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Evaluating *The Core*: The Prospect of Geodes

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Abstract
This paper analyses the legitimacy of some of the science behind the movie *The Core*. The feasibility of the formation of large amethyst geodes in the Earth's mantle as seen in *The Core* is investigated by calculating the pressure in the mantle and analyzing the effect of mantle temperature on amethyst crystallization. The analysis shows it to be extremely unlikely that geodes exist in the lower mantle.

Introduction
Released in 2003, *The Core* is a science fiction film in which the convective currents in the Earth's liquid outer core stop. A group of scientists must travel through the Earth's crust and mantle towards the centre of the Earth and attempt to restart convection in the outer core. During their journey, the scientists are amazed when their ship becomes damaged as they travel through a large amethyst geode in the mantle.

Amethyst Geode Formation
A geode is a geological formation which is typically spherical, with a plain outer crust of igneous or sedimentary rock, followed by an inner cavity space partially or completely filled with crystallized minerals [1].

Amethyst bearing geodes appear in many regions around the world. The highly studied amethyst geodes of Rio Grande do Sul, Brazil can be used as an analog for their formation. The Rio Grande do Sul geodes were likely formed in a two-step process. The early stage 'protogeode' cavity was created as gases were released by cooling lava, and then trapped within the hot, molten rock. The later stage cavity infilling would have then occurred through the flow of mineral rich fluids in the cavity [2]. These fluids were expected to have been low temperature, gas-poor, aqueous solutions of very low salt content [2].

Conditions necessary for amethyst geode formation therefore include the presence of a cavity and low temperature, mineral rich fluid, in addition to the conditions necessary for amethyst crystallization.

Mantle Cavity
Within the mantle, the force of the overlying rocks would create a high amount of stress which would act against the formation of a cavity. The magnitude of stress present at the depth in the mantle where the amethyst geode was found is dependent on the density and thickness of the overlying rock, as well as the gravitational acceleration acting upon this rock. This stress can be approximated using the following equation [3]:

$$\sigma = \rho g z$$
$$where\ \rho = density$$
$$g = gravitational\ accelleration$$
$$z = depth\ below\ Earth's\ surface$$

More simply, predetermined lithostatic stress gradients use average material density multiplied by the gravitational acceleration to replace these terms in the above equation [3]. For the Earth's crust, the lithostatic stress gradient is 26.5 MPa/km, while the gradient for the mantle is 35 MPa/km [3]. The geodes in the movie are found 700 miles, or greater than 1000 km, below the surface of the Earth. The total lithostatic stress experienced at this depth would be:

$$\sigma_{crust} = 40\ km \times lithostatic\ stress\ gradient$$
$$\sigma_{mantle} = 1078\ km \times lithostatic\ stress\ gradient$$
$$\sigma_{total} = 40\ km \times 26.5\ MPa/km + 1087\ km \times 35\ MPa/km$$
$$\sigma_{total} = 39105\ MPa$$

$$\sigma \approx 39\, GPa$$

The closest analogue we have at the Earth's surface for mantle material is olivine rich basalt. Under pure stress conditions caused by the weight of overlying rock, less than 300 Pa would be needed to overcome the strength of the crystal network in basalt and induce melting [4]. Thus, under the extreme stress conditions of approximately 39 GPa experienced at a depth of over 1000 km, minerals in the mantle would undergo ductile deformation and would flow rather than form the solid crust of a hollow sphere. This makes it highly unlikely that a cavity in which amethyst crystals could form would be located deep within the Earth's mantle.

Amethyst Crystals

The formation of amethyst crystals in the mantle may seem acceptable, maybe even probable, but this is not the case. Amethyst is the violet variety of alpha-quartz with its slight purple colouring attributed to trace amounts of iron in the crystal composition [2]. From alpine clefts to miaroles in granite rock, amethyst crystals form in various geologic environments [2]. It is important to understand the characteristics of each setting to determine whether the growth of these crystals is supported.

Different temperatures have been attributed to the growth of amethyst crystals. In the amethyst mines of Thunder Bay, Ontario the crystals were determined to form in 40-90 degrees Celsius temperatures [2]. Brazilian amethyst formation temperatures ranged from 50-100 degrees; with a general consensus they did not exceed 100 degrees Celsius. In Scotland, amethyst formation temperatures are expected to have been less than 150 degrees Celsius. These temperatures are expected to have been between 150-250 degrees in Hungary and have reached 280-400 degrees in South Korea [2].

Individual quartz grains form a tetrahedron of four shared oxygen atoms [5]. Due to the shared nature of the atoms, increasing temperatures causes this framework silicate to break down into simpler silicate forms. Using Bowen's Reaction Series, it can be determined that the ideal temperatures for quartz to form are below 750 degrees Celsius (Figure 1) [5]. Above these temperatures more mafic minerals are expected to form such as biotite, amphibole and pyroxene. In the movie, the crew finds the amethyst geode in the lower mantle. While the temperature of the lower mantle is unknown, plate tectonic models have estimated mantle temperatures as high as 3726 degrees Celsius [6]. These drastically high temperatures illustrate the unlikelihood of quartz and therefore amethyst crystals forming so deep within the Earth.

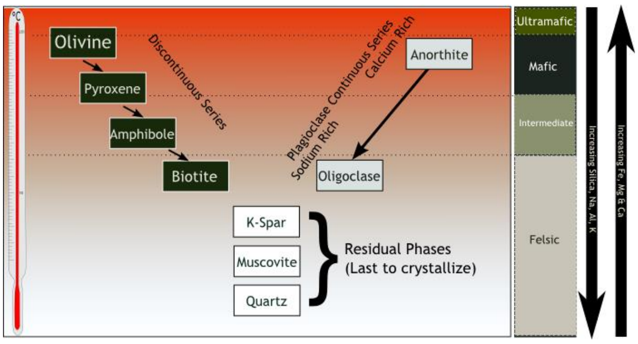

Figure 1: Bowen's Reaction Series showing the lower temperatures at which quartz crystallizes [7].

Conclusion

While a geode of amethyst crystals offers visual appeal and interest to the film, the chance of finding this geologic formation deep within the mantle is highly unlikely. The stress at this depth would be too great for mantle rocks to form a solid shell for a cavity. Additionally, the formation of amethyst crystals deep in the mantle would be impossible due to very high temperatures.

References

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