

Prospection of Rare Earth Elements (REE's) in the Peshawar Plain Alkaline Igneous Province (PPAIP), Khyber Pakhtunkhwa, Pakistan

Zohaib Imtiaz¹

¹Pakistan Petroleum Limited, Islamabad, Pakistan

Rare earth element (REE) deposits are globally associated with carbonatite and alkaline silicate magmatic systems emplaced in extensional tectonic regimes. The Peshawar Plain Alkaline Igneous Province (PPAIP), developed along the northwestern margin of the Indo-Pakistan plate, comprises Permo-Carboniferous alkaline and carbonatitic intrusions analogous to major REE provinces worldwide. This study evaluates REE prospectivity across the PPAIP domains including Malakand, Warsak (Zagi and Shina Ghundai), and Buner regions in northwestern Pakistan through an integrated program of geological mapping, petrography and whole-rock geochemistry.

Field mapping, supported by GIS integration and 3D modelling, delineated carbonatite bodies and associated alkaline silicate lithologies, including alkali granites, syenites, nepheline syenites, and pyroxenites. Petrographic investigations identified primary REE-bearing phases such as bastnaesite, xenotime in the Warsak plutons, while allanite, apatite, and titanite in the Malakand pluton. Sillai Patti Carbonatites in the Malakand region represent the most enriched system (average total REE's 2103 ppm), characterized by abundant apatite (up to 20%) and calcite-dominated mineralogy, consistent with primary magmatic concentration typical of carbonatite-hosted REE systems. In contrast, alkaline silicate rocks exhibit moderate REE enrichment, including Zagi granites (451 ppm) hosting xenotime and bastnaesite, and Buner syenites (411 ppm) enriched relative to associated granites (287 ppm), reflecting accessory phase-controlled REE distribution.

The Shina Ghundai complex displays a coeval association of carbonatite and alkaline silicate suites, supporting a shared mantle-derived magmatic lineage. Local saprolitic enrichment (up to 549 ppm) suggests supergene concentration superimposed on primary magmatic signatures.

The results indicate two principal REE system styles within the PPAIP: (1) carbonatite-dominated primary enrichment (Sillai Patti) and (2) alkaline silicate-hosted accessory mineral-controlled enrichment (Zagi, Buner). This study establishes a metallogenic framework for REE exploration within the PPAIP and underscores its significance as an underexplored alkaline province.