The Case for Magmatic Triggering

In his recent posting on the Feb/Mar 2005 Endeavour Earthquake Sequence, Macdonald states that this activity was '*almost certainly caused by lithospheric deformation*' and '*not by magmatic or volcanic activity*'. Below, I outline why such claims are not well-supported by the seismo-acoustic observations and argue that the decision by our TCS colleagues to dispatch a response cruise was (in my opinion) based on sound scientific reasoning.

Macdonald was correct to point out that the portion of the seafloor within the overlap zone is undergoing bookshelf faulting, and in fact moment-tensor solutions for the largest events are consistent with dominantly right-lateral slip along roughly N-S trending fault planes [1] (Fig. 1). Making an assumption that such activity precludes the involvement of magma, however, neglects the fact that small-to-moderate size triggered earthquakes would occur almost exclusively along pre-existing faults within an existing stress field. Hence, the movement or intrusion of magma at depth beneath the northern limb of the Endeavour Segment or beneath the overlap zone would be expected to trigger some component of bookshelf faulting. The presence of magma within the overlap zone is quite reasonable in this setting due to its proximity to the Heck Seamount Chain and notably the Endeavour Seamount, which resides within the northern part of the overlapper (Fig. 1). However, given our understanding of the absolute SOSUS location errors, the TCS group was correct not to rule out either scenario.

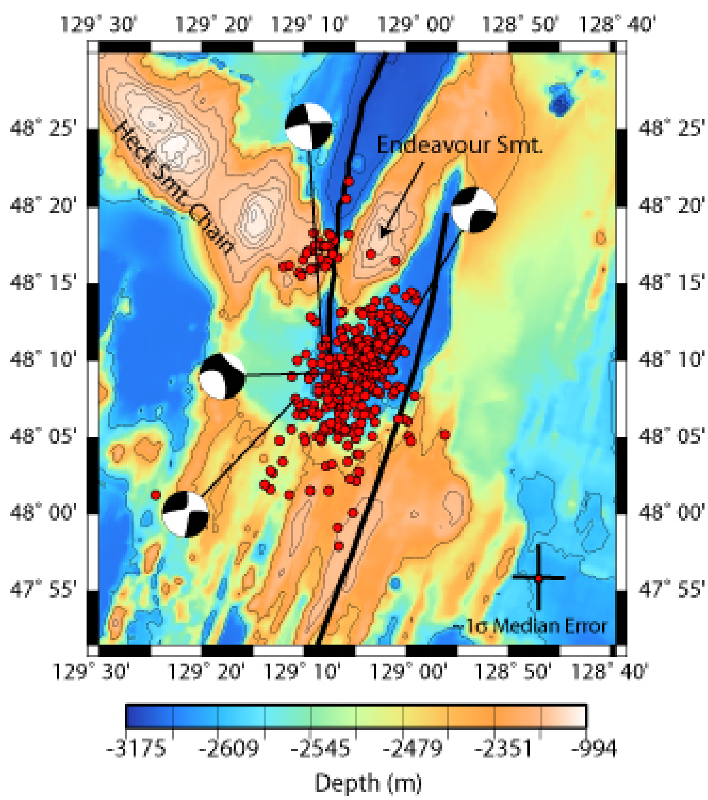

Figure 1. SOSUS epicenters and Harvard CMT solutions (28 Feb. – 03 Mar., 2005). The smallest events located have a magnitude of ~2.5 M.

The most compelling case for dispatching a response, however, comes from the time-magnitude distribution of events within the earthquake sequence. It is generally known that any earthquake that occurs in response to tectonic stresses may trigger other earthquakes. The classic manifestation of this process is a mainshock-aftershock sequence, whereby the number of triggered events scales with the size of the mainshock. In such cases, the seismicity rate should decay as $\sim t^{-p}$ following the mainshock, where p is an empirical constant [2,3]. This power-law temporal behavior reflects the relaxation of stresses within the lithosphere following an abrupt change in stress due to the mainshock.

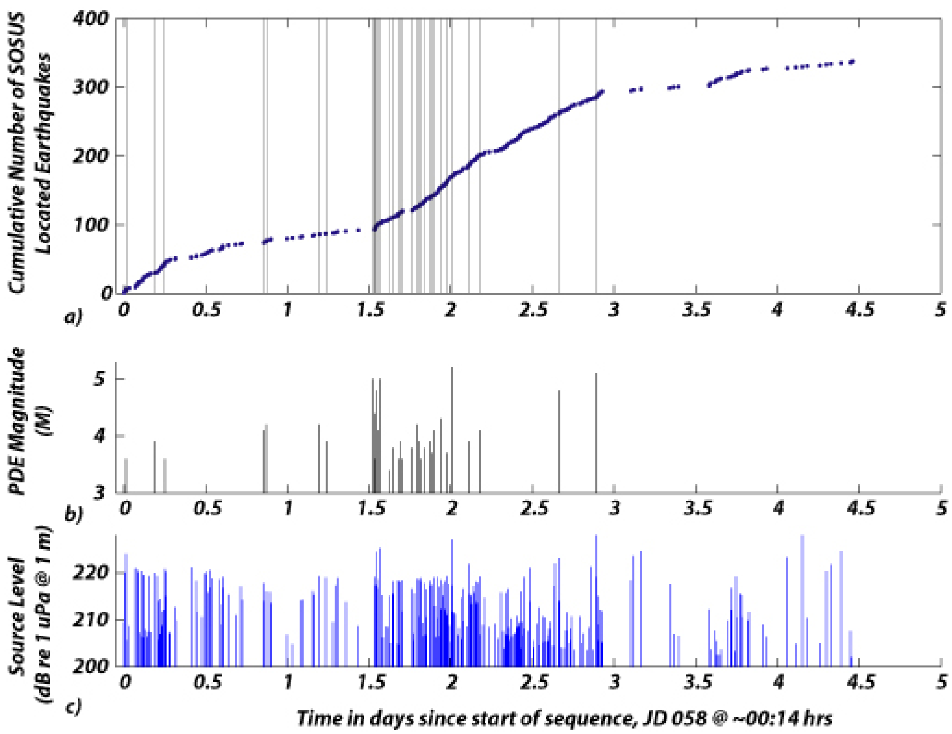

Figure 2. a) Cumulative event count for SOSUS-locatable (> ~2.5 M) earthquakes within the Endeavour swarm. Faint gray lines mark the time of earthquakes large enough to be located by land-based seismic stations. **b)** Magnitude-time history of these seismically-located earthquakes, extracted from the NEIC's weekly-PDE catalog. **c)** Source level-time history of SOSUS-located earthquakes. Acoustic source-level is a measure of the mean amplitude of the recorded T-waves, corrected for transmission loss along the propagation path.

The seismicity rate of the Feb/Mar activity, however, is not well described by this type of relaxation process, and a comparison with hydroacoustically-recorded aftershock sequences shows dramatic differences in the number of 'triggered' events (Figs. 2 and 3). In contrast to a tectonic mainshock-aftershock sequence, where one (or perhaps a few) large magnitude events dominate, the Feb/Mar activity consists of a number of similar-size earthquakes distributed throughout the sequence (Fig. 2). Such sequences, termed earthquake swarms, are common in volcanic regions, and nearly all models for their generation involve the movement of magma, or in some instances magma-induced pore-pressure transients, as a triggering mechanism.

Periods of greatly elevated (relative to background), but nearly-constant event rate, have now been observed within a number of mid-ocean ridge magmatic swarms [3, 5, 6] and appear within this recent sequence as well (Fig. 2). This reflects the fact that the seismicity rate is governed by the elevated stressing rate associated with the intrusion, as opposed to a sudden stress step associated with the mainshock. Although the largest magma-triggered events will themselves produce aftershocks, the duration of these aftershock sequences is inversely proportional to the stressing rate, and therefore suppressed relative to a tectonic event [7].

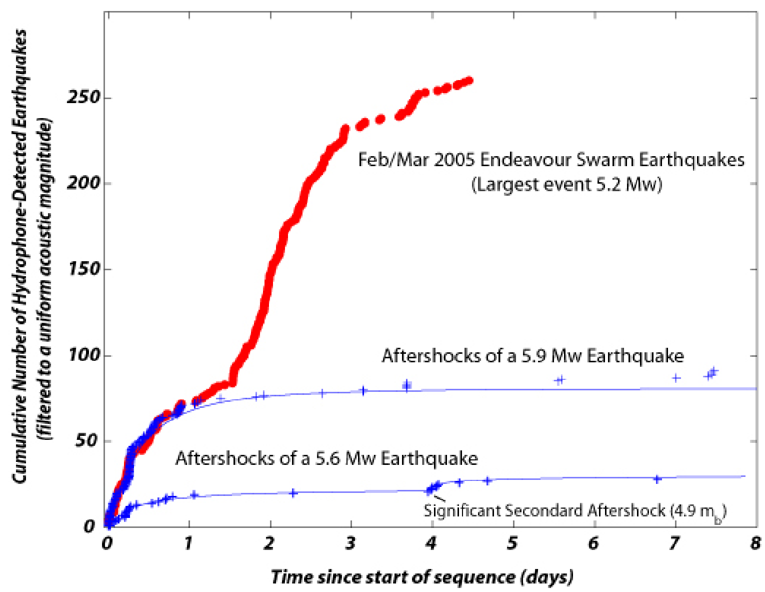

Figure 3. Comparison of Endeavour activity (red) with two previously recorded aftershock sequences (blue) [3]. Solid lines show best-fitting Modified Omori Law curves for the aftershock sequences. Events have been filtered with regard to acoustic magnitude, removing earthquakes with source levels < 207 dB, to minimize any difference in detection threshold between the three datasets. The largest Endeavour earthquake had a magnitude of only 5.2 Mw (at t = 2 days); however, the total number of earthquakes dwarfs the event count associated with much larger tectonic mainshocks.

With regard to Macdonald's reference to OBS work at the Galapagos 95.5W-Propagator [8], this study, which lasted for only 21 days, reported a consistent event count of 10-17 micro-earthquakes (~0.0-2.3 M) per day and noted no indication of swarm activity. This steady rate of diffuse micro-earthquake production likely does reflect tectonic deformation in the overlap zone; however, it bares little resemblance to the intense period of small-to-moderate magnitude earthquake activity recently observed by the SOSUS arrays (~350 events having M ~2.5-5.2, with several thousand smaller events detected, during a ~5 day period).

In this instance, I believe that similarities in event rate and scale between the Feb/Mar 2005 activity and previous Endeavour segment activity in June of 1999 and January of 2000 provided additional motivation for a cruise [3, 4]. Although rapid response efforts were not launched following these previous episodes, independent seismic [4] and geochemical analysis [9,10,11] have since made a very strong case for the involvement of magmatic activity, and it could be argued (in hindsight) that an opportunity was missed by not responding.

Since not all magmatic episodes will result in volcanism, our community could adopt a policy of responding only to the largest Axial-type swarms, which last several weeks and exhibit clear evidence for lateral dike propagation [12]. Such response efforts would likely have a greater probability of identifying seafloor eruptions or significant water-column anomalies. This strategy, however, would severely limit our ability to explore the short time-scale response of the ridge system and prevent us from understanding the potentially important impacts of smaller-scale (but more frequently occurring) perturbations.

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http://www.pgc.nrcan.gc.ca/seismo/MTS/2005q1_mts.html (Pacific Geoscience Center/GSC)

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