Teaching Students to Question Earth-Core Convection

by

J. Marvin Herndon
Transdyne Corporation
11044 Red Rock Drive
San Diego, CA 92131 USA

Communications: mherndon@san.rr.com http://NuclearPlanet.com

Abstract: Science progresses by making important observations, and by discovering what is wrong with present thinking. For 70 years convection has been hypothesized to exist within the Earth's fluid core, and has become the stuff of textbooks, but there are serious problems with that concept. Teaching students to question Earth-core convection can lead them to learn about the behavior and the properties of matter, and can help to bring into focus the importance of discussing, debating, and challenging current thinking in science.

The process called convection is easily observed in ordinary experience, but has been greatly misunderstood in the geosciences for decades. In the subject of convection, there are important lessons to be learned about scientific inquiry and scientific discovery and about the necessity of careful, precise reasoning. The subject of convection can be a jumping off point for stimulating classroom discussions about what is wrong with textbook presentations of Earth-core convection. And, importantly, the subject can help to bring into focus the importance of discussing, debating, and challenging current thinking in a variety of areas.

Heat a pot of water on the stovetop. Before it starts to boil, the water begins to circulate from bottom to top and from top to bottom. This is called convection and it can be better observed by adding a few tea leaves, coffee grounds, celery seeds, or the like, which are carried along by the circulation of water. Convection occurs because heat at the bottom causes the water to expand a bit, becoming lighter, less dense, than the cooler water at the top. The warmer, less dense, water rises to the top as the cooler, denser, water descends. This all seems so simple that it is no wonder that the convection process has been widely (but falsely) assumed to occur deep within the Earth's core. In this case truly *the devil is in the details*, and teaching students those details is an important gateway for understanding not only convection, but the nature of one of the most fundamental mistakes which underlies textbook Earth science.

About 95% of the mass of the Earth consists of just two parts; the fluid, iron-alloy core and the solid, silicate-rock mantle. In 1939, Walter Elsasser postulated Earth-core convection to make tenable his idea that the Earth's magnetic field is generated by convection-driven dynamo action within the Earth's fluid core [1]. At the time, and until recently, there was no reason to suppose that any fluid, electrically conducting region, except the main core, exists within the Earth [2, 3]. Note that Earth-core convection was not independently observed, but rather, was assumed to exist so as to satisfy the underlying conditions for a different theory. As the popular convection-driven dynamo theory appears to explain the generation of the Earth's magnetic field, at least superficially, can one say that Earth-core convection must therefore exist? Emphatically, no! In science, and in other human affairs, such as business management, progress is made, not by cataloguing apparent successes, but rather by finding out what is wrong with current thinking and current activities. So, one might ask, "What's wrong with this picture?" But first, it is important to understand what convection is and what convection entails from a physical standpoint, in other words, from the properties and behavior of matter.

Subrahmanyan Chandrasekhar [4] described convection in the following way: "*The simplest example of thermally induced convection arises when a horizontal layer of fluid is heated from below and an adverse temperature gradient* [*i.e.*, the top is cooler than the bottom] *is maintained. The adjective 'adverse' is used to qualify the prevailing temperature gradient, since, on account of thermal expansion, the fluid at the bottom becomes lighter than the fluid at the top; and this is a top-heavy arrangement which is potentially unstable. Under these circumstances the fluid will try to redistribute itself to redress this weakness in its arrangement. This is how thermal convection originates: It represents the efforts of the fluid to restore to itself some degree of stability.*"

In 1900, Bénard observed the formation of a pattern of cells [convection cells] developing in a thin layer of water heated from beneath [5]. In 1916, Lord Rayleigh [6] derived a dimensionless number – now called the Rayleigh Number – to quantify the onset of instability, which would lead to convection in a thin, horizontal layer of fluid heated from beneath. For decades, calculation of a high Rayleigh Number has been taken to justify the existence of Earth-core convection. The advice for students, generally speaking, as stated in my book, *Maverick's Earth and Universe* [7] is to "Look deeper and look questioningly." And, certainly, that is the case here.

What seems to have been overlooked is that the Rayleigh Number was derived from assumptions that are inconsistent with the physical parameters of the Earth's core. Rayleigh assumed an "incompressible" fluid, *i.e.*, a fluid of "constant" density throughout, except as modified by thermal expansion at the base, and pressure being "unimportant" (quotes from Lord Rayleigh

[6]). The Earth's core is not "incompressible", but consists of a compressible fluid which is, in fact, compressed by the weight of the mantle and crust above and by its own weight. The Earth's core is not of "constant" density; its base is about 23% more dense than its top [see Figure 1] due to the pressure of the weight above [8]. Thus, the dimensionless Rayleigh Number is an inappropriate indicator of convection in the Earth's core.

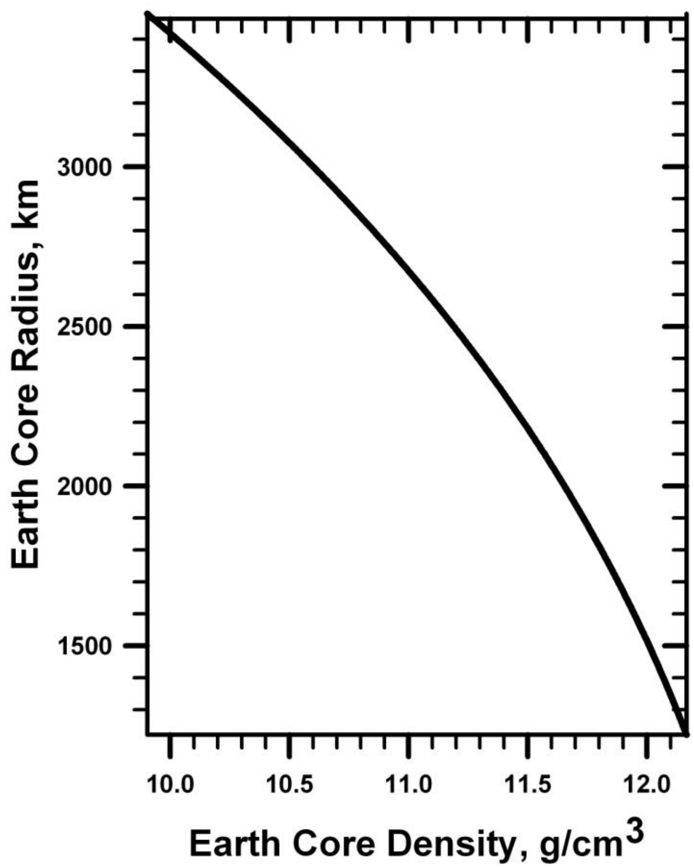

Figure 1. Density as a function of radius in the Earth's core [8].

It is instructive to consider and to discuss some of the reasons why convection, as commonly observed on the stovetop and as described above by Nobel Laureate Chandrasekhar, is impossible within the Earth's core. On the stovetop, convection occurs because heat at the bottom causes the water to expand a bit [much less than 1%], becoming lighter, less dense, than the cooler water at the top. This is a potentially unstable, top-heavy arrangement which the fluid attempts to redress by convection. So, in what ways is that different from the Earth's core and how do those differences impact the convection process?

The Earth's core differs from the stovetop example in two important ways. First, as shown in Figure 1, because of the over-burden weight, the Earth's core is about 23% more dense at the bottom than at the top [8]. The tiny, tiny amount of thermal expansion at the bottom cannot make the Earth's core top-heavy and cannot cause a thermally-expanded "parcel" from the bottom to float to the top of the core as required for convection. Thus, the Earth's core cannot engage in convection. Second, because the Earth's core is wrapped in a thermally insulating blanket, the silicate-rock mantle, heat cannot be efficiently removed from the top of the core. So, maintaining an "adverse temperature gradient" [*i.e.*, the top of the core being cooler than the bottom] for extended periods of time, a condition necessary for convection, is impossible [3]. The former may lead to lively discussions of buoyancy, gravitational layering, and the energetics involved, while thermal properties and heat transport discussions may follow from the latter. But perhaps the most stimulating discussions might center on the geophysical implications that result from the physical impossibility of Earth-core convection, especially as regards the origin of the geomagnetic field.

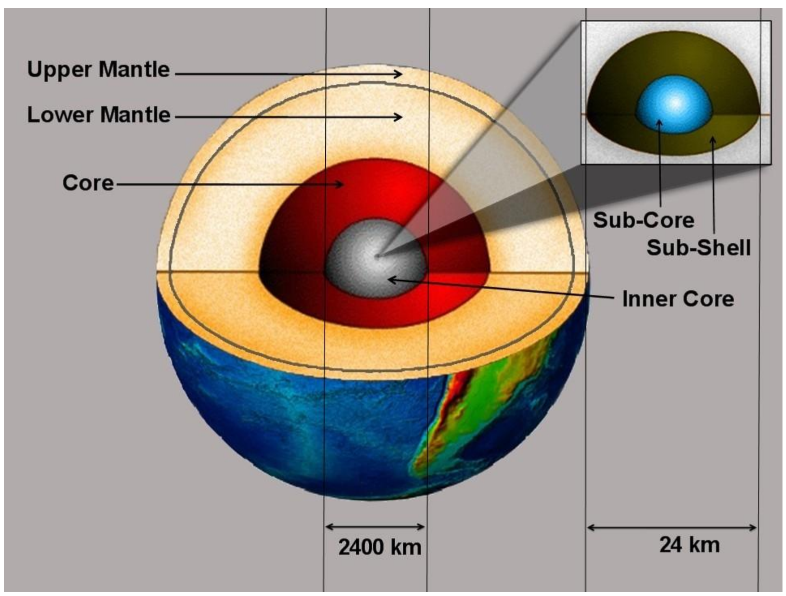

Figure 2. Earth showing georeactor detail, from [7].

What is the main implication of no Earth-core convection? From the standpoint of geomagnetic field generation, the implication is quite clear: Either the geomagnetic field is generated by a process other than the convection-driven dynamo-mechanism, or there exists another fluid region within the deep-interior of Earth which can sustain convection for extended periods of time. I have provided the reasonable basis to expect long-term, stable convection in the georeactor sub-shell, and have proposed that the geomagnetic field is generated therein by the convection-driven dynamo mechanism [3, 9, 10]. Figure 2 is a schematic representation of the interior of the Earth showing Herndon's georeactor. Heat produced by the georeactor nuclear sub-core is expected to cause convection in the georeactor sub-shell. Heat brought to the top of the sub-shell is expected to be transported away by the thermally-conducting inner core heat sink which is surrounded by an even more massive thermally-conducting fluid core heat sink. I have postulated that the geomagnetic field is generated by convection-driven dynamo action in the georeactor sub-shell [3, 10], as illustrated in Figure 3.

Figure 3. Schematic representation of convection-driven dynamo generation of the geomagnetic field within the georeactor sub-shell.

So, what is the most important lesson for students to learn from all this? From the standpoint of the properties and behavior of matter, look deeper, and look questioningly at current thinking.

References

1. Elsasser, W.M., *On the origin of the Earth's magnetic field.* Phys. Rev., 1939. **55**: p. 489-498.
2. Herndon, J.M., *Sub-structure of the inner core of the earth.* Proc. Nat. Acad. Sci. USA, 1996. **93**: p. 646-648.
3. Herndon, J.M., *Nuclear georeactor generation of the earth's geomagnetic field.* Curr. Sci., 2007. **93**(11): p. 1485-1487.
4. Chandrasekhar, S., *Thermal Convection.* Proc. Amer. Acad. Arts Sci., 1957. **86**(4): p. 323-339.
5. Bénard, H., *Les Tourbillions cellulaires dans une nappe liquide.* Renue generale des Sciences pures et appliquees, 1900. **11**: p. 1261-1271 and 1309-1328.
6. Lord_Rayleigh, *On convection currents in a horizontal layer of fluid where the higher temperature is on the under side.* Phil. Mag., 1916. **32**: p. 529-546.
7. Herndon, J.M., *Maverick's Earth and Universe*. 2008, Vancouver: Trafford Publishing. ISBN 978-1-4251-4132-5.
8. Dziewonski, A.M. and D.A. Anderson, *Preliminary reference Earth model.* Phys. Earth Planet. Inter., 1981. **25**: p. 297-356.
9. Herndon, J.M., *Magnetic field generation in planets and satellites by natural nuclear fission reactors.* Submitted to Curr. Sci., 2008.
10. Herndon, J.M., *Uniqueness of Herndon's georeactor: Energy source and production mechanism for Earth's magnetic field.* http://arXiv.org/abs/0901.4509, 2009.