Water Content of Earth's Continental Mantle Is Controlled by the Circulation of Fluids or Melts

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A key mission of the ARES Directorate at JSC is to constrain models of the formation and geological history of terrestrial planets. Water is a crucial parameter to be measured with the aim to determine its amount and distribution in the interior of Earth, Mars, and the Moon. Most of that "water" is not liquid water *per se*, but rather hydrogen dissolved as a trace element in the minerals of the rocks at depth. Even so, the middle layer of differentiated planets, the mantle, occupies such a large volume and mass of each planet that when it is added at the planetary scale, oceans worth of water could be stored in its interior. The mantle is where magmas originate. Moreover, on Earth, the mantle is where the boundary between tectonic plates and the underlying asthenosphere is located. Even if mantle rocks in Earth typically contain less than 200 ppm H_2O, such small quantities have tremendous influence on how easily they melt (*i.e.*, the more water there is, the more magma is produced) and deform (the more water there is, the less viscous they are). These two properties alone emphasize that to understand the distribution of volcanism and the mechanism of plate tectonics, the water content of the mantle must be determined – Earth being a template to which all other terrestrial planets can be compared.

With that goal in mind, ARES scientists have studied the mantle beneath the oldest continents since 2007. These ancient continental fragments are called cratons and are underlain by a mantle keel of very old mantle rocks that have not participated in the general mantle convection (*i.e.*, the engine for plate tectonics) for more than 3 billion years (figure 1). Using Fourier transform infrared spectrometry, the water content in minerals from the Kaapvaal craton (southern Africa, figure 2) was measured and combined with other chemical tracers of mantle processes. The study shows that water in mantle rocks was brought by fluids and melts circulating through the craton keel (figure 3). The distribution of water in the continental mantle is thus heterogeneous and depends on the nature and water content of the fluid or melt and the path of the melt in the mantle. It is likely that these fluids or melts are related to subduction events in the Archean and Proterozoic Eons; *i.e.*, more than 500 million years ago. The study is being expanded with ongoing similar projects on the mantles beneath the Siberian craton and the southwestern United States.

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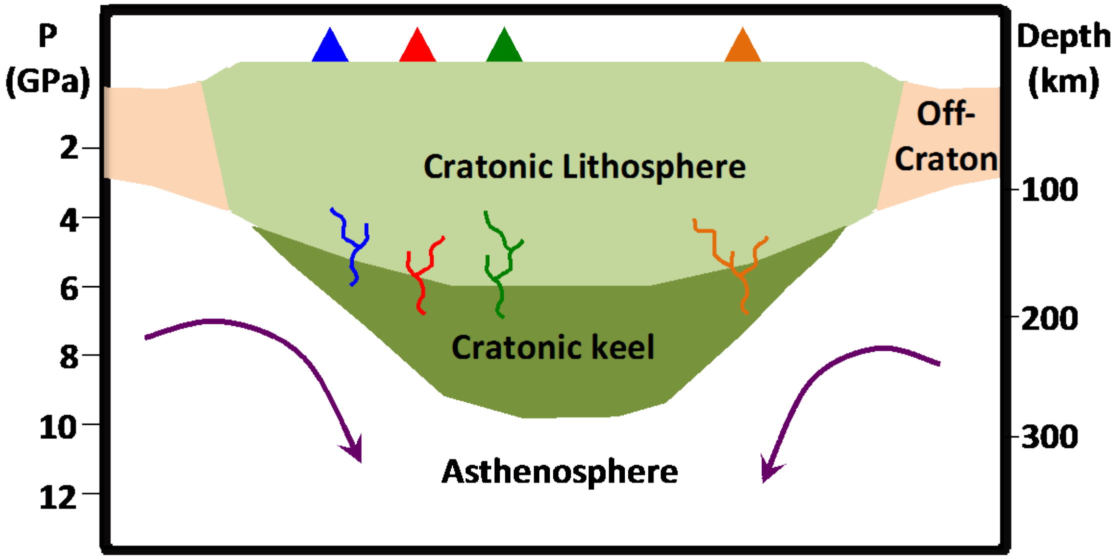

Figure 1.– Sketch of the cross-section of a craton showing the path of melts or fluids of various chemical compositions and water contents (colors) through the cratonic mantle and the corresponding xenolith locations at the surface (triangles). Purple arrows in the asthenosphere indicate mantle convection responsible for plate tectonics, from which cratonic keels appear isolated.

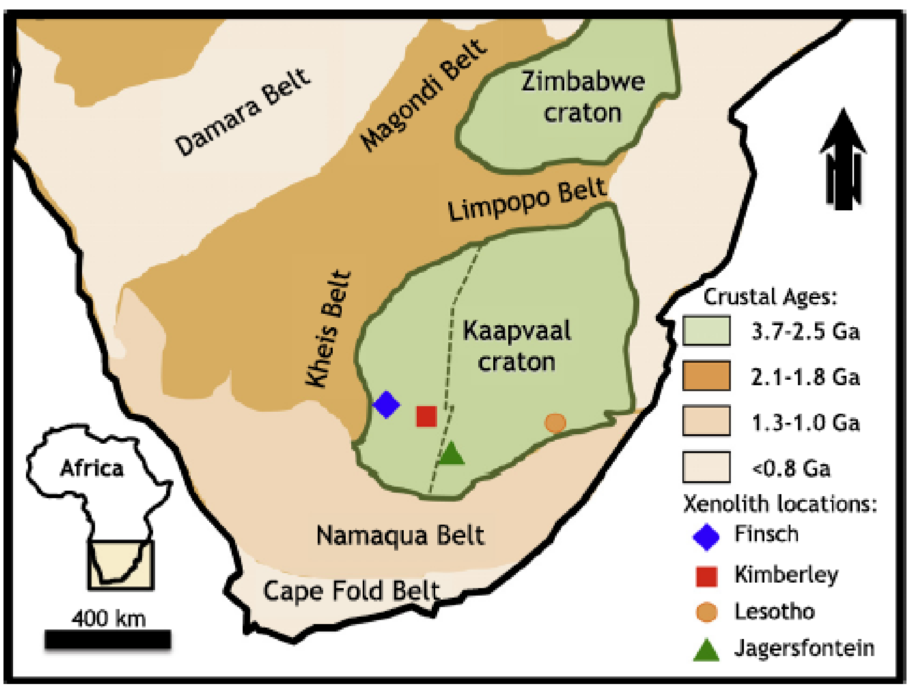

Figure 2.– Location of the Kaapvaal craton. Finsch, Kimberley, Lesotho, and Jagersfontein are diamond mines. The magma that brings up diamonds, called kimberlite, also brings up pieces of the mantle (from 100- to 200-km depth) it passes through on its way to the surface. These pieces of mantle, called xenoliths, are being analyzed for water in the present study.

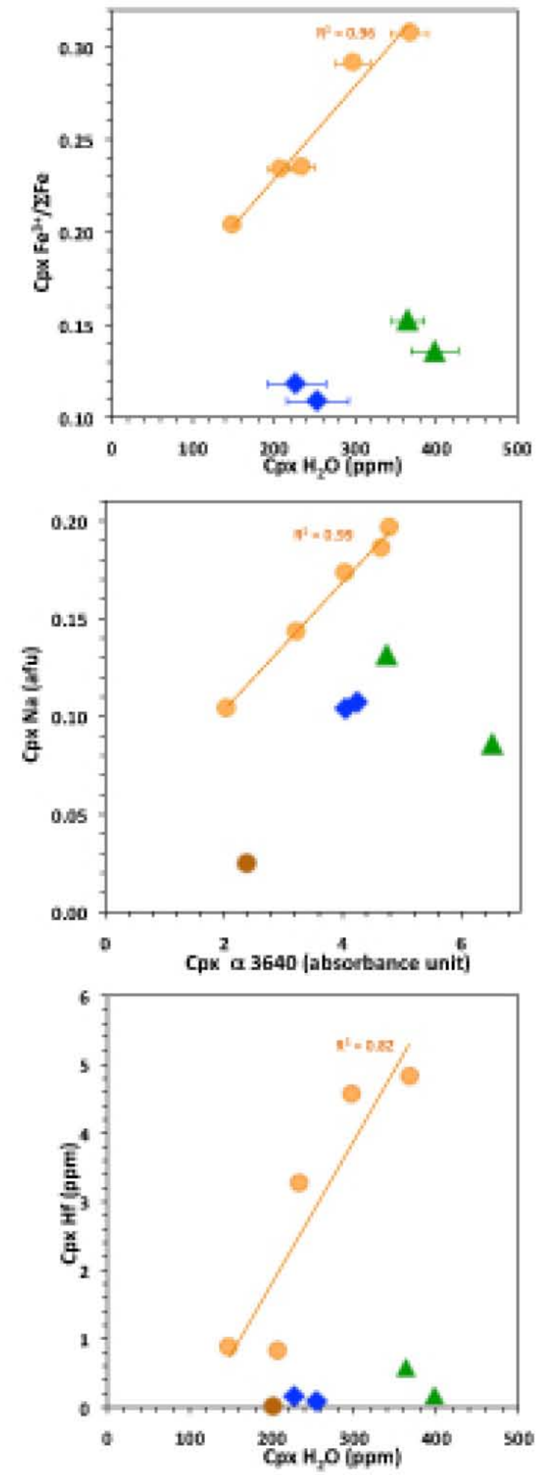

Figure 3.– Water contents of clinopyroxene minerals in Kaapvaal craton xenoliths from Lesotho (orange-filled circles) correlate with tracers of fluid or melt interaction, for example, ferric iron, sodium, and hafnium contents.