

Structural inheritance and transient coupling govern porphyry W-Mo mineralization

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Abstract

Porphyry-related tungsten (W) deposits commonly record prolonged, multistage magmatism, yet economic mineralization is restricted to particular episodes. What controls recurrent magmatic localization and selective mineralization remains unclear. At the Larong tungsten-molybdenum (W-Mo) deposit on the eastern Tibetan Plateau, three-dimensional magnetotelluric imaging reveals a connected, deposit-focused conductive system comprising a broad middle-lower crustal conductor and a localized middle-crustal conductor extending beneath the deposit. Integrated conductivity, thermal and seismic constraints suggest that the deeper conductor represents a thermally weakened domain containing minor hydrous melt and fluids, whereas the shallower conductor is dominated by structurally localized fluids and other conductive phases. The deposit-focused geometry and a ca. 36 Ma post-ore intrusion support interpreting this system as the present-day electrical expression of a reactivated inherited tectono-magmatic pathway. Paired thermomechanical simulations demonstrate that a pre-existing weak zone can focus low-viscosity domains and upward motion during renewed heating. Together, these results suggest that inherited crustal architecture localized recurrent magmatism, whereas economic W-Mo mineralization at ca. 93 Ma required effective coupling among magma fertility, transcrustal transfer and ore deposition. Such transient coupling converts the long-lived metallogenic potential of inherited crustal architecture into economic mineralization.

Introduction

Porphyry-related W deposits worldwide commonly record prolonged, multistage magmatism, yet economic W-Mo mineralization is typically restricted to one or a few magmatic-hydrothermal episodes^{1–3} (Fig. 1a and Supplementary Table 1). This contrast indicates that repeated magma emplacement alone is insufficient for economic mineralization and raises two related questions: what causes magmatism to repeatedly return to the same crustal domain, and why do only particular episodes generate economic mineralization? Previous studies have identified magma fertility, metal and volatile budgets, crustal storage and differentiation, fluid release, and depositional triggers as important controls on porphyry ore formation^{4–8}. However, how these ore-forming conditions interact with the long-lived crustal structures that localize successive magmatic episodes remains poorly resolved. Resolving this relationship is essential for understanding both the recurrent spatial focusing of magmatism and the temporal selectivity of W-Mo mineralization.

Geochronological, whole-rock geochemical, mineral-geochemical, and fluid-inclusion studies constrain the timing of mineralization, magma fertility, and fluid evolution, but provide limited direct information on the deep structures that focus magmatic and hydrothermal transport through the crust. Magnetotellurics (MT) can image conductive middle-lower crustal domains associated with interconnected fluids, partial melt, graphite, sulfides, or other conductive phases, some of which may coincide with mechanically weak transfer zones^{9,10}. However, MT reflects the present-day electrical state of the crust, and low resistivity can arise from multiple physical sources. Identifying a conductor beneath a deposit is consequently insufficient to establish its relationship to an ancient magmatic-hydrothermal system. Its

geometry and physical origin must instead be assessed using independent thermal, seismic, structural, and geochronological constraints.

Structural inheritance provides a mechanism for sustaining spatial focus across widely separated magmatic episodes. Pre-existing faults and damage zones can preserve pronounced mechanical and hydraulic heterogeneity and can be reactivated during subsequent deformation, thereby enhancing permeability and focusing fluid flow^{11,12,13}. These structures can also channel magma ascent and control its emplacement. The Larong porphyry W-Mo deposit in the Sanjiang-Tethyan tectonic belt of the eastern Tibetan Plateau records Late Triassic, Late Cretaceous, and Eocene granitic magmatism (Fig. 1c). Its principal W-Mo mineralization formed at ca. 93 Ma in association with a Late Cretaceous monzogranite porphyry, whereas a ca. 36 Ma granite aplite crosscuts the earlier quartz-scheelite veins but produced no mineralization of comparable scale^{14,15}. This history provides a natural test of whether successive magmatic episodes repeatedly exploited inherited crustal architecture and why major W-Mo mineralization developed during only one of these episodes.

Here, we use data from 22 broadband MT stations to construct a three-dimensional resistivity model beneath the Larong deposit. We integrate the electrical structure with regional thermal and seismic constraints and the published magmatic-hydrothermal chronology to evaluate the geological significance of the imaged conductive system. Conceptual thermomechanical simulations further test whether a pre-existing weak zone simplified from the MT geometry can localize low-viscosity domains and upward motion during renewed heating. By comparing the ca. 93 Ma mineralizing episode with the ca. 36 Ma post-ore intrusion, we distinguish the inherited architecture that localized recurrent magmatism from the transient conditions associated with economic W-Mo mineralization.

Results

Broadband MT data were collected in 2025 from 22 stations surrounding the Larong W-Mo deposit and adjacent areas, with an average spacing of 6 km (Fig. 1c). The apparent-resistivity and phase responses are generally continuous throughout the analyzed period range (Supplementary Fig. 1). Phase-tensor ellipses are nearly circular at short periods but become progressively elongated at intermediate to long periods, with spatially variable principal-axis orientations and $|\beta|$ values exceeding 3° at multiple stations (Supplementary Fig. 2). These observations indicate a pronounced three-dimensional electrical response and support the use of full impedance tensor three-dimensional inversion. To resolve the three-dimensional electrical structure beneath Larong, we performed full-impedance-tensor three-dimensional inversion using ModEM¹⁶. The preferred model has a normalized root-mean-square misfit of 1.95 and reproduces the principal apparent-resistivity and phase responses at representative MT stations (Supplementary Figs. 4 and 5).

The preferred model reveals a connected crustal conductive system beneath Larong, comprising a middle-lower crustal conductor (C1) and a more localized middle-crustal conductor (C2) (Fig. 2). The shallow crust is predominantly resistive. C1 occurs mainly below approximately 20 km depth between

the major fault systems, with resistivity generally below 50 $\Omega\cdot\text{m}$ and locally below 10 $\Omega\cdot\text{m}$. C2 is concentrated at depths of approximately 10 to 20 km west of Larong and extends laterally beneath the deposit. Within the resolution of the model, C2 appears to connect downward to C1. Together, C1 and C2 define a continuous conductive system extending from the middle-lower crust to directly beneath the Larong deposit.

We used anomaly-replacement tests to evaluate whether C1, C2, and the conductive connection between them are required by the MT data. C1 and C2 were replaced individually and simultaneously with a homogeneous 100 $\Omega\cdot\text{m}$ background, and the corresponding model responses were recalculated without further inversion (Supplementary Fig. 6). Replacing C1 increased the overall nRMS misfit from 1.95 to 2.06, replacing C2 increased it to 2.48, and replacing both conductors increased it to 2.64. To test the connection separately, its shallower and deeper segments were replaced in turn. Both perturbations produced spatially coherent increases in station-level RMS, locally approaching 20% (Supplementary Fig. 7). The systematic degradation of the data fit demonstrates that the MT data require both C1 and C2 and support the conductive connection between them.

Discussion

Physical origin of the C1-C2 conductive system

The C1-C2 conductive system is geometrically continuous but spans contrasting depth and thermal regimes, making a single conductive phase unlikely to account for the entire anomaly. Low crustal resistivity can result from interconnected hydrous melt, saline fluids, graphite, sulfides, or combinations of these phases^{9,10,17}. The physical origin of the two conductors is therefore assessed separately, before considering the significance of their spatial connection.

C1 is a broad conductor in the middle-lower crust. Conductive and low-velocity zones at comparable depths are widespread beneath Tibet and its eastern margin and are commonly associated with thermally weakened crust containing interconnected hydrous melt or fluids^{9,18–22}. To evaluate whether such a state can account for C1, we applied the modified Archie's law for two conducting phases. Using an Archie exponent of $m = 1.5$ and an assumed melt resistivity of 0.2 $\Omega\cdot\text{m}$, the representative resistivity of C1 (33.1 $\Omega\cdot\text{m}$) can be reproduced by an interconnected hydrous silicate melt fraction of approximately 3.3 vol.%^{19,23} (Fig. 3). Because the Archie exponent and melt resistivity are not independently constrained by the MT data, the inferred melt fraction should be regarded as an approximation rather than a unique value. The observed $\sim 6\%$ reduction in V_S at 30 km depth beneath Larong relative to the surrounding crust provides an independent constraint consistent with a fluid- or melt-bearing weak lower crust²⁴ (Supplementary Fig. 8). Together, these observations suggest that C1 represents a thermally and mechanically weakened middle-lower crustal domain containing minor interconnected hydrous melt and fluids, rather than a discrete magma chamber. Details of the electrical and seismic calculations are provided in Supplementary Texts S3 and S4.

C2 differs from C1 principally in its shallower thermal setting and localized distribution. At its inferred depth of approximately 10–20 km, regional heat-flow estimates and granitic solidus constraints indicate temperatures insufficient to sustain a volumetrically significant fraction of silicate melt^{25,26,27}, making a melt-dominated origin unlikely. Its low resistivity is therefore more plausibly explained by interconnected saline fluids together with graphite, sulfides, or other electronically conductive minerals concentrated within a structurally localized middle-crustal zone^{28,29}. The required electrical connectivity of these phases is consistent with focused fluid migration and localized accumulation of conductive material, rather than a regionally extensive thermal anomaly.

C1 and C2 thus represent physically distinct but spatially connected components of one crustal conductive system. C1 may mark a deeper thermal-fluid weak domain containing minor interconnected hydrous melt, whereas C2 likely delineates a shallower, structurally localized zone dominated by fluids and other conductive phases. The ca. 93 Ma magmatic-hydrothermal system has long since cooled and crystallized; the present conductivity therefore cannot represent either a homogeneous active magma system or an unchanged remnant of the ore-forming magma and fluids. Instead, different conductive phases may maintain electrical connectivity along a connected crustal weak structure.

Inherited crustal control on recurrent magmatism

The MT model reveals a deposit-focused conductive geometry beneath Larong. Larong also records Late Triassic, Late Cretaceous, and Eocene magmatism, and the ca. 36 Ma granite aplite cuts the earlier quartz-scheelite veins, demonstrating that magma returned to the deposit area after the principal W-Mo mineralization at ca. 93 Ma^{14,15}. Taken together, the deposit-focused electrical geometry and the intrusive record support an interpretation in which successive magmatic episodes exploited an inherited crustal corridor beneath Larong.

Structural inheritance provides a mechanism for maintaining this long-lived spatial focus. Pre-existing faults and their damage zones can preserve pronounced structural and hydraulic heterogeneity, with fault cores and fracture networks acting either as barriers or conduits to fluid flow^{11,12}. During later deformation, these structures may be reactivated and repeatedly reused, thereby localizing subsequent tectonic, magmatic, and hydrothermal activity¹³. Geophysical studies further show that inherited crustal or lithospheric structures can guide later magmatism, preserve transcrustal magma-plumbing architectures, and provide pathways for the transfer of deep-sourced materials into mineralized regions^{30–34}. Repeated reactivation allows the permeability, fluid content, and conductive phases within the pathway to evolve while its spatial influence persists, consistent with evidence that conductive phases can preserve signatures of ancient crustal fluid flow in other mineral systems³⁵.

To test the physical feasibility of this localization mechanism, we performed paired two-dimensional thermomechanical simulations under identical extensional boundary conditions and basal thermal input. The models differed only in whether they contained a prescribed weak zone simplified from the C1-C2-

Larong geometry; detailed model setup and parameters are provided in Supplementary Text S5 and Supplementary Table 3. In the absence of this weak zone, thermal weakening and upward motion remained diffuse; with it, low-viscosity domains and upward motion became focused along the prescribed structure (Fig. 4). Because the weak-zone geometry was derived from the MT model, the simulations do not independently identify the pathway. Instead, they demonstrate that the imaged crustal architecture is mechanically capable of focusing the response of the crust to renewed thermal forcing.

The MT model constrains the geometry and connectivity of the deposit-focused C1-C2 conductive system, the ca. 36 Ma intrusion records renewed magma emplacement at Larong, and the paired simulations demonstrate that a pre-existing weak zone can focus low-viscosity domains and upward motion of crustal material during renewed heating. This present-day electrical architecture provides a spatial framework for interpreting recurrent magma emplacement at the deposit. Together, these observations and simulations support interpreting the C1-C2 conductive system as the present-day electrical expression of a reactivated inherited tectono-magmatic pathway that repeatedly localized magmatic activity beneath Larong.

Structural inheritance and selective W-Mo mineralization

Inherited crustal architecture provides a structural basis for recurrent magma emplacement at Larong, raising the question of how repeated spatial localization translates into substantial W-Mo mineralization during particular intrusive episodes. Tungsten occurs at concentrations of only a few parts per million in the continental crust, and its enrichment to economic grades requires extensive magmatic differentiation and hydrothermal transfer^{3,36,37}. Porphyry W deposits are commonly associated with prolonged, multistage magmatism, with principal mineralization generally linked to late-stage magma emplacement^{1,2,3} (Fig. 1a and Supplementary Table 1). These associations emphasize the importance of sustained magmatic evolution in establishing conditions favorable for W enrichment. Structural inheritance can maintain the spatial focus of successive intrusive episodes, whereas metal and volatile accumulation depends on the evolution of the individual magmatic systems occupying that crustal domain. Understanding selective mineralization therefore requires linking this persistent structural influence to the magmatic-hydrothermal processes operating during the principal ore-forming episode.

Larong provides a geological record of this relationship. The principal W-Mo mineralization was associated with the ca. 93.9 Ma monzogranite porphyry, and the ca. 91.8 Ma molybdenite Re-Os age places mineralization within the same Late Cretaceous magmatic episode^{14,15}. Highly fractionated, F-rich magma favored W-Mo enrichment and transfer into exsolved magmatic fluids, followed by cooling and fluid-rock interaction that promoted scheelite and molybdenite precipitation in the upper crust^{14,15,38}. The ca. 36 Ma granite aplite subsequently crosscut the earlier quartz-scheelite veins, recording renewed magma emplacement at the deposit after the principal mineralizing event, without documented W-Mo mineralization of comparable scale¹⁴. These relationships show that recurrent magma emplacement

and the establishment of a productive ore-forming system represent distinct aspects of the magmatic history at Larong (Fig. 5).

The MT imaging and paired thermomechanical simulations constrain the structural component of this relationship. The connected C1-C2 conductive system extends from the middle-lower crust to beneath the deposit, and the simulations demonstrate that a pre-existing weak zone can focus low-viscosity domains and upward motion of crustal material during renewed heating. Together with the intrusive record, these results support an inherited architecture that repeatedly concentrated magmatic activity beneath Larong. Such spatial focusing provides a structural framework for linking deep magmatic processing to upper-crustal emplacement and hydrothermal activity^{39,40,41}. Prolonged magma accumulation and differentiation can build the metal and volatile budget available for mineralization; models of porphyry Cu systems demonstrate the importance of deep accumulation followed by transfer to shallower levels⁴². The approximately 10-km ascent of ore-forming fluids documented elsewhere in the Sanjiang region further illustrates the potential for vertically extensive hydrothermal transport⁴³. At Larong, the mineralizing episode records the conjunction of evolved magma, magmatic fluid release and effective upper-crustal precipitation^{14,15,38}. Recent evidence from collisional porphyry Cu-Mo systems likewise indicates that magma fertility can arise from transient mantle-crust thermochemical coupling rather than persistent source enrichment⁴⁴. We interpret the contrast between the mineralizing and post-ore episodes at Larong within a transient-coupling framework, in which magma fertility, focused transcrustal transfer and favorable depositional conditions are effectively linked during particular intrusive episodes within a longer-lived structural setting.

The Larong deposit distinguishes the long-term controls on the spatial localization of magmatism from the transient conditions governing the timing of economic mineralization. Inherited crustal architecture focuses successive episodes of magma, heat and fluid transfer, thereby enhancing the metallogenic potential of a crustal domain. This interpretation can be tested in other porphyry W-Mo districts with multistage intrusive histories: intrusions of different ages, regardless of their degree of mineralization, should preferentially cluster along the same structural corridors, whereas major mineralization should be concentrated in episodes when extensive magmatic evolution, fluid release and mineral precipitation were effectively linked. Within this framework, inherited crustal architecture determines where magmatic-hydrothermal activity repeatedly converges, whereas transient coupling among these ore-forming processes determines when this long-lived metallogenic potential is converted into an economic deposit.

Methods

MT data acquisition and processing

Broadband MT data were collected in August and September 2025 from 22 MT stations across the Larong W-Mo deposit and adjacent structural areas. The stations were distributed across the deposit,

adjacent tectonic units, and major regional faults, with an average spacing of approximately 6 km. Natural electromagnetic fields were recorded using Phoenix Geophysics MTU-5A systems. At each station, two horizontal electric-field components (E_x and E_y) and three magnetic-field components (H_x , H_y , and H_z) were measured. Full impedance tensors spanning 0.00042 to 320 Hz, corresponding to periods of approximately 0.003 to 2400 s, were obtained. Recordings at most stations exceeded 48 h.

Raw time series were processed using SSMT2000, and the estimated impedance responses were inspected and edited using MT-Editor; both programs were supplied by Phoenix Geophysics. Processing included transformation to the frequency domain and robust estimation of frequency-dependent transfer functions to suppress nonstationary noise and outliers. Data points affected by cultural or instrumental noise were manually rejected on the basis of the continuity of the apparent-resistivity and phase curves and their consistency among neighboring stations. The final apparent-resistivity and phase curves are shown in Supplementary Fig. 1. Phase tensor analysis was used to assess the dimensionality of the electrical structure independently of galvanic distortion. The absolute phase tensor skew angle $|\beta|$ served as an indicator of three-dimensionality, with values exceeding approximately 3° taken to indicate appreciable 3D effects⁴⁵. Phase tensor maps at representative periods are shown in Supplementary Fig. 2.

MT modeling and inversion

We inverted the full complex impedance tensor from 22 MT stations using ModEM^{16,46}, with 21 periods spanning approximately 0.003–2400 s. The model comprised $54 \times 64 \times 68$ cells, with horizontal cell dimensions of approximately 1.32×2.0 km in the core survey area. Laterally expanding padding cells surrounded the core mesh. The vertical mesh comprised 68 layers, with thicknesses increasing progressively from 30 m at the surface to a total model depth of approximately 555 km. The starting model was a homogeneous half-space with a resistivity of $100 \Omega \cdot \text{m}$. Error floors were 5% of $|Z_{xy}Z_{yx}|^{1/2}$ for off-diagonal impedance components and 10% for diagonal components, retaining larger uncertainties estimated during data processing. A smoothing parameter of 0.3 was applied in all three directions, and topographic effects were not included. After 125 iterations, the inversion reached a normalized root-mean-square (nRMS) misfit of 1.95. The mesh, inversion parameters and data fits are provided in Supplementary Figs. 3–5 and Supplementary Table 2.

Sensitivity to C1, C2 and their conductive connection was assessed by replacing the targeted cells with $100 \Omega \cdot \text{m}$ while holding all other cells fixed. Responses were recalculated without reinversion, and changes in overall and station-level RMS misfits were evaluated. Detailed test configurations and results are provided in Supplementary Information and Supplementary Figs. 6 and 7.

Petrophysical estimates

We used a two-phase form of modified Archie's law to estimate the fraction of interconnected hydrous silicate melt required to reproduce the representative bulk resistivity of C1²³. The governing equations, conductivity parameters, model-cell selection and sensitivity analyses are provided in Supplementary Text S3 and Fig. 3b.

As an independent seismic constraint, we extracted the S-wave velocity V_S at 30 km depth beneath Larong from a regional three-dimensional velocity model of the Tibetan Plateau²⁴. We converted the V_S reduction relative to the surrounding crust into an equivalent porosity using a linearized empirical granite velocity-porosity relation⁴⁷. Details of the reference velocity, conversion procedure and sensitivity tests are provided in Supplementary Text S4 and Supplementary Fig. 8.

Thermomechanical simulations

We used ASPECT version 3.1.0-pre^{48,49} to solve the conservation equations of mass, momentum and energy under the Boussinesq approximation. The two-dimensional Cartesian domain was 300 km wide and 120 km deep, comprising a 20-km-thick upper crust, a 40-km-thick lower crust and 60 km of lithospheric mantle. Deformation followed a temperature-dependent viscoplastic rheology combining dislocation creep with Drucker-Prager plastic yielding.

A pre-existing weak zone was prescribed with an idealized geometry based on the MT-imaged C1-C2-Larong conductive system. An initial accumulated plastic strain of 1.5 was assigned within this zone, reducing cohesion and the friction coefficient to 25% of their initial values through the prescribed strain-weakening law. A reference model was initialized with zero plastic strain throughout. All other model settings were identical between the two simulations.

The initial geotherm increased from 273 K at the surface to 633 K at 20 km depth, 1113 K at the Moho and 1613 K at the model base. The upper boundary was a free surface. Outward velocities of 1 mm/yr were imposed at each lateral boundary, with a compensating upward velocity of 0.8 mm/yr at the base. Temperatures were fixed at the upper and lower boundaries, and the lateral boundaries were thermally insulating. Renewed deep heating was represented by a continuous Gaussian heat source centered at approximately 75 km depth.

Both models were evolved for 3 Myr. Temperature, effective viscosity and solid-matrix velocity fields were compared at 1 and 3 Myr to assess how the prescribed weak zone influenced deformation and upward motion during deep heating. The governing equations, detailed heat-source specification, rheological parameters and numerical settings are provided in Supplementary Text S5 and Supplementary Table 3.

Data availability

The processed magnetotelluric inversion models and thermomechanical simulation files generated in this study have been deposited in Figshare at <https://figshare.com/s/76433cda086df76ede88>.

Additional supporting data are provided in the main text and Supplementary Information.

Code availability

The three-dimensional magnetotelluric inversion code ModEM is available at <https://doi.org/10.5281/zenodo.17229555>. Thermomechanical simulations were performed using ASPECT version 3.1.0-pre, available at <https://github.com/geodynamics/aspect>.

Declarations

Competing interests

The authors declare no competing interests.

Supplementary Information

Supplementary Information accompanies this manuscript and contains Supplementary Texts S1-S5, Supplementary Tables 1–3, Supplementary Figs. 1–8 and Supplementary References.

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Declaration

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Author Contributions

Y.X. and T.W. conceived the study and contributed to the methodology and formal analysis. Y.X. and T.W. conducted the MT data analysis. Y.X., T.W. and Z.Z. performed the thermomechanical simulations. Y.X. wrote the original manuscript. T.W., N.Y., Z.Z., C.Z., X.W., W.K., K.L. and S.X. contributed to data interpretation and manuscript revision. N.Y. supervised the project and acquired funding. All authors approved the final manuscript.

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Maps and selected figures were prepared using the Generic Mapping Tools (GMT)⁵⁰. Thermomechanical simulation results were visualized using ParaView⁵¹.

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Figures

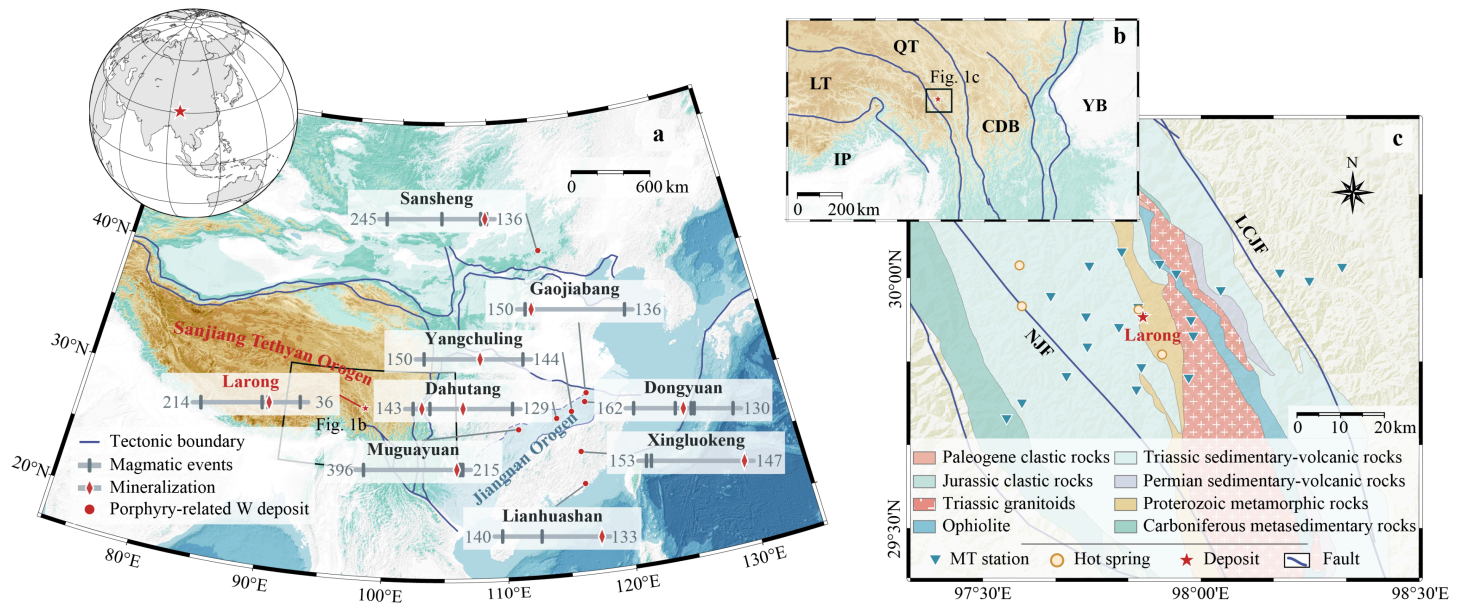


Figure 1

Geological setting and magmatic-mineralization history of the Larong W-Mo deposit. **a** Distribution of representative porphyry-related W deposits in the Sanjiang-Tethyan tectonic belt and the Jiangnan Orogen. Red circles mark deposit locations, blue lines indicate major tectonic boundaries, horizontal bars denote the ages and durations of associated magmatic events, and red diamonds denote mineralization ages; numerical values are in Ma. The globe inset shows the location of the mapped region. Age data and their sources are summarized in Supplementary Table 1. **b** Regional tectonic framework of eastern Tibet showing the location of the Larong area and the extent of the geological map in (c). **c** Simplified geological map of the Larong area showing the principal lithological units, major faults, the Larong deposit, hot springs, and 22 broadband magnetotelluric (MT) stations. The geological map in (c) is modified from Liu et al.¹⁴. IP, Indian plate; LT, Lhasa terrane; QT, Qiangtang terrane; CDB, Chuan-Dian Block; YB, Yangtze Block; NJF, Nujiang fault; LCJF, Lancangjiang fault.

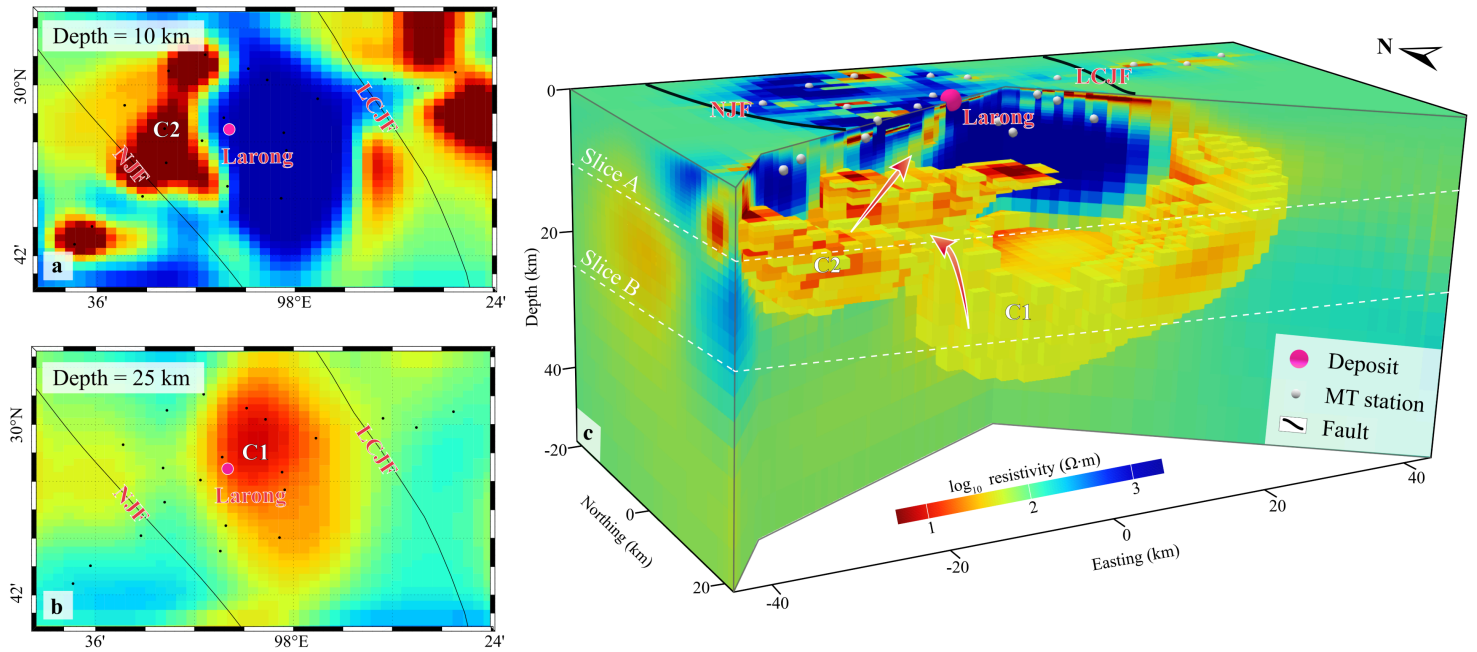


Figure 2

Connected C1-C2 conductive system beneath the Larong W-Mo deposit. **a and b** Horizontal slices through the preferred three-dimensional resistivity model at depths of 10 and 25 km, respectively. The 10-km slice images the localized middle-crustal conductor C2 west of Larong and extending beneath the deposit, whereas the 25-km slice images the deeper conductor C1. **c** Perspective view showing the spatial continuity between C1 and C2 and the extension of C2 directly beneath the Larong deposit, together defining a conductive system from the middle-lower crust to the Larong deposit area. Conductive volumes in (c) are visualized using model cells with resistivity $\rho < 50 \Omega \cdot m$. White dashed lines mark the depths of the horizontal slices in (a) and (b). Black dots in (a) and (b) and gray spheres in (c) mark MT stations; magenta symbols mark the Larong deposit; and black lines denote major faults. Colors indicate $\log_{10}\rho$, where ρ is resistivity in $\Omega \cdot m$. NJF, Nujiang fault; LCJF, Lancangjiang fault.

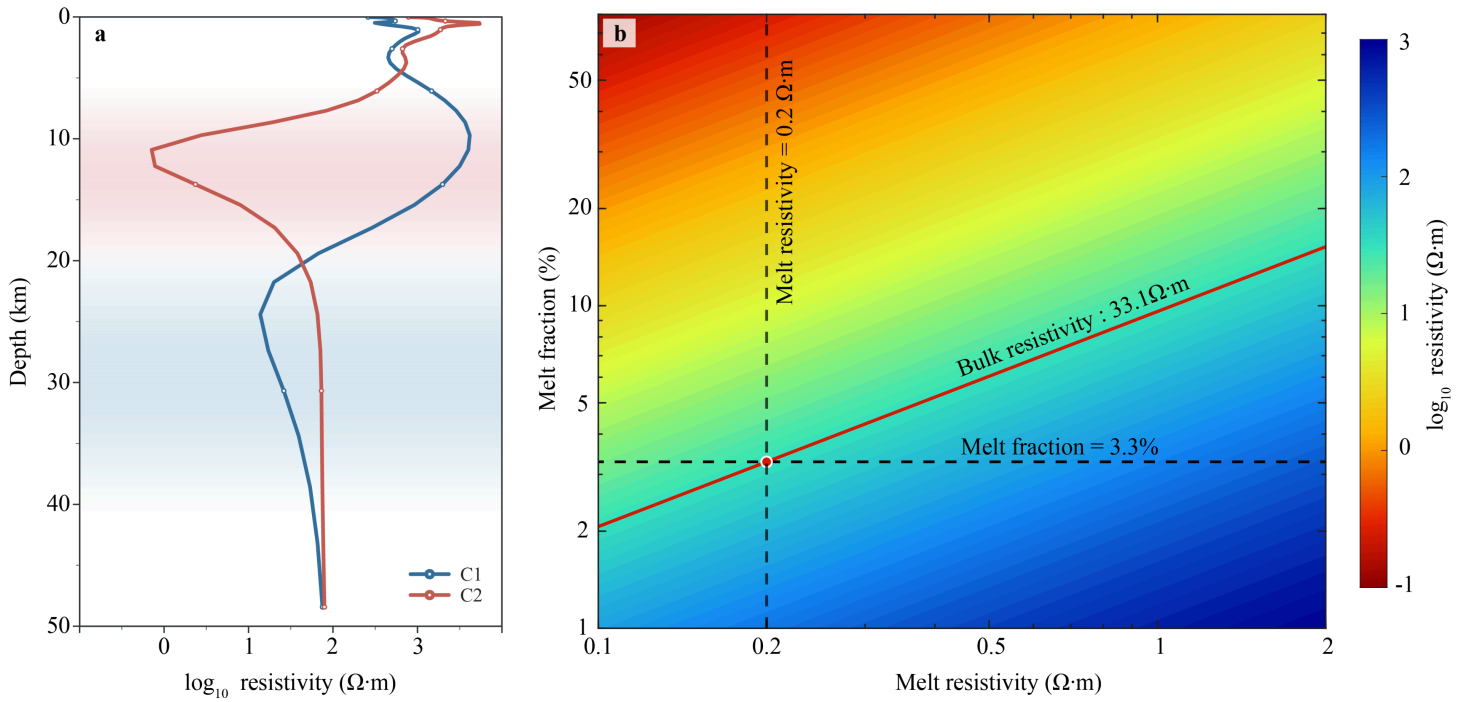


Figure 3

Physical constraints on the C1 conductor. **a** Representative vertical resistivity profiles through C1 and C2. Resistivity is expressed as $\log_{10}\rho$, where ρ is in $\Omega \cdot m$. **b** Bulk resistivity calculated as a function of melt resistivity and melt fraction using the modified Archie relation. Colors indicate $\log_{10}$ bulk resistivity. The red contour marks the characteristic resistivity of C1 (33.1 $\Omega \cdot m$). For an assumed melt resistivity of 0.2 $\Omega \cdot m$, the corresponding melt fraction is approximately 3.3 vol.%, as indicated by the dashed lines and red circle.

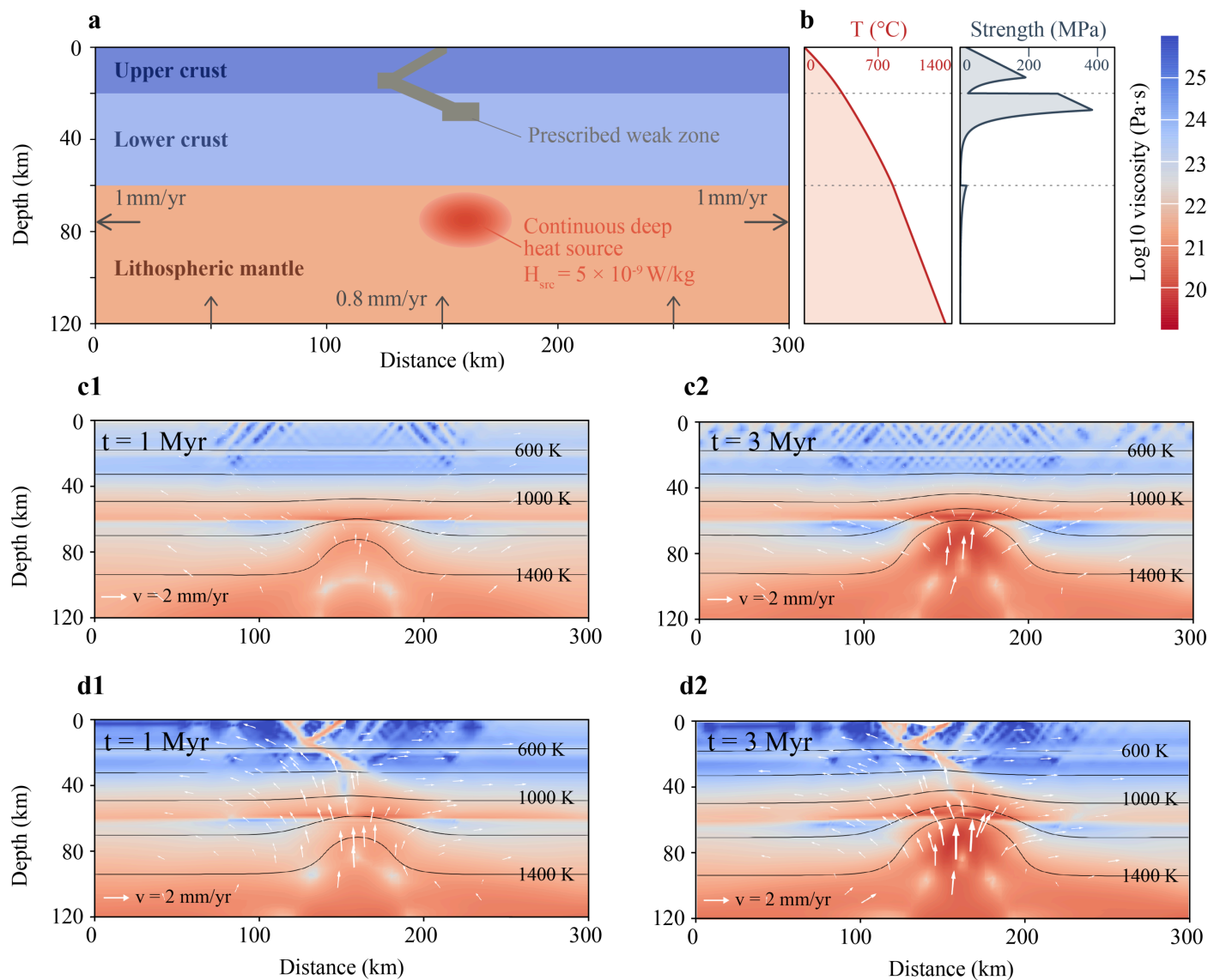


Figure 4

Conceptual thermomechanical test of localization by an inherited weak zone. **a** Model geometry and boundary conditions. The model comprises the upper crust, lower crust, and lithospheric mantle, with an inclined inherited weak zone schematically simplified from the geometry of the C1-C2 conductive system beneath Larong. Symmetric extension of 1 mm/yr was imposed on each side, corresponding to a total extension rate of 2 mm/yr, and was balanced by an upward basal velocity of 0.8 mm/yr. **b** Initial temperature profile (red) and lithospheric strength profile (black); the horizontal dashed line marks the Moho. **c1 and c2** Reference model without the prescribed weak zone at 1 and 3 Myr, respectively. **d1 and d2** Paired model containing the prescribed weak zone at 1 and 3 Myr, respectively. Colors show $\log_{10}\eta_{\text{eff}}$, where η_{eff} is effective viscosity in Pa·s; white arrows show velocity vectors with a reference magnitude of 2 mm/yr, and black contours denote the 600, 1000, and 1400 K isotherms.

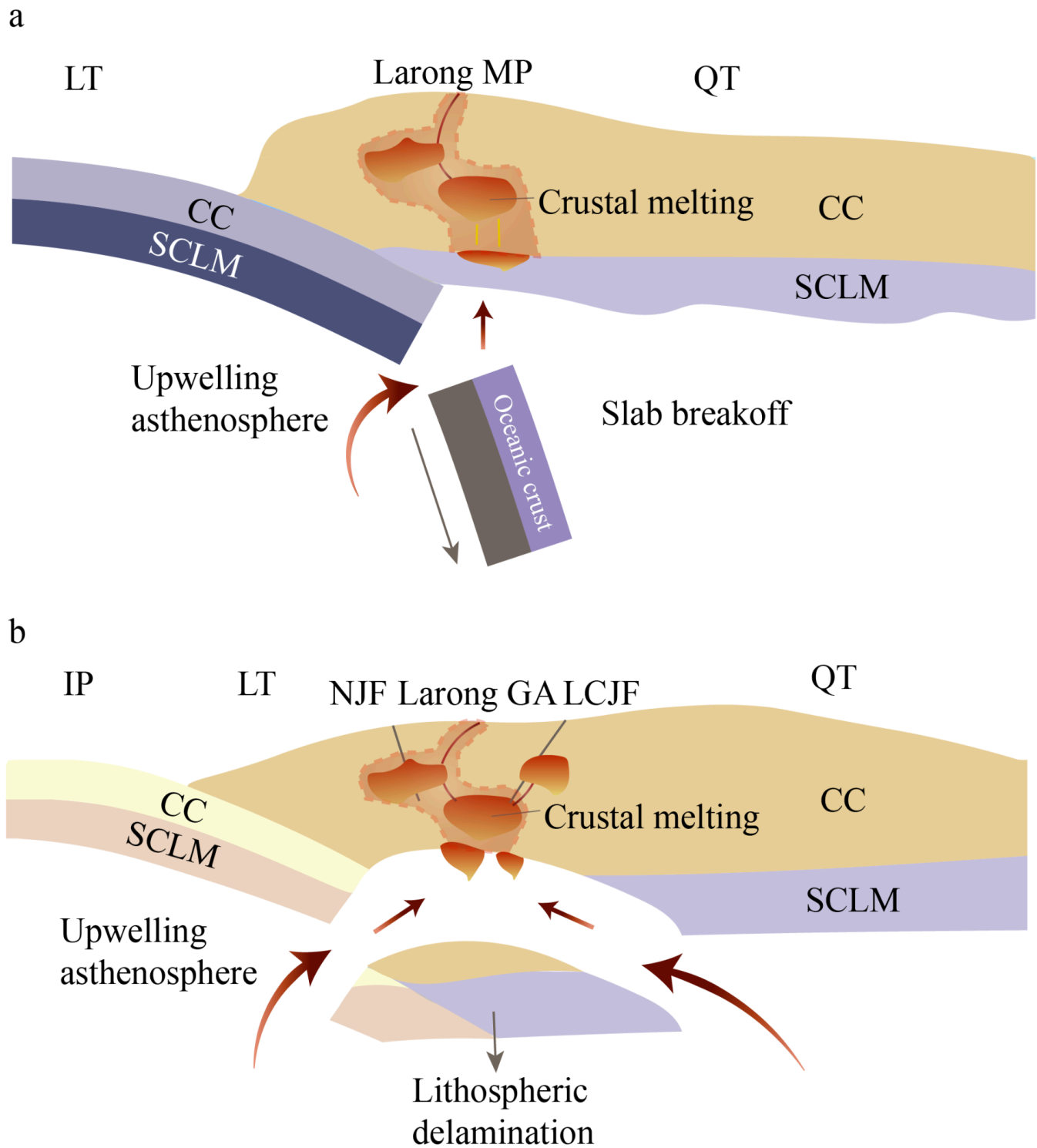


Figure 5

Conceptual model for the establishment and reactivation of an inherited tectono-magmatic pathway beneath Larong. **a** During Late Cretaceous magmatism at ca. 97-87 Ma, deep thermal input promoted crustal melting, magma accumulation, and differentiation. The pathway focused magma and magmatic-hydrothermal fluids toward Larong, where emplacement of the monzogranite porphyry at ca. 93 Ma was associated with the principal W-Mo mineralization. **b** During Eocene post-ore magmatism at ca. 43-35

Ma, renewed deep thermal perturbation and crustal melting reactivated the pathway, allowing emplacement of the ca. 36 Ma granite aplite along regional structures. In this interpretation, the later intrusion reused the inherited pathway without documented W-Mo mineralization of comparable scale. The regional tectonic context follows Liu et al.¹⁴. IP, Indian plate; LT, Lhasa terrane; QT, Qiangtang terrane; CC, continental crust; SCLM, subcontinental lithospheric mantle; NJF, Nujiang fault; LCJF, Lancangjiang fault; MP, monzogranite porphyry; GA, granite aplite.

Supplementary Files

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- [NCSupplementaryMaterial0915.pdf](#)