RECYCLING PROCESSES AND FLUID FLUXES IN SUBDUCTION ZONES

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Earth's surface is covered by about 43,500 km of active subduction zones, dynamic arcs where one lithospheric plate descends beneath another (see figure). About a dozen of these zones have been sampled by the ODP and imaged by geophysical and geochemical means. The results have advanced our knowledge of (1) the mass fluxes into these systems, (2) the central role fluids play in the mechanical, thermal, and geochemical evolution of subduction zones, and (3) the chemical and isotopic compositions of these fluids. All of these provide new insight into key questions: how does recycling in this tectonic setting affect the chemical budgets of the ocean and mantle on various time scales and what relationships exist between earthquake cycles and the generation and flow of fluids?

The subducting oceanic plate and overlying sediment are porous and contain variable amounts of hydrous and carbonate minerals. With the increasing temperature and pressure that are encountered in subduction zones, compaction, diagenesis, and metamorphism expel fluids at various rates and depths. Chemosynthetic benthic biological communities, sustained by venting volatiles (i.e., H, C, O, N, S), are the most direct evidence that significant amounts of fluids are expelled and returned to the ocean [*Kulm et al.,* 1986]. These fluids are chemically and isotopically very different from seawater, therefore, their fluxes must be known to better understand these communities and global geochemical budgets.
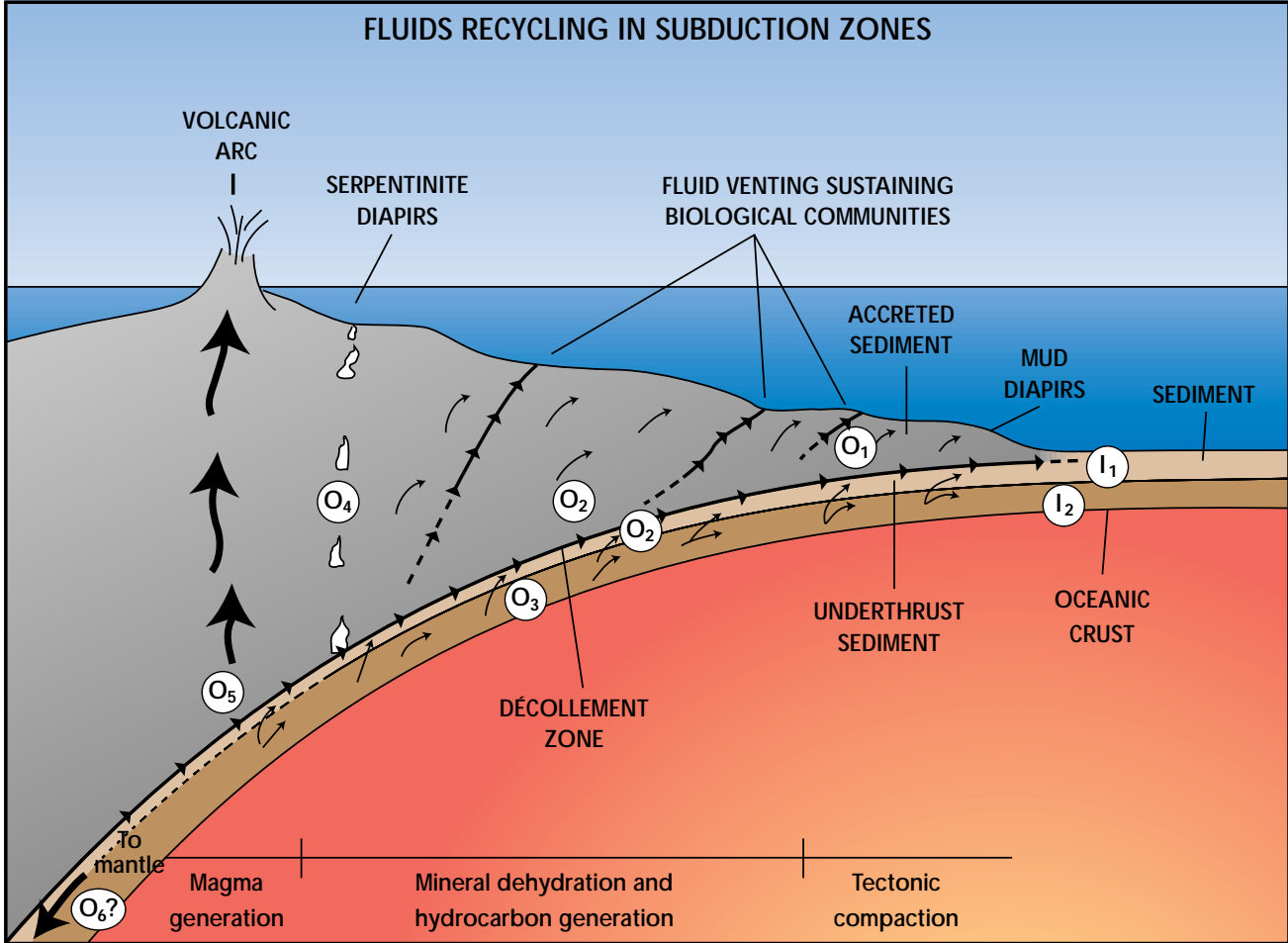
The most important characteristic of these fluids is that they are fresher than seawater. When normal seawater mixes with water that is driven off hydrous minerals, the chloride concentration in the resulting fluid is depleted by 20 to 65 percent [*Kastner et al.,* 1991]. Subduction zone fluids are also enriched in B, Li, Ca, Sr, and Ba and have variable H, O, C, B, Cl, and Sr isotope ratios. High methane concentrations are also characteristic of many subduction zones, often leading to the formation and accumulation of gas hydrate deposits when appropriate temperature and pressure levels are encountered. Methane hydrate is the most common natural gas hydrate in the marine environment, storing about 10,000 gigatons of carbon globally [*Kvenvolden,* 1988]. Subduction zone fluids also reach great depths and have been incorporated in magmas, as demonstrated by [10]Be and

[207]Pb data in volcanic arcs. Such recycling is also reflected in the minor and trace element chemistry of arc magmas [*Tera et al.,* 1986, *Plank and Langmuir,* 1993]. Compared to mid-ocean ridge basalts, these magmas are enriched in water, B, Be, Sr, Ba, K, Rb, Sc, Pb, and U. In the early stages of subduction zone development, the pathways for flow are both diffuse and focused. Over time, however, compaction, deformation, and cementation increase the importance of focused flow, which becomes dominant.

Because the estimated global flux of fluids expelled by tectonic compaction and dehydration of the sediments and oceanic slab is 2 to 3 km^3/yr [*Von Huene and Scholl,* 1991], extrapolation suggests that all seawater in the global ocean cycles through subduction zones within 350 to 500 million years. The chemical and isotopic significance of such a global fluid flux is rather small. For example, this flux has no more than one to two percent of the impact that global networks of rivers and hydrothermal systems have on the rates at which the seawater levels of $^{87}Sr/^{86}Sr$ and Li change. However, geologists know that hydrologic flow, including the meteoric (e.g., rain) component, which returns to the ocean through continental margins, is much larger. How much of this hydrologic flow occurs through subduction zones is important, yet still entirely underconstrained. If we assume a hydrologic flow of 70 to 100 km^3/yr when constructing a global mass balance, then the chemical and isotopic fluxes of some elements and isotope ratios are considerable, perhaps equal to or even exceeding riverine or hydrothermal fluxes.

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FLUIDS RECYCLING IN SUBDUCTION ZONES

VOLCANIC ARC

SERPENTINITE DIAPIRS

FLUID VENTING SUSTAINING BIOLOGICAL COMMUNITIES

ACCRETED SEDIMENT

MUD DIAPIRS

SEDIMENT

O_1

O_4

O_2

O_2

I_1

I_2

O_3

UNDERTHRUST SEDIMENT

OCEANIC CRUST

O_5

DÉCOLLEMENT ZONE

To mantle

O_6?

Magma generation

Mineral dehydration and hydrocarbon generation

Tectonic compaction

I = Input   O = Output

= Diffuse fluid flow

= Focussed fluid flow along the décollement and other high permeability faults

FLUID MASS BALANCE

$I_1 + I_2 = O_1 + O_2 + O_3 + O_4 + O_5 + O_6 + R$

I_1 = Sediment with pore fluid

I_2 = Hydrated oceanic crust

O_1 = Tectonic compaction

O_2 = Dehydration of hydrous minerals and hydrocarbon generation

O_3 = Dehydration of oceanic crust

O_4 = Serpentinization and diapirism

O_5 = Magma generation

O_6 = To mantle (?)

R = Residual fluid