Discussion on structure and evolution of hydrothermal vent complexes in the Karoo Basin, South Africa

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B. E. Lock & J. A. Robey write: We were interested to read the paper by Svensen *et al*. (2006) on South African hydrothermal vents within the Karoo Basin, particularly concerning two vent complexes known as Witkop II and Witkop III. One of us (B.E.L.) had barely initiated a study of the Stormberg diatremes when he left South Africa to accept a faculty position in Louisiana in 1977, and the project was not continued. However, the Svensen paper reminded us of features we had seen in the field at the Mackay's Kop diatreme, near Jamestown, in the mid-1970s. This diatreme is in the same general area as those described by Svensen *et al*. but had not been visited by the latter because of their difficulty in locating the absentee landowner (G. Marsh, pers. comm.). In particular, we note the description of 'a partly undulating border zone… typical for the pipes at Witkop III' complex, which the authors interpreted as a 'deformation zone'. Based on figures in the original paper, particularly their figure 7c, a similar zone surrounds the Mackay's Kop diatreme, but our interpretation differs significantly from that of Svensen *et al*., and bears on the mechanisms involved in diatreme formation and evolution.

The pipe at Mackay's Kop has a central fill consisting of a variety of lithofacies: massive sandstone, heterolithic breccias with sandstone and mudstone clasts, and small pebble conglomerates consisting of well-rounded sandstone clasts (Fig. 1). A narrow marginal zone (15–40 cm wide) of sandstone is the equivalent, we believe, of the 'deformation zone' of Svensen *et al*. Because the diatreme lithologies are more resistant than the country rock, the outer surface of the marginal zone is exposed and displays some relief that reflects a mould of the original pipe wall, with horizontal country-rock bedding picked out by hardness variations (Fig. 2). The marginal sandstone facies displays complex vertical laminations with curved forms and repeated truncation surfaces, resembling ripple structures of sedimentary deposits (Fig. 3). Where the truncation surfaces are exposed in three dimensions, the commonest structure is seen to consist of vertical grooves (Fig. 2), mainly convex outwards (compare with grooved surfaces illustrated by Svensen *et al*. in their fig. 7c).

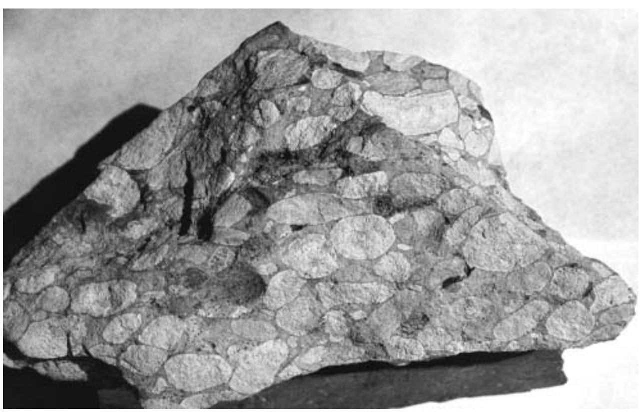

Fig. 1. Sample from core lithology, Mackay's Kop diatreme. The well-rounded pebbles, averaging 1 cm in diameter, should be noted (sample is 15 cm long).

It is our interpretation that the marginal zone reflects the processes of pipe formation. An initial explosion of groundwater flashed to vapour by contact with magma eroded the country rock to create the tubular pipe. A jet of high-velocity gases (presumably a mixture of water vapour with some condensation to steam droplets) at first enlarged the pipe but then started to deposit wet sand as a smear against the pipe wall. The cohesive effects of water droplets condensed from volcanic gases are well documented by accretionary lapilli in tuff rings around maar-type vents around the world: Kilbourne Hole in New Mexico and Lago di Albano (Castel Gandolfo), Italy, are two examples with which the senior author is familiar. The gas jet continued to deposit and erode the sand smear during this phase of the eruption and the term scour and plaster is appropriate to describe the structures in the accumulated layer. During the subsequent stage, the pipe was filled with the central fill facies; rounding of sandstone clasts is attributed to abrasion, in the streaming jet of gas, of fragments derived from the country rock.

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H. Svensen, S. Planke, B. Jamtveit & L. Chevallier write: We would like to thank Lock & Robey for their interest in our paper on hydrothermal vent complexes in the Karoo Basin (Svensen *et al*. 2006). Based on their experience with similar structures near our study area (the Mackay's Kop hydrothermal vent complex), they raise some questions about our interpretations. Lock & Robey specifically address the deformation zones along the borders of the hydrothermal vent complexes. If we understand Lock & Robey correctly, they argue that these zones represent sediments 'smeared against the pipe wall' during phreatic eruptions. We would like to clarify our view on the formation of the hydrothermal vent complexes and the structures referred to by Lock & Robey.

(1) We did reconnaissance field work at the Mackay's Kop hydrothermal vent complex (Fig. 4a) in 2002, and it shares many of the features that we have observed elsewhere in the region. We have studied more that 20 vent complexes in the Karoo Basin dominated by sedimentary breccias and sedimentary deposits. We chose to focus on the Witkop II and Witkop III localities because of good exposures and a high diversity of unique geological structures.

(2) We have not worked on the details of Mackay's Kop, and can thus not comment on the pictures shown by Lock & Robey. However, our original figure 7 (Svensen *et al*. 2006) does not represent the outer rim of the Witkop III hydrothermal vent complex, but the boundary zone of an 8 m wide sandstone pipe located within the hydrothermal vent complex (Fig. 4b). More than 30 of these pipes cut the breccia fill of the vent complex,

Fig. 2. Marginal zone at Mackay's Kop, view towards pipe centre. The surface closest to the camera (by face of hammer head) is the outer surface of the marginal zone; horizontal features are impressions of bedding from country rock. The vertical grooves, particularly on the interior surface, should be noted.

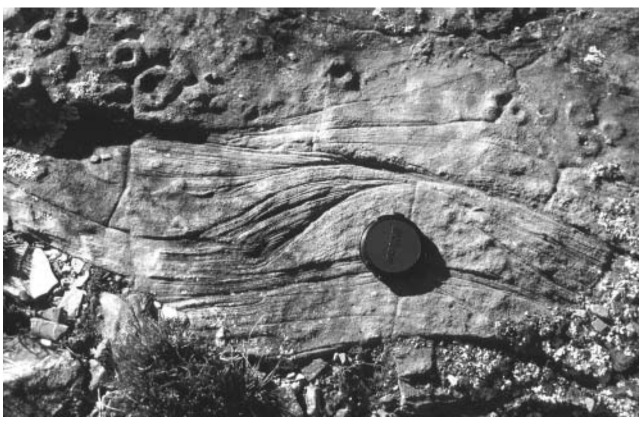

Fig. 3. Example of scour and plaster structures in the marginal zone, McKay's Kop. Circular features towards the top of the image are ferruginous concretions in country rock, common in local sandstones.

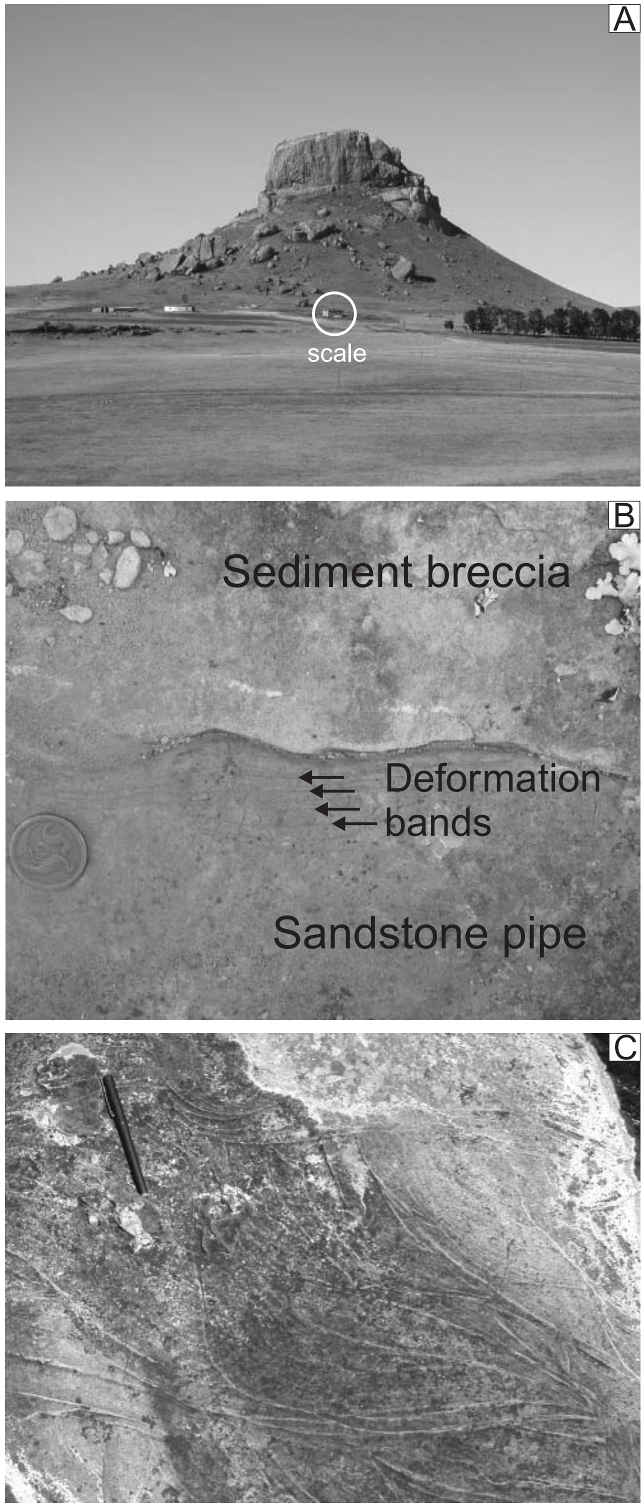

Fig. 4. (**a**) The Mackay's Kop hydrothermal vent complex is located in the Eastern Cape in South Africa (31°19′57″S, E 27°12′59″). The complexes comprise breccia deposits in a near-vertical conduit zone that cut surrounding sedimentary strata. The house indicates scale. (**b**) Boundary between sediment pipe and breccia deposits (seen from above) within the Witkop III hydrothermal vent complex. (Note the deformation bands in the pipe wall.) (**c**) Undulating sedimentary structures, interpreted as slumps, at the boundary between the inner and outer zones of the Witkop III hydrothermal vent complex.

with distinct deformation zones including both horizontal and vertical deformation grooves. Thus, in our case, these structures do not give information about the initial phreatic processes forming the vent complexes, or the possible 'smearing' of sediments along the crater rims during eruptions.

(3) At Witkop III, slumped sediments are present at the boundary between the dipping strata of the outer zone and the breccias of the inner zone (see Svensen *et al*. 2006, fig. 5a). We relate the structure of these deposits to tilting during early stages of vent formation, and not to smearing. Tilting of sedimentary strata is commonly observed adjacent to piercement structures in sedimentary basins, and is related to mass transport processes (e.g. Planke *et al*. 2003, 2005; Hovland *et al*. 2005). Slumping of near-surface sediments would be an expected consequence of this tilting.

(4) Lock & Robey argue that the hydrothermal vent complexes were formed as a result of explosions triggered when magma interacted with ground water. However, our model relates the formation of hydrothermal vent complexes to processes in the sediments surrounding sill intrusions, where a low permeability of the host rock will cause pressure build-up during fluid expansion and boiling (Jamtveit *et al*. 2004). This may furthermore explain why the hydrothermal vent complexes are dominated by sedimentary and not volcanic rocks.

There are still many important questions that need to be addressed to fully understand the formation of hydrothermal vent complexes in volcanic basins. We encourage Lock & Robey to revisit the complexes in the Karoo Basin, in particular Mackay's Kop. We believe that these complexes represent structures relevant for understanding climate changes and carbon cycle perturbations (Svensen *et al*. 2004, 2005), and clearly deserve a broader attention.

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References

Hovland, M., Svensen, H. & Forsberg, C.F. *et al.* 2005. Complex pockmarks with carbonate-ridges off mid-Norway: products of sediment degassing. *Marine Geology*, **218**, 191–206.

Jamtveit, B., Svensen, H., Podladchikov, Y.Y. & Planke, S. 2004. Hydrothermal vent complexes associated with sill intrusions in sedimentary basins. *In:* Breitkreuz, C. & Petford, N. (eds) *Physical Geology of High-Level Magmatic Systems*. Geological Society, London, Special Publications, **234**, 233–241.

Planke, S., Svensen, H., Hovland, M., Banks, D.A. & Jamtveit, B. 2003. Mud and fluid migration in active mud volcanoes in Azerbaijan. *Geo-Marine Letters*, **23**, 258–268.

Planke, S., Rassmussen, T., Rey, S.S. & Myklebust, R. 2005. Seismic characteristics and distribution of volcanic intrusions and hydrothermal vent complexes in the Vøring and Møre basins. *In:* Doré, A.G. & Vining, B. (eds) *Petroleum Geology: North-West Europe and Global Perspectives—Proceedings of the 6th Petroleum Geology Conference*. Geological Society, London, 833–844.

Svensen, H., Planke, S., Malthe-Sørenssen, A., Jamtveit, B., Myklebust, R., Eidem, T. & Rey, S.S. 2004. Release of methane from a volcanic basin as a mechanism for initial Eocene global warming. *Nature*, **429**, 542–545.

Svensen, H., Planke, S., Chevallier, L., Malthe-Sørenssen, A., Jamtveit, B. and Corfu, F. 2005. A new model for the Toarcian global climate change: explosive venting of greenhouse gases from metamorphic aureoles around sill complexes in the Karoo Basin. *EOS Transactions, American Geophysical Union, Fall Meeting Supplement*, **86**(52), Abstract PP51B-0601.

Svensen, H., Jamtveit, B., Planke, S. & Chevallier, L. 2006. Structure and evolution of hydrothermal vent complexes in the Karoo Basin, South Africa. *Journal of the Geological Society, London*, **163**, 671–682.

B. E. Lock, Department of Geology, University of Louisiana, Lafayette, LA 70504-4530, USA (e-mail: belock@louisiana.edu)

J. A. Robey, De Beers Group Services, PO Box 47, Kimberley 8300, South Africa

H. Svensen, Physics of Geological Processes, Department of Physics, University of Oslo, PO Box 1048, Blindern, 0316 Oslo, Norway (e-mail: henrik.svensen@fys.uio.no)

S. Planke, Physics of Geological Processes, Department of Physics, University of Oslo, PO Box 1048, Blindern, Norway, Volcanic Basin Petroleum Research, Oslo Research Park, 0349 Oslo, Norway

B. Jamtveit, Physics of Geological Processes, Department of Physics, University of Oslo, PO Box 1048, Blindern, Norway

L. Chevallier, Council for Geoscience, PO Box 572, Bellville 7535, Cape Town, South Africa

Scientific editing by Sally Gibson