A Digital Earth's Crust for Modeling Continental Fluid Flow

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Fluid flow in the earth's crust is driven by the product of material permeability and the hydraulic gradient (Darcy's Law). The fact that permeability in natural earth materials varies over 13 orders of magnitude [Freeze and Cherry, 1979] makes it essential to quantify the distribution of this parameter throughout the earth's crust if we hope to understand fluid flow and the associated mass and energy transport, and its role in earth processes from the land surface downward.

Significant permeability exists from the land surface to the base of the crust and a quasi-exponential decay with depth has been inferred from inverse modeling of thermal and metamorphic fluxes [e.g., Manning and Ingebritsen, 1999; Rojstaczer, et al., 2008]. In the lower part of the crust (> ~5km), fluid migration affects fundamental geologic processes such as ore deposition, hydrocarbon maturation and migration, seismicity and metamorphism [e.g., Garven, 1995; Ingebristen and Sanford, 1998]. In the middle part of the crust (~50m-5km) sedimentary rocks form aquifers that hold the largest store of terrestrial freshwater for societies and the memories of part climate change [e.g., Alley et al., 2002; Person et al., 2007; Lemieux et al., 2008a, 2008b]. Quantifying the stores and fluxes of freshwater aquifers of the world is a key challenge in managing water resources in the presence of ever increasing human demands and degradations. In the shallowest part of the crust (0-50m) life is made possible by the constant circulation of water and nutrients, and this is where the geosphere, the atmosphere, and hydrosphere and the biosphere most actively interact to form the so-call "critical zone" of earth surface processes [Brantley et al., 2007]. Understanding the fluid movement is a prerequisite to understanding the water, carbon and nutrient cycles of the earth's terrestrial system.

As we shift our scope from characterizing an individual aquifer or hydrocarbon reservoir or a small watershed toward characterizing the whole earth system with its large-scale and deep-time interactions among the biotic and abiotic spheres, our data needs also shifts: we need a full, 3-dimensional description of the earth's crustal permeability and porosity, from the land surface to ~20km depth, covering all continental land masses. This 3-D geovolume must have very fine spatial resolutions near the surface where great changes in space and time occur, with decreasing detail with depth. One can envision the entire land masses of the earth described in small cubes stacked together, each with different storage and permeability, through which fluid flow can be calculated. The Earth Cube framework is the perfect place and time to make this happen.

We have made millions and millions of measurements of the earth's crust, from geologic bore holes, to seismic profiles, to aquifer pumping tests, to detailed soil surveys. This huge amount of information is lying around as maps and cross sections in the drawers and hard drives of every geologic survey of the world and many individual academic and private investigators. We don't even have continental-scale maps of the depth to the bedrocks which represents a fundamental boundary for many near surface processes such as weathering, shallow groundwater flow, and soil formation. Global soil maps exist but it does not go below ~1.5m depth. Can we integrate this vast amount of spatial data from all kind of sources for the benefit of constructing a coherent, 3D description of crustal permeability of the land masses, so that we can begin to represent fluid flow in the subsurface in earth system models and elucidate its roles in the evolution of the earth system from the past to the present, and from the present to the future?

Indeed the permeability and porosity are only part of the ambition. The very geology of each cube, its type and age, determines the chemical weathering products as the fluids move through it [Durr et al., 2005], and hence the carbon and nutrient fluxes, and the biogeochemistry of the terrestrial and alluvial waters, and their interactions with the atmosphere and the coastal oceans, and so on.

To build such an Earth Cube is a huge challenge, requiring international coordination, interdisciplinary collaboration, and the determination on the part of geosciences community and their leaderships. The tectonics community is thinking along the same lines [Hammer et al., 2011], and so are the seismology community (http://www.earthscope.org/home), the geochemistry community [Durr et al., 2005], and the EU-UNESCO hydrogeology community [Richts, 2009]. The Australian government has started an initiative to build the Geofabric to integrate existing river and aquifer information for continental-scale water cycle research (see details at http://www.bom.gov.au/water/geofabric/index.shtml). The US Geologic Survey (USGS) has been engaged in an ambition to build the Global Crustal Database and Models (see http://earthquake.usgs.gov/research/structure/crust/database.php).

We envision CUAHSI playing a central role in bringing together all the international and interdisciplinary leaders of current initiatives in developing digital representations of the Earth's crust, with the purpose to quantify fluid flow. We can start with North America, building upon the decades-long work of USGS in mapping the nation's aquifers (see RASA: http://water.usgs.gov/ogw/rasa/html/introduction.html), working with the NSF-funded Earth Scope community (http://www.earthscope.org/home) to map North American continent.

We also envision CUAHSI being the coordinator with other federal agencies with missions to understand fluid flow in the shallow subsurface such as NOAA, DOE, EPA and USDA. CUAHSI has ongoing dialogues with these agencies and therefore is in the right position to coordinate with multiple leaderships and to energize the hydrologic sciences community to take on this enormous challenge.

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