Tectono-Metamorphic Evolution of the Pre-Cambrian rocks of the Champaner Group, Southern Aravalli Mountain Belt, Western India.

Executive summary

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1. Introduction

The Precambrian supracrustal rocks of the Champaner Group are exposed in the eastern periphery of Gujarat along the western margin of India and constitute a significant segment of the arcuate Greater Indian Proterozoic Fold Belt (GIPFB), extending from the Aravalli–Delhi Fold Belt (ADFB) through the Central Indian Tectonic Zone (CITZ) to the eastern Indian gneissic complexes. The Champaner succession forms a horseshoe-shaped arcuate bend at the southern termination of the ADFB and serves as a structural link connecting the ADFB with the CITZ, showing eastward strike continuity with the latter.

Despite being known since the early twentieth century for economically important manganese mineralization, the stratigraphic position and tectonic affinity of the Champaner Group have remained controversial. Earlier workers placed it within the Aravalli succession above the Lunavada Group, whereas later interpretations suggested it to be younger than both the Aravalli and Delhi Supergroups. Lithological associations, deformation patterns, structural trends, and metamorphic characteristics of the Champaner rocks are distinctly different from adjacent supracrustal sequences, including the Lunavada Group and pre-Champaner gneissic complexes.

2. Problem statement/Research Gap

The region exhibits complex structural architecture marked by three phases of deformation, superposed fold interference patterns, syn-kinematic shear zones, and multiple phases of syn- to post-tectonic granitic intrusions. These features contrast sharply with earlier interpretations that considered the metamorphic history of the Champaner Group to be simple and uniformly low grade. Furthermore, the temporal relationship between deformation and metamorphism, the influence of granitic intrusions on regional and contact metamorphic mineral development, variations in mineral chemistry and bulk-rock geochemistry, and the pressure–temperature conditions governing burial and exhumation history have remained inadequately constrained.

3. Objectives

1. To define the architecture of contact aureole within the Champaner Group and to evaluate its mineral paragenesis.

2. To characterize the pressure-temperature-time-deformation (P-T-t-D) evolution of the metapelitic rocks of the Champaner Group.

3. To refine the facies condition of the regional and contact metamorphic rocks of the Champaner Group and to assess its protolith composition. 4. To elucidate the exhumation history pertaining to the rocks of the Champaner Group.

4. Methodology

1. **Isograd/zone Mapping:** Geological mapping of the contact aureole and isograd zoning of the study area was carried out along with its detailed sampling.
2. **Thin section studies:** Petrographic and microstructural analysis were done to establish the textural relations, reactions, relationship between porphyroblast growth and tectonic fabric development i.e., deformation and metamorphism.

3. **Mineral Chemical compositional analysis:** Electron probe micro analysis (EPMA) studies were done at Department of Geology, Institute of Science, Banaras Hindu University, Varanasi, Uttar Pradesh to know the mineral chemistry (composition) of rocks of the study area.
4. **Bulk rock compositional studies:** WD-XRF and HR-ICP-MS studies were performed at the CSIR-National Geophysical Research Institute (NGRI), Hyderabad to know the whole rock chemical composition i.e. major oxides and trace/rare earth elements compositions respectively.
5. **Pressure-Temperature estimation:** Conventional geothermobarometry was carried with appropriate geothermometers and geobarometers to know the P-T estimates of peak metamorphic conditions.
6. **Thermodynamic modelling:** P-T Pseudosection models were constructed using PERPLEX_6.9.1 software for various rock types with distinct whole rock compositions in order to know the P-T stability field of the peak metamorphic assemblage.

5. Field and Lithostructural relations

This chapter presents a comprehensive field-based investigation of the Champaner Group, a Mesoproterozoic to early Neoproterozoic low-grade metamorphic terrane exhibiting a distinct arcuate, U-shaped map pattern. The supracrustal succession predominantly comprises meta-pelites, meta-arenites, and meta-carbonates, including slates, phyllites, spotted phyllites, mica-schists, hornfelses, quartzites, calc-silicates, and manganese-rich horizons. These rocks unconformably overlie basement gneisses and granitoids and are intruded by multiple generations of felsic plutons collectively referred to as the Godhra granites. Emplacement ages indicate several intrusive phases, including Archean (2.5 Ga), pre-D2 (1.03–1.02 Ga), and post-D_2 syn-D_3 (0.95–0.93 Ga) granitoids, along with associated anatectic gneisses (~1.65 Ga). The Champaner supracrustals are structurally separated from adjacent terranes by felsic plutons and display variable degrees of regional and contact metamorphism.

Field studies reveal that contact metamorphic effects are most pronounced along the eastern margin near granitic intrusions, while western exposures preserve dominant regional metamorphic fabrics. Based on proximity to granitoids and mineralogical changes, three contact aureole zones are identified: (i) outer zone (regional metamorphism; phyllites), (ii) middle zone (spotted phyllites with andalusite and cordierite porphyroblasts), and (iii) inner zone (hornfels with complete recrystallization and maculose texture). Five progressive metamorphic zones are recognized from west to east, representing a low-pressure, high-temperature Buchan-type metamorphic sequence: muscovite–biotite zone, andalusite–biotite zone, andalusite–garnet zone, andalusite–cordierite–biotite zone, and andalusite ± cordierite–sillimanite zone. The prograde sequence transitions from phyllite to spotted phyllite, hornfels, and locally to migmatite/gneiss near intrusive contacts. Porphyroblast growth relations indicate syn- to post-deformational crystallization linked to multiple deformation phases. Three major deformation events (D_1, D_2, D_3) are documented. D_1 produced tight isoclinal folds and S_1 schistosity (S0 || S1). D_2 is the dominant fabric, characterized by open to tight folds (F_2) with top-to-the-south transport sense. D_3 generated N–S trending open folds, kink bands, and S_3

cleavages, particularly prominent near granitic contacts. Superposition of these events resulted in type-1 (dome and basin) and type-3 (hook-shaped) fold interference patterns, especially in metacarbonates. Inner zone hornfelses include biotite hornfels, andalusite–cordierite hornfels, and andalusite–sillimanite hornfels, characterized by maculose structures, unoriented porphyroblasts, and evidence of thermal recrystallization. A newly reported metamafic unit occurs in the southwestern sector, interpreted as a mafic sill metamorphosed to mafic hornfels and exhibiting polymetamorphism. Migmatitic gneisses occur near intrusive contacts and display stromatic to diatexite structures, with evidence of anatexis and late-stage pegmatitic/aplitic injections. Basement gneisses and pseudo-gneisses underlie the supracrustals and show metasomatic modification and deformation fabrics comparable to the supracrustal sequence. Granites form a dominant intrusive component and are classified into multiple types based on texture, grain size, mineralogy, and structural relations. Fine-grained grey granites are interpreted as pre-D_2, whereas coarse K-feldspar-rich varieties are post-D_2 and syn- to post-tectonic, hosting xenoliths of earlier granitoids and supracrustals. Their intrusion is inferred to have driven peak metamorphism and deformation.

6. Petrography and Microstructures

This chapter presents a detailed petrographic and microstructural analysis of the metamorphic rocks of the Champaner Group, challenging the earlier interpretation of a simple greenschist facies regional metamorphism overprinted by contact metamorphism. Instead, the study demonstrates a progressive west-to-east increase in metamorphic grade, closely linked to proximity to granitic intrusions. Through thin-section petrography (~80–90 samples), the chapter establishes mineral assemblages, textural relationships, porphyroblast growth histories, and time-relations between deformation phases (D_1, D_2, D_3) and metamorphic events (M_1, M_2, M_3).

The metapelitic rocks are subdivided into outer, middle, and inner zones corresponding to phyllites, spotted phyllites/schists, and hornfels. A well-defined prograde sequence of low-pressure, high-temperature assemblages is documented: biotite → biotite + andalusite → andalusite + garnet → andalusite + cordierite → andalusite ± cordierite + sillimanite → andalusite ± cordierite + sillimanite + K-feldspar (migmatite). Notably, staurolite and kyanite are absent, confirming Buchan-type metamorphism. In porphyroblast-free phyllites (Zone A), S1 schistosity defined by phengite ± biotite ± chlorite is microfolded by penetrative S_2 crenulation cleavage, with local S_3 development in high-strain eastern zones. Progressive metamorphism leads to porphyroblast growth. Andalusite in Zone B initially overprints S_1 (post-D_1) and later aligns parallel to S_2 (syn-D_2). Garnet (Zone C) shows protracted growth, from pre-S_2 pressure-shadow-bearing crystals to later inclusion-poor porphyroblasts. In Zone D, cordierite porphyroblasts wrapped by S_2 suggest syn- to post-D_2 growth, with sectoral twinning (trilling and sixling) reflecting transformation from indialite during cooling. In Zone E, fibrolite sillimanite occurs interstitially and post-D_2, marking peak thermal conditions prior to migmatization. Migmatitic gneisses display leucosome–mesosome segregation, symplectite textures (cordierite breakdown), chessboard quartz, and retrograde sericitization. Inner zone hornfels preserve mineral assemblages similar to high-grade schists but exhibit static, coarse-grained hornfelsic textures produced by thermal overprinting. Biotite hornfels records multiple biotite generations (Bt_2 regional, Bt_3 contact). Andalusite–cordierite hornfels contains coarse poikiloblasts formed by static recrystallization, whereas andalusite–sillimanite hornfels shows chiastolite with re-entrant zones, cleavage domes, and retrograde muscovite pseudomorphs. Metamafic hornfels reveal polymetamorphism with three metamorphic stages: Early regional actinolite–epidote–plagioclase assemblage (S_1), Amphibolite facies hornblende–plagioclase–titanite assemblage (S_2), Contact metamorphic actinolite–biotite–tourmaline growth followed by retrograde chlorite, epidote, and sericite (S_3). Corona textures (ilmenite → titanite), inclusion trails, and orthogonal opaque needles record progressive and retrogressive reactions.

Diagnostic microstructures include mantled porphyroclasts (δ and φ types) indicating dextral shear; deflection folds and oppositely concave microfolds (OCMs) around rigid porphyroblasts; crystallographically controlled graphite inclusion patterns in chiastolite formed under low differential stress; corona and pseudomorph textures from retrograde replacement; and vermicular symplectite from cordierite breakdown. Granitoids are divided into foliated fine-grained (low-temperature, high-strain) and coarse-grained (high-temperature, low-strain) varieties. Microstructures include grain boundary migration, undulose extinction, perthite/microperthite exsolution, myrmekite, flame perthite, and chessboard quartz, indicating variable deformation conditions. Quartzites display sequential dynamic recrystallization mechanisms with increasing grade: Bulging recrystallization (BLG) in western low-temperature domains (D_1), Grain boundary migration (GBM) under moderate temperatures (D_2), Grain boundary area reduction (GBAR) in eastern high-temperature zones.

7. Mineral Chemistry

This chapter presents a detailed mineral chemical investigation of the Champaner supracrustal rocks based on quantitative EPMA analyses, with major oxide data recalculated into structural formulae to evaluate compositional variations, substitution mechanisms, and metamorphic evolution across different metamorphic zones.

The analytical work demonstrates systematic chemical changes from outer to inner zones and integrates mineral chemistry with petrographic and microstructural observations to constrain pressure–temperature conditions and petrogenetic history. White mica compositions vary from phengitic to muscovitic, with phengitic micas preserved mainly in S_1 fabrics of porphyroblast-free phyllites showing higher Si and celadonitic substitution, indicative of relatively higher-pressure conditions during early deformation. In contrast, S_2–S_3 micas are more muscovitic, reflecting stabilization under comparatively lower-pressure conditions. Biotite compositions display a clear prograde trend from Fe-rich varieties in lower-grade zones toward progressively Mg-rich compositions in higher-grade zones, accompanied by systematic redistribution of Al between tetrahedral and octahedral sites, confirming increasing temperature toward the eastern sector. Andalusite compositions approach the ideal Al_2SiO_5 end-member with minor Fe substitution, whereas cordierite is consistently Mg-rich, supporting low-pressure, high-temperature Buchan-type metamorphism. Garnets from andalusite–garnet-bearing rocks exhibit well-developed core–rim zoning characterized by Mn-rich cores and progressively Mg- and Fe-enriched rims, reflecting normal prograde zoning and continuous growth during rising temperature conditions from epidote-amphibolite to amphibolite facies. Chlorites are predominantly Mg-rich clinochlore (Type-I trioctahedral) and show compositional variations consistent with metamorphic rather than diagenetic origin, with subtle pressure-sensitive deviations from ideal Tschermak substitution. Ilmenite compositions indicate both near-stoichiometric and Fe-modified varieties, with preservation of primary cores despite partial metamorphic modification. In inner zone pelitic hornfels, cordierite and biotite remain Mg-rich, andalusite shows limited Fe substitution, chlorites retain clinochlore compositions, and tourmalines are classified mainly as dravite within the alkali group, all consistent with thermal overprinting under contact metamorphic conditions. In metamafic hornfels, amphiboles are dominantly calcic magnesio-hornblende with compositional trends reflecting edenitic and tschermakitic substitutions, low Ti contents, and oxidizing metamorphic conditions, indicating recrystallization from a mafic crustal protolith rather than primary magmatic origin. Plagioclase compositions range from albite to oligoclase along the Ab–An join, consistent with low- to medium-grade metamorphism. Titanite forms as prograde rims around ilmenite, epidote compositions suggest formation through plagioclase breakdown, and chlorites and biotites show metamorphic re-equilibration trends. The chapter further emphasizes the role of biotite chemistry as a petrogenetic discriminator, demonstrating that dominant substitution mechanisms such as Al-Tschermak exchange vary systematically with lithology, bulk composition, coexisting mineral assemblages, and metamorphic grade. Correlation analyses of tetrahedral and octahedral Al, as well as relationships between Al and divalent cations, reveal distinct substitution patterns in phyllites, spotted phyllites, and hornfelses, reflecting differences in temperature conditions and equilibrium phase relations.

8. Bulk-rock Geochemistry

This chapter presents a comprehensive bulk rock geochemical investigation of the Champaner Group, integrating major oxides, trace elements, and rare earth elements (REEs) data to constrain protolith composition, provenance, weathering history, magmatic evolution, and tectonic setting. Whole-rock analyses of twenty-five samples, including metapelitic rocks from outer and middle zones and both pelitic and metamafic hornfels from the inner zone, were conducted using WD-XRF and HR-ICP-MS, and the resulting data were further utilized for P–T pseudosection modelling and reconstruction of the Pressure–Temperature–time–Deformation (P–T–t–D) evolution.

The outer and middle zone metapelites are dominated by SiO_2, Al_2O_3, K_2O, and Fe_2O_3, with low CaO and Na_2O contents, indicating aluminous pelitic compositions. Variation diagrams show systematic relationships such as positive Al_2O_3–K_2O correlations reflecting mica-rich protoliths, poor Al_2O_3–TiO_2 correlation indicating immobility of Ti, and negative SiO_2–Al_2O_3 trends consistent with quartz addition and sedimentary sorting under moderate chemical weathering conditions. AKF and AFM projections demonstrate progressive metamorphic evolution from chlorite–muscovite phyllites to biotite–garnet–cordierite and locally sillimanite-bearing assemblages, indicating increasing temperature from greenschist to lower amphibolite facies. Trace element behaviour, particularly positive correlations of Rb, Ba, Th, Sc, and Y with Al_2O_3, indicates clay-rich argillaceous control and felsic upper continental crust provenance. UCC-normalized spider diagrams display LILE enrichment (Rb, Ba, Th, U, K) and HFSE depletion (Nb, Ta, Ti), along with negative Nb–Ta–Ti anomalies, suggesting derivation from subduction-modified felsic continental sources. Chondrite-normalized REE patterns show LREE enrichment, relatively flat HREEs, and negative Eu anomalies, consistent with evolved continental crustal sources and plagioclase fractionation. Discrimination diagrams such as log (Fe_2O_3/K_2O) vs log (SiO_2/Al_2O_3), $Zr–TiO_2–Al_2O_3$, and Th/Sc vs Zr/Sc collectively indicate shale to Fe-shale protoliths derived from recycled, felsic continental crust under an active continental margin setting. Inner zone pelitic hornfels display elevated Al_2O_3, low CaO and Na_2O, and bulk compositions closely comparable to PAAS and NASC, reinforcing a felsic, clay-rich sedimentary protolith. Strong negative $SiO_2–Al_2O_3$ correlation and positive $Al_2O_3–TiO_2$ and $Al_2O_3–K_2O$ relationships suggest weathered, compositionally mature source terrains. CIA values between 75 and 84 plotted on the A–CN–K diagram indicate intense chemical weathering and feldspar breakdown prior to metamorphism. Trace element systematics show Sr depletion and Th enrichment, with variations in Th reflecting fluctuating redox conditions during sediment deposition. REE patterns remain LREE-enriched with moderate negative Eu anomalies, further confirming felsic continental provenance. Discrimination diagrams place the sediments within recycled quartz-rich sedimentary fields and support deposition along an active continental margin with significant sediment recycling. The metamafic hornfels exhibit SiO_2 contents of ~53–55 wt%, moderate Al_2O_3, higher FeO, and variable CaO and Na_2O, consistent with basaltic to basaltic–andesitic precursors. Trace elements and HFSE show largely immobile behaviour, preserving primary magmatic signatures. Geochemical classification diagrams (Nb/Y vs SiO_2, TAS, AFM, Jensen cation plots, FeO/MgO vs SiO_2) consistently indicate sub-alkaline affinity with predominantly calc-alkaline trends and low to medium Mg#. Harker variation diagrams reveal negative correlations of SiO_2 and CaO with MgO, reflecting magmatic differentiation and plagioclase involvement, while poor correlation of TiO_2 suggests immobility during metamorphism. Trace element modelling and ratio plots (Zr vs Zr/Y, Cr vs V, Ce vs Ce/Yb, Sm vs Sm/Yb) indicate low to moderate degrees of partial melting within the shallow spinel-lherzolite field and significant fractional crystallization dominated by clinopyroxene ± plagioclase. Elevated La/Sm and fluid-mobile element ratios (Ba/Th, Pb/Ce) imply derivation from a metasomatized subcontinental lithospheric mantle source influenced by slab-derived hydrous fluids. Tectonic discrimination diagrams further support generation in a subduction-modified arc to back-arc setting rather than MORB or plume-related environments.

9. P-T Conditions of Metamorphism

This chapter presents a quantitative evaluation of metamorphic pressure–temperature (P–T) conditions of the Champaner Group and reconstructs its Pressure–Temperature–time–Deformation (P–T–t–D) evolution through integrated mineral thermo-barometry and phase equilibria modelling. Earlier studies had suggested low-grade greenschist facies regional metamorphism overprinted by hornblende-hornfels facies contact metamorphism, but no explicit quantitative P–T estimates were available. The present study addresses this gap by applying calibrated mineral geothermometers and geobarometers to EPMA-derived mineral compositions and bulk-rock geochemistry, and by constructing P–T pseudosections using Perple_X thermodynamic modelling.

Temperature estimates for metapelitic rocks were obtained using Ti-in-biotite, biotite–muscovite, garnet–muscovite, and garnet–biotite thermometers, whereas pressure was constrained using biotite–muscovite and GBMAQ barometers. Phengite-bearing porphyroblast-free phyllites yield high-pressure, low-temperature conditions of ~6.5–7.4 kbar and ~430–480 °C, indicating stabilization under tectonic burial in epidote-amphibolite facies conditions. Andalusite-bearing phyllites record lower pressures (~2.5–3.5 kbar) and temperatures of ~510–530 °C, while garnet-bearing assemblages indicate medium to locally higher pressures (~3–5 kbar) and ~525–560 °C. Andalusite–cordierite and sillimanite-bearing assemblages reflect medium-temperature, low-pressure conditions (~2–3 kbar; ~565–595 °C). Contact metamorphosed pelitic hornfelses yield peak temperatures of ~575–600 °C at low pressures (~1.5–2.9 kbar), consistent with high-temperature, low-pressure metamorphism below the muscovite + quartz breakdown curve. Metamafic hornfels P–T conditions were constrained using amphibole–plagioclase thermometry and hornblende-based barometry. Edenite–tremolite and edenite–richterite formulations yield temperatures between ~440–630 °C, with average values clustering around 470–540 °C. Pressure estimates from hornblende–plagioclase–quartz and Al-in-hornblende barometers range from ~2–5 kbar, with average values near 3–4 kbar. Geothermobarometric plots and discrimination diagrams consistently indicate greenschist to amphibolite transitional facies, confirming medium-pressure amphibolite facies metamorphism for metamafic rocks. P–T pseudosections were constructed in MnNCKFMASHTi, NCKFMASHTi, and KFMASHTi systems for representative metapelitic phyllites/schists and hornfelses, and in NCKFMASHTi system for metamafic hornfelses. Mineral compositional isopleths (e.g., XMg and XFe in garnet, Si in mica, XFe in biotite, XMg in cordierite) were contoured to define equilibrium stability fields. For andalusite + garnet ± sillimanite phyllite/schist, high-pressure S_1 assemblages stabilize at ~5.9–6.6 kbar and 400–480 °C, whereas garnet-bearing M_2 assemblages occur at ~3.8–5.8 kbar and 520–560 °C, and low-pressure andalusite-bearing assemblages stabilize at ~2.4–2.8 kbar and 490–560 °C. Cordierite-bearing assemblages define stability at ~2–3 kbar and ~500–560 °C. Hornfels pseudosections constrain biotite hornfels assemblages at ~480–500 °C and <3.7 kbar, andalusite–cordierite hornfels at ~500–600 °C and <2.5 kbar, and andalusite–sillimanite hornfels at ~500–600 °C and <4.6 kbar. Metamafic hornfels pseudosections record early high-pressure low-temperature assemblages (>6 kbar; ~300–400 °C) and subsequent medium-pressure medium-temperature assemblages (~2.7–5 kbar; ~470–550 °C).

Integration of petrography, microstructures, quantitative thermobarometry, pseudosection modelling, and geochronological constraints on granitoid intrusions permits reconstruction of a clockwise P–T–t–D path. The D_1 phase corresponds to M_1 high-pressure, low-temperature burial metamorphism (~6.5–7.4 kbar; ~430–480 °C) under a low geothermal gradient in regional epidote-amphibolite facies. During D_2, decompression accompanied by progressive heating (~500–570 °C; ~2.3–5.2 kbar) led to growth of andalusite, garnet, and cordierite under Buchan-type regional-contact amphibolite facies conditions, associated with pre- to syn-D_2 granitoid emplacement. A thermal peak (M_3-1) during syn- to post-D_2 and D_3 granitic intrusions produced high-temperature, low-pressure contact metamorphism and local migmatization (~565–600 °C; ~1.5–2.9 kbar). Subsequent cooling, decompression, and fluid-assisted retrogression ($M_{3\text{-}2}$) generated low-temperature, low-pressure assemblages such as chlorite, muscovite, and andalusite pseudomorphs corresponding to greenschist facies conditions during exhumation.

10. Discussion and Summary

The Champaner supracrustal succession, though dominated by low-grade regional metamorphism, records a distinct contact metamorphic overprint along its eastern margin manifested by the development of pelitic hornfels. Multiple granitoid pulses are documented in the region, but field relationships, geochronology, mineral isograd distribution, and thermobarometric constraints collectively indicate that the hornfels described in this study are genetically linked to the late- to syn-tectonic emplacement of the 0.95–0.93 Ga Godhra granites during post-D_2 to syn-D_3 deformation. Contact metamorphism is spatially restricted to the eastern boundary (Kevra–Dhanpur–Jharva–Wadek sectors), whereas the northern margin preserves low-grade phyllites despite granitoid proximity, reflecting spatial variation in pluton geometry and emplacement level. Geophysical data indicate that the granite roof is shallowest beneath the Wadek sector, where andalusite–sillimanite hornfels are developed, and progressively deepens westward and northward, corresponding to decreasing metamorphic grade. The distribution of biotite, andalusite–cordierite, and andalusite–sillimanite isograds thus directly reflects variations in pluton depth and thermal gradients imposed by the Godhra intrusion. Pelitic hornfels show systematic mineralogical and geochemical zonation. Biotite hornfels grade inward to andalusite–cordierite and ultimately andalusite–sillimanite hornfels, marking a temperature-dominated metamorphic gradient at relatively low pressures. Whole-rock chemistry is aluminous and comparable to PAAS, with elevated Al_2O_3, low MnO, LREE enrichment, subdued HREE, negative Eu anomalies, and high CIA values indicative of intense pre-depositional weathering of a shale-dominated protolith deposited in an active continental margin setting. Thermobarometric estimates constrain contact metamorphism to ~150–260 MPa and ~480–600 °C, with mineral reactions primarily controlled by increasing temperature rather than pressure variation or fluid activity. The 0.95–0.93 Ga granitoids therefore represent the principal orogenic heat source responsible for the hornfelsic overprint along the eastern Champaner margin.

Tectono-Metamorphic Evolution of the Champaner Supracrustals

The tectono-metamorphic evolution of the Champaner Group is interpreted within the broader framework of interaction between the Aravalli–Delhi Fold Belt (ADFB) and the Central Indian Tectonic Zone (CITZ). Stage I (D_1–M_1): North-directed subduction of the CITZ beneath the ADFB led to crustal thickening, tight to isoclinal folding, and development of penetrative S_1 foliation. Regional high-pressure, low-temperature metamorphism (M_1) produced phengite–epidote–albite–chlorite assemblages under epidote–amphibolite facies conditions at ~6.5–7.4 kbar and ~430–480 °C, reflecting a low geothermal gradient. Stage II (D_2–M_2): Slab break-off and detachment-initiated decompression accompanied by heating. D_2 deformation generated open to tight folds and S_2 cleavage, while M_2 metamorphism stabilized garnet-, andalusite-, and cordierite-bearing assemblages at ~2.3–5.2 kbar and ~500–570 °C. This stage marks transition toward Buchan-type metamorphism characterized by increasing thermal input during exhumation of previously thickened crust. Stage III (D_3–M_3): Reversal in subduction polarity and shallow emplacement of 0.95–0.93 Ga granites produced weak D_3 deformation expressed as broad open warps and S_3 cleavages. Peak high-temperature, low-pressure conditions (~565–600 °C; ~1.5–2.9 kbar) generated sillimanite-bearing assemblages and localized hornfels and migmatization (M_3-1). Subsequent cooling and uplift resulted in retrograde metamorphism (M_3-2) marked by chlorite ± muscovite ± epidote growth.The Champaner Group thus records a clockwise P–T trajectory involving initial burial and HP–LT metamorphism, decompression with progressive heating, attainment of peak temperatures at shallow crustal levels during granitoid emplacement, and final cooling during exhumation. The evolution reflects transition from an early low geothermal gradient subduction regime to a high geothermal gradient, Buchan-type metamorphic regime strongly influenced by syn- to post-tectonic granitic intrusions.

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