Abstract Volume of

Research Scholars' Day 2026

Department of Earth Sciences, IIT Kanpur

भारतीय प्रौद्योगिकी संस्थान कानपुर

Indian Institute of Technology Kanpur

Earth Sciences

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Head's Message:

Santanu Misra

It gives me great pleasure to welcome you to the Research Scholars' Day 2026 (RSD'26) of the Department of Earth Sciences, IIT Kanpur. This annual event celebrates the curiosity, dedication, and scientific enthusiasm of our students, who are at the heart of the department's research and outreach activities. Through their presentations, they share new findings, ideas, and perspectives that help us better understand the Earth. It is their opportunity to present their work, ask hard questions, exchange ideas, and perhaps discover that explaining years of research in ten minutes or standing in front of a poster can sometimes be harder than doing the research itself.

Research Scholars' Day also brings together people from academia and industry. We are happy to welcome our Guests of Honour, Dr. Waliur Rahaman (Scientist, NCPOR, Goa) and Mr. Shameek Chattopadhyay (MD, SRK Consulting, India) from both sectors, whose presence and experiences will add valuable perspectives to the discussions.

The Department of Earth Sciences at IIT Kanpur is home to a diverse group of researchers working in areas such as geochemistry, geophysics, petrology, planetary sciences, structural geology, surface and sedimentary processes, tectonics, along with emerging topics related to energy resources, climate, and natural hazards. Over the years, the department has built strong experimental and analytical facilities and continues to engage with academic institutions, research organisations, and industry.

I congratulate all the students for their hard work and thank the organizers for putting together this event. I hope the day brings engaging discussions, new ideas, and encouragement for young researchers as they continue their journey.

Jai Hind!

Guest of Honour

Waliur Rahaman

Dr. Waliur Rahaman is an Indian geochemist specializing in isotope geochemistry, paleo-oceanography, and paleoclimatology. He is currently Scientist-F and Head of the Isotope Geochemistry Section at the National Centre for Polar and Ocean Research (NCPOR), Goa, India. Dr. Rahaman completed his B.Sc. (Hons.) in Geology (1999–2002) and M.Sc. in Applied Geology (2002–2004) from Aligarh Muslim University. He earned his Ph.D. in Geochemistry from the Physical Research Laboratory (PRL), Ahmedabad (2005–2011), where he began his research career as a Junior Research Fellow. Following his doctoral work, he conducted postdoctoral research at PRL and later at GFZ Potsdam, Germany (2012–2013) as an Alexander von Humboldt Fellow.

In 2012, he joined NCPOR, Goa as a Scientist. At NCPOR, he established the "ISOTRACE" metal-free clean chemistry laboratory, equipped with advanced instruments such as Multi-Collector ICP-MS (MC-ICP-MS) and Quadrupole ICP-MS for high-precision measurements of trace elements and radiogenic and stable isotopes. The ISOTRACE facility has become one of the leading isotope geochemistry laboratories in India, supporting national and international research.

Dr. Rahman's research focuses on paleoclimate reconstruction from Antarctic ice cores, paleo-oceanography using radiogenic and stable isotopes, Himalayan weathering and erosion processes, cosmogenic nuclides (^{10}Be), and non-traditional stable isotopes such as $\delta^{7}Li$, $\delta^{11}B$, $\delta^{30}Si$, and $\delta^{98}Mo$ to understand Earth surface and oceanic processes. He has supervised five Ph.D. students, trained several early-career scientists, and collaborated widely with institutions across India.

Dr. Rahaman has received several prestigious honors, including the Vigyan Yuva–Shanti Swarup Bhatnagar Award in Earth Sciences (2025), the National Geoscience Award (2023), the Alexander von Humboldt Fellowship for Senior Researchers (2022), and the Young Researcher Award from the Ministry of Earth Sciences (2021).a

Guest of Honour

Shameek Chattopadhyay

Mr. Shameek Chattopadhyay is a geologist with more than two decades of experience in mineral exploration, geological modelling, and mineral resource evaluation. He currently serves as the Managing Director of SRK Mining Services (India) Pvt. Ltd., which is the part of the global SRK Consulting group, where he leads technical consulting services for the mining industry in India and internationally.

A graduate of the Indian School of Mines (ISM), Dhanbad, Mr. Chattopadhyay has built a distinguished career in exploration geology and mineral resource assessment. Before joining SRK Consulting in 2007, he worked with international mining companies including De Beers and Pebble Creek, gaining valuable experience in exploration and resource evaluation.

Mr. Chattopadhyay has worked on a wide range of commodities - including gold, copper, lead-zinc, iron ore, bauxite, chromite, manganese, diamond, graphite, lithium, nickel laterite, REEs and some industrial minerals in different geological settings across more than 30 countries. Over his career, he has been involved in planning, managing and reviewing advanced exploration projects, developing and auditing QA/QC protocols, undertaking and reviewing geological modelling and geostatistical analyses, and preparing mineral resource estimates and reporting in accordance with different CRIRSCO-type international reporting standards. In addition to core geological works, his expertise also includes undertaking technical due diligence studies for merger and acquisitions, managing feasibility assessments, and preparing independent technical reports of mining assets for listing in the London stock exchange.

Mr. Chattopadhyay is a member of different professional societies where he actively contributes. These include Australasian Institute of Mining and Metallurgy, Geological Society of India, International Mathematical Geoscience, Society of Economic Geology, Mining Engineers Association of India and National Committee for Reporting Mineral Resources and Reserves in India. Through his leadership and global experience, Mr. Chattopadhyay continues to play a significant role in advancing modern mineral exploration and resource evaluation practices in the mining sector.

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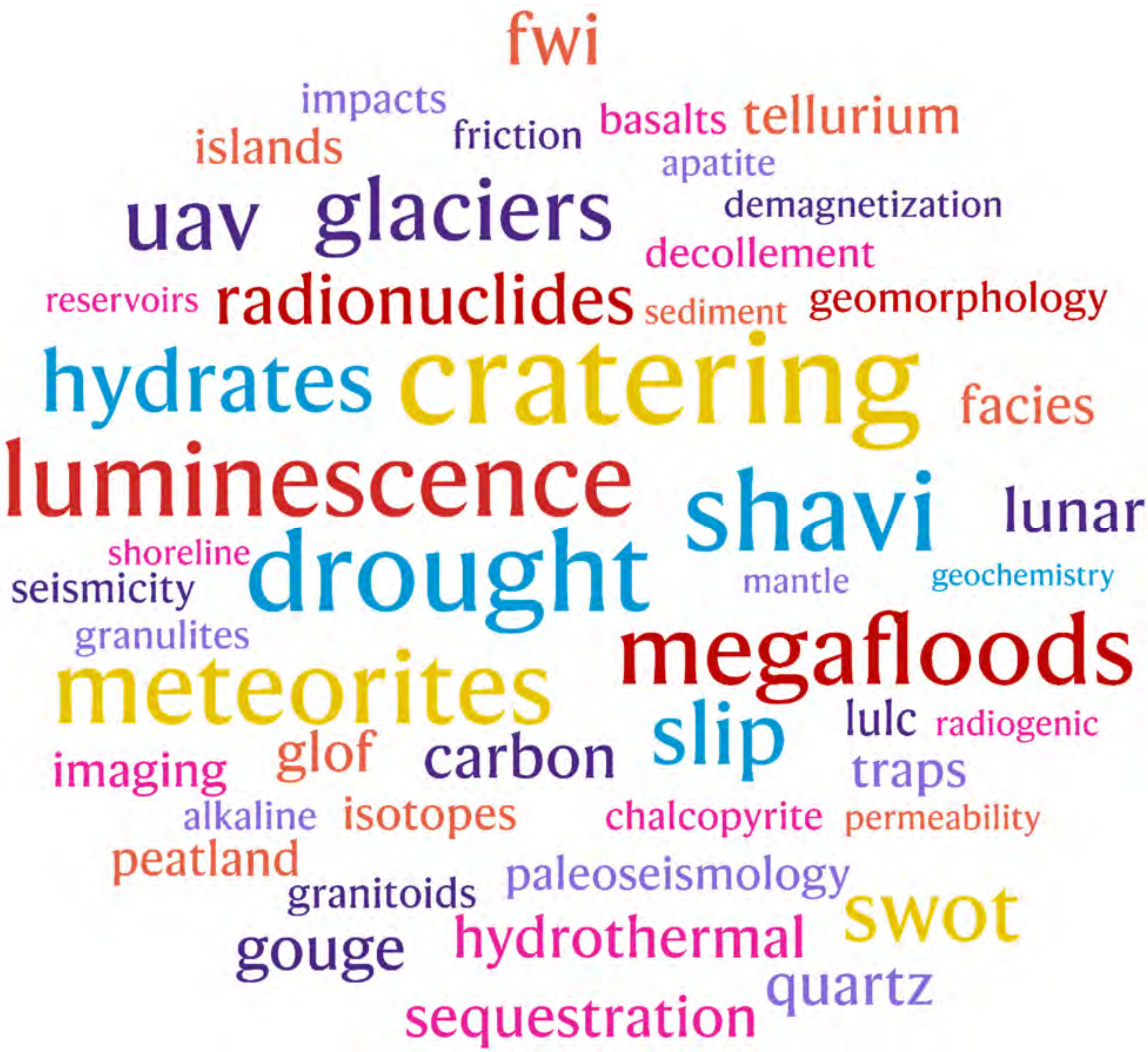
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Controls on Seismic and Aseismic Slip in 2-D Quasi-Dynamic Fault Models

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We investigate how frictional properties control the transition between seismic and aseismic slip using 2-D rate-and-state friction (RSF) models within a quasi-dynamic framework. Seismic and aseismic slip are both observed on natural faults, and rate-and-state friction (RSF) theory provides a powerful framework to describe their behavior. However, the combined influence of frictional parameters and effective normal stress on the stability of fault slip has not yet been systematically mapped across parameter space within a unified quasi-dynamic framework.

We use a 2-D RSF fault model with radiation damping to explore how variations in friction parameters (b - a), critical slip distance D_{rs}, and effective normal stress $\bar{\sigma}$ affect fault slip behavior. For each parameter combination, we simulate sequences of events and quantify mean slip, maximum slip velocity, stress drop, event duration, recurrence interval, and nucleation size.

Our simulations show that system behavior is primarily governed by the effective instability parameter (b-a) $\bar{\sigma}$/G, where G is the rigidity modulus. Larger (b-a) $\bar{\sigma}$ promotes dynamic rupture with peak slip rates that exceed a dynamic threshold, characteristic of seismic events, whereas reducing (b-a) or increasing D_{rs} enlarges the critical nucleation length, suppresses rapid acceleration, and produces slow slip or fully aseismic creep. We identify distinct parameter domains that generate slow slip events and others that produce unstable, high-velocity ruptures.

These results reveal regimes of seismic and aseismic events that arise from variations in frictional parameters and effective normal stress, underscoring the central role of frictional parameter contrasts in governing fault slip modes across a continuum from aseismic creep to dynamic rupture. By mapping parameter regimes to specific slip behaviors, this work clarifies the mechanical conditions under which faults can exhibit slow slip, stable sliding, and seismic rupture, and provides a controlled basis for interpreting observed fault behaviors. As a future direction, we aim to extend this framework to long-term seismic-cycle simulations that incorporate heterogeneous friction and fault geometry within a unified rate-and-state modeling framework, in order to study magnitude variability, recurrence patterns, and stress evolution.

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Spatio-temporal LULC dynamics and landscape fragmentation in the Loktak wetland system

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The Loktak Wetlandscape, a landscape rich in wetlands and channels located in Manipur, is ecologically and hydrologically important ecosystem belonging to the Indo-Burman biodiversity hotspot. The listing of Loktak Wetland, a Ramsar site, in the Montreux Record for the past several decades highlights the need for its management and conservation. Previous wetland research emphasized the importance of incorporating the health of wetland landscape pattern in wetland management along with temporal wetland cover changes [1, 2]. Our work focuses on evaluating the major changes in land use and land cover of Loktak, Ikop, and Pumlen wetland complexes and understanding their impacts on the landscape structural pattern of these 3 complexes. We used a random forest classifier to generate land use and land cover maps using the Landsat series of optical images in Google Earth Engine from 1989 to 2024, at a frequency of 5-7 years. Aquaculture, the major land use cover in the wetlandscape has been expanding at an astonishing rate as documented by four times increase between 1989 and 2024. The two main natural wetland covers—open surface water and phumdi, the floating biomass that is a distinctive feature of Loktak—were lost because of the expansion of aquaculture (42 km^2 in Loktak). The overall accuracy of classification lies in the range of 80-95%. Further, landscape and class-level indices such as PLAND, LPI, TE, ED, NP, and PD were used to analyse the spatio-temporal landscape dynamics of the wetland. Our study shows that fragmentation significantly increased between 1989 and 2024 as the number of wetland patches increased. Loktak exhibits a higher level of fragmentation with diverse and irregular landscapes. Ikop and Pumlen are less fragmented with aggregated and clumped patches. Landscape pattern analysis backed by LULC changes signifies the ecological degradation the wetlandscape has been undergoing. The reproducible remote sensing-based approach will help to develop sustainable management strategies for wetland conservation.

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ShaVi: A Scalable MPI-Based Full-Waveform Inversion Engine for High-Performance Seismic Imaging

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Full-waveform inversion (FWI) is a high-resolution seismic imaging technique used to estimate subsurface physical properties by minimizing the misfit between observed and simulated seismic wavefields. Although FWI provides superior imaging resolution compared to conventional inversion methods, it is computationally intensive due to repeated numerical solutions of the wave equation and large-scale gradient evaluations. To address these challenges, we present ShaVi, a scalable full-waveform inversion engine designed for distributed-memory high-performance computing environments using the Message Passing Interface (MPI). ShaVi implements forward and adjoint simulations based on finite-difference time-domain discretization of the acoustic wave equation. Gradients are computed using the adjoint-state method by correlating forward propagated wavefields with time-reversed residual wavefields. The inversion workflow includes objective function evaluation, gradient computation, and model updates using optimization algorithms such as nonlinear conjugate gradient and limited-memory BFGS with line search strategies [1] . The modular software design allows extension to alternative physics (e.g., elastic or visco-acoustic formulations) and incorporation of regularization constraints. Parallelization in ShaVi is achieved through spatial domain decomposition, where each MPI rank handles a subdomain of the computational grid. Halo exchanges are performed at every time step for stencil updates, and global reductions are used for objective and gradient aggregation. The engine incorporates checkpointing strategies to balance memory usage and recomputation costs, enabling efficient large-scale simulations. Performance benchmarks on synthetic models such as layered velocity structures and the Marmousi model demonstrate stable convergence behavior and strong scaling efficiency with increasing MPI ranks. ShaVi serves as both a research and educational platform for experimentation with FWI algorithms under realistic HPC constraints. By combining numerical accuracy, modular design, and MPI-based scalability, ShaVi provides a robust framework for large-scale seismic inversion studies in academic and applied geophysical research.

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Shock demagnetization in an ambient magnetic field at the Dhala impact structure, India

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Impact-generated shock waves can significantly modify the magnetic properties of target rocks and may contribute to weak magnetic anomalies observed over large Martian impact basins, such as Hellas and Argyre. Several processes have been proposed to explain these anomalies, including shock-induced demagnetization, the absence of thermal remanent magnetization after dynamo shutdown, excavation of magnetized crust, and cooling in a reversing magnetic field [1,2]. To evaluate the role of shock waves on the remanent magnetization of target rocks, we conducted paleomagnetic and rock magnetic investigations on impactites and unshocked target lithologies of the Dhala impact structure, India. Thermomagnetic analyses indicate that unshocked granites and diorites are dominated by Ti-poor magnetite and display narrow hysteresis loops characteristic of multidomain grains. These rocks record the highest remanent magnetization and Königsberger (Q) ratios. In contrast, impact melt rocks exhibit multiple Curie temperatures, indicating the presence of Ti-rich magnetite, pyrrhotite, and hematite, together with wasp-waisted hysteresis behavior. These features indicate mixtures of pseudo-single-domain and superparamagnetic grains formed during rapid cooling and recrystallization, supported by high frequency-dependent magnetic susceptibility values. Impact melts show intermediate remanent magnetization but the highest magnetic susceptibility. Monomict breccias, containing Ti-magnetite and Ti-hematite, exhibit the weakest magnetic signatures, with extremely low natural remanent magnetization and Q ratios. Compared to unshocked rocks, monomict breccia record shock modification, including microfracturing, grain-size reduction, domain wall pinning, and random clast orientations, leading to cancellation of magnetic vectors at the sample scale. Overall, our results demonstrate that shock processes can substantially weaken remanent magnetization, even in the presence of Earth's ambient magnetic field. Shock-induced demagnetization therefore, provides a plausible explanation for subdued magnetic anomalies around terrestrial impact structures and offers important insight into the weak crustal magnetization observed at the margins of large Martian basins [3].

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Multi-Proxy Insights into Climatic and Environmental Influences on Peat Development in India

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Peat deposits act as important archives of wetland ecosystems, maintaining signals of past environmental change. Exploring the temporal evolution of peatland dynamics across climatically diverse regions of India allows the identification of regional environmental variability and provides an understanding on the connections between ecosystem processes and peat formation [1]. This study presents a multiproxy analysis of peat deposits from four climatically and environmentally distinct regions, using stable carbon and nitrogen isotopes, C/N ratios, rare earth element (REE) geochemistry, and scanning electron microscopy (SEM) to determine spatial and temporal variations in peat composition and preservation. The $\delta^{13}C$ values from all the four locations varies between -30.1‰ -19.2‰ and have predominantly C3 vegetation inputs. The C/N ratios (11.1 to 55.7) and $\delta^{13}C$ exhibit significant spatial variability which implies change in the organic matter composition and degree of humification. The $\delta^{15}N$ values varies from -0.9‰ to 3.3‰. The down-core variability in $\delta^{13}C$ of Nilgiris and Khecheopalri reveal distinct temporal fluctuations, and the Nilgiris core displays signal of global climatic events such as 4.2ka event, Roman Warm Period (RWP), Dark Ages Cold Period (DACP) and Little Ice Age (LIA) [2]. The site-specific distribution is also exhibited by the IPAS-normalized REE patterns across the four locations. Changes in detrital inputs and geochemical conditions in Khecheopalri were identified based on the presence of Eu and infrequent Ce anomalies.

This study thus shows the importance of a multiproxy approach to effectively understand the response of peat formation and preservation to regional climate variability.

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Sediment Dynamics and associated cascading hazards in the Garhwal Himalaya: A Process-Based Framework

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Mountain river basins of the western Himalaya represent some of the world's most dynamic sediment cascades, shaped by steep relief, active tectonics, intense monsoonal precipitation, glacial–paraglacial legacies, and accelerating anthropogenic pressures. Sediment processes exert first-order control over channel morphology and underpin cascading hazard chains encompassing landslides, debris flows, glacial lake outburst floods, and reservoir sedimentation [1]. Yet regional hazard assessments frequently treat sediment dynamics implicitly, with inadequate attention to connectivity structures and spatially variable transport efficiency [2].

This study develops an integrated, process-based modelling framework to quantify soil erosion, sediment connectivity, and downstream delivery across the Alaknanda–Bhagirathi river system in the Garhwal Himalaya, a basin of approximately 20,000 km² that has experienced repeated catastrophic flood and landslide events. The framework couples RUSLE-derived erosion estimates with a Sediment Connectivity Index (SCI) inspired by Zingaro et al. (2019) and Stream Power Index to produce spatially explicit metrics of Sediment Transport Potential, Sediment Delivery Ratio, and a composite Soil Erosion Transport Index (SETI)[3]. Multi-source geospatial inputs include the Copernicus 30 m DEM, CHIRPS rainfall data, Sentinel-2 NDVI-derived land cover, SoilGrids soil properties, and regional geological maps [2].

Results reveal pronounced spatial heterogeneity in erosion intensity and delivery efficiency across the basin. Critically, smaller, topographically confined sub-catchments exhibit disproportionately high sediment delivery ratios relative to their area, demonstrating that topographic connectivity exerts dominant control over sediment transfer independent of basin scale. Elevated SETI values delineate critical source-to-sink sediment corridors that show strong spatial correspondence with documented landslide clusters and flood-affected reaches associated with the 2013, 2021, and 2025 disaster events [1]. This framework offers a transferable, spatially explicit tool for multi-hazard assessment, prioritisation of early warning systems, and evidence-based basin management in tectonically active mountain environments.

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Experimental work of flow measurements and flow laws in low porous sandstone

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Depletion of hydrocarbon reserves in porous reservoirs have forced the hydrocarbon exploration to look for oil and gas reserves hosted in low porous geomaterials. Gas flow in low porous sandstone reservoir is a complex function of the flow regime. The micro and nano pore network in low porous sandstone led to significant interaction of pore walls and gas molecules, resulting in gas slippage effect. Characterizing the fluid flow in low porous sandstone considering laminar flow and Darcy’s Law will involve erroneous estimation of permeability. In this study, two low porous sandstone samples from lower Vindhyan Basin having porosities of 9% (LP_SST) and 4% (Lvi) were tested for gas permeability measurements. Apparent permeabilities (K_{app}) were measured in an existing pulse decay permeameter at two different conditions- constant effective stress and constant confining stress. The low pore pressure data at constant effective stress was used to determine the Klinkenberg slippage coefficient (b) and intrinsic permeabilities (K_{∞}). The slippage coefficient ranges from $2*10^{-8}$ to $3*10^{-8}$ for Lvi specimens, while for LP_SST the variation is limited to $1.11*10^{-8}$ to $.5*10^{-8}$ for a effective stress range of 4.8 to 48.3 MPa. The slippage coefficient for both the samples increased linearly with effective stress, as the pore apertures reduced at higher effective stress leading to larger gas molecule pore wall interaction and higher slippage. The apparent permeability variation at different constant confining stress ranges 6.9 MPa – 27.57 MPa helps to understand the superposition of slippage and stress on permeability. The study will try to separate the component of slippage from permeability of the low porous sandstones to obtain the influence of stress on permeability evolution and determine the effective stress coefficient. This method will lead to development of flow laws in low porous sandstone reservoirs.

A Comprehensive Two-Dimensional Elastic Full Waveform Inversion Package with PINN-Based Surrogate Forward Modeling

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Full waveform elastic inversion (FWI) offers a physically consistent framework for reconstructing subsurface properties by modeling both compressional and shear wave propagation, including mode conversions and elastic effects. Compared to acoustic formulations, elastic FWI improves sensitivity to lithological and mechanical variations and enables the recovery of multiple parameters, including P-wave velocity (V_p), S-wave velocity (V_s), and density. We present a comprehensive two-dimensional elastic FWI package built on a fourth-order staggered-grid finite-difference formulation with Convolutional Perfectly Matched Layer (CPML) absorbing boundaries. The forward module solves the elastic wave equation in stress–velocity form, transforming physical parameters (V_p, V_s, density) into elastic stiffness coefficients and constructing frequency-dependent damping profiles for boundary absorption. The coupled stress and particle velocity fields are advanced through explicit time stepping, ensuring numerical stability and high-order spatial accuracy.

A fully consistent adjoint module completes the inversion framework. During forward propagation, the vertical particle velocity wavefield is stored to enable gradient evaluation. In the adjoint stage, data residuals between observed and synthetic seismograms are injected at receiver locations in reverse time order, and the elastic system is solved backward using the identical staggered-grid and CPML formulation. Model gradients are computed via zero-lag cross-correlation between stored forward and reconstructed adjoint wavefields, with optional illumination-based normalization to stabilize parameter updates. This strict operator consistency ensures physically meaningful sensitivity kernels and stable gradient-based optimization. To enhance computational efficiency, we integrate physics-informed neural networks (PINNs) as surrogate forward solvers. The PINN module embeds the elastic wave equation into the loss function through automatic differentiation and is trained using high-fidelity finite-difference simulations. This hybrid architecture establishes a complete, self-contained elastic FWI workflow; forward modeling, residual evaluation, adjoint back-propagation, gradient construction, and accelerated surrogate simulation; combining numerical rigor with neural efficiency for scalable and physically consistent inversion.

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First application of combined ^{10}Be and rock surface luminescence dating techniques in Jankar Valley, Lahaul Himalaya

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Reconstructing the timing of glaciations and post-glacial erosion rates is essential for understanding past climate variability, the interaction between climatic systems and landforms, and for predicting future glacier behaviour under global warming [1]. Exposure age and erosion rates are often evaluated using a paired-nuclide approach for CRN dating or by complementary dating techniques. Recently, rock surface luminescence dating (RSLD) has emerged as a promising technique for constraining exposure and erosion rates of rock surfaces. A few recent studies have used a combined approach integrating RSLD with ^{10}Be dating to constrain post-exposure erosion rates and erosion-corrected exposure ages [2]. This method relies on the propagation of a sigmoidal luminescence signal distribution with depth, called the luminescence depth profile (LDP). The LDP is highly sensitive to both exposure duration and erosion rate. The accuracy of RSLD has been further improved through the application of the General order kinetic (GOK) model, which incorporates the non-exponential decay of the feldspar IRSL (Infrared Stimulated luminescence) signal within RSLD modelling [3].

Furthermore, the development of CoRSEER (Calculator of rock surface exposure age and erosion) has led to a paradigm shift in LDP analysis [4]. This advanced approach has been applied in Lahaul Himalaya to determine the timing of past glacial activity and quantify post-glacial erosion rates. Preliminary analysis revealed that the order of kinetics ranged from 2.17 to 2.45, indicating the nonlinearity of feldspar. Furthermore, the exposure ages derived from RSLD were significantly underestimated, suggesting relatively high surface erosion rates. The erosion rates were estimated as $0.064^{+0.020}_{-0.015}$ to $0.236^{+0.03}_{-0.03}$ mm/yr, which are considerably higher than the previously reported rates of 0.0008 mm/yr. These elevated erosion rates are expected to influence the apparent exposure ages obtained from TCN dating substantially.

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Riverine island dynamics of the Lower Ganga River over multi-decadal timescales

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A riverine island is a geomorphic landform located within a river channel, surrounded by water-filled channels that separate it from the adjacent floodplain [1,2]. Island dynamics (formation, development, and destruction) are important indicators of river processes [3]. The Lower Ganga River (LGR) hosts several riverine islands, and this work aims to understand the morphodynamics of these islands and drivers using geomorphic and hydrological datasets. We have analysed the spatial and temporal variation of different types of riverine islands along the Lower Ganga River using multi-temporal satellite images for 35 years between 1989 and 2024. By utilizing Google Earth Engine (GEE) platform and GIS software, four different types of islands were identified and mapped. We further investigate the major drivers of island dynamics using time-series hydrological datasets.

Our results show that the temporal variation of the riverine islands along the LGR exhibits a distinct pattern of evolution. Mid-Channel Islands occupied the largest area in the initial phase of the study period, which shifted to the confluence islands in later years. In terms of island number, the dominance shifted frequently between mid-channel and lateral islands. Moreover, six pathways of island morphological changes were identified, and these changes reflect different geomorphic mechanisms acting on individual island types. These pathways are fundamentally linked to fluvial processes of erosion and accretion. Further, window-scale analysis revealed distinct island morphological dynamics in each geomorphic window driven by a dominant island type in terms of area and an abundant type in terms of number, both of which also vary temporally. In addition, the diversity of the island assemblage also changes through both space and time. This highlights the spatial heterogeneity of windows since large rivers exhibit natural lateral variability in form-process associations. We attribute the temporal variability of riverine islands to fluctuations in the hydrological regime and sediment supply.

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Controls on Tellurium Partitioning in Hydrothermal Systems: Insights from Chalcopyrite–Fluid Experiments

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Tellurium (Te) is considered a critical element due to its limited availability and complex extraction, and it plays a vital role in green energy technologies such as solar panels, thermoelectric devices, batteries, and photoelectric systems. As a rare chalcogen metalloids, tellurium displays remarkable mineralogical diversity in the Earth's crust. It occurs as primary tellurides (oxidation states −II to 0) formed under anoxic, deep-crustal conditions and as secondary tellurites (+IV to +VI) produced through oxidative weathering [1]. Its concentration is mainly controlled by magmatic and hydrothermal processes. Te substitutes for S in common sulfide mineral such as chalcopyrite, covellite and pyrite in the late stage of fluid interaction with these minerals. However, chalcopyrite is formed earliest during the porphyry type deposit and VMS type hydrothermal deposit. In such environment the interaction of late hydrothermal fluid with the chalcopyrite can modify both fluid and the solid surface [2]. But such fluid-mineral interaction is poorly understood. To investigate fluid–chalcopyrite interactions and the mechanisms of tellurium incorporation, we conducted hydrothermal batch experiments using chalcopyrite grains (0.1–0.2 g) and Te-bearing solutions (5 ppm, 20 mL) at varying temperatures (140 °C, 150 °C, 160 °C, and 170 °C) under constant acidic conditions (pH 3.5–4) for 24 hours. Results show Chalcopyrite dissolution increases with temperature, as evidenced by the more abundant red precipitates observed at higher temperatures. Compared to the initial chalcopyrite composition, most reacted samples show enrichment in Cu and depletion in Fe and S. However, few point analyses indicate higher Fe and lower Cu and S. SEM–EDX elemental mapping of the reacted products shows a scattered distribution of tellurium on the chalcopyrite surfaces, with concentrations ranging from 0.1 to 6.1 wt.%. Higher Te concentrations are observed in zones depleted in Cu and S. The detected oxygen content (0.2–20 wt.%) indicates the formation of Cu and Fe-oxide phases on the surface of the reacted chalcopyrite. However, these secondary phases are confined to a thin surface layer, as no oxide phases are observed in the polished chalcopyrite grains, likely due to their removal during polishing. ICP-MS shows Te depletion from 5ppm to 2 ppm at 140℃ and 100ppb removed at 180 ℃ due to absorption onto chalcopyrite;6ppm Ni mobilized under acidic condition. In ion chromatography it has shown that Nitrate in tellurium act as a oxidising agent for the dissolution of chalcopyrite and as the temperature increases formation of sulphide to sulfate (SO_4^{2-}) anion increases. The depression mechanism observed in the ATR FTIR analysis of chalcopyrite indicates surface complex formation, resulting decrease in characteristics Fe-S or Cu-S absorption intensity.

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Field-machine-learning-integrated predictions of a fluvial unconventional reservoir analog at inter-channel-belt-scales: Cretaceous Blackhawk Formation, USA

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River avulsion-driven fluvial successions commonly exhibit strong lateral variability and complex reservoir architecture which challenges conventional methods of correlation. This study used an Extreme Gradient Boosting (*XG-Boost;*[1]) machine learning algorithm to evaluate the depositional characteristics and reservoir heterogeneity potentials within the avulsion-generated Blackhawk Formation, USA. The studied dataset constitutes an analog for the unconventional fluvial tight-gas reservoirs in the Rocky Mountain Region of USA. Our study focused twelve lithologs distributed along both strike and dip orientations in order to analyze the spatial heterogeneity associated with channel and floodplain facies at inter-channel-belt scales.

In our machine learning technique, we undertook three facies classification: Sand (reservoir rock), mud (cap rock) and coal (source rock). Out of the twelve logs, eight (W1-8) are upstream and remaining four (W9-12) are downstream locations. Two prediction experiments were conducted to assess directional variabilities. The first prediction performed for the along-the-strike logs; good predictability (>85% accuracy) is observed in true vs. predicted calibration of logs W9, W10, W11, respectively. Such high accuracy provides a quantitative framework reflecting the continuation of lithofacies in along-strike orientation. However, W12 prediction was found to be poor (~35%) in along-strike analysis, reflecting increased inter-channel-belt-scale uncertainties. The second prediction conducted for the downstream analysis of logs using data of upstream logs; herein, the predicted logs (W9, W10 and W11) showed good accuracy (60-70%); in contrast, downstream prediction of W12 showed poor accuracy (~35%) again.

Prior studies [e.g., 2] have characterized the range of sedimentologic and stratigraphic variabilities conditioned in this fluvial unconventional (tight gas) reservoir analog. Variabilities such as fluvial styles (e.g., meandering river pattern) and sandbody continuity problems have been prior interpreted for this studied dataset. Collectively, our machine-learning-based predictions yielded a quantitative framework (high vs. low accuracy) in assessment of such variabilities at inter-channel-belt scale. Therefore, this study demonstrates the utility of machine-learning analysis for additional and independent lines of result towards improved and integrated analysis of this fluvial reservoir analogue.

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Hydrocode simulation of Lonar impact event: insights into brittle deformation and formation of simple craters in basalt

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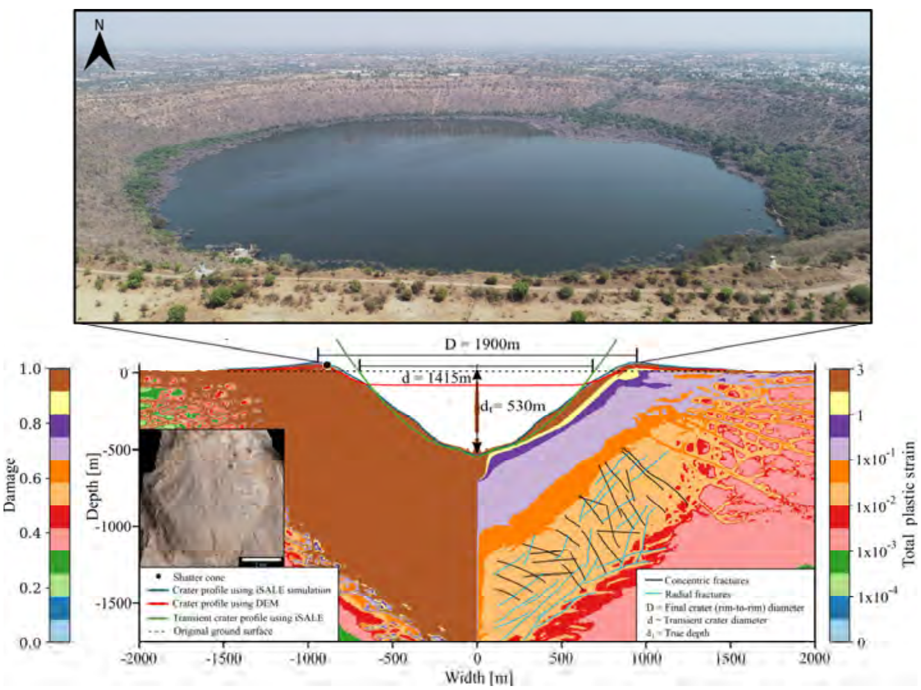
The Lonar crater is one of the few well-preserved impact craters on Earth and provides an important analogue for impact processes in basaltic target. We model the Lonar impact event using iSALE-2D simulations incorporating ANEOS basalt–dunite equations of state, rock strength, and resolution test to determine the transient crater dimensions, shock pressure, strain distribution, and fracture formation, bridging numerical simulations with field observations. The best-fit model produces a transient cavity 1415 m in diameter and 530 m deep at ~5 s after impact, evolving into a final crater ~1.90 km in diameter. Peak shock pressures of ~10 GPa and temperatures of ~1000 K occur at the crater floor, while pressures of 2–3 GPa at the crater wall. The simulation tracks the progressive formation of near-surface tensile fractures followed by radial and concentric fractures, accompanied by zones of high plastic strain near the crater floor. By linking the modeled deformation fields with field-documented fracture geometries, this study provides new constraints on the mechanical and thermal evolution of Lonar-scale impact craters in basaltic targets. Modeled pressure conditions at the crater wall agree with the field occurrence of a shatter cone. Comparison with empirical scaling relations and multi-resolution tests demonstrates that the crater dimensions, shock field, and fracture architecture are robust and converge at resolutions of CPPR ≥ 20. These results refine constraints on the formation conditions of the Lonar crater and provide a validated framework for interpreting impact cratering in basaltic terrains on Earth and other planetary bodies.



Magnesium Isotopic Fractionation in Magnesio and Fero-Carbonatites

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Carbonatites are unique magmatic rocks with more than 50% modal carbonate minerals. They are produced by low degree (<1%) partial melting of CO_2 rich mantle peridotite followed by fractional crystallization and carbonate-silicate liquid immiscibility. Magnesio- carbonatite melts are considered direct mantle derivatives, while ferro-carbonatites are primarily formed during the later stage of carbonatite magma evolution. Therefore, an association of magnesio- and ferro-carbonatites from a complex will provide origin and evolutionary history of carbonatite magma.

We report major element concentrations and $\delta^{26}Mg_{DSM-3}$ values four magnesio and four ferro-carbonatites from the ~1460 Ma old Newania carbonatite complex of India. These carbonatites display a wide range in MgO (0.80- 14 wt.%), CaO (25- 42 wt.%), and FeO (11-17 wt.%). The $\delta^{26}Mg_{DSM-3}$ values of magnesio- carbonatites display constricted variability (-0.35 to -0.41‰), by contrast, ferro carbonatites display lower and wider range in $\delta^{26}Mg_{DSM-3}$ values (-1.71 to –2.26‰) **(Fig. 1)**. A strong positive correlation is observed between the $\delta^{26}Mg_{DSM-3}$ values of all carbonatites and their MgO concentrations, MgO/CaO and MgO/FeO ratios. Carbonatites were leached with dilute acid, and the leachates were further used for their Mg isotopic ratio measurements. Leachates (essentially carbonates) of these carbonatites also display strong positive correlation with their MgO/CaO and MgO/FeO ratios. These findings suggest that the $\delta^{26}Mg_{DSM-3}$ values of magnesio-carbonatite samples preserve their source signature, while those of ferro-carbonatites are perhaps influenced by the fractional crystallization process.

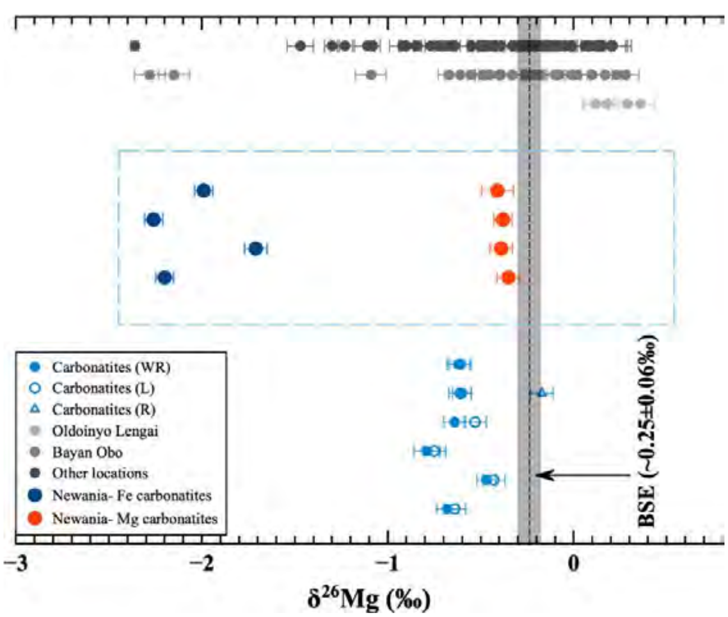

Figure 1. The $\delta^{26}Mg$ values of Newania and global carbonatites from other locations [1]

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Integrated Spatio-Temporal-Depth Seismicity and b-Value Variability in the Eastern Himalaya-Indo-Burma Transition Zone (1986-2025)

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The Eastern Himalaya–Indo-Burma transition zone is a tectonically complex region governed by plate convergence, oblique subduction, and distributed faulting, resulting in significant seismic hazard. Previous studies have primarily examined spatial or temporal variations of seismicity parameters independently, often treating magnitude–frequency distribution, clustering behavior, and hazard assessment separately. However, an integrated framework that simultaneously addresses spatio-temporal-depth-dependent variability with statistical validation and hazard implications for the 1986–2025 instrumental period remains limited. This study addresses this gap by developing a unified analysis of seismicity and b-value variability in the Eastern Himalaya–Indo-Burma transition zone.

A homogenized moment magnitude (Mw) catalog (1986–2025) from the International Seismological Centre (ISC) was analyzed. Magnitude of completeness (Mc) was determined using maximum curvature, goodness-of-fit testing, bootstrap resampling, and Stepp (1972) analysis. Following magnitude-dependent Gardner–Knopoff declustering, Gutenberg–Richter b-values were estimated using the maximum likelihood method. Spatial variability was examined using a fixed grid (0.5° × 0.5°) and adaptive nearest-neighbor mapping, while temporal evolution was evaluated through moving-window analysis supported by Z-test and Kolmogorov–Smirnov validation. Fractal dimension (D_2), recurrence modeling, and extreme value statistical assessment were also explored to characterize seismic clustering and constrain regional maximum magnitude potential. The results reveal statistically significant low b-value anomalies along major fault segments, systematic depth-dependent variation across crustal levels, and temporal fluctuations associated with moderate seismic activity. By integrating spatio-temporal-depth variability, clustering metrics, and hazard modeling within a single statistical framework, this study provides improved constraints on stress heterogeneity and regional seismic hazard assessment in the Eastern Himalaya–Indo-Burma transition zone.

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Spatiotemporal Dynamics and Risk Assessment of Gya Glacier-Lake System in Trans-Himalayan region Ladakh (2015–2025)

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The increased glacier melting across the Himalayan region leads to the formation of new glacial lakes and the expansion of existing ones, particularly after the mid-20th century. These high-altitude glacial lakes pose a serious threat to the downstream communities and infrastructure [3], as evidenced by the events, including the 2013 Kedarnath tragedy & 2023 South Lhonak Lake outburst flood. A glacial lake outburst flood (GLOF) occurred on 06 August 2014 due to the sudden release of water from a proglacial lake (5400 m a.s.l) on Gya glacier in the Trans-Himalayan region of Ladakh. The GLOF event hits the Gya village with an estimated pre-GLOF volume of 1.49 Mm^3 destroyed bridges, houses, and agricultural fields [1][2]. The Gya glacier-lake system is one of the sole water sources for the village and is increasingly threatened by changing glacier-lake dynamics. This study utilizes multitemporal & multispectral high-resolution remote sensing data to monitor the spatiotemporal evolution of the Gya glacier-lake system between 2015 & 2025. A hydrodynamic modelling HEC-RAS is used to model a flooding event for hazard assessment & impact on the downstream region. Remote sensing observations reveal that the lake has experienced a substantial expansion after the flood event, reaching its maximum extent of 0.12 km^2, corresponding to the estimated lake volume of 1.74 Mm^3 in 2021, which is comparable to pre GLOF lake volume in 2024. Interestingly, in the year 2025, the lake volume has drained more water than in the 2014 GLOF event without any GLOF event. The volume drained in 2025 is due to a subsurface drainage channel, which is evident from field observation data, suggesting unstable buried ice moraine dam conditions. Furthermore, the glacier has experienced significant ice loss shortly after 2020 by a major calving event, resulting in a glacier retreat of up to 50m & total snout area loss of 0.011 km^2 within three years. Further, the HEC-RAS flood model shows the area of inundation at the Gya village under the simulated outburst flood scenarios which is evident from the field observations. Therefore, this study is essential for future planning and risk reduction by the development of disaster-resilient infrastructure in the lake environment and mitigating the potential hazards for downstream communities.

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Meteoroid Orbital Path Prediction Using Thermoluminescence

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Meteorites that contain signatures of the primordial solar system revolve around the Sun in an elliptical orbit for millions of years before falling on the Earth's surface. To understand the spatial distribution of meteorites in space, their thermal histories and to assess their impact risks, many space agencies monitor near-Earth objects (NEOs) to calculate their orbital paths through sky monitoring, which faces significant hurdles, including high costs for specialised cameras, massive data storage requirements, and limited sensitivity to precise timing. Exploring the thermoluminescence (TL) of meteorites, Melcher (1981) showed, for the first time, that natural TL, particularly the low-temperature TL peak (LT), could be used to constrain the perihelion distance using a simplistic kinetic model with many other assumptions [1]. Recent advances in a more accurate kinetic model of TL in Earth's rocks and its potential to estimate small temperature fluctuations at Earth's surface [2] rekindled our interest in applying these state-of-the-art techniques to planetary samples. Natural TL in meteorites is in equilibrium due to Galactic Cosmic Ray (GCR) radiation-induced growth and loss of the TL signal, driven by ambient temperature (orbital path) and athermal decay. Assuming a GCR dose rate constant over time, particularly for the LT signal, which is highly sensitive to ambient temperature, and constraining the athermal loss in the laboratory, we aim to constrain the elliptical orbits through inverse modelling of natural TL data with an accurate kinetic model (General Order Kinetics; GOK), constraining sample-specific kinetic parameters and an appropriate inversion strategy. We performed TL measurements of five meteorite samples, Dhajala, Kendrapara, Kopargaon, Ararki, and Bansur, at BSIP, Lucknow. First-order analysis showed that they might have significantly different orbits. First, we constrained all the kinetic parameters for all samples. We then applied forward modelling and observed that the LT peak (TL signals in the 240-260°C temperature range) is sensitive to slight variations in orbits. The inverse modelling work is ongoing, and complete results will be reported in the presentation.

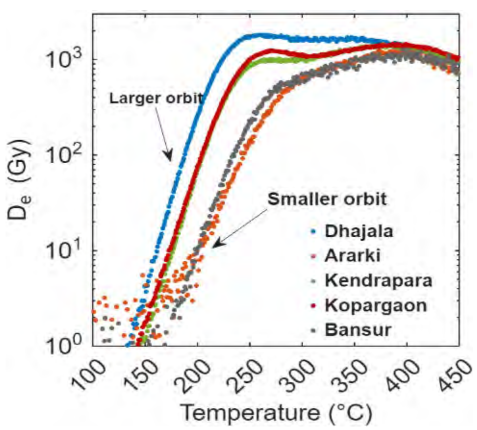

Fig.1: Equivalent dose (estimated using Melcher's approach) as a function of glow curve temperature

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Sediment Dynamics in a High-Mountain Himalayan Catchment Using a Functional Geomorphic Framework: Upper Bhagirathi Basin, Uttarakhand

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High-altitude Himalayan catchments are characterised by extreme relief, active tectonics, and frequent hydro-meteorological extremes, leading to intense sediment production and complex sediment routing [1]. Conventional flood and erosion assessments primarily rely on static physiographic indicators and often fail to capture the functional role of geomorphic units in regulating sediment transfer. This study develops a process-based functional geomorphic framework to characterise sediment dynamics in the upper Bhagirathi basin by explicitly linking geomorphic organisation with sediment production, transfer, and storage processes.

The methodology adopts a hierarchical geomorphometric classification to delineate the basin into functional geomorphic units (GUs) based on integrated terrain attributes representing relief structure, surface roughness, and slope. These units are interpreted in terms of dominant geomorphic processes using morphometric indicators reflecting landscape maturity, erosional efficiency, and energy conditions. To evaluate basin-scale sediment transfer, a sediment connectivity framework is implemented, incorporating terrain impedance and transport potential to assess functional linkages between hillslopes and the channel network, enabling differentiation between sediment source areas, transfer corridors, and potential storage domains [2].

Preliminary results indicate that highly rugged and steep geomorphic units exhibit consistently high sediment connectivity, identifying them as key sediment delivery hotspots. In contrast, several units with high erosional potential display relatively low connectivity, suggesting their role as zones of internal sediment redistribution or transient storage rather than effective contributors to downstream sediment flux [3]. Ongoing work focuses on integrating event-scale hydrological forcing and landslide information to refine process attribution within geomorphic units and to assess the sensitivity of sediment connectivity under extreme rainfall scenarios, providing a robust basis for sediment-induced flood hazard assessment in tectonically active Himalayan basins.

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Sandbody-scale Heterogeneity and Flow Diagnostics of a Fluvial Reservoir Analog Using Rapid Reservoir Modelling

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Fluvial reservoirs exhibit significant facies- to sandbody-scale heterogeneities that strongly control fluid flow and reservoir performance. Reliable quantification of these heterogeneities is essential for reservoir characterization and subsurface CO_2 storage evaluation. This study presents an integrated geological modeling and flow diagnostics workflow using Rapid Reservoir Modeling (*RRM*) applied to a fluvial tight-gas unconventional reservoir analog [1].

Field data were collected along strike and dip using GPS measurements and high-resolution photomosaics. Six lithofacies were identified and incorporated into a three-dimensional (3D) model covering 1.5 km × 200 m × 90 m extent. Stratigraphic surfaces and facies bodies were digitized using the sketch-based interface of *RRM* [2,3].

Heterogeneity was quantified through vertical (Y-axis) and horizontal (Z-axis) slicing at the length-scale of the studied dataset. Fifteen vertical slices (100 m spacing) were used to calculate net sand thickness and floodplain fines across three stratigraphic intervals. Thirty horizontal slices (3 m spacing) were analyzed to determine sand vs. mud proportions and statistical trends. Study findings reveal that right-half of the dataset is relatively sand-poor (values consistently below the dataset mean). Moreover, in vertical evaluation, it was found that the two upper intervals generally contain net-sand proportions above average. In terms of sandbody geometry and stacking styles, studied dataset is interpreted to manifest distinct reservoir prototypes (layer cake, jigsaw, and labyrinth, etc.). Flow diagnostics were performed analogously to evaluate well-sandbody connectivity and reservoir drainage attributes. Outcomes suggest that dissimilar well-layout should be tailored for optimal exploitation of different reservoir compartments in this fluvial tight-gas unconventional reservoir analog. Overall, this study demonstrates that Rapid Reservoir Modeling provides an efficient framework for rapid geological prototyping with use in fluvial reservoir analysis.

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Elastic Monitoring CO_2 storage and leakage: Insights from a Synthetic Seismic Imaging

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Geological sequestration of CO_2 and early detection of potential leakage pathways beneath the surface are crucial for ensuring the long-term integrity of its storage. In this context, seismic imaging techniques play an essential role by providing high-resolution subsurface characterization of the elastic properties and by monitoring time-lapse changes in velocity and density induced by CO_2 injection. Here, we present a synthetic modelling and imaging workflow based on 2D time-domain elastic multiscale Full Waveform Inversion (FWI) to obtain a reliable, high-resolution subsurface velocity-depth model for CO_2 storage and monitoring leakage pathways. The FWI workflow uses the entire recorded seismic waveform data and an initial subsurface velocity-depth model, which is refined iteratively in a least-squares sense to minimize the misfit between the observed and synthetic waveforms, thereby yielding an inverted velocity model most representative of the subsurface. We use two synthetic velocity-depth models that mimic a marine acquisition scenario, with variations in the elastic properties (V_p, V_s, and ρ) over a CO_2 reservoir, where changes induced by CO_2 injection or potential leakage affect the key elastic parameters that function as diagnostic properties. The subsurface velocity and density distribution for the synthetic dataset is known in advance, so the inversion methodology applied to it can help provide confidence in the inverted subsurface velocity-depth models. The FWI workflow is computationally intensive; therefore, we utilize the PARAM SANGANAK facility at IITK, which is available under the National Supercomputing Mission, Government of India, to reduce the computational time required for forward modeling and initial model update, thereby obtaining a high-resolution velocity model of the subsurface. The inversion results show that the recovered velocity model using the FWI framework closely matches the true subsurface velocity model, validating the potential of FWI to resolve fine-scale subsurface features and to monitor, in real time, the long-term feasibility of CO2 storage and the risks of leakage beneath the surface.

Keywords: Sequestration, Elastic, Velocity, Synthetic, PARAM Sanganak

Flow direction and internal structure of Seaward Dipping Reflectors along the Mid-Norwegian Volcanic Margin

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The Mid-Norwegian margin is a volcanic rifted margin formed during the initial stages of the North Atlantic opening in the early Paleogene. We have studied the magnetic fabrics of the basalts comprising the seaward-dipping reflectors (SDRs) along the margin. Azimuthally unoriented samples were collected from three holes located along the feeder edge of the thick SDR succession. Petrographic and rock magnetic analysis reveal PSD Ti-magnetite as the main magnetic carrier. NRM preserved in basalt is used to reorient specimens into their in-situ orientation, allowing the interpretation of the magnetic fabrics in a geographic coordinate system. The reliability of reorientation is supported by the systematic alignment of magnetic fabrics with independently observed flow indicators.

The AMS in SDR basalt may be owed to the distribution anisotropy produced by subhedral/euhedral Ti-magnetite grains dispersed within an early-formed silicate framework. The flow fabrics are internally zoned with oppositely dipping foliations in the top and basal parts of individual lava lobes. The opposing pair of foliations is related to flow-induced shear strain within a lobe, once a solid or semi-solid upper crust has developed in the distal parts, away from the source. The basal imbrication of the magnetic foliation is used to deduce lava flow direction, which indicates landward-directed lava flows towards the south. AMS-derived flow fabrics are consistent with geophysical evidence showing subvertical dyke swarms at the seaward termination of the inner SDR, which likely served as feeders to the thick volcanic succession.

Rock Surface Burial Dating of Cobbles to constrain Late Quaternary Megafloods in Upper Alakananda Valley

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Megafloods are high-discharge events, capable of valley-scale to catchment-scale landscape alteration. Paleo-megaflood events in the Himalayas have been constrained earlier using optical dating of slack water deposits and massive sand deposits, and 14C dating of organic remains especially in the downstream valleys. However, upper constricted valley witnesses' major impact due to higher hydraulic thresholds of flood. Fine sediments and organic fragments in such environment are poorly preserved whereas coarser clasts like cobbles are abundant, typically preserved as thick meter scale units at higher elevations above the riverbed. We adopt a novel technique, Rock Surface Burial Dating (RSBD), improve the methodology and apply in Indian Himalaya for the first time. Luminescence Depth Profile (LDP) in cobbles, initially at saturation, evolves according to their subsequent exposure and burial history as illustrated in Fig. We apply RSBD of cobbles (~ 50 mm diameter), to constrain the timing of a flash flood event in the Saraswati valley of Upper Alakananda catchment. Precise experimental measurement, identification of well bleached slices through modelling of LDP data using General Order Kinetics and improved dose rate estimation in heterogeneous environment leads to successful results. Within a continuous aggregational phase of ~17 to 7 kyr (30 m deposit), a hyper-concentrated flood deposit (~5 m thick cobble deposit) is constrained around 12.6 ± 0.8 kyr using this new technique, corroborated by radiocarbon age and luminescence ages from fine sediments. The event dates to the Bølling–Allerød warm phase.

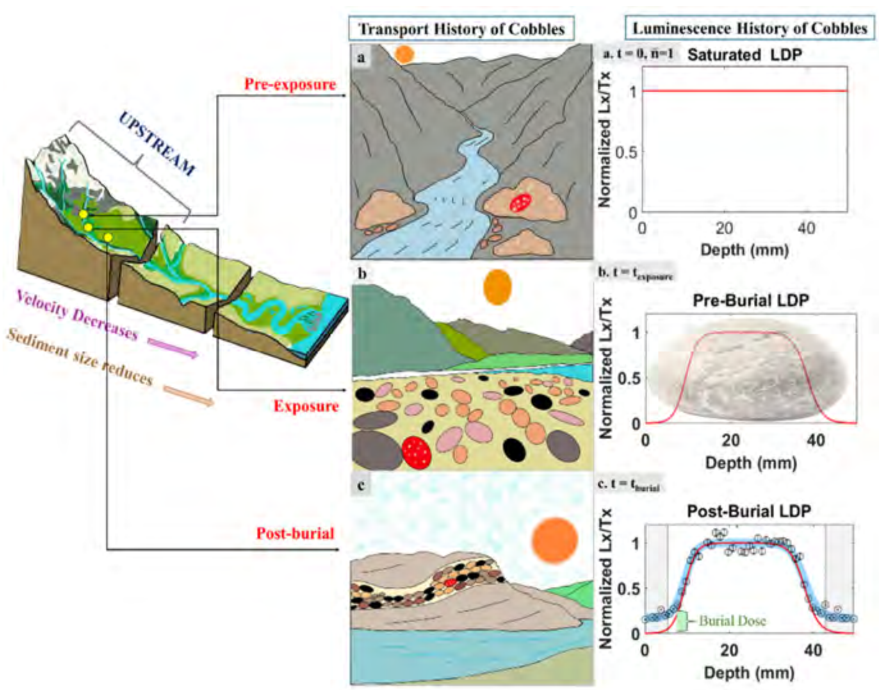

Figure 1:

Transport and Luminescence histories of cobble (in red), where; (a) cobble as part of the bed rock has luminescence signal at saturation (b) Face of the cobble exposed to sunlight causes decay of luminescence signal, and (c) megaflood driven deposition and burial of bleached cobble allow growth of luminescence signal creating an offset in first few mm of LDP.

Radiogenic Thermal Buffering by Thorium-Bearing Granitoids During Post-Peak Evolution of Granulite-Facies Terranes: Insights from the Central Indian Tectonic Zone

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Granulite-facies metamorphism of the continental lower crust reflects not only peak high temperatures but also prolonged residence at elevated thermal conditions, essential for mineral equilibration and preservation of high-grade assemblages. In the Central Indian Tectonic Zone, peak temperatures are widely attributed to externally driven tectono-thermal processes such as crustal thickening, magmatic underplating, and mantle heat input. However, controls on post-peak thermal evolution remain poorly constrained.

This study evaluates the role of thorium-bearing granitoids in modifying crustal cooling histories. Whole-rock trace element data reveal significant heterogeneity in thorium concentrations, with some granitoids showing enrichment relative to surrounding lithologies and average lower crustal values. Although radiogenic heat production from thorium is insufficient to generate granulite-facies conditions independently, localized Th enrichment represents zones of enhanced internal heat production. Once high temperatures are established by tectonic processes, these Th-rich domains may retard isotherm relaxation during cooling and exhumation, contributing to prolonged high-temperature residence of granulite-facies assemblages. The results highlight the importance of heterogeneous radiogenic heat distribution in shaping crustal thermal evolution and suggest that thorium systematics constrain the duration, rather than the origin, of high-grade metamorphism.

Keywords: isotherm relaxation, thermal buffering, thorium enrichment,

Selenium and Tellurium distribution in Chalcopyrite

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Selenium (Se) and Tellurium (Te) are widely used in high-tech industries, with the growing global importance of green energy and low-carbon technologies, the demand for these elements is steadily increasing. However, due to their limited natural distribution, most of the global supply of Se and Te is recovered as secondary by-products from copper concentrates. Chalcopyrite ($CuFeS_2$), the most abundant copper-bearing sulfide mineral, often incorporates trace amounts of elements like Se and Te within its crystal structure, making it an economically significant source of these elements [1]. Due to the complex distribution of Se and Te within chalcopyrite, accurately estimating their resource potential and applying extraction technologies to recover them as by-products is challenging. It also examines and compares the distribution patterns of these elements in the MCD chalcopyrite with those found in chalcopyrite from different ore-genetic types to gain insight into the distribution of Se and Te in chalcopyrite. Chalcopyrite samples from various parts of the Malanjkhand Copper Deposit (MCD) underground mine were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) to quantify Se and Te concentrations. Results show that Se is more abundant than Te in these ores, with Se concentrations ranging from 34 to 113 ppm (average 86 ppm) and Te ranging from 1 to 2 ppm (average 1 ppm). These values are comparatively lower than those observed in Phanerozoic porphyry copper deposits, where the average concentrations of Se and Te are 170 ppm and 1.8 ppm, respectively. Principal component analysis (PCA) Positive loading of Se–Ag–Hg and Te show distinct covariation patterns, likely reflecting their occurrence as nanoscale or complex coupled substitution mechanisms and PCA highlights systematic covariation among elements with similar lattice compatibility and incorporation mechanisms [2]. Selenium geochemistry in pyrite has been used as a geothermometric tool in hydrothermal and magmatic environments [3], and a similar approach can be applied to chalcopyrite, where trace element data can reveal temperature conditions of mineralization. The findings of the present study highlight the potential of MCD as supplementary source of critical elements such as Se and, to a lesser extent of Te, while also providing valuable geochemical insights into ore-forming processes. As demand continues to rise, optimizing recovery from existing deposits such as MCD becomes increasingly important for securing future supplies.

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Understanding slip rate variation and the role of the Karakoram Fault in the Himalayan/Tibetan Orogeny

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To understand the deformation associated with the Himalayan–Tibetan orogeny, it is essential to examine the role of the Karakoram Fault (KF), a ~1200 km-long, NNW-SSE-striking intracontinental dextral fault that accommodates this deformation. A critical challenge lies in resolving the variation between its measured long-term and short-term slip rates. This study focuses on the Pangong strand of the KF in the Pangong–Chaxikang segment, on the western side of Pangong Lake in eastern Ladakh. We present a tectonic–geomorphic map showing three offset moraine stages (M1, M2, and M3) on the eastern side of the Pangong Range. The offset moraines M1, M2, and M3, displaced by ~55 m, ~372 m, and ~475 m, respectively, are interpreted to have formed during three major glacial advance stages in the region—Dikshit-1, Dikshit-2, and Dikshit-3 (~45 ka, ~81 ka, and ~144 ka, respectively) [1] —indicating slip rates in the range of 1.25–4.6 mm/yr. The absence of visible offset geomorphic features along the Tangste strand indicates that deformation has mainly accumulated along the Pangong strand, at least since the late Quaternary. Moreover, a 4 m offset terrace on another strand in the same section, with a depositional age of 7.04 ± 0.43 ka determined by OSL dating, yields a slip rate of ~0.53–0.61 mm/yr.

To understand temporal variations in slip-rate trends across the Karakoram Fault, we conducted a temporal analysis of all published slip rates from the Miocene to the present. Our results show a decreasing trend in slip rate across the KF, from higher Miocene rates to lower Quaternary[2] and geodetic rates. Furthermore, spatial analysis of slip rates across the six segments of the KF indicates that each segment exhibits distinct slip-rate accumulation. Thus, the segmental behaviour and decreasing slip-rate trends support the "Continuous Deformation Model," suggesting that the KF plays a more limited role in accommodating deformation across the Himalayan–Tibetan orogeny. It exhibits more transient behaviour but continues to accumulate slip, which means its seismic potential should not be underestimated [3].

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Investigating Frictional Properties in NW Himalayan Faults: High Pressure-Temperature Experiments

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Seismic behaviour along active plate-boundary thrust systems is fundamentally governed by the frictional properties of fault gouges, commonly described using rate-and-state friction (RSF) formulations. Frictional strength and stability are known to depend on mineralogy, effective normal stress, temperature, and pore-fluid conditions, yet the Himalayan orogen, one of the most seismically hazardous continental collision zones. lacks controlled laboratory measurements on natural Himalayan fault materials. This knowledge gap limits our ability to evaluate whether major structures such as the Main Frontal Thrust (MFT), and its associated splay faults preferentially host earthquake nucleation or accommodate stable creep.

Here we present new laboratory measurements of frictional strength and RSF parameters obtained from natural gouge sampled from the Paonta Thrust within the MFT system. Experiments were performed using a servo-controlled oil-medium triaxial deformation apparatus installed at IIT Kanpur. Protocols were first calibrated using synthetic quartz gouge, followed by velocity-stepping tests on natural gouges at confining pressures of 25–175 MPa, temperatures up to 125 °C, and sliding velocities of 1–10 μm s^{-1}. Shear strength increases systematically with pressure (~10 MPa at 25 MPa to ~60–65 MPa at 175 MPa), whereas increasing temperature reduces peak strength. At room temperature, gouges exhibit velocity-strengthening behaviour ($a-b > 0$) across all pressures, consistent with stable or conditionally stable sliding expected for shallow frontal segments. However, at ≥125 °C, the gouge transitions to velocity-weakening ($a-b < 0$) at higher confining pressures, indicating that combined thermal and burial effects can promote unstable slip.

Our results suggest that shallow Himalayan frontal and splay faults may largely creep or slip stably, while deeper segments approaching the brittle–ductile transition may become seismogenic once temperature–pressure thresholds are exceeded. Our experiments constrained this threshold to be approximately 125°C and 100MPa, which is equivalent to a depth of ~5km. We, therefore, provide the first quantitative frictional constraints on Himalayan thrust gouges and offer a physics-based framework for evaluating earthquake nucleation potential along the MFT system and associated secondary splays that locally control strain partitioning and rupture segmentation.

Numerical Simulation of Fold-and-Thrust Belts (FTBs): Role of the Basal Décollement Angle

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The geometry and kinematics of fold-and-thrust belts (FTBs) mainly depend on the rheological properties and spatial configuration of the basal décollement [1]. While physical sandbox experiments are effective for visualizing thrust-wedge development, numerical simulations [2, 3] provide the spatial and temporal resolution needed to characterize internal stress distribution and progressive strain localization through time. In this study, we use a high-resolution 2D numerical model to examine how the dip angle of the basal décollement influences FTB formation. The model uses a staggered-grid finite difference method along with a Lagrangian Marker-in-Cell (MIC) technique to solve the coupled Stokes, continuity, and heat transfer equations for an incompressible medium.

Our model domain (19 cm × 6 cm) replicates a scaled laboratory sandbox setup, with stratified granular layers (representing brittle sand) over a distinct, weaker basal detachment horizon (representing microbeads). Deformation is driven kinematically by a rigid mobile wall moving at a constant velocity of ~2.5 cm/hour. We implement a Maxwell viscoelastic constitutive law combined with a strain-dependent Mohr-Coulomb yield criterion to reproduce the material behavior. In the model, strain softening occurs through a progressive reduction in cohesion and internal friction angles as deformation accumulates. By varying the dip angle of the basal detachment layer across model runs, we quantify its impact on thrust-ramp spacing, forethrust-backthrust ratios, and the evolution of the wedge's critical taper geometry. This numerical modeling approach provides a framework to bridge scaled analogue experiments and the complex kinematics observed in natural FTBs.

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The SWOT Mission for India: Identifying Drivers of Variability in the Water Surface Elevation Accuracy

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The Surface Water and Ocean Topography (SWOT) mission is the first ever satellite to provide two-dimensional and high-resolution measurements of water surface elevation (WSE) with the help of its Ka-band Radar Interferometer (KaRIn) instrument. SWOT's high-resolution WSE observations are critical for revolutionizing India's water management and disaster preparedness. While several studies to date have confirmed SWOT's superior performance over existing altimetry missions, the accuracy of these measurements varies from site to site. In this study, we present a comprehensive analysis of the major sources of this variability in WSE measurements and their influence on accuracy across 285 gauge stations in 14 river basins in peninsular India. We assess quality flags corresponding to different sources of errors associated with each SWOT measurement and quantify their impact on accuracy and data retention. Our research identifies the exclusion of Flag 19 (degraded geolocation quality) produces the most robust WSE measurements. Furthermore, our analysis of morphological controls reveals that river width is the single most dominant morphological control on SWOT accuracy, surpassing secondary factors such as topographic relief and elevation. We also observe that incorrect delineation of reaches and exposure of the riverbed during the dry season significantly challenges the accuracy of WSE measurements in India. However, it is also important to acknowledge that poor-quality gauge measurements may contribute to the large errors observed over certain reaches. The findings of this study will provide a foundation for precisely identifying the sources of uncertainty and offering insights into the most effective filtering strategies to obtain the most reliable WSE estimates.

Circulation Depths of Meteoric Water in the Himalayas: Controls and Implications for Seismicity

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Coseismic changes in the hydrogeochemistry of hot springs link meteoric water circulation and seismic activity in an uplifting orogen. However, the impact of tectonic structure on meteoric water circulation through the crust and, conversely, meteoric water's influence on seismicity within the Himalayan orogeny remains unknown. In this study, we investigate deep meteoric water circulation and its relationship to regional tectonics and seismic activity by analyzing the stable isotope compositions ($^{18}O/^{16}O$ and $^{2}H/^{1}H$, expressed as $\delta^{18}O$ and δD) and water chemistry of hot springs located across three major tectonic boundaries. We integrate geothermometry-derived reservoir temperatures with the spatial distribution and hypocentral depths of earthquakes to investigate the dynamics of deep meteoric water circulation in the Himalayas. We find that the maximum depth of the meteoric water circulation is ~3-5 km, which is shallower than earthquake hypocenter depths (5-25 km). The dataset reveals that meteoric water circulation is deeper in extensional settings or in the presence of an additional heat source. Although meteoric water circulation is typically shallower in compressional settings, it can still be prevalent when thrust faults are tectonically active. We conclude that deep meteoric water circulation in the Himalayas generally does not reach earthquake hypocentral depths but is strongly controlled by the subsurface tectonic structure and fault activity.

Evolving Boundaries: Multi-Decadal Shoreline Evolution and Spatial Variability of Chilika Lagoon (1972–2025) using geospatial data

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Coastal lagoons are geomorphically dynamic systems where shoreline configuration reflects interactions among hydrodynamic forces, sediment redistribution, geomorphic setting, marine processes, and anthropogenic interventions. Asia's largest brackish water wetland, Chilika Lagoon, a Ramsar site along India's east coast, has undergone significant morphodynamic reorganisation over recent decades. This study examines the spatial patterns and long-term trajectory of these changes to evaluate lagoon stability and associated landscape transformations [1]. A geospatial framework using Landsat and Sentinel imagery (1972–2025) was implemented in Google Earth Engine. Shorelines were delineated using the Automated Water Extraction Index (AWEI) with Otsu thresholding to ensure inter-sensor consistency [2]. The lagoon boundary and adjacent coastline were subdivided into eight sectors. Shoreline change metrics were computed using DSAS v5.1 at 40 m transect spacing, and geomorphic hotspots were identified through percentile-based thresholds of erosion and accretion [3]. LULC change analysis (1972–2024) quantified landscape transformation and its geomorphic implications. Results indicate strong spatial heterogeneity with three dominant geomorphic hotspots. Northern and north-eastern sectors show persistent lakeward shifts, with Sector 2 recording the highest advance (>9,000 m; ~150 m yr^{-1}), marking a major accretion hotspot. Western sectors (S3–S6) exhibit moderate progradation and relative stability, influenced by Eastern Ghats lithology and shoreline stabilisation structures, though cyclonic events periodically modify local configurations. In contrast, Sectors 1 and 7 display localised retreat (>2,000 m; ~40 m yr^{-1}), while coastal Sector 8 shows net erosion with limited downdrift accretion near active inlets. LULC results reveal substantial conversion of open water to mudflats, aquaculture, and agriculture, particularly in northern sectors, reflecting progressive morphological adjustment and anthropogenic modification. Overall, Chilika Lagoon exhibits sectoral asymmetry in shoreline evolution, dominated by lakeward shifts in the north and relatively stable to accretional trends elsewhere. The findings indicate an emerging imbalance between fluvial sedimentation and marine reworking, altering lagoon connectivity, salinity gradients, and habitat distribution. Sediment-budget-aware, connectivity-focused management is therefore essential to enhance long-term resilience under increasing climatic and anthropogenic pressures.

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High resolution Seismic Imaging of Gas Hydrates deposits in Offshore Krishna-Godavari Basin

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The Krishna–Godavari (KG) offshore basin along India's eastern continental margin is a major pericratonic rift basin and an important province for gas hydrate investigations. In this study, we analyze a 2D seismic profile from the KG-DWN-98/2 block of the KG Basin, acquired by Oil and Natural Gas Corporation of India (ONGC), covering the continental shelf–slope transition where water depths increase from ~100 m to nearly 1.3 km. The dataset consists of 861 shots, each containing 955 traces, with trace spacing of 6.25 m, and a CDP interval of 3.125 m. The primary objective is to map the Bottom Simulating Reflector (BSR), whose character and continuity provide critical insights into gas hydrate distribution, subsurface fluid migration, and associated geohazards. The seismic data were processed using a standard workflow including geometry merging, band-pass and FK filtering, top muting, WEMA (applied on shot gathers), CDP sorting, velocity analysis, NMO correction, Radon filtering, stacking, and post-stack time migration. The processed section reveals a complex seafloor morphology and multiple growth faults, indicating rapid sedimentation and structurally controlled fluid pathways. The presence of structural complexity suggests that Prestack Depth Migration (PSDM) could further enhance subsurface imaging. A strong BSR is identified by its polarity reversal relative to the seafloor reflection and its cross-cutting relationship with underlying strata. Future work will involve Constrained Velocity Inversion (CVI) to obtain a smooth interval velocity model, followed by Full Waveform Inversion (FWI) for high-resolution subsurface characterization. These advanced approaches are expected to improve understanding of the gas hydrate system, identify potential overpressure zones, delineate slope-failure-prone regions, and support geohazard assessment along the continental slope of the basin.

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Keywords: BSR, Seismic, FWI, geohazards, PSDM

Petrogenetic Diversity of Bundelkhand Granitoids: Insights from Major Trace Element Systematics

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The Bundelkhand Craton represents one of the major Archean cratonic blocks of the Indian Shield and preserves extensive granitoid magmatism ranging from Paleoarchean to Neoarchean times. Granitoids form the fundamental framework of continental crust, yet the petrogenetic evolution of Bundelkhand granitoids remains comparatively underexplored despite their geological significance. The proposed research aims to investigate the petrogenetic diversity of Bundelkhand granitoids through integrated major and trace element systematics to better understand Archean crustal evolution. The study will systematically characterize TTG (Tonalite-Trondhjemite-Granodiorite), transitional TTG, and potassic granitoid suites in order to constrain magma sources, melting regimes, and tectonic settings .Competing geodynamic models, including subduction related slab melting and intracrustal reworking, will be evaluated using geochemical evidence. Major element geochemistry will be utilized to interpret magma differentiation trends, calcalkaline affinity and pressure-temperature conditions of crystallization. Trace and rare earth element systematics will be employed to identify source mineralogy, residual phases and depth of partial melting. Geochemical discrimination diagrams and elemental ratios will be used to reconstruct tectonic environments and magmatic evolution pathways. The expected outcomes of this research include establishing a comprehensive geochemical framework for Bundelkhand granitoids, clarifying their petrogenetic history, and contributing to broader models of Archean continental crust formation and stabilization.

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Volcanic architecture of the Rajmahal Traps continental flood basalts, India and its tectonic implications

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The Rajmahal Traps of eastern India represent an Early Cretaceous continental flood basalt province linked to Kerguelen mantle plume activity during the breakup of Gondwana. Although their geochemical and geochronological characteristics are well constrained, their volcanological architecture and emplacement mechanisms remain less understood. This study combines detailed field-based stratigraphic observations with petrographic analysis to elucidate lava flow morphology, cooling regimes, and eruptive evolution of Rajmahal volcanic succession, and compare those features with other Phanerozoic large igneous provinces (LIPs) worldwide.

The Rajmahal volcanic succession is dominated by pahoehoe sheet flows displaying variable columnar jointing patterns. Multi-tiered flows with well-developed colonnade- entablature structures are predominantly observed in the northern part, suggesting emplacement of thick, ponded lava flows in water-rich environments, where episodic interaction with surface water resulted in rapid cooling of lava [1, 2]. By contrast, the southern sector is characterized by simpler flow units composed primarily of irregular colonnades, suggesting subaerial emplacement under relatively dry conditions and conductive cooling [1, 2]. Petrographic differences between colonnade and entablature zones further support these interpretations.

The north-south transition in flow architecture highlights the significant role of paleoenvironment, surface-water availability, and lava ponding in controlling flood basalt emplacement. The Rajmahal Traps thus provide an important volcanological analogue for other LIPs, including the Deccan, Columbia River Basalt Group (CRBG), and Paraná-Etendeka provinces, demonstrating comparable high-volume effusion dynamics and environmental controls on lava emplacement.

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Arc-Root Burial and Granulite-Facies Equilibration in the Western Nilgiri Block: Phase Equilibria Constraints on Neoarchean Lower Crust

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The Western Nilgiri Block of the Southern Granulite Terrane (SGT) exposes Neoarchean lower continental crust that preserves both arc-related magmatic signatures and granulite-facies metamorphism. Establishing the link between these two records is necessary to understand how arc crust was buried to lower crustal depths and subsequently stabilized. Whole-rock geochemistry of the mafic granulites indicates tholeiitic to calc-alkaline affinities, enrichment in large ion lithophile elements, and depletion in high field strength elements. These features are consistent with derivation from a subduction-modified mantle source and emplacement in a convergent margin setting [1]. The protoliths are therefore interpreted as arc-derived mafic magmas that formed part of a growing arc-root lower crust. The metamorphic assemblages record the conditions attained during burial of this arc crust. Phase equilibria modelling was carried out in the $Na_2O–CaO–K_2O–FeO–MgO–Al_2O_3–SiO_2–H_2O–TiO_2$ system using Perple_X [2], with bulk compositions constrained by modal data and electron probe microanalysis. The equilibrium assemblage Grt + Opx + Cpx + Pl ± Amp constrains peak conditions to *c.* 9–11 kbar and 800–950 °C. These pressures correspond to depths of *c.* 30–35 km, indicating equilibration within the mid- to lower crust under subsolidus granulite-facies conditions. Mineral zoning and reaction textures record subsequent cooling. Decreasing X_{Mg} in Grt rims and the development of Pl–Amp intergrowths indicate retrogression at *c.* 7–8 kbar and 700–750 °C. These conditions reflect decompression accompanied by cooling and fluid-assisted re-equilibration. The resulting pressure–temperature path is clockwise and characterized by progressive burial and heating followed by moderate decompression and cooling. Together, the arc-related geochemical signature and the thermodynamically constrained pressure–temperature evolution indicate that mafic arc crust was thickened and equilibrated at lower crustal depths under granulite-facies conditions. The moderate-pressure burial, subsolidus equilibration, and subsequent cooling are consistent with stabilization of a thickened arc root during Neoarchean continental assembly within the Southern Granulite Terrane [3]. The Western Nilgiri Block therefore represents a preserved segment of arc-derived lower crust that records crustal thickening and thermal relaxation during regional amalgamation.

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Integrating UAV-Derived Thermal and Multispectral datasets with Soil Texture for Field-Scale assessment of Soil Moisture Dynamics and Crop Water

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Unmanned Aerial Vehicles (UAVs) have emerged as powerful tools for field-scale agricultural monitoring, providing ultra-high spatial resolution and flexible acquisition that outperform conventional satellite systems in detecting crop water stress [1,2]. The synergistic acquisition of thermal and multispectral imagery enables detailed characterization of land surface temperature (LST) dynamics and vegetation condition within heterogeneous agricultural landscapes. This study develops an integrated UAV-based framework combining LST and Normalized Difference Vegetation Index (NDVI) to quantify surface soil moisture variability and crop stress across multiple cropping seasons.

The approach is grounded in the thermodynamic relationship between canopy temperature, vegetation health, and soil water availability, where temperature–vegetation feature space analysis is used to interpret moisture gradients [1]. To enhance spatial realism, soil texture variability is incorporated to account for differences in surface water retention and thermal response, following soil-adjusted vegetation modelling principles [3].Surface soil moisture estimates derived from the integrated framework show strong agreement with in-situ observations ($r > 0.90$), demonstrating the robustness of coupling thermal and vegetation signals [2,3]. Crop stress dynamics are further evaluated using canopy–atmosphere thermal contrasts, capturing short-term physiological responses that complement spatial dryness patterns. Strong agreement between UAV-based and ground-measured temperatures ($R^2 = 0.88$; RMSE ±1.3 K) confirms the radiometric reliability of high-resolution thermal observations [1].By integrating surface temperature dynamics, vegetation response, and soil physical controls within a unified analytical framework, this study advances scalable methodologies for diagnosing surface moisture stress and provides actionable insights for precision irrigation scheduling and sustainable water resource management.

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Beyond Surface Compositional Maps of Lunar Maria

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Basalts cover 17% of the Moon's surface, representing layered volcanic flows of varying age, composition and thickness [1]. On the surface, these flows have previously been treated as laterally homogeneous in composition and mapped as discrete units [2]. However, systematic compositional stratigraphy of the mare units is poorly constrained.

We are investigating the spectral variability within and across selected basalt units in the Serenitatis and Tranquillitatis regions using hyperspectral data from the Chandrayaan-1 Moon Mineralogy Mapper (M^3) (yellow box in fig. 1). Fresh impact craters are used as natural stratigraphic probes, excavating materials from different depths depending on their crater diameter (fig. 2). Crater spectra are extracted and screened from heavily space weathered mature spectra, before statistical analysis.

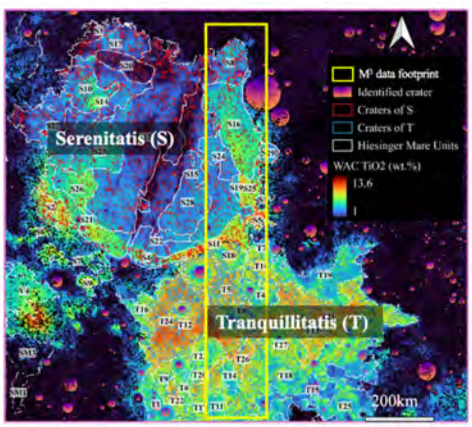

Fig. 1: Study area: Map of TiO_2 abundance + detected craters + basalt units of Serenitatis and Tranquillitatis. The yellow box shows the footprint of M^3 data analysed in this study.

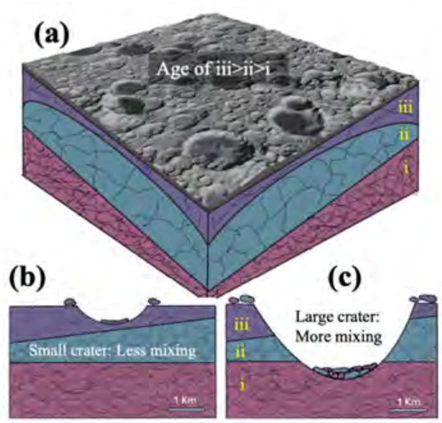

Fig 2: Craters: Natural stratigraphic probe. (a) Layered basalt unit. (b) & (c) crater excavation depth and vertical mixing of mare units of small & large crater.

Our results show significant intra-unit spectral variability, and variation in spectral trends with crater diameter. These observations suggest that mapped mare units show greater lateral and vertical compositional diversity than inferred from previously mapped units.This work shows the importance of crater-based spectral analysis in refining our understanding of lunar basalt stratigraphy.

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Petrogenetic evolution of alkaline silicate rocks of Kamthai complex, India

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The 69 Ma old Kamthai Alkaline Complex of India represents a natural geological museum of a wide range of silica undersaturated rocks including carbonatites and alkaline silicate rocks. Carbonatites of this complex have been extensively studied because of their extremely high rare earth element (REE) concentrations. By contrast, the alkaline silicate rocks of this complex is relatively underexplored in terms of their evolutionary history.

Here we provide insights into the petrogenetic evolution of these alkaline silicate rocks using their major oxide and trace element concentrations. Based on total alkali and silica contents, these rocks have been classified as foidite, phonolite, tephrite-basanite and tephri phonolite. The low Mg# [defined as MgO/(MgO+FeO)] values (2-45) of these rocks suggest their highly differentiated nature. Strong positive correlation between Al_2O_3 and SiO_2 and negative trend between CaO/Al_2O_3 and SiO_2 suggest fractionation of alkali feldspar and nepheline, while a strong positive correlation between CaO and P_2O_5 and a strong negative trend between P_2O_5 and SiO_2 suggest significant apatite fractionation in these rocks. Strong negative trends displayed by SiO_2, and MgO, CaO and FeO concentrations in these rocks suggest removal of pyroxene and diopside from the evolving melts.

Trace element concentration ratios of these rocks suggest the nature of their source composition and tectonic framework. For example, ΔNb >1 [(1.74+log(Nb/Y)-1.92log(Zr/Y)] of these rocks is suggestive of their plume origin. High $Gd/Yb_{(N)}$ (>2) values of most of these rocks suggest their derivation from a garnet bearing mantle peridotite, while their low K/Rb (~320) values indicate phlogopite bearing mantle source. Presence of phlogopite and garnet in the mantle source suggest generation of these magmas from a depth greater than 90 km where both garnet and phlogopite are stable. Further, a carbonate metasomatized mantle source is likely as these rocks display super-chondritic Zr/Hf ratios (42-78).

The state and fate of soil organic matter in alpine ecosystems of the Indian Himalayas

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The Himalayas and the recipients of its natural resources are both under threat from recent climate change, leading to accelerated glacier loss, extended growing seasons, and increased occurrence of extreme rainfall events. Microbial degradation of soil organic matter due to climate warming further converts long-stored organic carbon (OC) into greenhouse gases (GHGs) that can influence the regional carbon budget and future climate feedback. However, soil carbon dynamics in these high-altitude Indian Himalayan ecosystems remain poorly understood. This study investigates soil CO_2 fluxes and biogeochemical characteristics of soil substrates from two distinct climatic regions of the Indian Himalayas across elevations: the cold, arid Ladakh and the warmer, wetter Central Himalayas. Soil CO_2 flux measurements revealed nearly twice the emissions in the Central Himalaya compared to the Ladakh Himalaya, driven by a warmer, wetter climate and denser vegetation cover. The CO_2 fluxes are comparable to those reported from other high-elevation forest and grassland ecosystems. Central Himalayan soils exhibited significantly higher total organic carbon (TOC) content, with deep peat layers indicating substantial carbon storage susceptible to decomposition under continued warming. In contrast, Ladakh soils contain relatively low organic carbon, consistent with limited biomass input and stronger decomposition. Geochemical and biomarker proxies (C/N, CPI, OEP, ACL, bulk $\delta^{13}C$, and nC_{29}-$\delta^{13}C$) suggest that soil organic matter (OM) in both regions is predominantly derived from C3 higher terrestrial plants; however, the Central Himalayas retain less degraded OM and show evidence of vegetation shifts from woody to herbaceous inputs. The carbon isotopic composition of soil-respired CO_2 ($\delta^{13}C$-CO_2) was enriched in ^{13}C relative to the bulk OM, likely driven by microbial metabolic processes and partial contributions from older, deeper carbon sources. Radiocarbon dating indicates mid-to-late Holocene ages for subsurface OM, demonstrating long-term carbon accumulation under historically cooler and wetter conditions. Hydrogen isotope (δ^2H) profiles of n-alkanes reveal a transition toward warmer and/or drier conditions in the late Holocene, consistent with regional paleoclimate records. Together, these findings highlight the vulnerability of deep-seated old carbon mobilization in Himalayan alpine ecosystems to climate warming, with implications for increased GHG emissions from high-mountain landscapes in the future.

Decoding fluid-rock interactions: A Reaction-path modeling approach

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Fluids play a major role in the ongoing evolution of the Earth's crust and lithospheric mantle. However, fluid-mediated mass transfer– including the mobility of traditionally "immobile" REEs and HFSEs, remains poorly understood due to complex nature of fluid-rock interaction (*i.e.*, the chemical reactions and P-T-X conditions of fluids). This limits our understanding of how, where, and when such element redistribution occurs (or can occur) during crustal evolution.

Metasomatic reaction zones (MRZs) formed at the interface of contrasting lithologies provide a rare opportunity to investigate these elusive phenomena. This study integrates EQ3/6 reaction-path modeling, coupled with bulk-rock geochemistry, mineral chemistry, pseudosection modeling, and hydrothermal experiments, to investigate MRZ formation at the boundary between the country rock (pelitic garnet-mica schist) and metamafic dykes (epidote-amphibolite) in the Proterozoic North Singhbhum Mobile Belt, India. The observed sequence in outcrop is dyke–Zone 1 (amphibole-epidote-sodic-plagioclase-quartz-chlorite)–Zone 2 (Zone 1 assemblage minus amphibole)–pelitic schist.

Pseudosection modeling constrains peak P-T conditions at 6–8.5 kbar and 550–565°C for pelitic schist. Three scenarios were modelled using EQ3/6: (A) brine reacting with unaltered dyke, (B) brine reacting with pelitic schist, and (C) pelitic schist reacting with dyke-equilibrated fluid (*i.e.*, from Case A); across 1–5 kbar and 300–600°C. The models track mineral stability as a function of the rock-to-fluid ratio (r/f, expressed as log Xi) and P-T conditions. Case A reproduces the epidote-amphibolite assemblage of the dyke at 2–5 kbar and 500–600°C under fluid-dominated conditions (log Xi: −2 to −1). Case B predicts pelitic schist assemblages (garnet-biotite) and fails to generate MRZ assemblages. Only Case C predicts the observed MRZ assemblage (amphibole, represented by pargasite in the model calculations, epidote, plagioclase) when pelitic schist interacted with saline fluids pre-equilibrated with the dyke at 1–3 kbar and 400–600°C. The spatial variation in r/f controls assemblage development: under fluid-dominated conditions (log Xi −2 to 2) amphibole-epidote-plagioclase are formed, and under rock-dominated conditions (log Xi >4) pelitic schist assemblages (garnet-biotite-plagioclase). Hydrothermal experiments at 550°C and 1.6–2 kbar also confirms that saline fluids, not pure water, drive MRZ formation, validating the modeling approach.

The reaction-path models show that MRZs formed after peak metamorphic conditions to those on a stable continental geotherm (300–500°C, at mid-crustal depths) due to fluid-rock interactions. These interactions resulted mobilization of "immobile" elements with MRZs losing 50–87% REEs and 43–63% HFSEs while adjacent dykes gain 100–160% REEs, demonstrating importance of fluid-mediated mass transfer of these critical elements. The modeling results highlight that contrasting litho-contacts act as chemical barriers where crustal fluids, equilibrated with a host rock, becomes disequilibrium encountering another, driving reactions that redistribute elements during post-orogenic fluid flow.

Quaternary Deformation Associated with an Active Hinterland Fault in the Kashmir Basin, Northwest Himalaya, India

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The Kashmir Basin, situated within the tectonically active hinterland of the northwest Himalaya, represents a critical yet comparatively understudied region for evaluating Quaternary deformation and regional seismic hazard. Historical records document damaging intrabasin earthquakes, including the 1555 CE event (estimated Mw ~7.6–8.2) and the 1885 CE event (estimated Mw ~6.3–6.8) [1]. However, paleoseismological and Quaternary deformation studies across the Himalayan orogen have largely focused on frontal thrust systems. Consequently, the kinematics, strain partitioning, slip history, and seismic potential of hinterland faults remain poorly constrained, contributing to gaps in the regional earthquake catalogue and an incomplete understanding of Quaternary strain accommodation mechanisms within the orogen. This study investigates the Balapur Fault, an active hinterland fault located within the Kashmir seismic gap of the northwest Himalaya. The fault displaces Late Quaternary Karewa deposits [2] and is well exposed along river-cut sections, preserving a clear geomorphic and stratigraphic record of geologically recent deformation. Uplifted and unpaired fluvial terraces, together with offset alluvial fan surfaces, define a prominent fault scarp, with terrace levels preserved at systematically varying elevations above the modern riverbed, indicating progressive surface uplift associated with sustained Quaternary fault activity. An integrated approach combining detailed geomorphological mapping of fault scarps, associated splays, and river terraces, spatial analysis of soft-sediment deformation structures, and paleoseismic investigation is employed to reconstruct the fault's activity history. OSL dating of multiple terrace levels constrains Quaternary uplift and shortening rates, while stratigraphic correlation, radiocarbon (^{14}C) dating, and sedimentological analysis of trench exposures provide temporal constraints on surface-rupturing paleo-earthquake events. The results aim to refine existing models of Quaternary deformation and landscape evolution of the Kashmir Basin and to highlight the role of hinterland fault systems in accommodating strain in the northwest Himalaya. The outcomes will be relevant to seismic hazard evaluation in the densely populated Kashmir Basin, where incomplete characterization of active faults may lead to an underestimation of regional seismic risk.

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Hotspot (Pressure-Temperature excursions) formation in heterogeneous targets due to shock waves from hypervelocity impact

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Heterogeneities like pores, grains and layers in the target material may lead to localization of shock waves, resulting in localized zones with elevated shock pressures and temperatures. This phenomenon is of particular interest as it can lead to the formation of high-pressure polymorphs of minerals and melts in rocks that have seemingly experienced low to moderate shock pressures. This has implications for established methods of shock barometry and classification of impactites, as well as mesoscopic deformation at impact structures and broader implications for cratering mechanics. In this ongoing study, we carry out simulations in iSALE-2D to understand the effect of layering on the localization of shock waves and crater morphology. We consider a simple 3-layer heterogeneous target. The initial cases are validated using results from [1]. The depth, thickness, and properties of the layers are varied to conduct a systematic analysis of excursions in shock pressures and temperatures. Preliminary observations indicate that the superposition of shock waves due to reflections and transmissions from layer boundaries, and the permanent deformation of the layers, is responsible for these excursions.

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Geodetic Mass Balance Estimation of Glacier in the Chandra-Bhaga Basin, Western Himalaya, India (2000–2023)

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Glaciers in the Indian western Himalaya play a crucial role in sustaining regional hydrology and freshwater availability. However, they are highly sensitive to climatic and topographic controls, making their long-term monitoring essential [1,2]. In this study, the geodetic mass balance method was applied to evaluate glacier elevation changes in the Chandra–Bhaga basin, Himachal Pradesh, over a 23 year period between 2000 and 2023. A total of 181 glaciers were evaluated using Digital Elevation Models (DEMs) from Shuttle Radar Topography Mission (2000) and ASTER (2023) stereo imagery, of 30 m spatial resolution. Glacier Elevation changes were estimated through systematic co-registration and bias correction to minimize uncertainties, and glacier volume changes were converted to water equivalent mass balance. The results indicate a mean annual glacier mass balance of -0.29 ± 0.02 m w.e. yr^{-1} during the study period. Spatial variability within glaciers as well as among different glaciers was clearly observed across the basin. Larger glaciers showed greater thinning than smaller ones, primarily because their extensive ablation zones are situated at lower elevations where melting is more intense. In contrast, smaller glaciers located at higher elevations exhibited relatively lower mass loss. Both topographic and non-climatic factors were found to exert a strong control on glacier behaviour. Glaciers characterised by gentle slopes (0°–10°) and those with south or southeast-facing aspects experienced the maximum surface lowering. Additionally, glacier characteristics such as slope, aspect, and debris cover displayed significant spatial variability and contributed to differences in melt rates. Similar regional patterns of glacier mass loss across the Himalaya and High Mountain Asia have been reported in previous studies [2]. Overall, this study provides a comprehensive assessment of glacier mass changes in the Chandra–Bhaga basin and highlights the combined role of climatic and non-climatic controls in regulating glacier dynamics. The continued negative mass balance indicates increasing vulnerability of glacier-fed river systems, which may have significant implications for future water availability, hydropower generation, and climate adaptation strategies in the western Himalaya.

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Apatite zoning as a tracer of anatexis and fluid overprint in granitic gneiss from a collisional suture zone

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Apatite is increasingly recognized as a recorder of metamorphic and fluid processes in collisional orogens, yet its behavior in granitic gneisses from suture zones remains scarcely examined. This study investigates apatite hosted by quartz-plagioclase-K-feldspar-biotite gneiss from a tectonic suture to constrain the evolution of melt and fluids during high-grade metamorphism. Backscattered electron imaging and quantitative *X*-ray mapping reveal well-developed core-rim chemical zoning in apatite grains. Cores are enriched in La, Gd, Yb, and Th, display slight Si contents, and show comparatively lower Ca, whereas rims are exhibiting higher Ca, marked enrichment in Cl and F along grain boundaries, depletion in Si, and strongly reduced REE and Th concentrations. P is essentially homogeneous across individual grains, and U is predominantly hosted by adjacent silicate phases rather than by apatite.

These features are interpreted to reflect two chemically distinct growth stages. The REE- and Th-rich, Si-bearing cores are attributed to early crystallization from an evolved felsic melt or high T melt-like metamorphic fluid during crustal anatexis in the suture zone lower crust. In contrast, the Ca-rich, Si-poor, Cl-F-enriched rims are ascribed to later interaction with a halogen-rich, REE-poor fluid during cooling and retrogression, overgrowing and partially modifying the earlier core compositions. The decoupling of Th-rich apatite from U-enriched neighboring silicates implies evolving redox conditions and changing fluid composition. It suggests that in-situ apatite U-Pb dating would have the potential to distinguish between magmatic-metamorphic and fluid-dominated events.

Overall, the apatite chemistry demonstrates that even in apparently simple quartz of feldspathic gneiss, accessory phosphates retain a sensitive record of melt production and subsequent fluid infiltration in suture-zone crust. This highlights apatite as a powerful micro-scale tracer of anatexis and fluid-rock interaction in collisional orogens.

Microstructural Evolution and Deformation Mechanisms in the Mahakoshal Belt: Insights from EBSD and Petrographic Analyses

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The Mahakoshal Supracrustal Belt (MSB) situated at the northern part of the Central Indian Tectonic Zone (CITZ), preserves evidence of Paleoproterozoic collisional processes between the northern and southern Indian shields. While previous studies identify three major deformation episodes in the MSB, a quantitative evaluation of the deformation pattern in the evolution of MSB remains poorly addressed. This study focuses on quantitative characterization of the deformation intensity and related mechanisms via detailed microstructural observations, and electron backscatter diffraction (EBSD) analyses from oriented quartzite samples—systematically collected along multiple north-south transects across the MSB.

The microstructural studies on the samples from the northern and central MSB exhibit initial stages of dynamic recrystallization, whereas samples from the southern part of MSB, near the Son-Narmada south fault (SNSF) show evidence of grain boundary migration indicating higher deformation temperature and intensity near SNSF. Such intensification of deformation might be caused by syn-kinematic granite intrusion along SNSF. EBSD analyses provide quantitative information of spatial variation of deformation across the MSB. The deformation intensities, characterized by the misorientation indices of the analyzed samples, increase as we move towards southern MSB. Similar trend is observed in another orientation parameter, the misorientation angle distribution of correlated (neighbor-pair) and uncorrelated (random-pair). The crystallographic preferred orientation of samples evolves from cross-girdles in the north to point distribution in the south, confirming a southward increase in deformation intensity and temperature. Misorientation axis distribution of subgrain boundaries indicates prism-<a> slip as the dominant slip-system in quartz, constraining the peak deformation temperature within 500–700°C. Crystallographic vorticity analysis indicates that the bulk vorticity axes are at low-angle to the kinematic Y-direction across all samples. Such observation suggests a dominance of simple shear component and minor pure shear contribution in regional deformation of the MSB. The signatures of simple shear support an oblique-type collisional tectonic model responsible for the formation of the CITZ.

Collectively, all these results establish an understanding of the nature and magnitude of strain heterogeneity across the MSB, where deformation intensity increases southward, towards the SNSF. The field observations, optical microstructural analyses, and EBSD-based textural data, put forth the first quantitative constraints on the spatial distribution of Paleoproterozoic deformation, providing validation of the existing tectonic model of oblique collision in CITZ.

Hydrothermal Synthesis of Chalcopyrite: Implications for Phase Purity Assessment

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Chalcopyrite ($CuFeS_2$) is the most abundant copper-bearing sulfide mineral and serves as a primary copper source. Numerous studies have investigated the synthesis of chalcopyrite to gain insights into its formation mechanisms and stability under controlled conditions of temperature, pressure, and fluid composition [1]. These investigations enhance the understanding of its physicochemical properties, reaction pathways, and phase relationships that are critical to ore-forming environments. Experimental synthesis of pure, single-phase chalcopyrite also serves as an essential reference material for designing and improving metallurgical technologies aimed at securing a stable and sustainable copper supply [1]. However, in most previous studies, the phase purity of synthetic chalcopyrite powder was primarily analyzed using XRD, SEM-EDX, XPS, and TEM, and these methods may overlook amorphous and impure phases due to a lack of crystallinity and the nanoparticle nature. In this study, the synthesis of chalcopyrite by hydrothermal processes was investigated using conventional and microwave-assisted methods at a temperature of 180 °C, and phase purity was checked using XRD, SEM-EDX, along with optical microscopy, which was missing in previous studies. Accurately weighed amounts of $CuCl_2.2H_2O$, $FeCl_3$, and thiourea were mixed in 15 ml of milli-Q water and heated conventionally for 48 hours using a Teflon-lined autoclave at 180 °C, while similar bulk compositions were heated using a microwave for 2 hours at 180 °C. A few experiments also involved 10 ppm of a 15 ml solution instead of milli-Q water. XRD and SEM-EDX analysis of the synthetic powder showed the presence of chalcopyrite along with covellite and chalcocite in experiments containing milli-Q water, while pure chalcopyrite was found in Te-bearing solutions. Reflected light optical analysis of polished samples revealed the presence of pyrite alongside chalcopyrite and covellite in several experiments. While some XRD analyses indicated only chalcopyrite, reflected light microscopy identified chalcocite coexisting with chalcopyrite, suggesting that powder XRD may have limitations in detecting certain mineral phases. This discrepancy is likely due to the nanoparticle size of the minerals and the presence of amorphous phases such as pyrite, which can hinder accurate identification by XRD. These results highlight the importance role of optical microscopy in the comprehensive characterization of synthetic polished samples, emphasizing its necessity for verifying phase purity and complementing XRD findings. Thus, integrating reflected light optical microscopy with conventional XRD analysis provides a more reliable and thorough approach to mineral phase identification in nanoparticulate and complex systems.

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Geochemical constraints on Archean mantle heterogeneity from the Southern Bundelkhand Craton.

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The Southern Bundelkhand Craton (India) comprises the Girar Greenstone Belt and the Madawara Ultramafic Complex, which together record Archean crust–mantle interactions. The Madawara complex consists of layered talc–tremolite schists overlain by massive peridotites with associated gabbros, whereas the Girar belt includes metabasalts, TTG suites, and metasedimentary units such as BIFs and quartz-pebble conglomerates.

Geochemical data indicate that the ultramafic units and spinel peridotites were derived from compositionally distinct mantle sources. Talc–tremolite schists preserve deformation fabrics and signatures of high-temperature hydrothermal alteration, while the massive peridotites record moderate degrees of partial melting. Metabasalts are depleted in Ni and Cr relative to primitive mantle and display evolved tholeiitic to basaltic-andesitic affinities, suggesting derivation from a heterogeneous mantle source.

Integrated petrographic and geochemical evidence supports formation in a shallow subduction-related setting, with ultramafic rocks crystallizing in magma chambers at varying depths and metabasalts representing associated arc magmatism. These findings refine the genetic relationship between the Madawara Ultramafic Complex and the Girar Greenstone Belt and provide new constraints on Archean mantle heterogeneity, crustal growth, and geodynamic evolution of the Bundelkhand Craton.

Keywords: Greenstone belt; layered ultramafic complex; mantle heterogeneity; Archean geodynamics.

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Deciphering the Resilience of Indian Biomes to Flash Droughts: A SHAP-Based Analysis of Vegetation Recovery

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Flash droughts (FDs) pose a significant threat to the functional stability of India's diverse biomes due to their rapid intensification. While hydroclimatic drivers of FD onset are well-studied, the biome-specific factors governing post-FD recovery remain poorly understood. In this study, we used the Standardized Evaporative Stress Ratio (SESR) to characterize FDs (1979-2021) and their sub-periods ("hot periods"), identified by high temperatures and intense radiation. By assessing the individual and combined impacts of soil moisture (SM) and vapor pressure deficit (VPD), we find that while SM is the primary buffer in humid forest ecosystems, VPD is the predominant stressor—affecting up to 57% of semi-arid and semi-humid regions, particularly during the critical "hot periods" of FD.

Further, to identify the determinants of ecosystem recovery, we employed SHapley Additive exPlanations (SHAP) to rank the influence of physiological and FD-specific parameters. Our analysis reveals that resilience time, governed by plant physiology, is the primary determinant of FD recovery across all biomes, followed by drought severity. Drought duration is the least significant factor. Our biome-level assessments highlight a clear resilience gradient: croplands emerge as the most vulnerable, with 80% of the area responding within just 8 days of FD onset, while forests maintain greater resilience through deeper rooting systems and subsurface moisture buffering. Analysis of long-term trends indicates that while FD-affected areas are significantly declining across all biomes ($p < 0.01$), the rate of recovery is nearly twofold higher in forests (-0.27% yr^{-1}) than in croplands (-0.15% yr^{-1}). This persistent vulnerability in agricultural regions, despite anthropogenic interventions, underscores the limits of current water management under shifting monsoon variability. These findings provide a physical basis for developing biome-specific early warning systems and climate-resilience strategies tailored to India's unique ecological landscape.

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