Remote triggering of earthquakes – Some fresh views

A. V. Sankaran

Seismologists have shown that earthquakes occur along narrow belts of epicenters which coincide with oceanic ridges (e.g. crest of the mid-Atlantic, the east Pacific) and along transform faults where plates slide past each other. Apart from these sites, earthquakes also originate 100–300 km deep below the margins where plates collide. The foci of these earthquakes are distributed along a plane which actually mark the positions of lithospheric plates plunging or subducting into the mantle, beneath the adjacent or the overriding plate (Figure 1 *a*). Deep-sea trenches, island arcs, young mountains and volcanoes are associated with such boundaries. While the plots of most of these earthquakes fall along the plate boundaries, some are known to originate within the plates, as intraplate seismic events which are usually quite destructive. The cause of such intraplate seismicity has been attributed to the build-up of stresses in the lithospheric plate to a point exceeding its strength. Now a fresh view has been advanced that some of the intraplate earthquakes may be activated by post-seismic stress wave originating from remote earthquakes, thousands of miles away, and migrating slowly over the years through the asthenosphere below the lithospheric plate.

Asthenosphere is a low-seismic wave velocity zone in earth's interior lying between 70 and 250 km below and considered to be partially molten or a slushy mixture of liquid and solid (Figure 1 *a*). This is a peculiar layer which, though a solid, 'flows' over the years imperceptibly. According to plate tectonic concepts, earth's major plates are created along the mid-ocean ridges, where magma, pouring out from the interior, cools as it spreads on the surface to form a new crust. Ultimately, millions of years later, this crust re-enters the mantle by subduction and eventually gets destroyed. While this is the birth and death of earth's crust, during its existence as lithospheric plate resting on the weak and semi-molten asthenosphere it easily slides over, often along the transform faults, the slip caused by events like mantle current movements, deep earthquakes, or due to wander of earth's pole axis. Plate movements, whose rates of motion vary, are not simple and smooth everywhere, especially at the boundaries of the plates. Here stresses build up and at some stage the plate lurches, jerks or slides such movements, manifesting themselves as earthquakes. It is no surprise therefore that earthquake epicenters are aligned along the plate boundaries where the sliding takes place—some of these events arise deep below where plates collide or subduct.

Well-known early geophysicists like Walter Elasser, Don L. Anderson, and others have described how stress waves generated by earthquakes have been able to transmit changes via the ductile asthenosphere to a much wider area[1–3], and many are also aware of earthquake migration and how stress build-up, for example, in a rupturing fault in one place can be transmitted over long distances and induce earthquakes elsewhere[4,5]. But earthquake migration via the asthenosphere received only cursory attention from seismologists particularly with regard to quantitative data associated with such transmission. In fact, viscoelastic coupling of lithosphere and asthenosphere is known to influence stress migration. This aspect had been used to determine asthenospheric viscosity by measuring the speed of post-seismic diffusion through the latter, based on record of sequences of earthquake events[6]. However, detailed studies on the spatiotemporal progress of these waves through asthenosphere, the possible impact of their passage on the lithospheric plate above, the role of mantle viscosity on their diffusion, the rates of their passage through the ductile medium are some of the aspects that have received attention only since the past few years. Geophysicists Fred F. Politz, Roland Bürgmann and Barbara Romanowicz[7] (University of California, Berkeley) have shown recently how stress build-up by large subduction events can be transmitted

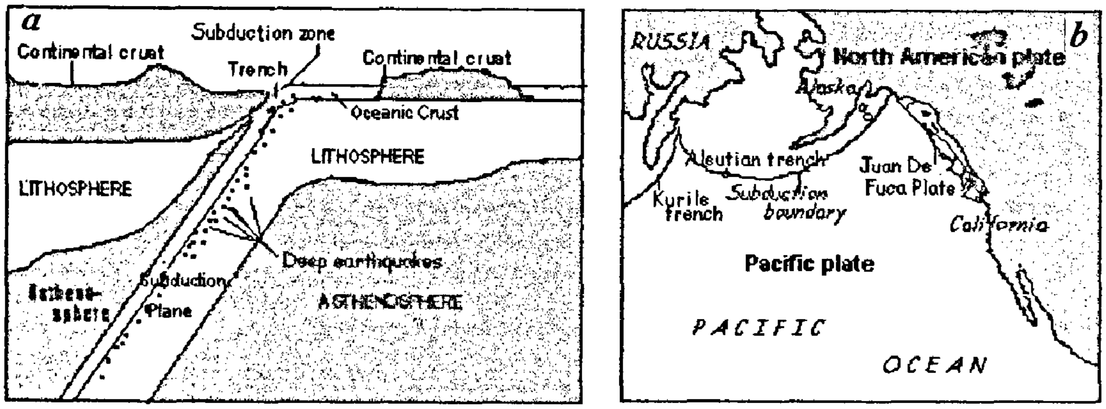

Figure 1. *a*, Convergence of leading edges of continental and oceanic lithosphere. The subducting plane forms the foci for deep earthquakes (black dots). Post-seismic waves diffusing through the asthenosphere slowly over the years are believed to trigger earthquakes in the plates above. *b*, The subducting Pacific plate boundary in the north Pacific ocean along the Aleutian and Kamchatka–Kurile trench where high magnitude earthquakes, during the 1952–1965 period, generated stress-pulses that diffused northward and southward to trigger a series of seismic events in the Arctic oceanic region and California several years later.

slowly, through the viscous asthenosphere, as a wave to precipitate earthquakes far away, years later. Such stress waves, arising generally in big magnitude earthquakes, like the ones they had studied along the North Pacific Ocean, are ascribed by them to have triggered a series of seismic activity in California, 20 years later. Their studies were primarily to determine the viscosity of oceanic asthenosphere, by evaluation of post-seismic stress evolution which is driven by large subduction events, and its correlation with chain of seismic events that occurred years later, thousands of miles away. Thus they investigated earthquakes of the north Pacific region along the northern part of the well-known 'ring-of-fire' (pattern of epicenters of some 30,000 earthquakes recorded between 1961 and 1967 around the Pacific plate boundary), events that had their foci along the subducting plane of the Pacific plate (Figure 1 *b*). Between 1952 and 1965, four great earthquakes (considered to be by far the largest to have occurred between 1950 and 1970 or even much earlier) occurred along the Aleutian arc and Kurile–Kamchatka trench formed by the Pacific plate subducting beneath the North American plate. After each earthquake, which marked the release of stress build-up, the Pacific plate readjusted to the new plate positions. The accumulated stress thus released, they argued, spread as a wave through the asthenosphere very slowly and travelled over long distances and triggered oceanic intraplate seismicity that spread over a large area of 7000 km^2.

The slow passage of the stress wave in the sub-lithospheric mushy layer is controlled by the viscosity of the latter layer. In order to establish how realistic the stress wave passage could be, they computer-simulated the various parameters that are associated with these earthquakes, including some of the minor but significant seismic events along these belts. Since the present estimates of asthenospheric viscosity in this region are not known, they assumed a reasonable value of 5×10^7 pascals second in their model. They examined the post-seismic gravitational–viscoelastic relaxation which rippled across the asthenosphere, like a wave in a pond, on a grid covering northern Pacific and Arctic Ocean basins. Under their simulated conditions, the stress wave generated by the earthquakes traversed northward under the Arctic Ocean and southward across the Pacific Ocean. Thus the leading edge of the stress pulse wave passed the Juan de Fuca plate (on the west coast of North America) in 1975, some 23 years later, and California in 1985. The northward bound stress wave entered the eastern Arctic Ocean in the 1970s and British Columbia around 1975. The regions along the advancing front, at a given time, experienced locally high horizontal velocities, or, in other words, wherever the stress wave passed it accelerated the plate motion that triggered earthquake activity. Thus, they could correlate the seismic activities, in western North American and the Arctic regions over the past four decades, with the passage of the predicted velocity front of the earthquake events of 1952–1965 in the Aleutian and Kurile–Kamchatka fronts. The type of earthquakes that took place in south California during the eighties were mostly on faults that underwent vertical motions, which are supposed to be characteristic of stress wave-induced seismicity. This feature, they claim, supported their predicted model. In an earlier study[3], Barbara Romanowicz (University of California, Berkeley) had linked the spate of earthquake events that took place in California, during the late eighties and later, to an 'acceleration of global strike-slip movement release, as regions of shear deformation mature after being reacted by stresses that have propagated away from regions of great subduction that decoupled earthquakes of 1960s'. She also studied the global transfer mechanism, arising from upwelling and downwelling currents (poloidal component) owing to density variations in the mantle, and horizontal shearing due to rigid lithospheric plates and associated heterogeneity in rheology (torroidal component) operating in time scales of several decades. From an examination of earthquake events since the 1920s, she noticed that strike-slip and thrust earthquakes have occurred in alternating cycles of 20–30 years.

Some geophysicists have expressed their doubts about these views that explain the seismic activity in California during the 1980s and feel that the observed agreement between seismicity and computer-based inferences on stress wave transit may be just fortuitous. However, Politz *et al.* feel that the links between post-seismic stress waves and some of the Californian earthquakes are more than mere chance. Earlier studies have in fact brought out how large land shocks which generate diffuse-like stress pulses unlock the thrust fault in the subduction zone and trigger earthquake events[6]. Notwithstanding the varied opinions about spatio-temporal patterns of earthquakes, the spate of recent studies are expected to stimulate further research concerning stress transfer from the underlying connective mantle to tectonic plates and relationships involving earth's rotation and internal processes[5]. If post-seismic stress waves trigger shocks several years later far away from the principal epicenter, as Politz *et al.* envisage, the phenomenon adds a new dimension to studies of earthquake occurrences and to the already frustrating research on earthquake predictions[8].

1. Elasser, W. M., *The Application of Modern Physics to Earth and Planetary Interiors* (ed. Runcorn, S. K.), John Wiley, New York, 1969, pp. 223–246.
2. Anderson, D. L., *Science*, 1975, **187**, 1077–1079.
3. Romanowicz, B., *Science*, 1993, **260**, 1923–1926.
4. Kerr, R. A., *Science*, 1998, **280**, 1194–1195.
5. Sanders, C. O., *Science*, 1993, **260**, 973–976.
6. Rydelek, P. A. and Sacks, S., *Nature*, 1988, **336**, 234–237.
7. Politz, F. F., Bürgmann, R. and Barbara Romanowicz, *Science*, 1998, **280**, 1245–1249.
8. Sankaran, A. V., *Curr. Sci.*, 1997, **73**, 315–316.

A. V. Sankaran lives at No. 10, P&T Colony, I Cross, II Block, RT Nagar, Bangalore 560 032, India.