The Permeability Structure of Oceanic Crust and Implications for Subduction Zone Hydrology

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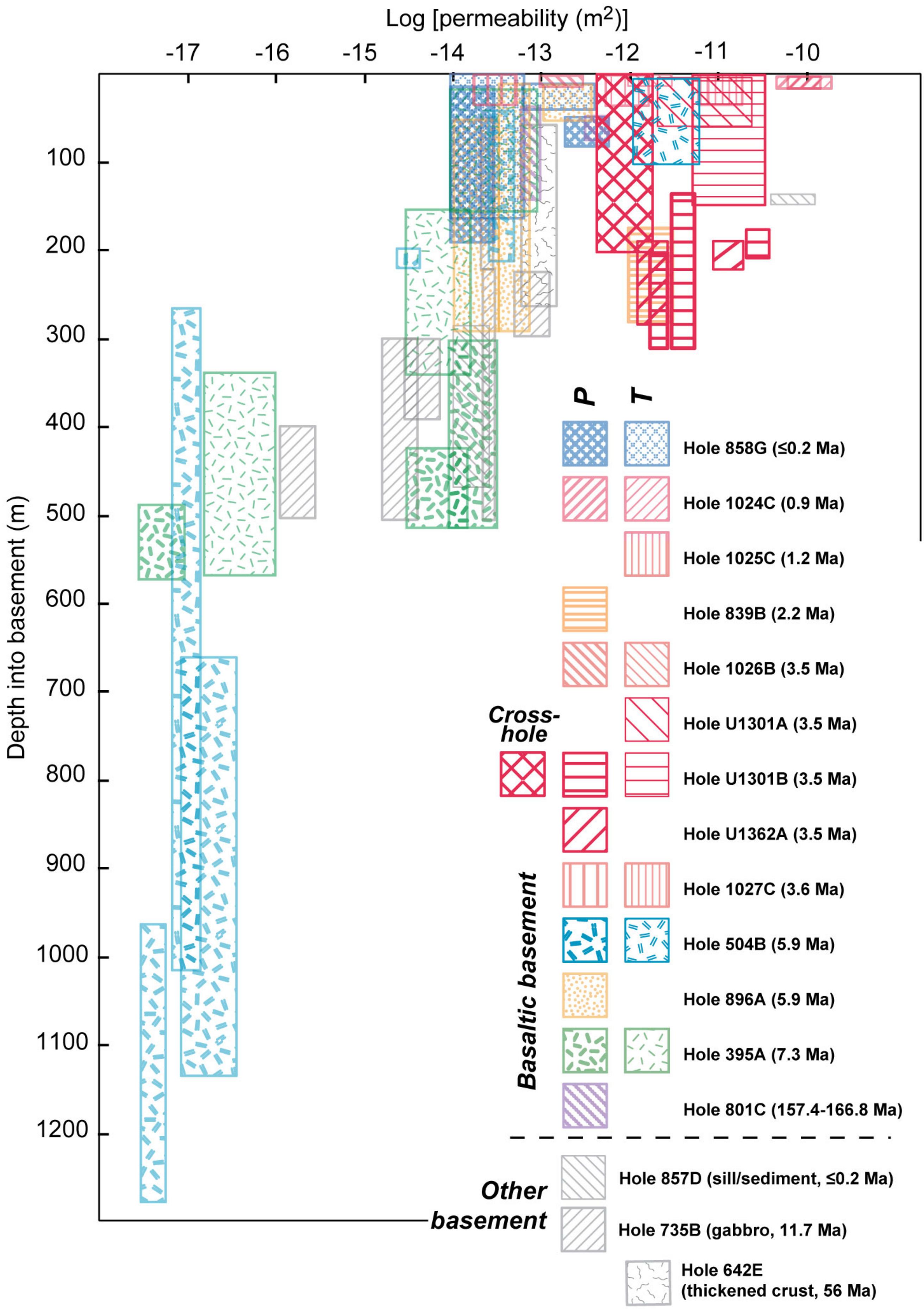
We review investigations of the permeability structure of the oceanic crust with a specific focus on implications for hydrogeological processes in incoming plates at subduction zones. Direct determinations of permeability require sampled materials or boreholes, so the cores and holes of DSDP, ODP, and IODP have been crucial to our understanding of ocean crustal permeability. Important techniques have included wireline logs, borehole temperature profiles, in-situ packer experiments, long-term records obtained with CORK sealed-hole hydrological observatories, and comparison of such in-situ results with constraints from numerical simulations.

Early DSDP packer measurements in 6-7 Ma off-axis settings suggested a simple layered permeability structure for upper oceanic basement in young ridge flanks, with a few hundred meters of permeable uppermost pillow lavas underlain by much less permeable deeper pillows and sheeted dikes. In ODP and IODP, there have been important new results on several fronts. Packer measurements and borehole flow permeability estimates have been completed in holes in oceanic crust spanning a wider range of age (0-12 Ma and 160 Ma; see attached figure). Permeability at larger spatial scales has also been estimated at some of these sites using other direct and indirect techniques including (a) analyses of the response of pressures recorded in sealed-hole CORK experiments to seafloor tidal loading and co-seismic deformation, and (b) numerical simulations of the nearly isothermal uppermost basement temperatures observed in paired ridge-flank CORK sites where there is considerable basement relief and large variation in sediment thickness. Combined results indicate the following: (1) Permeabilities of uppermost basement in sedimented young oceanic crust are very high. (2) Permeabilities of uppermost basement in young crust seem to decrease systematically as the crust ages, consistent with the evolution of seismic velocities in Layer 2A. (3) Permeabilities within oceanic crust seem to display a scale dependence, possibly as the result of the highly heterogeneous distribution of the permeable network within oceanic basement. (4) Lateral fluid fluxes are very high, but the inter-connected "effective porosity" that contributes to high permeability and fluxes is quite low; this has significant implications for fluid residence times and reactions with host rock depending on position within the network. (5) Lateral fluid flow directions in young crust must have a signficant component subparallel to the ridge axes and dominant tectonic structures, contrasting with earlier conceptual models configured as sections normal to structural strike.

Clearly, if relatively young oceanic crust is being subducted, as at Nankai, Central America, and Cascadia, its high permeability must be considered a signficant factor in the hydrology of the subducting slab (and, therefore, seismicity, volcanic activity, and related processes), even before accounting for the effects of plate-bending faults that, depending on geometry, may cross or reinforce large-scale lateral permeability provided by ridge-parallel tectonic fabric. Permeability data are much sparser in oceanic crust older than 10 Ma, but the few data points also indicate high permeability where fault zones or structural discontinuities are encountered. There is almost no data from deeper oceanic crust, and the nature and hydrologic significance of deep reflectors that penetrate the ocean crust and extend into the upper mantle remain to be determined. Plate-bending faults could augment permeability in subducting ocean crust of any age, and this effect could be particularly important when older, otherwise less permeable crust is subducted.

Keywords: Ocean crust permeability, Subduction zone hydrogeology, Plate-bending faults


Log [permeability (m2)]
-17
-16
-15
-14
-13
-12
-11
-10
Depth into basement (m)
100
200
300
400
500
600
700
800
900
1000
1100
1200
P
T
Hole 858G (≤0.2 Ma)
Hole 1024C (0.9 Ma)
Hole 1025C (1.2 Ma)
Hole 839B (2.2 Ma)
Hole 1026B (3.5 Ma)
Hole U1301A (3.5 Ma)
Cross-hole
Hole U1301B (3.5 Ma)
Hole U1362A (3.5 Ma)
Hole 1027C (3.6 Ma)
Hole 504B (5.9 Ma)
Hole 896A (5.9 Ma)
Hole 395A (7.3 Ma)
Hole 801C (157.4-166.8 Ma)
Basaltic basement
Other basement
Hole 857D (sill/sediment, ≤0.2 Ma)
Hole 735B (gabbro, 11.7 Ma)
Hole 642E
(thickened crust, 56 Ma)