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GEMS: the opportunity for stress-forecasting all damaging earthquakes worldwide

Stuart Crampin (1), Sergei Zatsepin (1), Chris Browitt (1), Vladimir Keilis-Borok (2), Kiyoshi Suyehiro (3), Yuan Gao (4), and Larry Walter (5)

(1) School of GeoSciences, University of Edinburgh, EH9 3JW, UK, (2) IGPP, University of California, Los Angeles, California, USA, (3) JAMSTEC, Yokosuka, Japan, (4) Institute of Earthquake Science, CEA, Beijing, China, (5) Geospace Engineering Research International, Texas, USA (scrampin@ed.ac.uk)

Strange as it may seem, we understand the distribution of matter in the interior of the sun far better than we understand the interior of the earth (Richard Feynman, 1985)

Widespread observations of stress-aligned shear-wave splitting (seismic birefringence) show that low-level (pre-fracturing) deformation modifies the geometry of the fluid-saturated microcrack geometry in almost all *in situ* rocks. Thus low-level deformation can be monitored by analysing shear-wave splitting. The use of swarms of small earthquakes as source of shear waves has, with hindsight, identified the accumulation of stress before some 15 earthquakes worldwide (see NH4.04 presentations). On one occasion the time, magnitude, and fault break of a M 5 earthquake in SW Iceland was successfully stress-forecast. Suitably persistent swarms of small earthquakes are too scarce and unreliable to use for routine forecasting. A routine earthquake forecasting service requires controlled-source cross-hole seismics in borehole Stress-Monitoring Sites (SMSs).

The prototype SMS used existing boreholes adjacent to the Húsavík-Flatey Fault (HFF) in northern Iceland, a transform fault of the Mid-Atlantic Ridge. The highly-repeatable Downhole Orbital Vibrator (DOV) source at 500m-depth was recorded at 500m-depth in a neighbouring well offset 315m, where hundred fold stacking yielded $\pm$0.02ms accuracy. Exceptionally well-recorded anomalies were measured in travel-times of P-, *SH*-, *SV*-waves, and *SV*-*SH* anisotropy, in addition to NS and EW GPS anomalies, and 1m pulse in water-well level. All seven measurements strongly correlated with small-scale seismicity (equivalent energy to one M 3.5 earthquake) on a neighbouring transform fault 70km NNW of the SMS. This exceptional sensitivity (at several hundred times the conventional source diameter) confirms the science and technology of SMSs for stress-forecasting impending earthquakes. The sensitivity suggests that the accumulation of stress before $M \geq 5$ earthquakes, that is all damaging earthquakes, would be recognised within 400km of a SMS. The proposed GEMS, a global network of SMSs, gives the opportunity to forecast all damaging earthquakes worldwide.

GEMS would require some 1500 SMSs, where each SMS employs three 1 to 2km-deep boreholes offset at $\sim$300m. Since the sensitivity of SMSs to microcrack geometry would identify all $M \geq 5$ within 400km (NH4.04 presentations), the GEMS grid would need a 400km-separation in any likely seismic areas and perhaps 1000km-separations in stable continental shields and oceanic basins.

GEMS would have manifold benefits.

1) The principal benefit would be to stress-forecast all damaging earthquakes worldwide, in both developing as in developed countries, so that the earthquake death toll could be largely eliminated.

2) GEMS would provide the data for a stress-forecasting service, analogous to the weather forecasting service, for a longer-term analyse of stress not previous available.

3) GEMS would provide the data for monitoring and controlling the release of hazardous stress when a vulnerable city or other important site was threatened. This would be by massive hydraulic fracturing in less vulnerable locations nearby, such as deserts, mountains and, with due caution for tsunamis, offshore. This would be possible only because GEMS could monitor the effects and optimise stress relaxation.

4) GEMS would provide a global network of 1 – 2km boreholes for siting passive geophysical instruments (broadband seismometers, gravimeters, magnetometers, etc.), where exceptionally quiet conditions would allow time-lapse analysis of the behaviour of the dynamic Earth which are completely impossible in noisy near-surface conditions.

5) These various benefits would help to solve the Feynman anomaly and, at the beginning of the 21^{st} century, stimulate geophysical investigation of the dynamic Earth, on which our lives and futures depend.