d4 Crust, mantle, and core < compositional and physical layering >

If the Earth were an apple, the deepest holes yet sunk by geologists would still not begin to penetrate the skin. —Bill Bryson, *A Short History of Nearly Everything,* 2003.[1]

Atmosphere, hydrosphere (rivers, lakes, groundwater and oceans), cryosphere (glaciers, permafrost and floating ice), unconsolidated sediments, and biosphere (where life exists),[2] are the outer part of Earth comprised of crust (top layer), mantle (medial layer), and central core.

The *crust* is 1 percent of Earth's volume. It is rocky (except for small volumes of lava and magma) and it can be directly sampled in outcrop and to shallow depths. Record mined depths are to 4 km (rock temperature 140 ºF) in ultradeep gold-and-platinum mines in the Witwatersrand continental basin, South Africa.[3] Drilling depths achieved are to 12.3 km (rock temperature 245ºC) in the continental rocks of the Kola peninsular, Russia. To scale, the crust is vanishingly thin. Its bottom boundary is called the *Moho*, named after its discoverer **Andrija Mohorovičić**.[4] In *continental* areas, the crust's thickness averages 36 km. Its local thickness is related to the age of the last tectonic event there and varies from 10-80 km in active regions and is about 25-35 km beneath stable low-lying plains. (The continental crust of North America has an average thickness of 36.5 km, ranging between 14 km and 60 km, and is uniformly thickest at 42 km where Late Proterozoic in age.) The density of the continental crust is 2.8 ± 0.1 gm/cc. Its chemical composition varies greatly on all scales but its average composition is that of andesite.[6] Continental rocks are many times reworked accumulates of plutonic, volcanic, metamorphic, and sedimentary rocks.[7] Quartz grains large enough to be seen are common in continental rocks. For that reason, the continental crust is usually said to be "granitic" (visible quartz grains is an identifying feature of granite). In *oceanic* areas, the crust's thickness beneath the seafloor varies from 4-8 km. Upon it is a veneer of seafloor sediments (ooze) of density ~2.3 gm/cc. Beneath this (***Footnote d4.1***), the oceanic crust is either serpentinite (metasomatic, reacted-with-seawater peridotite) or it is "basaltic" (volcanic basalt flows and pillows, density ~2.85 gm/cc, basalt feeder dikes for the flows, density ~2.9 gm/cc, and intrusive gabbro, density ~3.0 gm/cc). There are large igneous provinces totaling 10 percent of the ocean area where the basaltic oceanic crust thickness is 30 km or more.

Andrija Mohorovičić (1857-1836). A Wiechert (an early type of seismograph) that he installed at the Zagreb meteorological observatory, recorded in the same year the Pokupsko (Kupa Valley, Croatia), October 8, 1909, earthquake. Pairs of P- and S-wave arrivals were clearly evident. From these he reasoned that a major velocity discontinuity demarks the base of the crust. This was at surprisingly shallow depth (54 km, was his estimate). Seismic travel times are slower above and abruptly faster below this boundary.[5]

The *mantle* is below the crust and is separated from it by a distinct seismic and compositional discontinuity called the *Moho*. The ultramafic rock of the upper mantle just below the Moho has a density of ~3.3 gm/cc. The mantle accounts for 84 percent of Earth's volume. Locally, by upthrusting (obduction) it crops out. Mantle rock there and in kimberlite xenoliths is found to be a "marble cake" of eclogite (clinopyroxene + garnet + quartz which subducted crustal basalt or gabbro crystallizes to at pressures >2.5 Pa)[8] and varieties of peridotite: dunite (>90% olivine), harzburgite (olivine + enstatite), and lherzolite (olivine + enstatite + diopside + an Al-rich phase that, as set by pressure, may be plagioclase, spinel or pyrope-rich garnet)(***Figure d4.1***).[9] Mantle elements are mostly oxygen, iron, magnesium, and silicon. Unlike in continental crustal rock, aluminum is present only in small (but in chemically significant) amounts. The mantle is modeled as compositionally homogeneous at any level when seismically detected small lateral density (rigidity) variations are interpreted as temperature variations. At depth within the mantle, silicate minerals of the Fe/Mg rich peridotite cannot exist because of the higher temperature and pressure, and the rock below about 410 km must consist of high pressure-temperature silicates as garnet and simple oxide minerals as wadsleyite with a spinel crystal structure (as would replace olivine but can hold water and, by its abundance, as much as all the ocean Joseph R. Smyth calculates).[10] Below about 660 km, through to the bottom of the mantle at 2,883 km depth, is the lower mantle. Within it, pressure packs oxygen about silicon in an octahedral arrangement—six compressed oxygen atoms (instead of the four at lower pressure) surround each silicon atom. The iron and magnesium silicate, with silicon-oxygen octrahedra building blocks is called *perovskite* (as would replace spinel). The remainder of the iron and magnesium exists as magnesiowüstite which is an oxide with cubic lattice (like crystalline NaCl but highly compressed). The lower mantle is thought to be 95 percent composed of magnesiowüstite and a magnesium-rich form of perovskite, and 5 percent a calcium-rich form of perovskite. Motohiko Murakami in 2002 found that the former two can hold up to 0.2 percent of their weight in water and the latter 0.4 percent: The total amount of water in lower mantle minerals could equal five times that of Earth's oceans! [11]

Mantel (German for *coat*) was first used in 1897 by E. Weichert to picture Earth’s rocky outer shell wrapped about its Mars-sized metallic core that Newtonian mass and moment of inertia considerations indicate must exist.[12]

The *core* accounts for 1/3 of Earth’s mass. It begins just before halfway to Earth’s center and is 15 percent of Earth’s volume. Geophysics, and the study of meteorite compositions, together indicate that the core’s composition is Fe (85%), Ni (5%), Si (4-5%), S (1.9%), and O (possibly >1%).[13] The core’s density is 13.5 gm/cc (some 6 to 10 percent less than pure liquid iron would have at the pressures that exist there). Radioactive elements are not present. The core’s heat is primordial.[14]

The Earth’s core radius is 3473 km (Earth’s equatorial radius is 6378.137 km).[15] The core is molten in its uppermost 2252 km. Earth's main magnetic field is due to convection and electric currents in the molten outer core. As Earth cools, iron crystals from the molten outer core snow out and accrete to form the inner core the existence of which was first established in 1936 by Danish seismologist (Miss) **Inge Lehmann** (1888-1993) from studies of the refraction of seismic P-waves.[16] She found its present radius to be 1221 km. Under overburden high-pressure of 330 GPa (Gigapascals) and absence of internal radioactive heat sources, the inner core stays frozen at a temperature estimated to be between 3500 and 6000 kelvins. LASA (Large Aperture Seismic Array, NM) focused-study findings are that heterogeneity of the inner core is pronounced in its outer 200 km, and that the inner core is not a single iron crystal.[17] ❑

Footnote d4.1 In 1961, near Guadalupe Island, Mexico, five holes were drilled under 11,700 feet of water. One extended through 557 feet of sediment (seismic Layer 1) in which the lowest bed was Miocene in age and a further 34 feet of basalt below (into seismic Layer 2). This success was Phase I of the then abandoned Project Mohole that Walter Munk[18] in 1957 had suggested to retrieve a sample of the mantle by drilling a hole through the crust.[19]

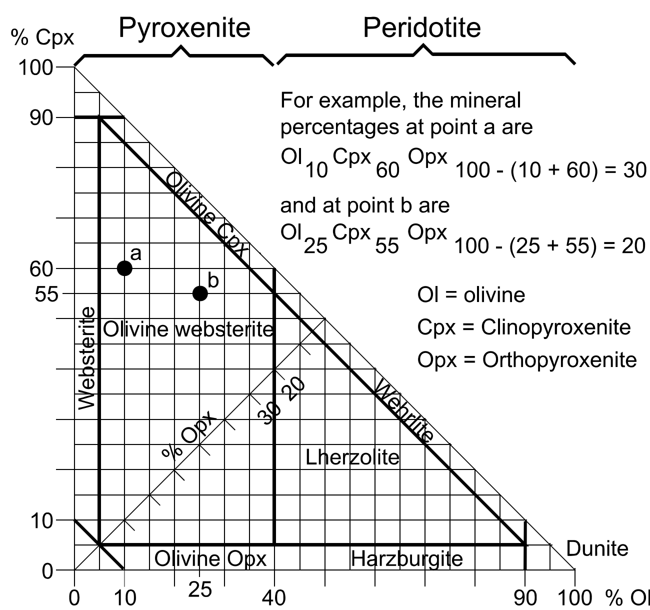

Figure d4.1 Olivine and two varieties of pyroxene are essential minerals for naming, by their % volumes, coarse-grained ultrabasic igneous and metamorphic rocks. Pressure (P) sensitive, Ca- and Al-bearing accessory minerals that may be present are: plagioclase (P<10Kb), spinel (10Kb<P<20Kb), or pyrope-rich garnet (P>20Kb). Mantle peridotites occur in tectonically-emplaced slices of oceanic lithosphere, referred to as ophiolites, and as xenoliths of spinel lherzolite in alkali olivine basalt and of garnet lherzolite in kimberlite.[20]