PLATE TECTONICS

Seamounts make earthquakes

Larry J. Ruff

IMAGINE a tremendous force pushing against the side of a huge mountain, so that the mountain is sheared off at its base. It may be difficult for us to comprehend the forces required for this mountain 'decapitation', but it is easy to believe that huge earthquakes might be caused by such an event. In their recent article published in *Geology*, Cloos and Shreve[1] speculate that shearing of seamounts buried in subduction zones causes many of the world's largest earthquakes.

Given the visual image of a decapitated mountain, Cloos and Shreve's speculation certainly has some intuitive appeal. Although the idea seems simple, the case for seamount decapitation causing large earthquakes draws upon diverse facts from subduction zone tectonics and global seismicity.

New oceanic lithosphere is created at mid-ocean ridges, and as it spreads and ages the sea floor gradually attains a typical depth of about five kilometres below sea level. Eventually, the lithosphere encounters a subduction zone, where it is forced beneath the wedge-shaped overlying plate (see figure). Sitting on top of the otherwise smooth sea floor are isolated mountains called seamounts. Their peaks are usually submerged, but their height above the sea floor can reach 4 km or so — they are big mountains.

So what happens to seamounts, or any other 'bumps', as the sea floor passes beneath the other plate? The pressure crushes any void below a depth of one kilometre, so either the bumps are all sheared off at a shallow depth to make the top of the subducting sea floor smooth, or sediments fill in around them to provide a smooth surface.

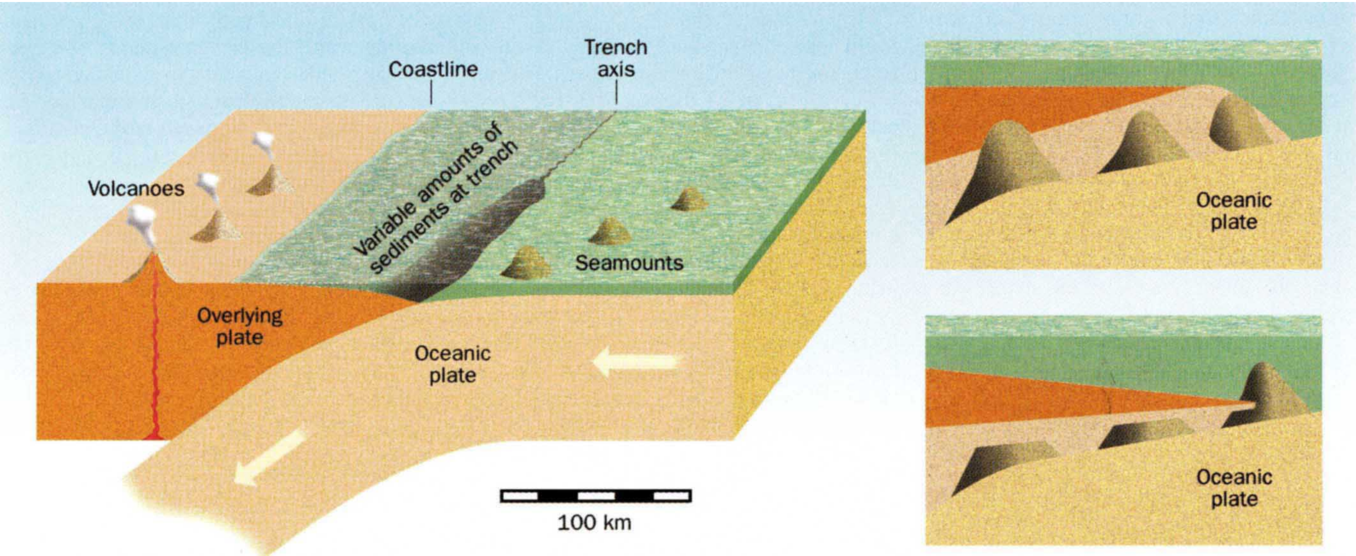
Most of the world's large earthquakes occur in the subduction zones around the rim of the Pacific Ocean. The largest of these earthquakes are caused by sudden slips at the interface between the two plates, above a depth of about 60 km (ref. 2). The Pacific subduction zones generate many magnitude-seven events a year, and three events this century have been larger than magnitude nine.

Seismologists have shown that larger earthquakes are caused by a larger fault area. For example, the greatest subduction earthquakes, of magnitude 8.5 or more, rupture fault areas that are 100 km wide and extend for several hundred kilometres along the subduction zone. The merely 'great' magnitude 8 events have rupture zones that are about 100 by 100 km, and 'modest' magnitude 7 events have fault areas that are about 20 km across. We also know that fault slip generally increases as the fault area increases — typical values range from 1 m to more than 10 m as earthquake size ranges from 7 to 9. So our visual image of instant mountain decapitation is a bit exaggerated. It takes one thousand magnitude-nine earthquakes to completely decapitate a typical seamount with a base 10 km wide.

In any one earthquake, the slip distance varies along the fault. One interpretation is that stronger portions of the plate interface slip further. These strong subregions are called asperities[3]. Rupture of these asperities controls the place, the time and the fault area of the largest earthquakes. Asperities are a useful concept, but 'strong subregion' is a rather vague definition. Suggestions for their physical nature include irregularities in the subducted sea floor[4], the overlying plate[5] or the interface itself[6]. Although we do not yet know what asperities are, we think they control the size of earthquakes!

Another key observation is that earthquake size varies between zones. Uyeda and Kanamori[7] noted that a few zones, such as the Chilean, consistently generate the largest earthquakes, while all other subduction zones, like the Marianas, generate smaller events. They speculated that this diversity is explained by the 'absolute' velocity of the overlying plate (relative to the deep mantle): Marianas-type zones result from the overlying plate moving back away from the oceanic plate, reducing the speed of subduction; Chilean-type zones have it charging over the trench. Scholz and Campos[8] have extended this idea. In their model, the subducted plate acts as a 'sea anchor' in the mantle 'ocean', and the resultant forces partly determine whether a particular subduction zone is a Chilean-type or Marianas-type. The connection between a global tectonic parameter, such as mantle flow, and plate interface asperities is not obvious.

In contrast, two local tectonic variables that may have a direct influence on asperities are sea floor roughness and the style of sediment subduction. We might expect that subduction of a 'rougher' sea floor with few sediments would result in larger earthquakes, but actually it produces smaller ones. The largest earthquakes occur in zones with tremendous



Two different ways a seamount can be subducted. Seamounts can cause small or large earthquakes depending on where they are decapitated, which depends on the amount of sediment at the trench. That in turn depends on the geometry of the 'subduction channel'. Top right: a narrow channel mouth scrapes off sediments and decapitates seamounts at the trench, causing small earthquakes. Bottom right: a channel that starts wide and narrows with depth allows sediments to accumulate and seamounts to reach a depth of perhaps 40 km, where their decapitation may be responsible for great earthquakes.

piles of sediments at the trench[4]. Further, the sea floor that subducts beneath northern Japan changes from 'smooth' to 'rough' along the trench, and the variations in sea floor roughness directly correspond to the pattern of earthquake occurrence[9]. In particular, large earthquakes occur where 'smooth' sea floor is subducted. It seems that plentiful sediments and smooth sea floor result in large asperities[4].

Cloos and Shreve[1] now offer a direct connection between a physical feature and the global variation in large earthquake occurrence. The idea is that subducted seamounts make the asperities that control earthquake occurrence, but that earthquake size depends on where the seamounts are decapitated, not, as in an earlier model, on their size[10]. If the seamounts are sheared off at the mouth of the trench, then only small earthquakes are produced. But if they are first subducted down to 40 km or so, the decapitation produces large to great earthquakes.

The amount of sediment present at the trench is connected to the geometry of the 'cutting blade' of the overlying plate (see figure). Seamounts that protrude from the sediment are decapitated at the trench, resulting in small earthquakes. There are no large earthquakes further down dip because the 'subduction channel' is filled with the rubble of sediments and sheared-off bumps, and this rubble does not make large asperities.

The other extreme is where the seamounts are covered by sediment, and easily subduct through the shallow part, but eventually encounter the roof of the overlying plate down at a depth of about 40 km. The seamount then becomes an asperity. Since great earthquakes require fault zones more than 100 km across, Cloos and Shreve suggest that the seamount asperity initiates the rupture, which then spreads over a much larger area into strong, metamorphosed sediments.

This idea seems to satisfy several observations about great earthquake occurrence. Of course, it must now be tested with new observations. The seismological literature is littered with intuitively appealing explanations that could not survive the grim reaper of closer scrutiny. But for the moment we can explain some aspects of earthquake occurrence with the following subduction tale: seamounts try to hide in sediments to escape the blade of the overlying plate, but they all lose their heads eventually. Those that are decapitated quickly, at the trench, do so with the minor complaints of small earthquakes, but those that evade decapitation for some time protest about their fate with the booms of great earthquakes. ☐

Larry J. Ruff is in the Department of Geological Sciences, University of Michigan, Ann Arbor, Michigan 48109, USA.

---

1. Cloos, M. & Shreve, R. L. *Geology* **24,** 107–110 (1996).
2. Tichelaar, B. & Ruff, L. J. *J. geophys. Res.* **98,** 2017–2037 (1993).
3. Kanamori, H. *A. Rev. Earth planet. Sci.* **14,** 293–322 (1986).
4. Ruff, L. J. *Pure appl. Geophys.* **129,** 263–282 (1989).
5. Beck, S. L. & Christensen, D. H. *J. geophys. Res.* **96,** 2205–2221 (1991).
6. Scholz, C. H. *The Mechanics of Earthquakes and Faulting* (Cambridge Univ. Press, 1990).
7. Uyeda, S. & Kanamori, H. *J. geophys. Res.* **84,** 1049–1061 (1979).
8. Scholz, C. H. & Campos, J. *J. geophys. Res.* **100,** 22103–22115 (1995).
9. Tanioka, Y., Ruff, L. J. & Satake, K. *The Island Arc* (submitted).
10. Cloos, M. *Geology* **20,** 601–604 (1992).

ECOLOGY

Invertebrates and mycophagy

Peter D. Moore

THERE is nothing very remarkable about eating fungi, although it does make life difficult for those who enjoy constructing diagrams of food webs and wish to assign organisms to neat trophic levels. Various animals from flies to reindeer take culinary delight in certain toadstools and some, such as termites and leaf-cutter ants, actually farm fungi by supplying them with a plant-based energy resource to ensure their productive growth. But the observations of M. Bass and J. M. Cherrett, published in the latest issue of *Functional Ecology*[1], show that the horticultural activities of some mycophagous ants even extend to pruning hyphae as a growth stimulant, and this adds a new dimension to an already remarkable story of invertebrate agriculture.

M. Bass

Down on the fungal farm — a worker ant consumes a staphyla.

Leaf-cutter ants gather fresh leaf material as a substrate for the cultivation of basidiomycete fungi which they cultivate within their nests. These fungi do not fruit but produce bunches of swollen hyphae (staphylae) that are used by the ants and their larvae as food, being relatively rich sources of energy and having a reasonable content of nitrogen and other nutrient elements[2]. Many ant workers spend time licking the hyphae, in the process of which some are broken and ingested by the ants, and Bass and Cherrett came up with the hypothesis that this activity constitutes a pruning process during which mycelial branching and the generation of staphylae is stimulated.

They tested the efficacy of ant care on fungal productivity by growing samples of fungus garden in petri dishes and exposing some of them to ant activity for just three hours, while control samples were isolated from the ants. The numbers of staphylae in each dish were counted and, predictably, significantly fewer staphylae survived in those samples exposed to the depredations of ants. Two days later, however, the situation was reversed and ant-exposed samples had 30 per cent more staphylae than the controls, so the attentions of the ants had generated a higher density of the swollen hyphal bunches.

The question arises whether the stimulation observed was simply a consequence of mechanical damage and resulting mycelial branching, or whether some chemical exudate is involved, as has been proposed for stimulation of herbaceous growth by mammalian grazers[3]. To test these options four experiments were set up, in which staphylae were harvested artificially using a needle; hyphae were stroked and broken with a needle; ant faeces were applied without causing physical damage; and the crushed heads of workers, suspended in water, were added to the culture (with the idea of simulating the effect of exudates from ant labial glands).

The first two treatments initially reduced the numbers of staphylae but after three days these gardens had significantly greater crops (including the harvested material) than the samples treated with ant faeces, head extracts or the untreated control. The conclusion, therefore, is that the mechanical pruning activity of the ants stimulates the fungus into producing new staphylae. This does not, however, preclude the possibility that some other gardening activities, such as the control of invasive fungi, may involve chemical treatments by ant exudates.

The process described here is entirely vegetative on the part of the fungus; no change in resource allocation to reproductive structures is involved. As the authors point out, this response is unlike that involved in the human pruning of fruit trees, where resources are channelled from