Contaminated komatiites

HUPPERT *et al.*[1] calculate that Ni ores in ultrabasic lavas could be formed by assimilation of sulphidic bedrocks and Nisbet[2] comments that models based on komatiite chemistry may be spurious artefacts of contamination. Here, we draw attention to field and geochemical aspects of komatiites strongly suggesting that melting of their bedrocks did not occur.

Ni-ores are rare in komatiite lavas and, if the ground-melting model were correct, areas where none occur should correlate with low abundances of sulphidic sediments. This is not so: in Western Australia, for example, such sediments are ubiquitous and have frustrated countless geophysically-targeted searches in barren komatiite piles. Thus, assimilation of surface sediments cannot be a major mechanism of Ni-sulphide genesis.

Support for thermal erosion theories comes from Kambalda, where a sediment marking the komatiite/basalt contact is absent in ore-bearing troughs[3]. However, 'hanging-wall' ores above the troughs form consistently-aligned vertical stacks of deposits[3] and the repetitive occurrence of ore-bearing flows, over the same area of sea floor, cannot be caused by assimilation, as the initial flow would deplete this area in sediments. The systematic pattern is more consistent with lavas flowing into pre-existing channels, as delineated elsewhere by sediments underlying komatiites[3-6]. Furthermore, there is little evidence for incipient melting or a thermal aureole in such sediments and there is a conspicuous absence of veining of bedrocks and of xenoliths in komatiite flows.

Surface-melting is distinct from other models for magma contamination in its selectivity; trace elements in each flow should reflect variable amounts of contamination from a wide range of possible substrates. However, it is difficult to explain observed systematic trends[7-10] in such terms and, in particular, the anomalous Sm–Nd isotopic data for Kambalda[11] are unlikely to reflect selective contamination because the tight grouping of both komatiites and basalts on the same isochron is too coherent. Sulphur isotopes in Kambalda ores cannot distinguish between surface and other crustal sulphur[12] but chalcophile-element depletions show that all komatiites were saturated with sulphur before eruption[13], which argues convincingly against selective assimilation of sulphur by ore-bearing flows.

That komatiites flow turbulently and so transfer heat efficiently seems inescapable. However, the chilled crust at the base of komatiite lavas[14,15] is free of cumulate olivine and so must have formed during the turbulent phase when olivines were in suspension and when melting of bedrock would otherwise be most efficient. We suggest that the basal crust develops in a manner similar to that at the flowtop (equation 7 in ref. 1) and that it forms an effective insulating layer between the ground and overlying hot, turbulent lava.

With no komatiites being erupted for us to observe today, theoretical treatments of what could occur are of great value. Nevertheless, it is apparent that the real lavas were more restrained and less voracious than their mathematical counterparts and this should impose a constraint on the physical properties to be modelled.

J. C. CLAOUÉ-LONG
R. W. NESBITT
Department of Geology,
The University, Southampton,
Hampshire SO9 5NH, UK

1. Huppert, H. E., Sparks, R. S. J., Turner, J. S. & Arndt, N. T. *Nature* **309**, 19-22 (1984).
2. Nisbet, E. G. *Nature* **309**, 14-15 (1984).
3. Gresham, J. J. & Loftus-Hills, G. D. *Econ. Geol.* **76**, 1373-1416 (1981).
4. Schmulian, M. L. in *Regional geology and nickel deposits of the Norseman-Wiluna belt, Western Australia* (eds Groves, D. I. & Lesher, C. M.) (University of Western Australia, Perth, 1982).
5. Stolz, G. W. & Nesbitt, R. W. *Econ. Geol.* **76**, 1480-1502 (1981).
6. Page, M. L. & Schmulian, M. L. *Econ. Geol.* **76**, 1469-1479 (1981).
7. Nesbitt, R. W. & Sun, S.-S. *Earth planet. Sci. Lett.* **31**, 433-453 (1976).
8. Sun, S.-S. & Nesbitt, R. W. *Contr. Miner. Petrol.* **65**, 301-325 (1978).
9. Nesbitt, R. W., Sun, S.-S. & Purvis, A. C. *Can. Miner.* **17**, 165-186 (1979).
10. Arndt, N. T. & Nesbitt, R. W. in *Komatiites* (eds Arndt, N. T. & Nisbet, E. G.) 309-330 (Allen & Unwin, London, 1982).
11. Claoué-Long, J. C., Thirlwall, M. F. & Nesbitt, R. W. *Nature* **307**, 697-701 (1984).
12. Groves, D. I., Barrett, F. M. & McQueen, K. G. *Can. Miner.* **17**, 319-336 (1979).
13. Lesher, C. M., Lee, R. F., Groves, D. I., Bickle, M. J. & Donaldson, M. J. *Econ. Geol.* **76**, 1714-1728 (1981).
14. Barnes, R. G., Lewis, J. D. & Gee, R. D. *A. Rep. Geol. Surv. West Australia*, 59-70 (1973).
15. Arndt, N. T., Francis, D. & Hynes, A. J. *Can. Miner.* **17**, 147-163 (1979).

HUPPERT *ET AL.* REPLY—Claoué-Long and Nesbitt present only some of the facts supporting thermal erosion and contamination in komatiites. Interpretations of these rocks are rarely straightforward, as their lavas are deformed and metamorphosed; primary volcanic features have only been well documented in a few places. However, we believe that Claoué-Long and Nesbitt may have failed to appreciate several aspects of our model[1], causing them to misinterpret some of the geological observations which they cite; we note specifically the following:

(1) Nickel ores are found commonly in komatiites[2-3] and there is a general connection between komatiite-associated ore occurrences and sediments in the Norseman–Wiluna Belt of Western Australia[4] and those in the Abitibi Belt, Ontario[5]. As in all ore deposits, a nickel-enriched mineralized locality must be complemented by much larger volumes of barren lava; only in this sense are the ores 'rare'.

(2) For Kambalda, there are several arguments favouring thermal erosion additional to those selected by Claoué-Long and Nesbitt (see, for example, ref. 6). Contrary to the given impression, interflow sediments do occur in komatiites at the same stratigraphic levels as the hanging-wall ores but are absent from the ore zones. Furthermore, it is not unreasonable for successive lavas to follow the same path, the previous flow forming a depression by partial drain-out or sagging above its thickest part and subsequent komatiites accentuating the depression by thermal erosion.

(3) The thermal aureole at the base of a channel would only be a few cm thick. Given the sheared and regionally-metamorphosed condition of many contacts and the limited number of detailed studies, we are not surprised that evidence for an aureole or for xenoliths has not yet emerged and we emphasize that thin aureoles should be present whether or not the komatiite has eroded its floor rocks.

(4) Variations in incompatible element ratios in komatiites have been interpreted[7-9] in terms of mantle heterogeneities but small amounts of contamination can produce similar effects. Thus we do not accept that contamination will necessarily produce non-systematic trends and emphasize the efficiency with which floor rocks would be homogenized during thermal erosion and assimilation.

(5) We are puzzled by Claoué-Long and Nesbitt's statement that the Nd isotopic data from Kambalda are anomalous. Claoué-Long *et al.*[10] interpret these data as defining an old, but acceptable isochron; others[11] have suggested that the Sm–Nd array is a mixing line, perhaps resulting from contamination of komatiite with older granitic or sedimentary rocks, an interpretation consistent with thermal erosion.

(6) Chalcophile-element depletion provides evidence of sulphide fractionation but not as to where, when or how it took place.

(7) The reason why basal crust should form while the flow is moving is not clear to us. If basal chills prove to be a general feature of komatiites (and only two examples have been described) they will form at a late stage in the lava's history when turbulent motions have weakened. The boundary conditions at the base and top of a flow are fundamentally different as sea water can remove heat efficiently by convection whereas rock is a poor conductor. We estimate elsewhere[12] that any initial chill on the base will be dissolved away in a lava with prolonged throughput, which is precisely what is observed at Kambalda where massive sulphide overlies footwall basalt with no intervening komatiite chill, a puzzling feature until explained by thermal erosion.

Komatiites are highly susceptible to contamination effects. This may be inconvenient, but geologists may have to get used to the idea in the future.