[Read before the Society March 22, 1930]

PILLOW-LAVA AND THE PYRITE ORES OF CYPRUS

By Victor C. Hills[1]

"Pillow-lava" is a geological formation supposed to be produced by molten lavas extruded in the bed of the sea; globular masses rising, more or less buoyed up by an enveloping bubble of steam generated by their own heat and then, with the escape of the steam, falling back to be embedded in a matrix of the finer material mixed with the sea-bottom slimes.

The accompanying plates I and II are reproductions of photographs loaned by the British Geological Survey and Museum and furnished me by Mr. A. Broughton Edge, Director of the Imperial Geophysical Experimental Survey of Australia. Plates III and IV are from my own photographs.

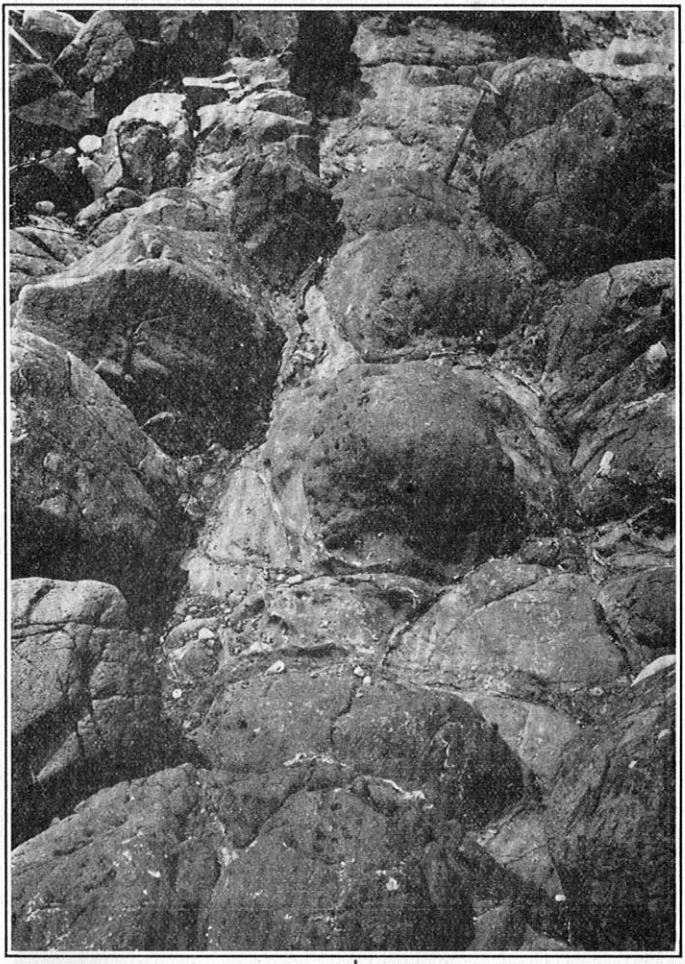
Mr. Edge, in a personal letter, states that "European geologists are in unanimous agreement regarding the origin of this structure, which is only developed in submarine lava flows." He further states that "The breaking up of molten lavas into these pillow-like bodies has actually been observed by geologists in areas where lava streams are entering the sea. The pillows, surrounded by an envelope of steam, will sometimes rise up toward the surface before finally settling to the sea bottom where, in a partly consolidated state, they pile up like bags of cement." This latter observation suggests that submarine extrusion is not a required assumption, and that any of these like formations might have been pro-

[1]Mining Engineer, Skouriotissa, Cyprus. [Died at Skouriotissa, July 13, 1930.]

PLATE I

Sack-like or pillow-form structure in diabase lava of Arenig age. Locality: shore 2⅓ miles south of Ballantrae, Ayr County, Scotland. Loaned by British Geological Survey and Museum. Registered No. C721.

PLATE II



Pillowy lavas of Arenig age with interstices filled with limestone and chert. Locality: Downan shore, 1½ miles south of Ballantrae, Ayr County, Scotland. Loaned by the British Geological Survey and Museum. Registered No. C713.

duced by lavas pouring from the land into the sea. However, this condition would be likely to produce only a quite limited extent of the pillow-structure, whereas such lavas seem to cover extensive areas. The pillows when broken frequently show distinctly a more rapid cooling at the outer crust. This also would naturally occur whether or not the extrusion was submarine.

There is no reason for doubting that submarine formation is the general explanation. Here in Cyprus, from their mass and extent, I should say that they were so formed.

Dewey and Flett[2] discuss the pillow-lavas of Scotland and Cornwall along with spilites and other basaltic rocks, but state that "acid and intermediate rocks also accompany the pillow-lavas." They state, as additional evidence of their marine formation, that the pillow-lavas are usually accompanied by radiolarian cherts.

Mr. M. E. Hubbard, one of our engineering staff here, states that a spilite lava, looking strikingly like the pictures of the Scotland formations, and also containing radiolarian cherts, occurs at 15 miles N. E. of Santa Maria, in central California; and that the University of California geologists have recognized it as of submarine extrusion and there call it "pillow-basalt."

The name "pillow-lava" is of comparatively recent coinage. Lyell, a standard English geological work does not use it, but Geike[3] used it in 1900. This formation is evidently widespread in Europe, and the term is commonly used by European geologists. In North America the occurrence seems to be comparatively rare. American geologists have recognized the formation, but have not generally used the name in writing. The term is properly one of structural form only, and is not naturally concerned with origin, age or composition of the rock. The name might as well have been "pudding-formation" or "dumpling-lava." In truth either

[2]Dewey, Henry, and Flett, John Smith, British pillow-lavas and rocks associated with them: Geological Magazine N. S., Decade V, Vol. VIII, pp. 202-9 and 241-8, May-June, 1911, London.

[3]Geikie, Archibald, Ancient volcanoes of Great Britain, Vol. I, pp. 26, 184, 193, 201, 1900.

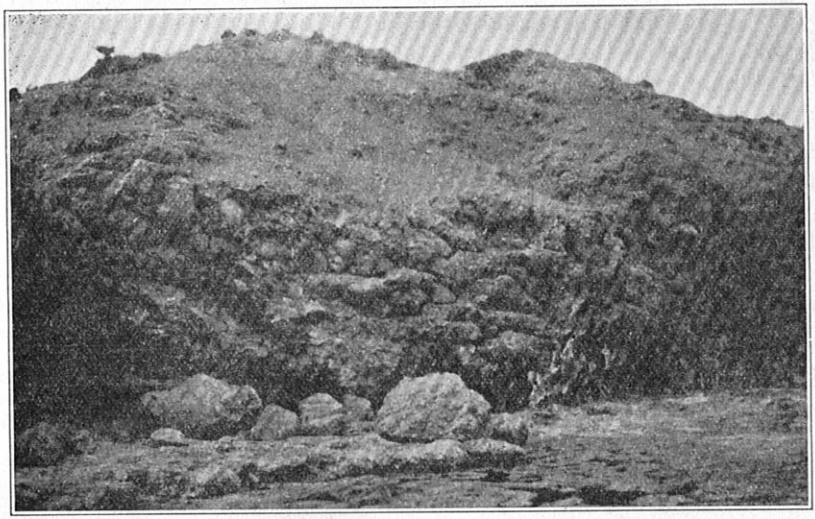
of these words would seem rather the more fitting to the formation in Cyprus and generally; and it is certainly *boiled rock!* However, the showing of plate I suggests the "pillows", and the term is now a standard one in geology.

The pyrite ore bodies of Cyprus are a replacement of these pillow-lavas where they are overlaid by sedimentary formations. At Skouriotissa the ore forms a lens-like basin at the top of the lava, where it is covered by a layer of umber, then marls; and above the marls, chalk and limestone. [See section in the Cyprus mine article in the Engineering and Mining Journal, Vol. 126, p. 54, July 14, 1928.] Cullis and Edge[4] in their report on the copper deposits of Cyprus state that the pillow-lava forms may be discerned in the massive pyrite ore. This is questioned by some of the observers here, and it may require some stretch of the imagination to identify the pillows. Yet there are frequent globular masses, called by the miners "nigger-heads" of solid pyrite in the generally loose and porous mass; hence the assumption that they represent the "pillows" is not unnatural; in truth it is quite reasonable. The place for my photograph—plate IV—was chosen in the attempt to show this feature of the ore formation, but the picture gives only mild satisfaction in this particular. The ore is soft and crumbling to the extent that sixty per cent of it, in mining, breaks into natural "fines"—minus a half inch. In this soft matrix are nodules, large and small, of hard pyrite which may be imagined to represent the "pillows" of the original country rock.

The overlying sedimentaries do not contain any ore; and the contact is quite regular and abrupt. The contact of the ore with the underlying andesite is also generally clearly defined; but in places there is at the bottom a grading into lean pyrite containing no copper. At the Mavrovouni mine, three miles distant from Skouriotissa, the pyrite ore body does not come up to the covering sedimentaries. Generally there is about one hundred feet of intervening andesite. Possibly

[4]Cullis, C. Gilbert, and Edge, A. Broughton, Report on the cupriferous deposits of Cyprus: Published by The Crown Agents for the Colonies, London, 1922.

PLATE III



Pillow-lava at a seashore cliff on Morphou Bay, Island of Cyprus.

PLATE IV

Pillow-lava formation in the andesite below the ore body at the 820-foot level of the Skouriotissa mine, Cyprus.

one side of the ore deposit originally reached the marl capping and was mined out by the ancients. Otherwise this ore body and the entire formation is the same as at Skouriotissa.

The ore deposition is considered to be subsequent to the sedimentary formations. The source of the ore is attributed to emanations from the deeper parts of the still molten magmas ascending through the comparatively porous pillow formation and hindered from escape by the impervious nature of the overlying marls.

These ores are similar to the cupriferous pyrite ores of Spain and Norway. The Cyprus ores are noted for their porous nature, requiring from 9¼ to 9½ cubic feet for a long ton of 2,240 pounds, while eight cubic feet of the Spanish pyrite bodies make a ton.

The Cyprus ores are noted for their cleanness and purity, being marketed just as broken in the mine without sorting or concentration of any sort. The following is a typical analysis of the ore as found in place:

Analysis of Cyprus Ores

	Per Cent
Copper	2.1
Iron	41.0
Sulphur	48.5
Alumina	1.25
Silica	1.75
Lime	trace
Magnesium	trace
Arsenic	0.01

A typical assay of Cyprus ores gives: Gold, 0.01 ounces per long ton and Silver, 0.40 ounces per long ton.

The conditions for secondary enrichment are unfavorable, owing to the flat-lying shape of the ore mass. In one place in the Skouriotissa mine, underlying the ore body, there was found a seam or layer of soft crumbling material which was named by the miners "devil's mud" on account of its peculiar property of passing into liquid slime when pressed between the fingers. Thirty per cent of it is soluble salts of iron and copper. A composite sample of this material assayed two ounces gold and 13 ounces silver to the ton of 2,240 pounds.

Native sulphur in quantity has been disclosed at one

place. It assayed per long ton: Sulphur 87 per cent, silver 2.02 oz. and gold 0.33 oz. It was in a layer about two feet thick and some of it was marketed for the sulphur during the great war. Thin layers of the "devil's mud" lay between the sulphur and the surrounding pyrites; and here it assayed up to 20 oz. silver and 5 to 8 oz. gold.

These secondary concentrations are only pockets of very limited extent and are not of commercial consequence; but they are of considerable scientific interest because native sulphur as a product from pyrite by chemical reactions is uncommon.

Ancient history credits Cyprus with the production of gold and silver as well as copper. No precious metal veins are now known on the island or any formation suggesting such veins. Throughout the island quartz is particularly noted for its absence. It would seem that the little pockets and the gossan outcrops of the great pyrite deposits must have supplied the reputed gold and silver product of ancient Cyprus.

I am indebted to Mr. Edge for the use of the photographs of pillow-lava of Scotland from the British Geological Survey, and for valuable information in personal conversation and by letters.

Skouriotissa, Cyprus,
December 14, 1929.

DISCUSSION

George E. Collins, Denver, Colo.: The occurrence of an earthy layer greatly enriched in gold and silver, immediately above a pyrite ore body, uncapped by gossan, seems remarkable. Such a layer between an oxidized gossan and the pyrite ore body was exemplified at Rio Tinto, and other of the great pyrite ore bodies in the south of Spain.[5]

[5]Finlayson, A. M., Secondary Enrichment in the Copper Deposits of Huelva, Spain, Trans. Inst. Min. & Met., Vol. XX, p. 64, 1911.

Mr. Hills' impression that formation of native sulphur from oxidation of sulphide ores is rare is, I think, mistaken. A layer of sulphur between the gossan and the underlying pyrite is frequently noted in the Huelva pyrite ore bodies, and is mentioned by Finlayson[6] and others.

A fact in connection with this which interests and puzzles me, but in which I have not succeeded in interesting anybody else, is that the occurrence of sulphur is particularly common in the gossans of sulphide ores at high altitudes, where the ground is frozen most or much of the time. Examples in Colorado; Mary Murphy mine, Chaffee County; North Star mine on Solomon Mt., San Juan County; Union Carbonate mine, Dolores County.

Denver, Colo., April 21, 1930.

[6]Op. cit., p. 64.