Petrological Systematics of the Electrical Conductivity Structure of Continental Subduction Arc-Extensional Backarc Regimes Including Closure and Stabilization

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The Wilson Cycle of continental margin formation, subduction, and closure represents a fundamental system of heat, volatile and material transfer shaping Earth and life evolution. The rock physical property of electrical conductivity can serve as a tracer for cycle processes. In this presentation, I attempt to follow aspects of conductivity evolution from initiation of subduction at a former passive margin, establishment of a volcanic arc system, development of an extensional back-arc regime, plate reorganization and possible slab breakoff/delamination, and final closure. Mechanisms of conductivity are diverse, and can include solute-bearing fluids, melts, intracrystalline defects including hydrous ones, and solid phases principally graphite. Mechanism domains and magnitudes are defined by ambient P-T-X state, mainly assuming equilibrium conditions. In particular, numerous conductivity mechanisms are strongly thermally activated such that constraints on temperature are of primary value in reducing non-uniqueness of interpretation.

At transpressive subduction initiation, crustal thickening occurs leading to lower crustal fluid production via Barrovian metamorphism detectable as high conductivity. Along the early-formed slip plane, upper and lower plate coupling is tight leading to substantial shearing that promotes backbone fault element creation and long range interconnection of conductive exsolved fluids. In established subduction, metasomatized oceanic crust releases volatiles shortly after encountering the mantle wedge, with prograde transition to eclogite creating a conductive fluid phase rising to the lower crust until the arc is reached. Wedge flux melting below and behind the arc may produce conductive mantle structure overlain by crustal melt underplating and mid-crustal storage.

Deeply extending subduction since late Archean time may have introduced several current ocean volumes of H_2O to the mantle. Under relatively cool conditions near the slab interface, released fluids may stabilize through the upper mantle in hydrous minerals such as phlogopite or amphibole and contribute little to conductivity. These minerals however at average upper mantle adiabatic temperatures would break down to form water-undersaturated melt, which could conduct if interconnected over regional distances and remain mechanically stable. The fractional water activity pertaining to this melt condition also determines the maximal concentration of hydrous defects in the nominally anhydrous peridotite minerals (NAMs), which laboratory measurements show may also contribute to bulk conductivity but not to lowering seismic velocity or Q.

Carbonate altered oceanic crust and possible residual carbonate sediments are estimated to carry orders of magnitude more CO_2 into the mantle than is contained in the crust or exosphere. Carbonate could be flushed upward by dehydration of oceanic crust, but ultra-deep diamonds indicate some is carried to the mantle transition zone. Slab geotherms reach carbonatite melting in the lower half of the upper mantle. If conditions are sufficiently oxidizing, these highly grain-wettable and conductive melts could migrate into higher temperature peridotite evolving to carbonated silicate melts. Current models of upper mantle oxidation state suggest that in the lower half of the upper mantle these melts should reduce to diamond, although channelized flow to higher levels is conceivable. Carbon isotopes of inclusions recovered from the shallowest mantle show juvenile values and commonly ancient origin. They form a portion of the often extensive metasomatism characteristic of mantle lithosphere including hydrous and exotic phases in typically veined textures arriving as complex lower temperature melts from depth.

Subduction ends with ocean closure and continental collision or plate reorganization. Breakoff and replacement with upwelling asthenosphere is a commonly invoked fate for the subducted slab and represents a back-arc field that becomes extensional. Basaltic magmas generated in upwelling fusion may underplate the lower crust, hybridize, and release saline H2O-CO2 fluids. Host lower crust is typically of high metamorphic grade, and compatible fluids must be of low water activity. High salt contents create such fluids, which are grain-wettable and highly conductive, and are immiscible with CO2 yielding two fluid phases. Experiments suggest these brines could be stable in high grade rocks down to ~550C, which is similar to the temperature estimated for the tops of lower crustal conductors in such domains. High-angle, crustal scale faults in extensional regimes can tap such fluids across the brittle-ductile transition that lead to magmatic indicators in near-surface geothermal systems and are conductive. Upon cooling, the CO2 phase either precipitates in quartz-carbonate veins or as graphite depending on host rock oxidation state, which is suggested to explain some conductors at depth in old, stable terrains.

Magmatically- or metamorphically-derived graphite as above is distinct from the regional-scale, highly-conductive, sinuous graphite/sulfide belts observed in conductivity surveys across continental suture zones. Such conductors were concentrated in the particularly active Paleoproterozoic and Neoproterozoic orogens which corresponded with global major oxygenation events. Nutrients delivered to the shallow marine environment through erosion spawned major blooms of cyanobacteria, which scavenged sulfide and deposited on the seafloor, and transformed to graphite in subsequent orogeny.

This trip through conductivity expressions of the Wilson cycle will be illustrated using global examples of deep-probing magnetotelluric (MT) surveys in active and fossil terranes.