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Contrasting styles of plate subduction: The role of continental mantle lithosphere rheology on the burial and exhumation of crustal rocks

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The dynamics of burial and exhumation of crustal rocks have often been investigated in terms of conventional plate subduction process. It is generally supposed that subducting (i.e. lower) plates do not create much disturbance on the upper plate, hence the subduction is one-sided. This basically means the coupling between the upper and lower plate is weak enough to prevent such disturbance. However, pre-existing conditions of continental mantle lithosphere (i.e. hydrated vs. dry) can modify the rheology, control the amount of coupling and influence the burial and exhumation process of crustal rocks. We investigate the effect of continental mantle lithosphere rheology on the subduction process as well as on the burial and exhumation of crustal rocks by using 2-D numerical models for the setting transitioning from oceanic subduction to continental collision.

We show that plate coupling and peak pressure-temperature conditions of buried and exhumed crustal rocks can be strikingly different depending on the rheology of continental mantle lithosphere. The models using a weaker rheology for both upper and lower plates (i.e. hydrated continental mantle lithosphere) give high-pressure (∼9 kbar - 22 kbar) / low temperature (350 C – 630 C) conditions, whereas models with stronger rheology (i.e. dry continental mantle lithosphere) result in ultra-high pressure (∼35 kbar) / high temperature (∼750 C) states.

In the weaker rheology case, the upper plate is highly disturbed and subduction is two-sided (i.e. ablative). Crustal rocks are effectively enclosed in ablatively subducting continental mantle lithosphere, and are exhumed due to dripping of the viscous lithospheric root. This variation from subduction to the dripping mode of 'vertical tectonics' ensures controlled temperatures for the crustal rocks and prevents advection of hot and buoyant asthenosphere into the subduction channel during the burial phase. The whole process is driven by the buoyancy forces with no resort to far-field plate convergence.

In the stronger rheology case, there is not much disturbance in the upper plate, and subduction is one-sided. 'Plate-like' subducting slab decouples from the upper plate, and delamination of mantle lithosphere results in hotter temperatures beneath the crust. Crustal rocks are buried down to >100 km depths, and are exhumed to near-surface facilitated by asthenospheric mantle intrusion into the subduction channel. The lithostatic pressure applied to the rocks increases from ∼28 kbar to ∼35 kbar by increasing imposed far-field plate convergence velocity from 4 cm/yr to 5 cm/yr.

The predicted pressure-temperature conditions for crustal rocks in models with contrasting continental mantle lithosphere rheologies (i.e. weak vs. strong or hydrated vs. dry) are compared to natural data. The results are in good agreement with peak pressure-temperature estimations from various (ultra-)high pressure terranes. We propose that the exhumation of high pressure / low temperature metamorphic rocks prevalent in Tavşanlı and Afyon Zones in western Anatolia may be caused by viscous dripping of mantle lithosphere implying a weaker rheology, whereas (ultra-)high pressure exhumation of crustal rocks in Dora Maira-western Alps, or Dabie Shan-eastern China may be explained with plate-like subduction indicating a stronger rheology.