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Decoding Subsurface Secondary Mineralisation and its Impact on Cohesive Strength: An Outcome of the Deep Scientific Drilling Program in the Koyna–Warna Seismogenic Region, Western India

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The Koyna–Warna seismogenic region overlying the Deccan volcanic province of Western India has been experiencing the recurrence of earthquakes since 1967 soon after the impoundment of the Koyna Dam. A large number of small to medium-magnitude shallow focus earthquakes (>100,000) have been detected in this intraplate region during the last six decades. In the present study, the core samples recovered from the borehole 'KBH3' drilled upto 1134 m depth in the pre-Deccan granitoids basement rocks of this region have been subjected to mineralogical and geochemical studies. Mesoscopic and microscopic observations have revealed the imprint of schistosity in the granite gneiss, in which the presence of fractures and faults denotes the later brittle deformation. Additionally, the occurrences of breccia and gouge provide evidence in support of fault reactivation while, the formation of secondary minerals such as chlorite, calcite, etc. in the pre-existing interconnected network of fractures and permeable fault planes reflects the significant degree of fluid-rock interaction. Overall, four different events have been identified in the basement rocks of the KBH3 borehole. On the other hand, the major elemental geochemistry has fetched light on the mineral transformation mechanism and confirmed the neoformation of chlorite from biotite through the dissolution of its potassium interlayer sheet by Mg-rich fluid percolating through the top Deccan basalt containing magnesian clinopyroxene and calcic plagioclase. The K released during this stage triggers the transition from plagioclase to microcline and liberates Ca. This Ca in addition to that leached out from the top basalt or weathered basaltic layers, paves the way for the formation of calcite too. Furthermore, the continuing fluid interaction introduces charge on the surface of neoformed chlorite-like clay minerals; as a result, a layer of water molecules forms strong hydrogen bonds with the oxygen atoms of the clay minerals and forms an ordered layer of water molecules around the clay surface. Due to such strengthening of intermolecular forces, the cohesive strength of clay-rich horizons in the basement rocks becomes typically higher which explains a wide range of cohesive strength varying from 3–25 MPa, as reported in earlier studies. The increase in cohesive strength also exerts a positive influence on the overall shear strength in contrast to the friction and suppresses its impact at shallow depths under low normal stress conditions. Thus, an increase in cohesive strength due to clay mineralization in the shallow crustal faults of the Koyna–Warna region prevents the catastrophic release of stress and results in creep motion which may be one of the reasons behind the recurrence of numerous low to moderate magnitude, less devastating shallow focus earthquakes in this region.

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1 Introduction

The interconnected network of fractures, permeable faults and fractures within the faults generated due to brittle or brittle-plastic deformation act as the percolation pathways of fluid and result in its interaction with the wall rocks (Duan et al., 2016). Such interaction of fluid is particularly more significant when the interval between two earthquakes is large enough and fluid reacts with the crushed wall rocks of the fault zones (Duan et al., 2016). The chemical and mineralogical transformation due to such fluid-rock interaction results in the formation of a set of new authigenic secondary minerals including clay minerals, calcite, epidote and a few more. These secondary minerals are not only the archive for providing information regarding the fluid-induced alteration process but also influence the fault behaviour. The minerals like quartz, calcite, etc., act as the cement in the faulted or fractured rocks and help in their healing, while the hydrophilic clay minerals weaken the faults by evolving fluid pressure and reducing the frictional strength of the faults (Collettini et al., 2019; Jensen et al., 2019). However, fault weakening by clay mineralisation is more well-documented than the healing of faults through cementation by new minerals.

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