Reprinted from Nature, Vol. 281, No. 5728, pp. 209-211, September 20 1979

ART N° **474**
Contribution COB N° **656**

Basaltic pillars in collapsed lava-pools on the deep ocean floor

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Observations of peculiar volcanic objects, made by a submersible on the deep sea floor at a depth of about 2,600 m at and near the axis of the East Pacific Rise during the CYAMEX expedition as part of the RITA Project[1] are presented here. Two basic types of flow forms were observed within the crestal area of the East Pacific Rise: pillow flows and fluid lavas, the latter sometimes overlying massive flows. The East Pacific Rise at 21° N comprises an axial, unfaulted extrusion zone bordered by an extension zone characterised by faulting[2,3]. Pillow flows occupy the innermost or extrusion zone and constitute small elongated volcanic highs. Fluid lavas tend to occur at the edge of the adjacent extension zone in bathymetric lows controlled by normal faults or steep primary slopes of constructional highs. In the 50 × 200 m lows which border the extrusion zone the fluid lava is smooth and lobate surfaces which represent the upper surface of the flow are locally collapsed and reveal the internal structure of the fluid lavas. Where the roof collapse is extensive, layered columnar features are visible and volcanic layering can be seen against the flank of the bordering volcanic highs (Figs 1–3). Similar features have been reported from the Galapagos Rift[4]. The diameter of the approximately cylindrical pillars ranges from 0.5 to 2 m. Some pillars are made of multiple coalescent cylinders. The tops of the pillars are glassy, funnel-shaped and always widening upwards. The pillars were presumed to be hollow from several observations of gashes or openings in the vertical walls of the pillars. This was demonstrated during dive CY 78–19 to the south where a small pillar was toppled by CYANA and subsequent examination revealed a circular canal along the axis of the pillar. The outer surface of the pillars is marked by centimetre-thick glassy, subhorizontal ledges extending several centimetres from the outer vertical surface of the pillars (Figs 2–4). The ledges are spaced every 2–5 cm and show small lava stalactites hanging on the underside of the ledges. Examination of large layered fragments of pillars recovered by CYANA demonstrated that the layering is only a surface feature as it does not extend through the basaltic mass of the pillars. The apparent layering is due to glass ledges adhering to a vertical basaltic pipe. In some rare instances the pillar outer surface showed no ledges and instead a smooth surface corrugated with vertical grooves. Some pillars are inclined or slightly curved; others get narrower towards the base. The pillars are almost totally aphyric and have the same bulk composition as other lava types recovered in the axial zone of the East Pacific Rise at 21° N (ref. 5).

Fig. 1 General landscape: pillars within collapsed lava pond.

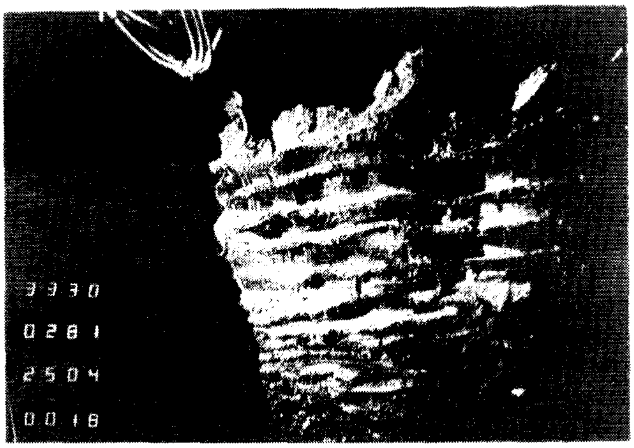

Fig. 2 Detail of a pillar showing the centimetric pseudo layering, with thin and darker salient glass layers projecting from the basaltic surface of the pillar.

The pillars occur in forest-like arrangement (Fig. 3). Their spacing ranges from 0.5 to 3 m and sometimes they coalesce, building walls, especially near the edges of the depressions. However, the pillars are not confined to the edges. The flanks of the lows show large segments of undisrupted glass ledges analogous to those observed on the pillar surfaces. In one case (dive CY 78–19) where the fluid flows partially filled a graben, the layered lateral margin could be seen to represent a chilled, 5–10 cm-thick wall plated against the truncated pillow basalts of the normal fault scarp. The chilled margin was partially detached from the scarp surface.

Non-collapsed glassy upper surfaces of fluid lavas surrounding the fields of pillars show that in the depressions, the thickness of the lobate fluid lava roof is about 10 cm. The horizontal dimension of the lobes is of the same order as the pillar spacing and pillars provide roof support at the junction between adjacent lobes. The geometry of the lobate roof junction is analogous to that of the funnel-shaped pillar tops. Pieces of the lobate roof are commonly preserved around the fluid lava depressions and also where they form bridges between adjacent pillars. In most cases the lava pool appears to be concave upward with a slight (a few metres) depression in the middle of the pool with respect to the edges.

The seafloor around the pillars is strewn by rubble made up of pillar fragments and roof slabs. A deeply incised rille-like canyon was observed near the axis of the fluid–lava depression.

These observations lead us to the following interpretations (Figs 5 and 6):

(1) The fluid lavas fill a preexisting depression either controlled by faulting or by adjacent constructional highs. This is proved by inspection of the lateral contact and by the contrast in lava freshness between the fill and the adjacent pillows. The remarkable fluidity of the lavas cannot be ascribed to chemical differences or to temperature of extrusion. It probably reflects the large volume of outpouring which could in turn be a function of a very high spreading rate over a short time span.

(2) The seawater which is trapped in the crust under the fluid lava pool is heated and expands (by a factor of 20 for a temperature of 800 °C at a depth of 2,600 m (see ref. 6), forcing its way up through the molten lava in a series of vertical conduits (J. Moore, personal communication) (Fig. 5). The walls of the conduits will be quenched at the boundary between the rising water and the hotter magma. The conduit walls will grow outward from the inner glassy walls of the conduits with time. This explains the hollow pillars found by CYANA. A similar

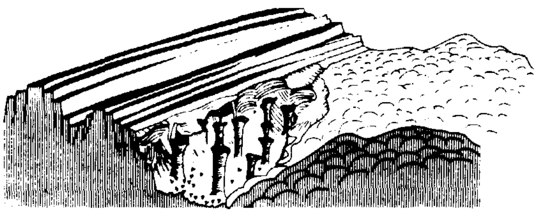

Fig. 3 Lava pool after roof collapse showing basaltic pillars at the boundary of the unfractured extrusion zone (on the right). The pillars are about 10–15 m high.

explanation has been put forward by Fuller[7] and Waters[8] to account for the existence of vertical cavities (spiracles) that cut massive lava on the Columbia River Plateau. These authors proposed that water vapour and other gases surge upward into liquid lava that covers marshy ground.

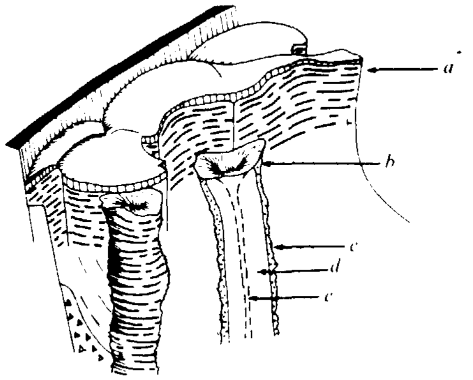

Fig. 4 Detail of basaltic pillar and of edge of magma pool. *a*, Pillar attached to the edge of the pool and capped by smooth lobate fluid lava. *b*, Pillar: funnel-shaped widening upwards Pillar cross-section showing: *c*, lava cooling ledges on outer margin; *d*, massive lava inside pillar wall; *e*, hollow conduit inside pillar.

(3) Before any extensive crystallisation takes place, the lava pool is drained rapidly in successive stages (Fig. 6). This leaves 'bath-tub' rings around the 'cold walls' present in the depression. This includes the pillars and the edges of the pool. This accounts for the apparent layering shown by the pillar samples. The rille-like canyon seen on the floor of the pool may be a drain path. Finally down-drag of either the roof or the outer rigid carapace of the pillars can scrape vertical grooves on the still plastic interior and explain the smooth corrugated outer surfaces of some pillars. A similar mechanism has been proposed by Moore and Richter[9] to explain the vertical striations on the surface of Hawaïan tree moulds.

(4) Solidification of the fluid lava against the cold wall at the bottom of the pool would help to maintain pillars in position after collapse of the roof.

Thus tall, near vertical and hollow pillars with rings of glassy ledges are found in dense arrangement within fossil pools of fluid lava. They are interpreted as the fossil witnesses of both temporary liquid magma pools which can fill topographic lows and smoth the ridge topography, and of the rhythmic nature and rapidity of the magma pool withdrawal. When drain-off is prevented or when it proceeds too slowly, massive lavas are created.

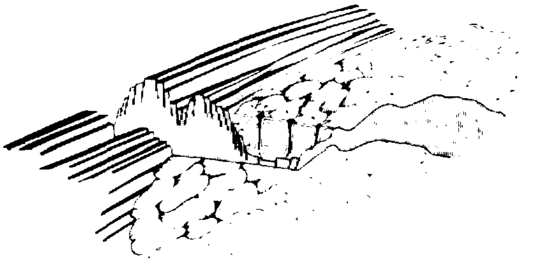

Fig. 5 Reconstruction of magma pool before the draining of lavas and roof collapse. The arrows at the pool surface represent escape of water.

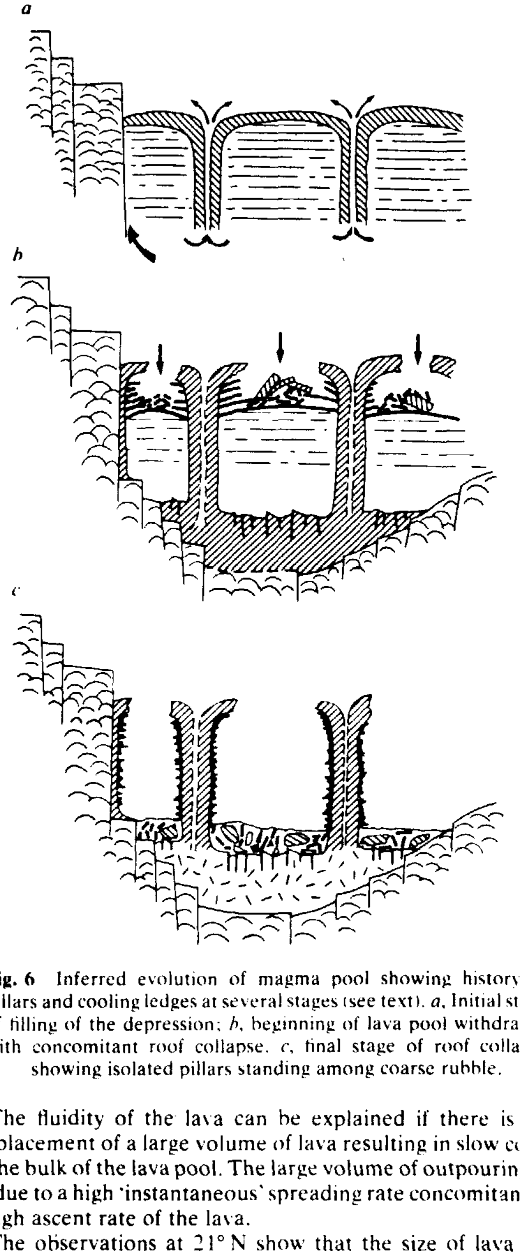

Fig. 6 Inferred evolution of magma pool showing history of pillars and cooling ledges at several stages (see text). *a*, Initial stage of filling of the depression; *b*, beginning of lava pool withdrawal with concomitant roof collapse. *c*, final stage of roof collapse showing isolated pillars standing among coarse rubble.

The fluidity of the lava can be explained if there is rapid emplacement of a large volume of lava resulting in slow cooling of the bulk of the lava pool. The large volume of outpouring may be due to a high 'instantaneous' spreading rate concomitant with a high ascent rate of the lava.

The observations at 21° N show that the size of lava pools increases southward along the axis and thus that the fluid lava regime in the south is predominant over the pillow lava regime. This suggests that instantaneous rates of spreading may be variable along the strike of the mid-ocean ridge.

Received 27 April; accepted 30 July 1979

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Printed in Great Britain by Macmillan Production Ltd., Basingstoke, Hampshire