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Can fluid-rock interaction act as a causal phenomenon behind recurring seismicity?: Unraveling the interplay of geochemistry and seismology

PIYAL HALDER[1,2], ANUPAM SHARMA[1,2], MATSYENDRA KUMAR SHUKLA[3] AND KAMLESH KUMAR[1,2]

[1]Birbal Sahni Institute of Palaeosciences (DST, Govt. of India), Lucknow-226007, India

[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002, India

[3]Govt. of India, Ministry of Earth Sciences (MoES), Borehole Geophysics Research Laboratory (BGRL), Karad-415105, India

Presenting Author: piyalhalder.org@gmail.com

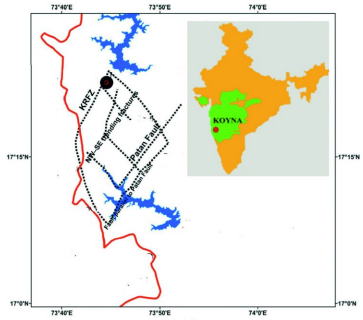
Since the impoundment of the Koyna Dam in 1962, a large number of small to medium-magnitude earthquakes have been felt in the Koyna-Warna intraplate region of Western India. The Koyna River fault zone and NE-SW trending Patan fault have bordered the eastern and western boundaries of this small Seismogenic region. The XRD investigations of the granitoid basement rocks of this region, recovered by the Continental Deep Drilling Program, have revealed occurrences of chlorite, illite, epidote, and calcite along several faults and fractures. Further, the biotitic remnants within the neoformed chlorite in close association with epidote, as observed under optical microscope, and the enrichment of MgO, Al_2O_3, FeO^t, and TiO_2 together with the depletion of K_2O indicates the formation of chlorite from biotite due to fluid-rock interaction.

Biotite + Al^{3+} + Mg^{2+} + Fe^{3+} + Ca^{2+} + H_2O + H^+ → chlorite + epidote + TiO_2 + H_4SiO_4 + K^+

Besides, the extremely weathered plagioclase surface and the surprising enrichment of K_2O at a few certain depths depict the dissolution of plagioclase and subsequent formation of illite.

Plagioclase + Fe^{2+} + Mg^{2+} + K^+ + H_2O→ albite + illite + Ca^{2+} + Al^{3+}

Thus, the basement rocks of the Koyna-Warna region have experienced a propylitic kind of hydrothermal alteration giving rise to greenschist facies of mineral assemblage. Furthermore, with rising or continued stress in this active seismic region, the anisotropic and weakly bonded layered crystal structure of neoformed chlorite suffers ripplocations and may develop kink bands. As a consequence, the yield strength of chlorite increases proportionally with rising pressure up to dehydration temperature and such visco-elastic behaviour of chlorite may lead to aseismic creep in the faults. On the other hand, another secondary mineral epidote promotes unstable sliding due to its velocity-weakening behaviour at high temperatures and high pore fluid pressure. However, as has been observed in this location over the previous 50 years, the chloritization in conjunction with epidote formation suppresses the velocity-weakening behaviour of epidote and promotes steady fault creep by releasing the accumulated strain through a succession of small magnitude earthquakes, probably saving the region from large magnitude earthquakes.



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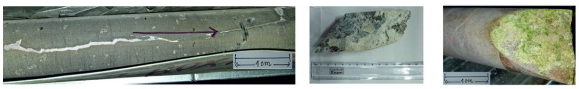

(2) (3) (4)

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(1) Location map of the Koyna-Warna Seismogenic region bordered by the Koyna River Fault Zone (KRFZ), Patan fault and NW-SE trending fractures. Inset shows Koyna's location on India's outline map (modified after Rao et. al, 2017); (2) calcified vein indicating fracture-scale mineralisation during fluid percolation along fracture; (3) Fault slip surface containing calcite; (4) Greenish tint on another slip surface indicating the presence of secondary chlorite or epidote; (5) Biotite remnant found in neoformed chlorite under PPL demonstrating its biotite origin; (6) The flow-like appearance of chlorite and kinking within the grain observed under Plane-Polarized light (PPL) confirms the formation of chlorite as the result of fluid-rock interaction and post-formation strain accommodation due to continuous stress build up in this active seismic region.