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# Comprehensive Analysis Of The Different Phases Of Water In The Earth's Mantle

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**Abstract**

Water is necessary for any living life form. However, it has been discovered that water in the mantle governs the mechanisms that drive the dynamic earth system and keep the planet alive, unlike other planets in the solar system, which are considered dead. Water regulates the rheological properties of rocks in the mantle, and its existence has been confirmed through seismic investigations, which have revealed two notable discontinuities at 410 km and 660 km. The transition zone between these zones is considered a water storage site. It has been proved to contain approximately 1000 ppm of water, consistent with several other estimations of water content. Seismic tomography depicts the water transport mechanism and provides insight into the phase transformation kinetics occurring at discontinuities.

**Keywords:** Water, mantle, seismic, rheology, melting

## Introduction

Earth is one of the only planets in the solar system which has water present. Water is one of the essential compounds needed for supporting life. Water is a life-supporting substance and a significant driver of coupled climate-tectonics systems. Water plays a vital role in earth surface processes. However, it also plays a vital role in subsurface processes, and it is believed that complete mantle dynamics are affected by the presence of water. There are various estimates of it in the mantle, which range from 400 ppm to 1200 ppm. Seismic tomography has revealed water transportation and has provided some water storage sites (Kawakatsu and Watada 2007).

Water in the mantle is present as hydrous phases, and only a fraction is present as free fluid (Kohlstedt et al 1996). Recently, only a terrestrial sample of ringwoodite in diamond has been obtained to estimate the amount of water present, but there are various arguments for these estimates as it is only a sample (Pearson 2014).

Even trace amounts of water in the Earth's mantle play a role in rheology, seismicity, phase equilibria, and melting behavior. Recent studies have shown that significant amounts of hydrogen can be contained in mantle minerals such as pyroxene, garnet, rutile, etc. Water has an important influence on the behavior of molten rock; the variability in style and vigor of volcanic eruptions is just one manifestation of this effect.

**Importance of Water in mantle**

Water plays a vital role in controlling the mantle dynamics and moderates the processes. Water is considered a lubricating agent that changes the friction between the subducting plates. It has found to be affecting the slip rates and also it is believed to be one of the cause of large seismic events caused due to sudden release of the energy from the slipping plates.

Water addition causes generation of excess melts due to lowering of melting temperature (Asimow 2003). Water addition at constant potential temperature causes excessive melting at lower temperature but much higher temperature. The melting behaviour has been modelled and shows the clear relation between the increasing potential temperature and amount of melt generated.

Water apart from controlling the general melting behaviour also controls the rheology (Hirth and Kohlstedt 1996). The changes in rock property are reflected in the seismic observations and it also provides essential evidence for the water storage sites.

Water changes the magma viscosity and also effects the magma migration also, which can lead to change in several other processes in the subsurface. There are proven effects of water in seismic discontinuities at 410 km and 660 km, which is discussed at a later stage.

**Evidence of Water**

Water is present in mantle and the evidences behind them are well developed and explained. The strongest evidence of presence of water is the presence of hydrous phases in minerals in the mantle xenoliths. Magma ascending from great depths with relatively high speed takes up rock fragments has greenish portions which are mantle xenoliths in basalts, which provides a window from where scientists peep into the deeper part of Earth (Karato et al 1986). These rock fragments having many hydrous phases shows clear evidence of presence of water as well as also throws light on the amount of water present.

The heterogeneous temperature distribution in the mantle as revealed from the seismic tomography has revealed various hot spots at varying distances (Wang and Zaho 2008). The thermal anomaly is closely related with the water content present in mantle. The shear produced in the seismic waves is related with the temperature and inhomogeneous shearing gives us a strong evidence of the thermal anomaly present in mantle (Kohlstedt 2006).

**Sources of water in mantle**

Water in mantle is known to coming from the subducting lithosphere and also various seismic studies have explained this based on the data obtained from experiments conducted near Japan where seismic tomography reveals the amount of water present in various portions of the subducting lithosphere. Shallow recycled water from hydrosphere is another source. The water assimilated from the subducting plates is relatively high. Water is also transported as hydrous minerals which carry hydrous molecules as a part of minerals present in subducting rock.

A huge amount of primordial water is believed to be present and a portion of it has been released during mantle degassing. The precise amount is not well constrained indeed and a lot of debate is still there for actual partitioning of amounts water presence in mantle.

**Storage of water in mantle**

Water is present as free fluid in shallower parts of lithosphere and mantle but with increasing it is present as hydrous minerals. These hydrous minerals are specially defined as Dense Hydrous Magnesium Silicates (DHMS) which are known to contain 0.01 wt. % to 2 wt. %. Data available from the first terrestrial ringwoodite sample shows it can hold

about 2.5 wt. % which can drastically change our present knowledge and estimates of water in mantle, but there are various counter arguments for this estimates, and one of them are the wet source of diamond is fairly reasonable also (Hacker and Abers 2004). The present knowledge of mineral transformations from one phase to another has been also incorporated in the estimates but a lot of uncertainties are there.Water is also present associated with silicate melts in various magma chambers (Smyth et al 2006).

**Storage sites of water**

Based on the thermal structure of mantle few sites of water can be proposed as follows:

1) In hot subduction zones, water release by dehydration of common hydrous minerals like mica, chlorite, etc (Schmandt et al 2014).
2) In cold subduction zone, as less common hydrous minerals like phengite, pumpellyite, etc.

**Various estimates of average water content in mantle**

Three major hypothesis had been accepted for estimation of water present in mantle. The multistage accretion model for solar system suggests the values to be near 1000 ppm to 40 ppm, which is a very long range. The Rubey's "excess" volatile estimation suggests this value to be near to 400 ppm (Wallace 2005).

The Ringwood had suggested that 90% of water resides in ocean and crust while remaining is distributed in mantle and core.

In a very recent finding, the first terrestrial ringwoodite obtained from a diamond suggests that it can account for about 2.5 wt. % of water, which is too high, and can drastically change the present estimates of water content in mantle.

**Conclusions**

Water is observed to be sitting in the transition zone in between 410 km – 660 km discontinuities which very closely related with the phase transformations taking place at those depths (Karato 2011). Although there are some estimates on amount of water content in mantle but much constrained relation is needed to arrive at any specific value. Similarly the storage sites are although very well hypothesised but many shortcomings are there in present models. Water changes the rheological properties of the rocks present and also brings a substantial change in melting behaviour of the rocks. Water plays an indispensable role in mantle dynamics and a better understanding of the water content in mantle in the last few years has been developed.

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