passive margin of the United States East Coast has long been regarded as the head of the household in the 'non-volcanic' family. The series of seismic studies that Holbrook and Keleman summarize shows that it actually has the appropriate attributes — dipping reflectors, high-velocity deep layer — for a volcanic margin.

Why has it taken so long to recognize these features? Well, only the most recent studies have used seismic sources powerful enough to penetrate the huge absorbing barrier of sediment on the margin. Also, because the margin lacks any evidence of flood basalt sequences or a hotspot trail associated with breakup, no one knew where to look for dipping reflectors. Hinz⁸ had actually suggested their presence in older, poorer reflection data, so perhaps we just didn't want to believe that the sequences were there because they did not fit our preconceptions. Now we are forced to conclude that the United States East Coast cannot belong to the 'volcanic' family if the hotspot mechanism is to be invoked, nor yet to the 'non-volcanic' family because it lacks the proper family resemblance.

Things may be even worse. Holbrook and Keleman estimate that the average seismic velocity in the lower crust could be as high as 7.5 km s^{-1} . A velocity of 7.2 km s^{-1} is possible in magma derived from partial melts⁷ because higher mantle temperatures produce more melting, and this forms magma with more of the dense magnesium oxide component. An increase of 300°C — a reasonable anomaly for a hotspot — gives a seismic velocity of 7.2 km s^{-1} . But extrapolating these results, we find that a leap of more than 550°C is required to reach 7.5 km s^{-1} . Such a temperature perturbation would produce almost twice the thickness of igneous crust estimated to be present on the East Coast margin. If it resulted from a hotspot, surely so fierce a hotspot would leave a huge trail?

Perhaps we can account for the high-velocity lower crust once we know just what rocks are present at depth in the crust; ultramafic rocks (those rich in iron and magnesium) can exhibit near-mantle velocities. More troublesome for models of margin evolution is the apparent lack of continental crust in the structure sections for the United States East Coast². Dipping reflector sequences lie in contact with the intrusive/plutonic section, with nothing in between. Either the continental crust is so thin or so intruded that it cannot be recognized, or it simply isn't there. The transition from clearly continental crust to a region with no continental character is completed in $\sim 20 \text{ km}$, half the crust's original thickness. Lithospheric rupture has apparently erased any vestige of continental crust to produce one of the most extraordinary geological boundaries on Earth. This boundary is, to my mind, as

critical to understanding the process of lithospheric rupture as the volcanic sequences themselves.

The action of a hotspot cannot reasonably be blamed for this boundary. It is as if the continental lithosphere that was broken here was extraordinarily weak. Anderson and others⁹ have suggested that continental flood basalts occur when rifting of very thick lithosphere causes mantle upwelling from unusual depths. If thick lithosphere includes a thick crust it may indeed be much weaker than thin lithosphere and rupture without a protracted period of extension or the formation of a wide, distended margin. For rapid separation, decompression melting would not be suppressed and, in fact, might be increased if convection due to lateral thermal gradients enhances the mantle flow. A regionally warm mantle, rather than an isolated hotspot, would further weaken the lithosphere throughout the extensional province, depress the solidus and reduce mantle viscosity, to give rapid upwelling along the entire margin. Holbrook and Keleman point out that this would lead to melting at initially low melt fractions and high pressure, as has been seen in basalts from the North Atlantic Tertiary province¹⁰.

Declassification

So where do we stand? It seems to me that the whole idea of making a strict bipolar classification of margins was an error. By labelling margins 'volcanic' and 'non-volcanic', we thought we had brought an understanding to them that we had not.

Surely the Earth does not behave this way. Surely tectonic stresses, combined with the strength of the lithosphere and the condition of the underlying mantle, will give rise to an essentially continuous range of responses and a corresponding variety of margin forms. Our challenge is not to classify the observable properties of the system, but to derive from them a closed set of parameters and physical laws that properly describe its behaviour. □

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Silver linings

Of the sunlight that hits the Earth, about 30 per cent is just reflected away again, largely from white cloud. The rest warms the Earth, and potentially contributes to the greenhouse effect. One way of countering this menace would be to increase the Earth's reflectivity. This journal has mooted some ways of doing this, such as covering the Sahara desert with mirrors or putting vast sunshades into orbit, which would embarrass even Daedalus. He has a far neater solution: increase the whiteness of the clouds.

Thanks to their surface tension, small cloud droplets have a higher vapour pressure than big ones. So small droplets tend to evaporate, while big ones take up the released vapour and grow even bigger. This slow replacement of many small droplets by a few bigger ones reduces the reflectivity of the cloud. Daedalus reckons that by adding detergent to a young cloud, you could reduce the surface tension of its droplets. They would cease to evaporate or merge into bigger ones, so the cloud would stay highly reflective. His new bubble-blowing machine releases thousands of buoyant, hydrogen-filled detergent bubbles every minute. Launched into young, growing clouds, the benevolent bubbles will dope them with detergent and stabilize them at their brightest and best.

A bubble barrage will not merely keep a cloud white. It will keep it in being. Normally, most clouds don't last long. Their droplets steadily merge and agglomerate and precipitate as rain. But detergent in a droplet can do more than merely reduce its vapour pressure. By covering the droplet with a monolayer of non-volatile surface-active molecules, it can cut its rate of evaporation almost to zero. Even better, two such coated droplets will not merge if they happen to collide; they will simply bounce apart again. (You can see this effect in the skating droplets often thrown up in detergent-laden washing-up water.) A detergent-doped cloud could neither evaporate nor rain. It should drift around the atmosphere almost permanently, reflecting sunlight away into space.

Thus the greenhouse effect will be brought under fine control. Daedalus's bubble barrages will load the atmosphere with an increasing population of highly reflective, permanent clouds. By reflecting so much light away on top, permanent clouds will seem dark and rain-charged from underneath. But with luck they will look odd in some way, so that we will soon come to recognize them as rainless frauds. Weather everywhere will get cloudier and colder, but not rainier.

David Jones