feet thick, about 4 tons being used. The fire was kindled at 11 a.m. on March 11 in a snowstorm, the wind blowing from the east with a velocity of 15 m.p.h. at noon and 25 m.p.h. later. The whole of the timber was ablaze within half an hour. When the timbers in the upper layers had burned one hour, the basalt could be heard falling to the layers below. The spaces between the fireclay bricks increased

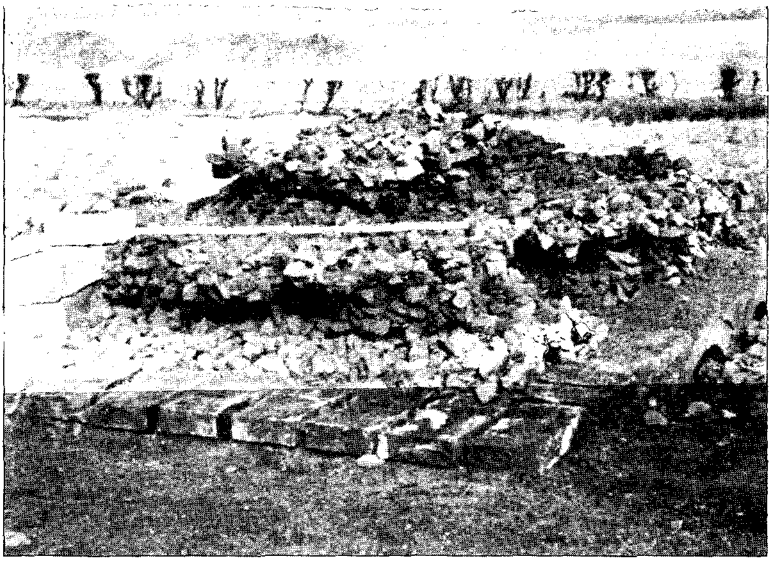

Fig. 4. Plean: The Vitrified Core.

(fig. 3) and the faces became increasingly unstable till, 3 hours after kindling, the entire outer face collapsed, followed by the collapse of the east end and two-thirds of the inner face. The collapse of the surrounding wall allowed the wind to play upon the upper layers of basalt and cool it, but the rubble in the centre of the wall that had found its natural angle of repose between the collapsed faces continued to get hotter and hotter until it was a glowing red mass, attaining its highest temperature 5 hours after kindling. An hour later it began to cool and next morning, 20 hours after kindling, it was only smouldering.

When the mass had cooled down it was taken to pieces, revealing the following results. At the west end of the wall there were three distinct layers of fused basalt rubble. The top layer was only 2 to 3 feet wide, but the lower layers were vitrified over the whole space between the brick faces (fig. 4). At the east end the two bottom layers of basalt

Fig. 5. Artificially Vitrified Basalt showing Drops.

Fig. 6. Artificially Vitrified Basalt showing casts of Timbers.

were fused into a solid mass 21 inches thick. The heaviest single block of vitrified basalt weighed 3·5 cwt., and the total weight of lumps, exceeding ·5 cwt. each, was 14·5 cwt. One lump had been fused onto the brick of the foundation course (just as at Rahoy a lump is fused onto bed-rock) and the distinctive phenomena emphasized above (drops (fig. 5), casts of timber (fig. 6), inclusions of charcoal), were all represented.

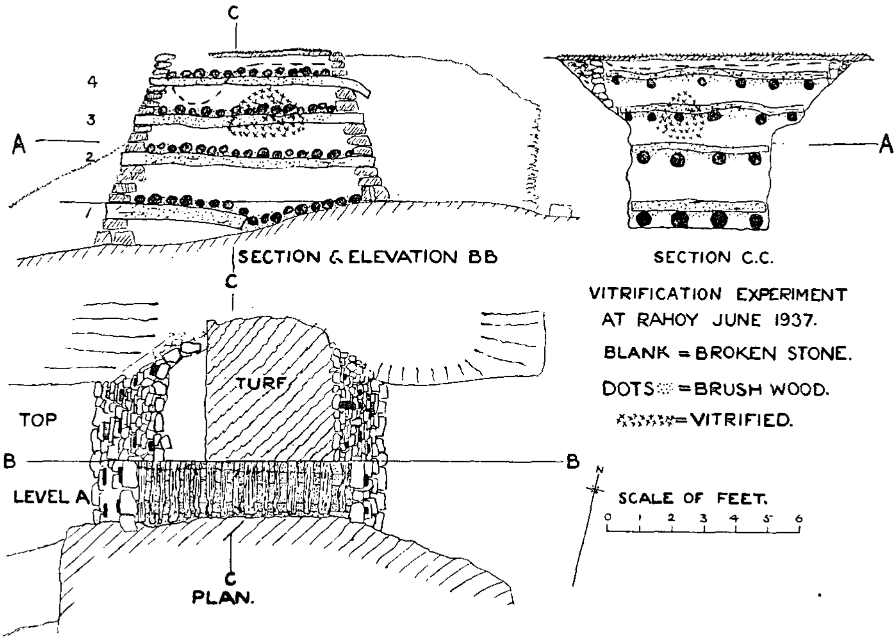

Fig. 7. Rahoy: Model Wall.

A thick layer of charred material covered the earth under the site of the wall.

2. A smaller *murus gallicus* was built at Rahoy in June 1937 out of stones that had been actually used in the ancient fort, but we were hampered by lack of suitable timber. The wall was built across the cut through the rampart that we had made the previous year. This was about 4·25 feet wide for the first 3 feet from bed-rock (*i.e.* to the tops of the original vitrified core in the cut's faces) and widened out above. The rock slopes up from the outside to the interior of the fort so that its surface was about 1·25 feet lower under the outer edge of our model than under its inner edge (fig. 7).

A rough foundation wall was first built on the outside. Four logs, 4·5 feet long and 6 to 8 inches in diameter, were laid horizontally on its top and on the rock slope, the spaces between them being filled as closely as possible with light dry brushwood. Across the logs short lengths of timber of 3 to 4 inches diameter were laid and continued on the rock up to the inner face's foundation, 8 feet from the outer face.

Fig. 8. Rahoy: Model Wall completed.

The spaces above and below the timbers were filled with schist broken to road-metal size and brought up to a level about 1 foot above the first logs. On these another four logs, about 8 feet long and 4 to 6 inches in diameter, were laid down transversely with smaller longitudinal timbers upon them as before, the facing stones being built up with considerable batter. In this way the wall was carried up till there were four tiers of transverse timbers, each supporting longitudinal timbers. The transverse timbers project through both faces (fig. 8).

All the timbers were covered with loose broken stones and a blanket of turf was laid upon the topmost layer of broken stones, not covering it entirely, but leaving an open strip along the outside edge. Rough logs and brushwood were then piled up against the inner and outer faces.

The piles of timber were kindled at 11.30 a.m. on June 24, when there was a light breeze from the north-west (our cut opens to the west). By 11.45 a little steam was rising from the unblanketed strip of the wall, and by 11.50 the turf was beginning to smoulder. The steam now had a bluish tinge, indicating that the process of distillation of the timber in the wall had begun with the formation of some charcoal. By 2 p.m. red glow was visible through chinks in the outer face, while blue smoke was pouring out from gaps in the upper courses of the inner face. During the afternoon these manifestations of combustion were intensified. But about 5 p.m., believing that too much cold air was reaching the core through gaps in the outer face, we temporarily rekindled the fire against it in the hope of warming up the draught. Actually the steam and products of combustion blown in from without seem to have damped down the combustion in the interior since at 5.45 no more red glow could be seen from outside, though the top and inner face were still smoking vigorously.

Revisiting the fire at 10.30 p.m., we saw no more smoke. The turf on the top had been entirely consumed, revealing the loose stones glowing dull red with flames flickering over them as the carbon monoxide, resulting from the incomplete combustion of the charcoal in the wall, caught fire. The upper courses of the inner face were also red hot over a space about 2 feet square with a brighter glow visible in the interior through the beam holes. Below all was black. As the wind had fallen we piled additional logs on the top to create a draught. These caught fire at once and did in fact seem to increase the heat at the centre. They were still burning when we went home at 11.30 p.m.

Next morning the fire was extinct. Both faces were standing, but the sagging and buckling due to the consumption of the tie-beams produced an effect very strongly reminiscent of the distorted inner face of the prehistoric rampart at Rahoy itself (fig. 9). The rubble core had subsided very little where the turf blanket had been. but at the north-west corner had subsided as much as 18 inches. The whole of the timber built into the wall had been consumed except the south transverse log in the top row and 5 longitudinal timbers resting on the ground at the base, but a number of fragments of charcoal were found among the loose broken stones. Some wood ash had fused into the stones.

When we cleared away the loose stones to the level between where the 4th and 3rd layers of tie beams had been, we began to find some vitrified stones in the centre, and they became more numerous down to a level between layers 3 and 2. This more or less vitrified mass is shown in the section and was estimated to weigh about 2·5 cwt. It broke up more or less when we removed it, but there were lumps weighing 5 to 10 lb. quite solidly welded together.

Fig. 9. Model Wall after burning.

An essential moment in the production of vitrifaction by the method just described is the conversion of the wood into charcoal by a process of distillation in which heat is absorbed by the timbers. It is only after the completion of this endothermic reaction that the combustion of the resultant charcoal under suitable conditions of ventilation and in contact with the stones produces the high temperature needed to fuse the rocks (*cf.* the glowing masses observed in the later phases of both experiments). The formation of casts of timbers would be an occasional and accidental by-product of the process. It means that a piece of wood became surrounded with molten stone so as to prevent the charcoal burning save very slowly and consequently without emitting enough heat to re-melt the cast.

We would insist on the small scale of both experiments. The total heat generated by the combustion of a wall 20 feet wide and 12 to 16 feet high as at Finavon or even 10 feet wide as at Rahoy would have been disproportionately greater than anything obtainable in a model. The Rahoy experiment was handicapped by the unsuitably shaped timbers, the small height, and the low wind. Bearing these facts in mind we submit that our experiments prove the following points.

1. The combustion of a *murus gallicus* will produce temperatures of the order requisite to fuse stones actually used in "vitrified forts" and will reproduce the outstanding phenomena of vitrifaction.

2. Under suitable conditions of wind such a wall could be set alight by an external fire—for instance a forest-fire, a fire kindled by enemies against the rampart, or the conflagration of thatched wooden houses built against the rampart inside the fort.

3. The consumption of the tie-beams may involve the almost complete collapse of the faces, leaving a core of vitrified material standing more or less on the line of the wall much in the manner apparently illustrated by *e.g.* Goat Island, or it may leave the face distorted like the inner face at Rahoy.

4. We admit that only rocks containing a suitable mixture of minerals in addition to silica could be vitrified under the conditions we envisage; for the range of temperatures producible would be between 950° C. and 1200° C. Highly silicious rocks such as Carboniferous Sandstones would not be fused; while the more mixed Old Red Sandstones, formed from broken down volcanic and metamorphic rocks, have yielded the vitrified ramparts of Finavon, Craig Phadrig, Ord of Kessock, Cnoc Farril, etc.

To this extent the hypothesis of French and German archæologists that vitrifaction is in general the by-product of the destruction by fire of a *murus gallicus* seems to be vindicated. Whether it be necessary to suppose that this process was deliberately imitated to produce the more or less vertical faces of vitrified material such as are visible for instance at Goat Island or Tap o' Noth may be left as an open question.