Tectonics of convergent plate margins: New insights into continental geology

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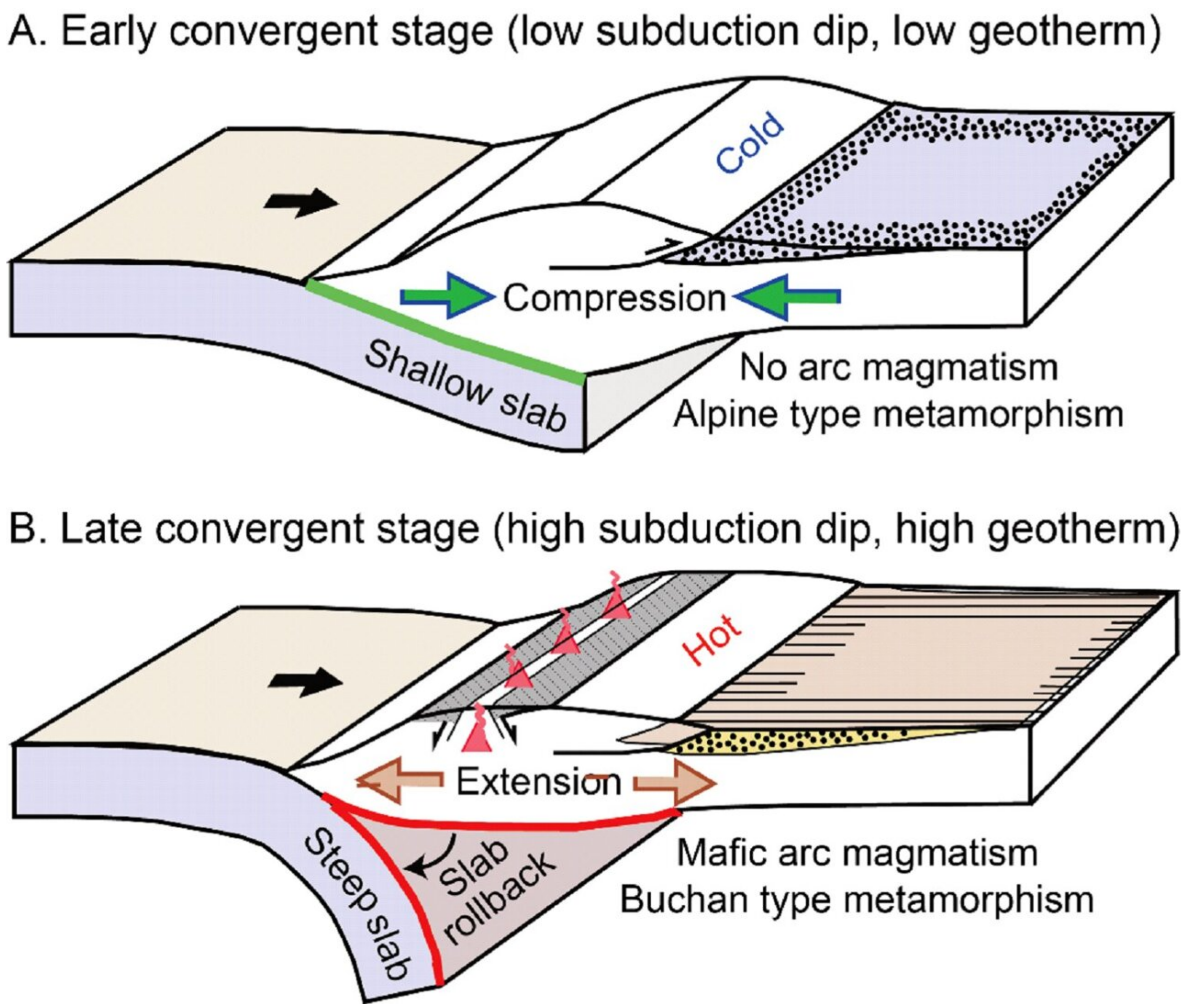

(a) Low-angle subduction, compressional regime prevails in the overlying plate. Because the plate interface is at low geothermal gradients, the subducting crust experiences ultrahigh pressure eclogite facies metamorphic dehydration at subarc depths, where partial melting of the hydrated small mantle wedge does not immediately happen and thus lack of arc magmatism. (b) High-angle subduction, rollback of the subducting slab results in its decoupling with the mantle wedge at subarc depths, leading to elevation of the geothermal gradient in the subduction zone and switch to extensional regime forming lithospheric rifting in the overlying plate. This would cause not only dehydration melting of the subducting crust but also partial melting of the metasomatites in the small mantle wedge. Credit: Science China Press

A study led by Prof. Yong-Fei Zheng at University of Science and Technology of China focused on the development of tectonic processes along convergent plate margins through inspection of recent advances in the fields of geology, geochemistry, geophysics and geodynamics. These advances are fundamental to our understanding of various phenomena at active and fossil plate margins, providing new insights into many first-order problems regarding geological occurrences in the interior of continents. They have great bearing on the transformation from accretionary and collisional orogens along actively convergent margins to rift failure orogens due to reactivation of fossil suture zones.

Convergent plate margins occur when two adjoining tectonic plates come together to form either a subduction zone, where at least one of the converging plates is oceanic and plunges beneath the other into the mantle, or a collision zone, where two continents or a continent and a magmatic arc collide. Convergent plate margins are arguably the most dynamic plate boundaries on Earth and have been the subject of many investigations and discussions since the advent of plate tectonic theory in the middle 1960s. They show the varied, heterogeneous and complex structure in both space and time due to the multiple geological, physical and chemical processes operating at these zones. Although the largest portion of convergent systems is hidden deep beneath the surface, Zheng and his colleagues have recognized a series of fundamental similarities and differences between active and fossil convergent plate margins.

According to the geometric structure, dynamic regime and thermal state of convergent plate margins, Zheng and his colleagues categorize them into three stages during their formation and evolution. The early stage is characterized by low-angle subduction in a compressional regime at low geothermal gradients, giving rise to Alpine to Barrovian type metamorphism but no mafic arc magmatism. The late stage is associated with high-angle subduction in an extensional regime at high geothermal gradients, giving rise to Barrovian to Buchen type metamorphism and mafic arc magmatism. The post stage is characterized by extensional regimes at high geothermal gradients with neither subduction not collision, giving rise to Buchan type metamorphism and granitic magmatism.

The formation of Alpine type blueschist facies to eclogite facies metamorphic rocks marks the subduction at low geothermal gradients, and the formation of Barrovian type amphibolite to granulite facies metamorphic rocks in the kyanite stability field indicates the collisional thickening at medium geothermal gradients through compressional shortening. Zheng and his colleagues have found two steps during the transformation from subduction zones to rifting zones. The first step is the foundering and thinning of the thickened lithosphere at convergent plate margins, and the second step is the asthenospheric upwelling to fill the space of lithospheric thinning and to transfer heat from the deep mantle to the shallow crust. This results in a significant increase in geothermal gradient and causes the thickened crustal rocks to undergo Buchan type anatectic metamorphism under upper amphibolite to granulite facies conditions in the adalusite to sillimanite stability fields.

As generalized by Zheng and his colleagues, material movement at convergent plate margins proceeds in the bottom-up and top-down ways, respectively, corresponding to changes of their thermal state from hot to cold and from cold to hot. In subduction zones, the cold lithosphere sinks into the hot asthenosphere, leading to cooling of the Earth's interior. In rifting zone, both heat and material are transferred rifting from the asthenosphere into the crust, resulting in heat loss from the Earth's interior to exterior. Because subduction and rifting are two key mechanisms for the mass and energy exchange between the Earth's spheres, identifying and distinguishing both tectonic mechanisms and their roles in the formation and evolution of convergent plate margins are the forefront area and major focus of future researches in Earth system science.

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