Fundamental discoveries about the growth and recycling of continents

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A paradigm-shifting discovery about the volumetric growth of terrestrial crustal material, i.e., the rocky stuff of continents and island arcs, arose largely serendipitously from scientific ocean drilling. Growth of continents and island arcs over a period of time principally reflects the net balance of new igneous rocks extracted from the mantle and added to the terrestrial-sphere, minus the mass of terrestrial matter recycled or returned to the mantle at subduction zones (see figure). Although the geochemistry of arc-volcanic rocks had suggested the possibility, in the late 1960s, at the beginning of scientific ocean drilling, the subduction zones were thought to be where material was added to the terrestrial-sphere. The notion that terrestrial material could be recycled to the mantle was not seriously considered.

Notwithstanding the certainty of this wisdom, by the late 1970s scientific ocean drilling began to turn up evidence that, in fact, at deep-sea trenches ocean-floor sediment is injected into the underlying mantle by processes of sediment subduction, which were set in motion by the subsurface sinking or subduction of oceanic plates. This revelation was accompanied by the unexpected discovery of evidence that the subducting lower plate of oceanic crust tectonically erodes the overlying plate of terrestrial crust, and that this material was also recycled to the mantle [*von Huene and Scholl,* 1991]. The concept of subduction erosion, similar to that of sediment subduction, had been previously proposed based on geologic studies, but was equally widely ignored on the grounds of counter-intuitiveness [*Scholl et al.,* 1980]. By the mid 1980s, trace-element and isotopic studies of ocean-floor sediment and arc eruptive rocks independently confirmed that terrestrial crustal material was being recycled at subduction zones. This convergence of separate lines of information, both made possible by scientific ocean drilling, meant that the mantle did not evolve as a closed system, but as one open to the input of material from Earth's overlying terrestrial-sphere. To roughly quote a colleague: "It's now clear that over geologic time continental debris has been trashing the mantle's chemistry." At this point questions turned to figuring out the rate at which chemical trashing has been occurring [*Scholl et al.,* 1996].

Quantitative information about rates of sediment subduction and subduction erosion has been gathered by scientific ocean drilling bordering Japan, the Marianas, Tonga, Chile, Peru, Costa Rica, Guatemala, Mexico, Alaska, and the Aleutians. Data from these sectors of the Pacific rim imply that, globally, the long-term (> 5-10 my) rate at which sediment is globally subducted to mantle depths is conservatively estimated at 0.7 km^3/yr (solid-volume). Upper plate material loss by subduction erosion is at least 1.0 km^3/yr. The global mass of subcrustally subducted terrestrial material is thus about 1.7 km^3/yr [*von Huene and Scholl,* 1991].

Subcrustally subducted material is either melted and returned to the terrestrial crust by arc volcanic processes, or added to the bottom of the terrestrial plate by underplating processes, or injected downward deep into the mantle by mixing processes (figure). Geochemical and isotopic data and the rock framework of coastal mountain belts imply that much of the subducted terrestrial material is recycled to the mantle, probably at a rate near 1.5 km^3/yr. If this rate is applicable over long periods of geologic time, then during the past 2.5 billion years (~half of Earth history) about 50% of the mass of terrestrial crust made before or during this time has been recycled.

Intriguingly, present estimates of the global rate of formation of new or juvenile terrestrial crust is also about 1.5 km^3/yr. If these formation and recycling figures are accurate, then during the recent geologic past Earth's store of terrestrial rock (8×10^9 km^3) has remained roughly the same. This balanced model matches predictions based on geochemical models of mantle evolution that permit an open system of terrestrial crustal recycling. The scientific results of the ODP have thus unexpectedly contributed to a paradigm shift toward understanding the growth history of our landmasses and the chemical evolution of the underlying mantle that involves a slow but continuous exchange of materials.

References:

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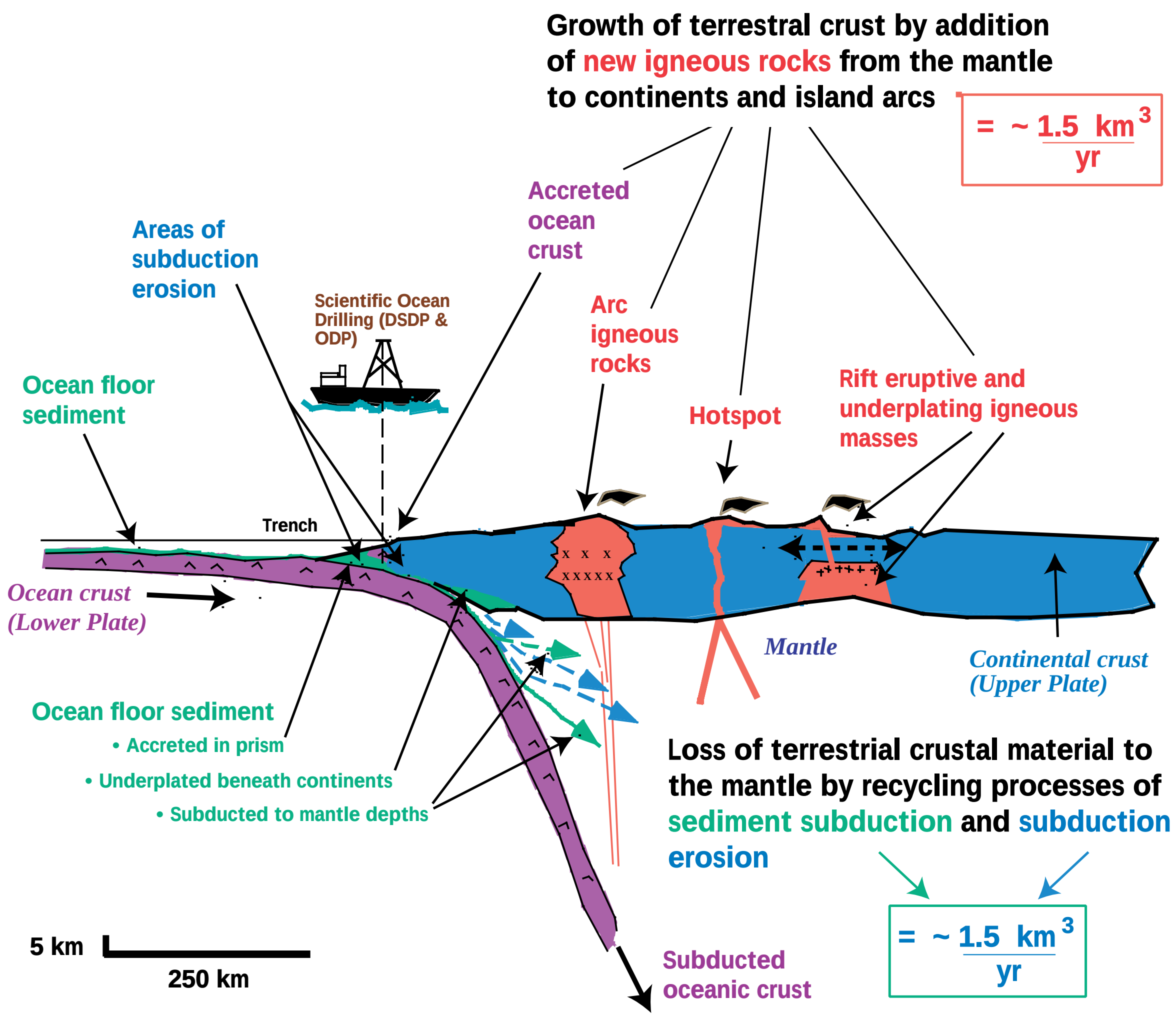
Growth of terrestral crust by addition of new igneous rocks from the mantle to continents and island arcs
= ~ 1.5 km³/yr
Accreted ocean crust
Areas of subduction erosion
Scientific Ocean Drilling (DSDP & ODP)
Arc igneous rocks
Hotspot
Rift eruptive and underplating igneous masses
Ocean floor sediment
Trench
Ocean crust (Lower Plate)
Mantle
Continental crust (Upper Plate)
Ocean floor sediment
• Accreted in prism
• Underplated beneath continents
• Subducted to mantle depths
Loss of terrestrial crustal material to the mantle by recycling processes of sediment subduction and subduction erosion
= ~ 1.5 km³/yr
5 km
250 km
Subducted oceanic crust