Hidden Wonders of Iron Slag

Leader: Clive Boulter 9 June 2018

A small intrepid band of members headed north from Harrington Harbour in conditions that had one member wishing she had brought her swimming costume. The topic for the day was the physical volcanology of the slag from iron working. Studying slag has provided invaluable information for our understanding of some volcanological systems and around the coast of Cumbria we still have many opportunities to examine this style of effusive activity though remedial operations have meant some classic sites have been lost.

Iron oxide is reduced in a blast furnace to metallic iron. The furnace is charged with iron ore and coke, together with limestone as a flux to reduce the melting temperature. All of these are impure. Even the purest limestone has a few weight percent of impurities such as quartz, iron oxides, micas, and other minerals. Similarly rock forming minerals are present in iron ore. In the blast furnace the molten iron sinks to the bottom, and the impurities float, forming a silicate liquid which is equivalent to a natural magma but very different in composition. Most slag magmas are more akin to carbonatites than any calc-alkaline magma but there are interesting variants including Fe-rich compositions with komatiitic (spinifex) textures.



Figure 1 A large cavity in a pudding – lava stalactites hang vertically from the roof.

Locality 1 NX 98743 25915 Pipe vesicles & lava dribbles

The slag that formed this large block (skull/pudding) was poured into a railway-mounted ladle and held until it was almost all solidified before tipping. Intact tipped blocks of slag are known as puddings in south Cumbria and skulls in the north. The top surface of the skull has a ropy pahoehoe surface structure (similar to Figure 2, Locality 3) indicative of a very fluidal, low viscosity, flow of liquid slag. The outer surface of the flow becomes chilled and solid but, in the case of pahoehoe, the crust is initially thin and flexible, deforming into wrinkles when it is impeded whilst the lava beneath is still moving. The uncertainty here is when did the pahoehoe form? Was it formed whilst appreciable amounts of liquid slag were present or does it represent small amounts of still-molten slag that escaped at the time of tipping – a dribble? Dribbles are very common in slag deposits on the Cumbrian coast.

Loose blocks of slag with pipe vesicles are found at this locality, immediately seaward of the skull block, at the head of the beach. In nature pipe vesicles are found perpendicular to the margins of a variety of features including lava flows and pillows.

Locality 2 Traverse from NX 98707 26060 to NX 98708 26132

Here an old railway embankment has been constructed from tipped slag. In early iron working operations only manually charged blast furnaces were used which, because of their lower temperatures, produced viscous slag that could be transported by rail in slag boxes sealed to waggon bogies by fireclay. At the slag tip, the box sides were lifted off and the solid block of slag could be tipped. Box shape evolved from octagonal through rectangular to circular and this is reflected in the morphology of the tipped material. Clearly the aim was not to have too much liquid in the box at the time of tipping. The nature of the slag deposits reflects varying lengths of cooling. Advanced cooling led to abundant fractures because the slag contracted as it cooled; such materials would break into many small pieces when tipped. Shorter cooling periods with less pervasive fracturing left intact blocks (puddings/skulls).



Figure 2 Twisted ropy pahoehoe (20p coin for scale) at Locality 3.

Several puddings containing liquid appear to have cracked open a bit on tipping and not moved further since they were tipped. The evidence for this interpretation is preserved as vertically-hanging lava stalactites, from residual liquid in the puddings, on the roofs of the cavities . Up to 3 similar cavities are seen in a stacked sequence at the top of many large pahoehoe lava flows and they were crucial in the realisation that these enormous flows were emplaced by inflation (the SWELL hypothesis, Self et al. (1998)).

Judging by the size of the cavity shown in Figure 1, this pudding seems to have arrived at the tip with quite a bit of liquid present. The cavity has a surround of vesicles and the present-day top has lava stalactites formed as the last of the liquid drained. The movement of vesicles will have been arrested at the inward-migrating solidification front and the relationships seen in various complete puddings indicate complex cooling patterns. Many puddings/ skulls were formed by discrete slag pouring events at variable time intervals. Some patterns in individual "flow" events are simple and mimic what you see in lava flows but others are much more complex.

Locality 3 NX 98749 26320

A fine example of twisted ropy pahoehoe is found at this locality though the most impressive examples in Cumbria are to be found at the end of Askam Pier, in south Cumbria where there are flow fields of pahoehoe lava.

At Askam Pier it would appear that most of the slag ladles were delivered to the tipping location either totally molten or with very little solid. The pier was built up by multiple thin flows rarely thicker than ten cm. Rather than the sectional views provided by the main slag tip at Workington, Askam allows you to walk over the tops of sheets of lava poured onto nearly horizontal surfaces (Figure 3).

Discovered on the Day

Spinifex texture (bladed olivine crystals) is common at Workington. This texture has rarely formed in nature since the Archaean where it is the defining characteristic of komatiitic lava flows. In komatiites the equivalent crystals are Mg-olivine but in the slag environment they are Fe-olivine. Walking north from Locality 2 the natural line is along the sandy strip of beach between the tipped slag and the head of the beach. On the seaward side of this strip, about 25m south of Locality 3, an excellent



Figure 3 Twisted ropy pahoehoe at the end of Askam Pier as part of a pahoehoe flow field.

block of spinifex-textured slag can be seen. Bladed spinifex is well developed and random spinifex (Figure 4) is exposed in 3D (possibly grown into a cavity).

At NX 98727 26289 there is a fine example of spinifex texture but this can be covered by sand following storms. If this has happened there is plenty of the same feature to be seen from NX 98715 26575 to NX 98661 26847.

Locality 4 NX 98756 26533 Volcanic Glass

Volcanic glass is scattered all along the excursion route but this pudding gives us the chance to see the original setting that produced this chilled/quenched magma. Within lava flows cooling rates are typically around one degree Celsius per hour whereas quenching involves rates 100s to 1000s times more rapid. Slag box material commonly has glass around the pudding margins whilst in the skulls glass is mainly from the portion in contact with the ladle base. Conchoidal fracturing, which is very characteristic of volcanic glass, is a striking feature at this locality. Some surgeons consider this fracture style produces a cutting edge better than steel! Some glass seen on the traverse has a greenish tinge probably from traces of other elements.

Locality 5 NX 98729 26664 Thin pahoehoe lava flows (you need a hard hat to examine this locality safely)

Very thin lava flows form most of the slag tip, as seen in Figure 6 below. Many of the flows are around 5 to 10 cm thick and have two to three internal subdivisions. The white components have pahoehoe structures on their upper surfaces which means they represent the top of these flows. Because the cliff face presents lava sections, the pahoehoe top surfaces are rarely exposed but some steps in the weathered face give limited opportunities to examine the ropy structure.

Many of the lava flows have a glassy bottom layer and a white upper layer. Some flows have a three-fold structure with a rusty (Fe-rich) layer in between the white and glassy parts.

There is a pronounced topography on the white tops of some flows which may have been hornitos/driblet spires where a weakness in the lava crust allows magma and volatiles to escape. Small fingers of the



Figure 4 Random spinifex texture showing bladed olivine crystals (25 m south of Locality 3).

brown component of some flows penetrate upwards into the white pahoehoe part showing the linkage in time between the two.

A Miscellany of Features to Look Out For Along the Traverse

If iron is tapped along with the slag, its density means it will sink to the bottom of the box/ladle and this provides a way-up criterion for puddings/skulls with iron in them that have tumbled down a slag bank and partially broke up. If tapping was done at discrete intervals the patterns may be complex.

The relationship between the margins of rock fragments and cooling joints provides crucial volcanological information. Some cracked open skulls from Workington have a good radial pattern of cooling joints mimicking patterns seen in lava balls detached from lava flows that broke open on coming to rest (e.g. Teide's Eggs on Tenerife). Similar patterns in pyroclasts in low-temperature ignimbrites (prismatic jointed blocks) identify fragments of the magma responsible for the explosive behaviour. Delicate blisters approximately one centimetre in size are preserved on some surfaces.



Figure 5 At 22 cm these are the longest bladed olivine crystals of spinifex textured slag seen at Workington. It is probable that this sample is often covered in sand (20p coin for scale).

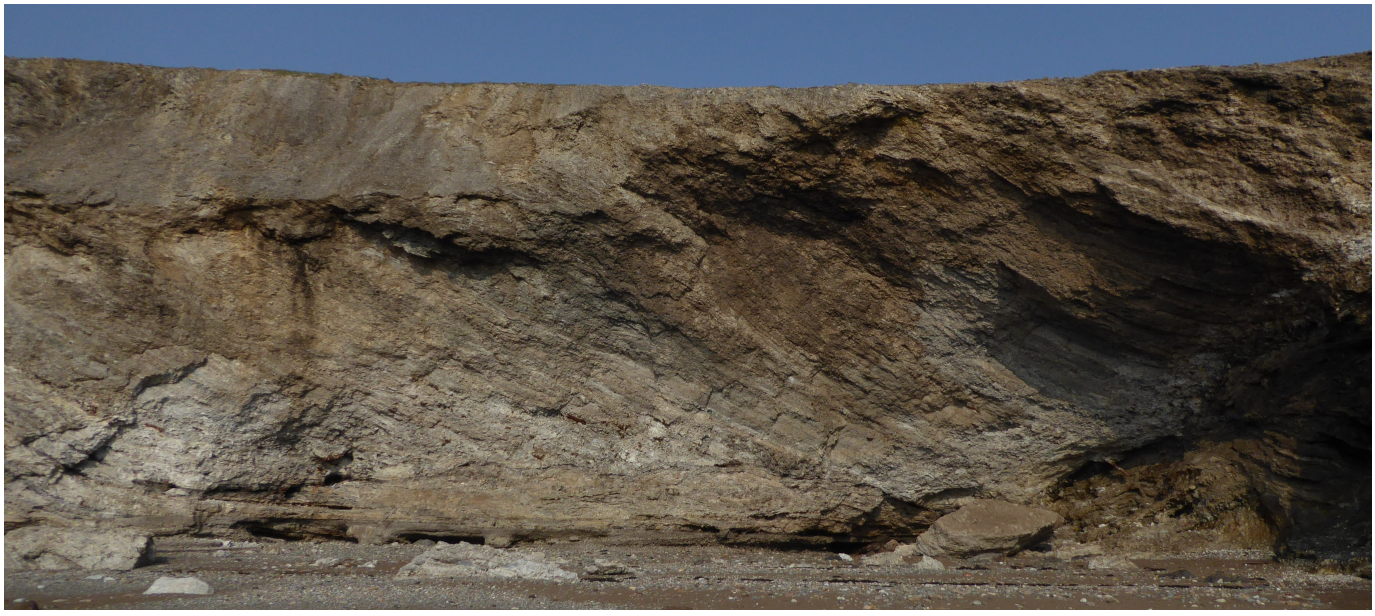


Figure 6 Cross-stratification created by multiple thin pahoehoe lavas from tipped slag. Cliff height approx. 10 metres.

References:

Self, S., Keszthelyi, L., and Thordarson, Th. (1998) The Importance of Pahoehoe, *Annual Reviews of Earth and Planetary Science,* vol. 26, 81-110.