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THE EARTH'S INNERMOST CORE

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A new earth model is advanced with a solid innermost core at the centre of the Earth where elements heavier than iron, over and above what can be retained in solution in the iron core, are collected. The innermost core is separated from the solid iron-nickel core by a shell of liquid copper. The innermost core has a natural vibration measured on the earth's surface as the long period 26 seconds microseisms.

The earth was formed initially as a liquid sphere with a relatively thin solid crust above the Byerly discontinuity. The trace elements that entered the innermost core amounted to only 0.925 ppm of the molten mass. Gravitational differentiation must have led to the separation of an explosive thickness of pure ^{235}U causing a fission explosion that could expel beyond the Roche limit a crustal scab which would form the centre piece of the moon. The presence of a density gradient in the scab should produce an eccentric mass distribution in the moon, which is observed. The proportion of uranium and thorium which is better known for the moon from its heat output data should also apply to the chondrite particles that formed the earth, to a large extent. This also needs only 82 ppm of K which besides giving the observed quantity of argon in the earth's atmosphere adequately explains the heat output both in the earth and the moon.

There is no room for invoking Ramsay collapse since sufficient contraction on progressive solidification will account for any anomalous recession of the moon. A reservoir of helium floats on the liquid copper. A small proportion of helium-3, a relic of the ancient fission explosion present there will spell the exciting magnetic field. The field is stable for thousands of years because of the presence of large quantity of helium-4 which accounts for most of the gaseous collisions that will not disturb the atomic spin of helium 3 atoms. This field is prone to sudden reversals after long periods of stability.

Key Words : Earth's Core; Microseisms; Origin of Moon; Planetary Explosion; Helium-3; Terrestrial Magnetism; Roche Limit; Ramsay Collapse

INTRODUCTION

A SMALL sphere of elements heavier than the iron-nickel alloy of the solid inner core situated at the centre of the earth parted from the solid inner core mass by liquid copper could explain the observed microseisms of 26 seconds period as its natural vibration. It is suggested that uranium and thorium and some other heavy elements from the primitive liquid bulk of the earth but for the upper solid crust above the Byerly discontinuity gravitated down to the centre of the earth. On account of the gravitational differentiation within the first few hundred million years a shell about 10cm thick of ^{235}U could build up at the outer edge of bulk uranium, causing a nuclear fission explosion which must have blown out a scab and raised a cloud of dust and debris to form the moon beyond the Roche limit.

Moon Material Represents the Material of the Earth

It is known for the earth's crust that when the rocks recrystallized from the magma there was a concentration of the high melting point elements in the lighter rocks close to the surface. It was believed that the earth's core will not have uranium as perhaps it was not compatible with iron. A recent laboratory study by Faber *et al.*[1] has shown that in the phase diagram of the binary system of steel and UO_2 there must be a temperature above which there is total miscibility between steel and UO_2 and they conclude that there is a strong likelihood that there would be uranium in the earth's core.

Another belief was that the content of radioactive elements in the present day chondrite meteorites represents the composition of the ancient chondrites that formed the bulk of the earth. The accidental coincidence of the heat output calculated from this composition with the observed heat outflow gave credence to this belief. The chondrites are observed to have much higher proportion (738ppm) of K and possibly much lower proportions of uranium and thorium (11ppb and 44ppb respectively). This is clear from the fact that argon which is produced from the radioactive decay of ^{40}K is only 1/9 of what may be expected from the present value of 738ppm. The K content should be closer to 82ppm. It is now established from the chemical abundance data that the material of the moon must be the same as the material of the earth (Ringwood).[2] We support the ideas of Darwin (1880) and others that a piece of the earth's crust was expelled leaving a scar on the earth, and around this piece other material of average density 3.30 after evaporating from the earth must have coalesced to form the moon. If the scab from the earth now at the centre of the moon has the same density variation across it as is now seen in the upper crust of the earth, the moon should have an eccentric mass distribution. It is well known that the centre of the moon is 2.5 km away from the earth than the centre of mass. From the size of the equatorial basin, the size of the scab is inferred to be 2.8×10^6 sq km in extent. By balancing the moments about the centre of mass of the moon, thickness of the scab is deduced to be 736 km. Thus under the assumptions made, the thickness of the solid crust at the time of formation of the moon must have been atleast 736 km. The density profile used in the above calculation for the earth's crust is given below from Jacobs.[3]

Depth (km) :	0	20	100	196	396	496	671	721	761
Density :	2.8	2.8							
		3.30	3.32	3.37	3.57	3.87	4.38	4.41	4.44

At 20km there is a sharp rise in density to 3.30. We have considered the density to be 3.0 in the upper 20km assuming that the mass of water now in the oceans was also hidden there. Initially the solid crust would have been only 400km thick upto the Byerly discontinuity and the solid phase extended downwards with time. The heavy elements from the liquid mass of the earth gravitated downwards.

It is not possible to arrive at the proportion of trace elements from some rock samples from the earth's crust or from sampling at the surface of the moon. From heat output figure and compatible with low K content, moon has 25ppm of uranium and 95ppb thorium and same increased to appropriate higher level five billion years before present should have been brought in by the then chondrites when forming the earth. The present radioactivity on the basis of these proportions produces the present observed heat output in the earth. The energy released on the complete decay of one atom is taken as 1.6 MeV for ^{40}K, 47.7 MeV for ^{238}U, 43.9 MeV for ^{235}U, and 40.5 MeV for Th.

SIZE AND VIBRATION OF THE INNERMOST CORE

The innermost core should contain all elements of unstressed density greater than 7.9, the density of the iron-nickel of the solid inner core. The elements lead, cadmium and mercury though heavier will not reach great depths since these elements vaporize at relatively low temperatures compared to that of the outer liquid core. A portion of the heavy elements will be retained and dissolved in the iron-nickel that exists now in the solid inner core. (The iron meteorites that also contributed to the growth of the earth, already have traces of such elements). The proportion in ppm of the liquid mass of the earth when formed can be estimated from the abundance data of elements in stony and the iron meteorites (Kaye and Laby). For any element of atomic weight A, the tables give the number of atoms x for 10^6 Si atoms for the chondrites and y in ppm for the iron meteorites. Since the proportion of Si in the earth is 0.147g/g and of iron 0.348g/g, the proportion in ppm of the differentiating mass for the element reaching the innermost core is c_i =

$$[0.147(A/28)x - 0.147 \times 1.38(y/0.91)]$$

or
$$C_i = 0.147\,x' - 0.223y, \qquad \ldots(1)$$

where $x' = (A/28)\,x$; 1.38 grams of iron accompany 1gram of silicon in the chondrites and 0.91 grams of iron are present in one gram of iron meteorites. In case the ppm proportion for the entire earth for figuring out the total heat output etc is required, the total mass of the earth i.e., 6.1×10^{27}g. is to be considered and not just 5.4×10^{27}g, the mass excluding the outer 400km. Since the iron brought in by the chondrites will be only 0.147×1.38 or 0.203g/g, the remaining iron content of the earth $(0.348 - 0.203 = 0.145$g/g) must have come from irons containing 0.91g/g of iron. Thus the proportion, chondrites to irons is 0.841 : 0.159. The ppm value for the entire earth will be

$$c_e = 0.147x' + 0.159y \qquad \ldots(2)$$

In case the actual ppm value for the chondrites x_m is known e.g. from the moon data for uranium and thorium now or at any time before the present, then using the applicable y value, the proportion c_i entering the innermost core will be

$$c_i = 0.841 x_m - 0.223 y \qquad ...(3)$$

Similarly equation (2) becomes

$$c_e = 0.841 x_m + 0.159 y \qquad ...(4)$$

Table I gives c values for uranium and thorium at various epochs, the present x_m being 25 and 95 ppb respectively.

TABLE I

c_e and c_i in ppb at various epochs for U and Th

Element	Density	5 billion years ago				4.5 b.y. ago		Present	
		x_m	y	c_e	c_i	c_e	c_i	c_e	c_i
^{238}U	19.05	54	15	48	42	44.4	40.1	22.1	19.4
^{235}U	19.05	25	7	22.1	19.2	13.5	11.7	0.15	0.14
^{232}U	11.72	122	51	110.7	91.2	108.0	89.0	86.4	71.2

In Table II below are given the c_i values for non-radioactive heavy elements from equation (1) that will enter the innermost core.

TABLE II

c_i in ppm from equation (1)

Element	Density	c_i	Element	Density	c_i
Cu	(liquid) 7.91	44.4	Er	9.04	0.066
Ag	(liquid) 8.6	0.052	Lu	9.84	0.028
Tb	8.27	0.043	Tl	11.87	0.0009
Dy	8.53	0.281	Hf	13.30	0.150
Ho	8.8	0.066	Ta	16.60	0.006

In addition to the above listed heavy elements there will be some lead in the innermost core due to radioactive decay of some uranium and thorium. The combined ppm proportion of the originally liquid mass of the earth that enters the innermost core will be 0.925. The average unstressed density of the mixture is 9.88. This means that the density *in situ* would be 21.25 since the unstressed density 7.9 becomes 17 at the centre of the earth according to Lyttleton[6]. Knowing the mass and the density, the radius is 38.4km. The speed β of shear waves and the period of the natural vibration T are related (Benmenahem and Singh[7]) according to the equation,

$$\beta = (2\pi/T)(R/z)$$

when $T = 26$ seconds, the period of long period microseisms, we get

$$R = 10.35\ \beta, \text{ since } z = 2.501, \text{ where}$$

z is the lowest root of the equation

$$(1/z) \tan z = (z^2 - 12)/(5z^2 - 12).$$

Thus for the innermost core of radius 38.4km, $\beta = 3.7$ km/sec.

The source of energy is the dissipation of energy from the fluctuation of temperature, for the continuous vibration. The energy dissipation sets up torsional vibrations that are absorbed due to viscous damping. The flux in the background field with a relaxation spectrum around seismic frequencies (Callen[8]) causes radiation transitions as in the case of stimulated emission of spectral lines, and the natural period of the innermost core is excited. We get the toroidal vibrations $(1 = 2)$ split into a multiplet by the rotation of the earth. A quintuplet with intensity rations $1 : \frac{1}{4} : 1/24 : 1/144 : 1/576$ is obtained. Only the first two components with $m = 2$ and $m = 1$ are prominent and the separation of the apparent doublet should be 0.06 seconds. Holcomb[9] has noticed some structure but the instruments did not have sufficient resolving power.

The innermost solid core is isolated from the solid inner iron core by an intervening shell of liquid copper with some trace of liquid silver. The copper shell extends from 38.4km radius to 151km radius. The helium reservoir must be existing on the outer surface of the copper shell due to practically the impenetrable barrier of more than a thousand kilometers of solid iron-nickel. Under the extremely high pressure the helium gas must be compressed practically into an amorphous mass of density close to the high density of liquid helium.

The Formation of the Earth

Lyttlenon[10] holds that the earth would have evaporated if it were not initially solid. On the other hand the initial state will depend on the rate of accretion and the heat generated when a particle is incident on a surface in space and the heat radiated out by the surface. The rate of growth will be changing depending on the increasing area of the surface and the density of particles in space. Initially when the growing planet is very small with a very small surface area, the rate of accretion has to be rather small and the body will initially grow as a solid, but soon the rate of accretion will become larger and the entire body will liquify and remain a liquid till the radiation cooling from the surface outstrips the heat on account of accretion and later the body will grow a solid outer crust till the incidence of particles is almost stopped. Byerly discontinuity 400km deep is very likely the outer limit of the growing liquid earth. Below is given a simple calculation in support of this. Latimer[11] estimated the energy released from astrophysical considerations when one gram of matter impacts on a surface to be 4×10^4 J. One could form an estimate of such energy from the melt zone on the surface of the moon when a meteor of a given mass forms a crater on the surface. Energy required to liquify one gram of silicate material is 1.5×10^{10} ergs. More than twenty times the mass of the impacting meteor is liquified. The average energy released on the impact of one gram could be only 3.2×10^4 J. The earth is estimated to have taken 50,000 years to form which gives an average accretion rate of 4×10^{15} g/sec, or the average energy released per second is 12.8×10^{26} ergs. Equating this amount to the energy radiated away per second from the surface of the growing earth of radius R we will get the maximum radius of the liquid part of the earth : this radius is 5956km using the Stefan constant $= 5.67 \times 10^{-5}$ cgs units and the melting point or the temperature of the limiting surface as 1500 K. Thus, about 400km will be the thickness of the outer solid crust.

On further cooling the outer solid crust will grow inwards to form the mantle and the liquid part will shrink to form the outer liquid core with solid iron-nickel inner core growing at the centre alongwith a tiny innermost core. Simple phase change from liquid to solid will involve a contraction of about 180km so far. Thus, there need not be recourse to an anomalous Ramsay collapse or the development of special high density liquid at the cost of the solid mantle.

The time taken in the gravitational differentiation can be calculated for the growth of an explosive layer of ^{225}U in the innermost core that would herald the formation of the moon, from the sedimentation equation (Auclair *et al.*[12]), Let the average viscosity of the liquid earth in the early phase be η. The time taken in seconds is

$$t = 4.5 \times 2.303 \times \eta \times (\log R_{max}/R_{min})/(\Delta\rho \cdot r^2 \cdot S/R),$$

where $\Delta\rho$ is the difference in density of the separating species

i.e. $\Delta\rho = \frac{3}{238} \cdot 19.05 \times \frac{17}{7.9} = 0.51$; ρ, the density of the medium

(innermost core) is 21.25 and

$$(S/R) = (4\pi/3)\,\rho\, G - \omega^2,$$

where ω the angular velocity is $2\pi/(24 \times 3600)$ and $G = 6.7 \times 10^{-8}$ and r, the radius of the particle is 1.48×10^{-8}cm. Let R_{max} be the radius of the sphere containing bulk uranium in the innermost core (= 12.8km). If ^{235}U is to separate out in pure form say about 10cm thick, the bulk uranium must reduce its radius by 43.3cm since ^{235}U is only 1/3.3 of ^{238}U during the first few hundred million years of the formation of the earth. Thus R_{min} would be 43.3cm less than 12.8km. From the equation given above the time in million years would be $T = 6.954\,\eta$my and for the expected $\eta = 0.072$, the time taken is atleast 500my. It appears that such explosions are fairly common in the early history of the planets.

In the case of the earth the first explosion did not shatter the earth as must have happened for the planet that had its orbit between that of Mars and Jupiter. For the earth only a scab flew beyond the Roche limit to form the center piece for the moon. It is probable that certain loci of weakness have been created in the mantle which have given rise to the tectonosphere model of the earth. Most of the helium released in the explosion including some ^{3}He is held below the iron core on the molten copper.

Helium in the Earth

With the new c_e values (Table I) for uranium and thorium, the helium produced in the earth is about 84000 cubic meters per day, since a disintegrating ^{238}U atom releases 8 helium atoms, ^{235}U releases 7 such atoms and thorium atom releases six. Some space scientists believe that the earth is releasing 100,000 cubic meters of helium per day into space. Near the earth this amounts to about 1 helium atom per cc while in motion at the escape velocity. Perhaps the helium in space as seen by the space probes is what is released from the planets since the stars like the sun will sweep away helium if any in space than emit helium. The production of helium on the present day chondritic proportions of uranium and thorium for the earth would produce only a fraction of the helium actually produced.

The presence of ^{3}He in the earth's atmosphere and its presence in the deep sea water samples as well as in rocks (Kurtz *et al.*[13]) needs an explanation. Helium resides only for about a million years in the earth's atmosphere before its escape to the outer space. It must therefore be replenished from below. During the formation of the earth any helium present in the accreting material must have immediately escaped from the molten mass of the growing earth. The helium that comes out of the earth now must be either from the atomic decay of uranium or thorium or from nuclear fission. Little ^{3}He would be produced by radioactivity. But in ternary fission which occurs for one atom in 200 fissioning atoms of ^{235}U, helium of both masses 3 and 4 is produced and ^{3}He is 1.5×10^{-5} of the helium produced (Vanden Bosch and Huizenga[14]). Since spontaneous fission is negligible, enhanced fission as in a nuclear reactor or as in case of a fission explosion must be the origin of ^{3}He.

It is possible that the helium accumulated around the innermost core over liquid copper, is the origin of the exciting field for the earth's convection dynamo responsible for the terrestrial magnetism. The ^{3}He atoms are surrounded by millions of ^{4}He atoms and most of the collisions of ferromagnetic ^{3}He atoms are with ^{4}He atoms which have zero angular momentum and zero magnetic moment and which have no effect on the ^{3}He atomic magnets. Thus the alignment brought about by the earth's rotation is not disturbed for a long time. Eventually, the negligible probability of ^{3}He—^{3}He collision brings about randomization in some hundreds of thousands of years depending on the ^{3}He : ^{4}He ratio. This system has also an automatic built-in probability of reversal of the exciting field since after each randomization there is an equal chance of alignment of spins with the earth's angular momentum in the up or down direction. The variation of declination of the bi-polar field will also follow the relative variation of direction of the earth's rotation with respect to the direction of earth's angular momentum at the time of setting down of ^{3}He spins. There would be additional effects of the variation of convection currents with time. This reversal of the exciting field explains very simply the reversal of paleomagnetic field from samples indicating same direction of motion of the sea bottom i.e. without reversal of convection currents.

Concluding Discussion

From elementary earth physics, we have shown the inevitability of the existence of an innermost core which is indicating its presence by the observed 26 seconds microseisms. The presence of uranium in the innermost core leads one to suspect the existence of a natural atomic reactor responsible for the detection of ^{3}He in samples of helium reaching the earth's surface from below. Naturally the possibility exists of fission explosions in the planets at an early stage of their existence. Many natural phenomena support such an inference like the existence of the moon and its formation long ago close to the earth or the existence of planetary fragments between the orbits of Mars and Jupiter or the occurrence of Saturn's rings, etc. There would however still be questions regarding the sufficiency of the fission energy for such planetary phenomena. One can easily argue in favour of the moon's core being formed as originally proposed by Darwin for the entire moon. If a scab from the earth's crust was expelled beyond the Roche limit and moon accreted around it and the scab carried the density variation with depth observed in the Earth's crust, the moon should show an eccentric mass distribution which has been observed. The energy required to throw off a scab needs fairly small amount of properly oriented energy of explosion than the energy required for shattering a solid mass. The energy required to throw off a scab of the size indicated is 4×10^{36} ergs. The 10 cm critical size of ^{235}U layer that we have used in the calculation in the text can produce only 4×10^{33} ergs. But the behaviour of the fission reactor under the intense pressure at the centre of the earth is not known and the explosions could occur perhaps only when sufficient size of ^{235}U was there to throw off the scab at escape velocity or may be the fission of ^{232}Th or ^{238}U or their transmutations was triggered by ^{235}U explosion and the energy was augmented manifold. This needs attention.

The existence of a helium reservoir is practically definite and the specific mixture of ^{3}He and ^{4}He at the prevailing high pressures would ensure a self reversing but stable over long periods magnetic field so necessary as exciting field for the convection dynamo. It is possible that Venus being a liquid planet must have convection currents but does not boast of a magnetic field because it lacks the exciting field, since no helium reservoir could exist in the depths of the liquid planet. The occurrence of an innermost core containing a fission reactor with helium surrounding it opens a new dimension in planetary Physics.

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