

# Tracing Gondwana's Legacy: Heavy Mineral Provenance of Middle Permian Clastics in the Indus Basin, Pakistan

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## Summary

Provenance studies are integral to understanding sedimentary processes and tectonic evolution in key geological settings. This research investigates the Middle Permian Amb Formation in the Indus Basin, Pakistan, a critical area at the intersection of Gondwana and the Tethyan realms. Heavy mineral assemblages, including zircon, rutile, allanite, and tourmaline, were identified from field samples collected at Zaluch Nala and Saiyiduwali sections in the Salt Range and Trans-Indus Ranges. These minerals, coupled with petrographic evidence such as abraded detrital quartz overgrowths and rounded zircons, point to a predominantly granitic source with sedimentary recycling. Paleoclimatic and tectonic interpretations reveal contributions from Precambrian granites, gneisses, and meta-sediments, with regional sediment transport and deposition shaped by active tectonics. The findings have broader implications for understanding sedimentary basin dynamics, source-to-sink processes, and the geodynamic evolution of Gondwana's margins during the Permian. This study contributes to global discussions on sediment provenance and its role in reconstructing ancient Earth systems.

## Method

The methodology used in this study of the Amb Formation included fieldwork, laboratory analyses, and computer-based techniques. Fieldwork involved measuring formation thickness, collecting samples, logging selected sections, recording field observations, and capturing photographs. Laboratory work focused on separating and preparing heavy mineral thin sections from the collected samples, examining these thin sections under a petrographic microscope, and conducting microscopic imaging. Computer-based tasks centred on utilizing graphic software tools for data analysis and presentation.

## Results and Observations

The geological fieldwork was carried out at two sections, Zaluch Gorge and Saiyiduwali, located in the Salt Range (SR) and Trans-Indus Ranges (TIR), respectively. In both sections, the Amb Formation was systematically measured, logged, and sampled at regular intervals. Outcrop features were carefully observed and documented. At both Zaluch and Saiyiduwali, the formation exhibited thin- to thick-bedded sandstone interbedded with limestone. The rock unit is notably characterized by an abundance of stylolites and fractures. Other prominent features include an abundance of bioclasts, chert nodules, cross-lamination, and burrows, all of which were observed in both sections.

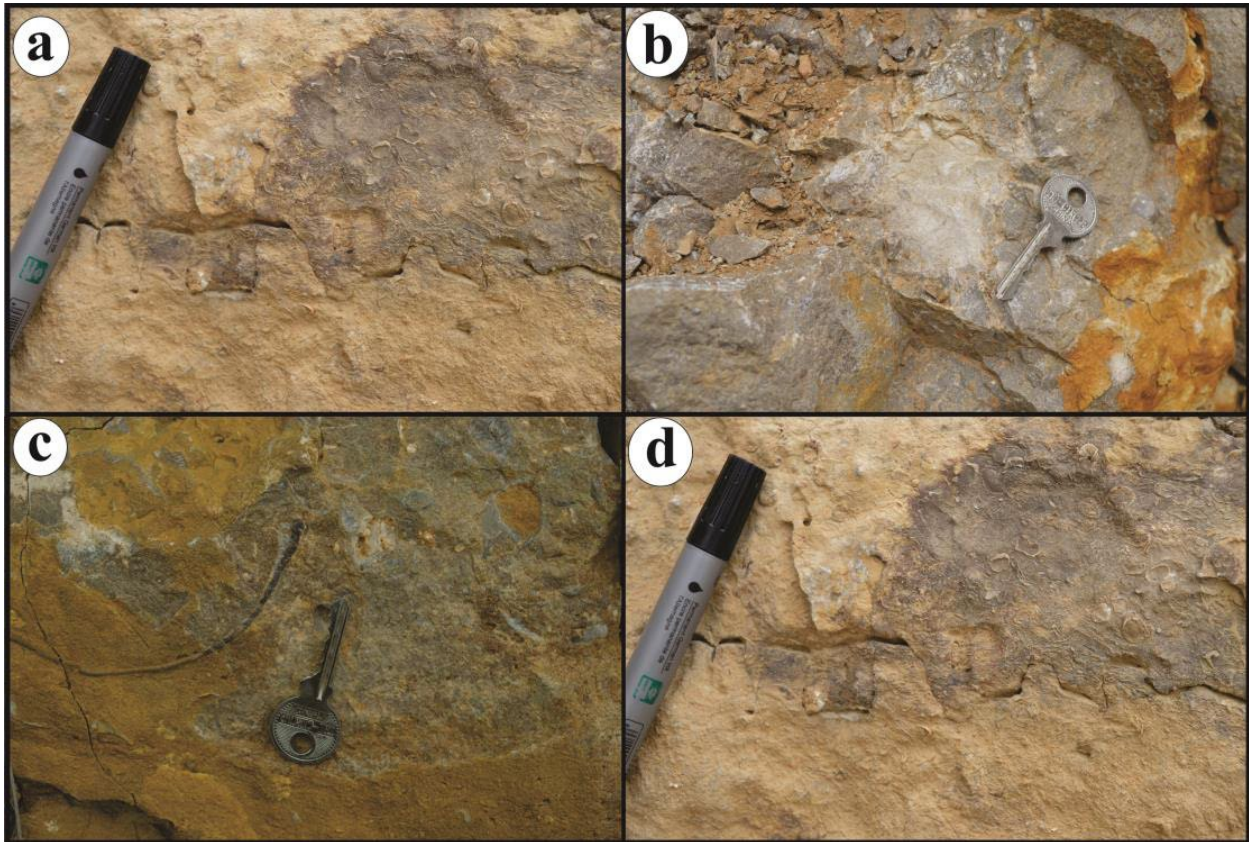


Figure: Field investigations of the Amb Formation in the Zaluch and Saiyiduwali sections showing stylolite.

## Conclusions

The geological analysis of the Amb Formation highlights a sedimentary sequence characterized by a mixture of clastic and carbonate components, enriched with bioclasts. Heavy mineral separation and identification revealed a diverse mineral assemblage, including zircon, rutile, allanite, anatase, axinite, cassiterite, chlorite, biotite, corundum, hornblende, muscovite, prehnite, fluorite, epidote, siderite, staurolite, and tourmaline. This mineral assemblage serves as a distinct geological fingerprint, suggesting that the sediments in the Indus Basin were sourced predominantly from the Aravalli and Malani Ranges in the southern region. These ranges, known for their complex geological history involving magmatism, metamorphism, and sedimentation, provided the granitic and metamorphic materials reflected in the heavy mineral composition of the Amb Formation. The findings provide critical insights into the provenance of these deposits and enhance understanding of the tectonic and sedimentary evolution of the region, underscoring the geological significance of the Amb Formation within the broader context of Permian palaeoenvironments.

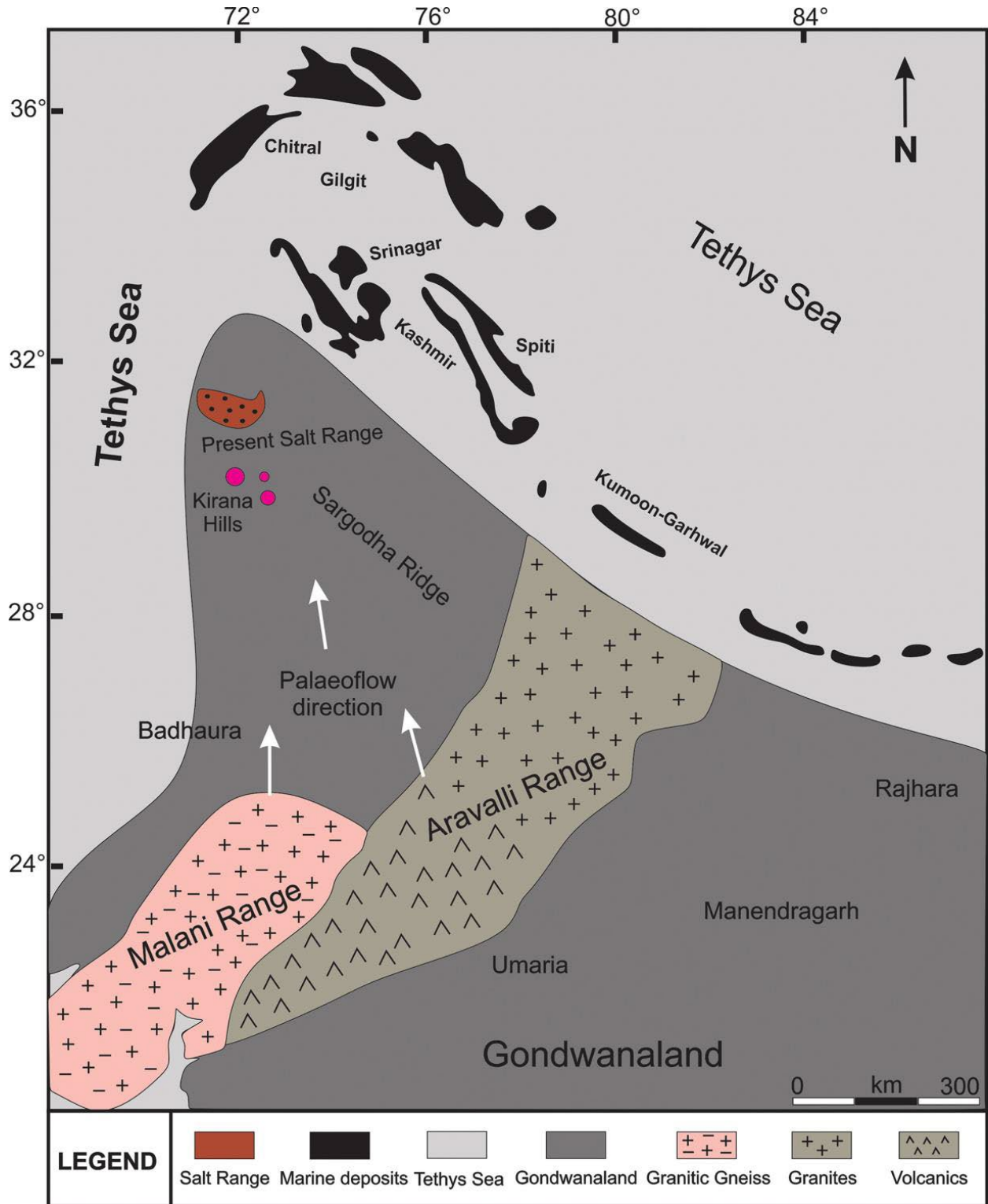


Figure: Sediment source for middle Permian clastic of Salt Range