TIME AND TIDES – MESSAGES FROM A RECEDING MOON

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The Moon is our nearest neighbour, and the study of the Moon is truely a multidiscipinary subject.

A quotation from a famous scientist sets the scene for this largely geological study of our natural satellite:
"a good scientist is not one that knows all of the answers, a good scientist is one that knows what questions to ask"

In the first half, I want to set the scene, and discuss some of the interesting features of the Moon........what do we know and how did we come to know it?

PART ONE
Introductory/Background information on the Moon

Members of the public were surveyed, " if you could ask only one question about the moon, what would that question be?".

The most frequent questions asked were

What is it made of?
How far away is it?
How did it get there?

It was interesting to note that no-one asked *"where was the Moon in the past, and where will it be in the future?".*

Humans have long studied the Moon and the Sun and tried to explain them in the context of their own experience. Imagine how significant the Moon and the Sun would have been to early humans – before we had electricity, before we had gas lamps, before we had candles, and perhaps even before we harnessed fire. The residents of New Grange and StoneHenge certainly observed the Moon, but we can only guess at what they made of it.

The scientific method which has evolved by humans asking questions involves the building of models and the testing these models. Do they explain our observations? , The models are accepted, modified or rejected. Over the thousands of years humans have built models, and understanding has been passed down from generation to generation.

Before we could progress in our understanding of the Earth-Moon system, we needed to understand a few things about the Earth itself.
The observation that a ship disappeared hull first over the horizon (and as he travelled North, stars disappeared to the south) led **Anaximander of Milutus**, in 550BC, to propose that the Earth was a cylinder! Subsequent observations in all directions soon determined that the Earth was a sphere. **Pythagorus** supported this view, adding his observations that the Moon and the Sun appeared to be circular discs,

or spherical objects, and in eclipses, the shadow of the Earth always seemed to be circular. This all represented a great advance in scientific thinking.

If the Earth were a sphere, then the sky, or celestial sphere, containing the Moon and the Sun had to be an even bigger sphere. It appeared to revolve around the Earth once in 24hours. **Ptolomy**, the Greek astronomer, devised the ‘Geocentric Model’ of the Universe (about 150 AD) – in which the Earth was static and everything else orbited the Earth.

Other Greek philosophers regarded the Sun as the centre of the Universe. Great debates ensued. Did the models explain all of the observations? Did they answer the questions being asked?

Prior to this, Eratosthenes, a Greek astronomer, in 235BC, had calculated the size of the Earth. This allowed great advances. In particular, the size of the Moon could be estimated from observation of eclipses, by estimating the ratio of the Earth:Moon radii.

The Moon was the nearest object in the sky because it passed in front of the other celestial objects – so was of particular interest.

Humans asked the question “just how far away is the moon?”. Without the aid of modern equipment, the ancient Greeks devised an ingenious method to ‘measure’ the distance to the Moon.

It is possible for anyone to repeat this.

Take a broom, and discard the brush. Attach a tape measure. A chair might be useful. You will need a few coins of different sizes. Move the coin along the broom handle until the coin just eclipses the moon. Note the distance between your eye and the disc. You can measure the diameter of the coin. We know the diameter of the Moon. The distance to the Moon can be calculated using similar triangles.

Thus we came to understand the shape and size of the Earth and Moon, and the distance between them. But we needed to understand the orbital motions of the Earth and its nearest neighbours.
How did we come to know that the Earth **spins** on its axis?
How did we come to know that the Moon orbits the Earth, and that the whole Earth/Moon system orbits the Sun?
Not by sitting still and trying to feel the motion.We cannot ‘feel’ the motions. When you are sitting still, the Earth seems to be still. Our senses are not telling us that we are on the move. Our understanding came from further scientific observation and by taking measurements.

In the early 1500s Copernicus simplified the model of the solar system by having the Sun at the centre, giving us the heliocentric model. We can thank **Tycho Brahe,** for his years of careful measurements of the solar system, and **Johann Kepler,** the puzzle solver, who gave us Kepler’s Laws and brought us on leaps and bounds in our understanding of orbital motions.

Foucalt's pendulum
It still took a leap of imagination to put oneself outside of the Earth and to look down to see a spinning Earth. This was when Leon Foucalt's pendulum experiment, carried out at the Parthenon in Paris, finally convinced the sceptics. The giant pendulum swung in a constant direction in space, while the Earth slowly spun beneath it.

We now know that the Moon orbits the Earth along an elliptical path – and the speed is greater at the close approach to the Earth, and slower when the moon is furthest away.

The motions are <u>periodic</u> (eg. night always follows day; spring always follows winter) and gave us some of our first natural units.

Solar Day – the interval between 2 consecutive culminations of the sun

Solar Year- the interval between 2 consecutive summer solstices

Lunar month – time between 2 consecutive full moon phases

These are perfectly adequate units for everyday use. But are they constants? we will come back to this question.

When Galileo first looked at the Moon by telescope, in December 1609, he saw dark areas and bright areas. He called the dark smooth lowlands the Maria, and the bright textured regions the Highlands**.**

There is an Irish connection. William Parsons, the 3rd Earl of Rosse, and Mary, Countess of Rosse, builders of the telescope at Birr Castle, played their parts in advancing the study of the Moon. Eminent scientists of the time visited Birr Castle to view the Moon and debate our nearest neighbour. Their eldest son, Laurence Parsons, the 4th Earl of Ross, living in Birr Castle in Co. Offaly, took some of the first photographs of the Moon, which could be used for study. (He inherited the photographic studio from his mother Mary Rosse, a pioneer photographer in the 1850s.) He also carried out experiments to measure the surface temperature of the Moon. His methodology and results are displayed in the Museum at Birr Castle.

So what were the features they could see? One very obvious feature of the Moon's surface are the profuse craters. Gilbert, in 1912, no doubt helped by Parsons photography, suggested that most of these were produced by the impacts of meteoroids. Some craters are overlapping, giving us age relationships
The debris thrown out by impacts also helped in the chronology. The Freshest rays were from the youngest craters. These early observations allowed us to create a timetable of events – a crater timetable. We could construct the sequence of events and a Moon Chronology was devised from this relative dating. The age of the events in years was unknown.

"and the eminent scientists over the ages have been the ones that changed the nature of the questions being asked" Encycl. Britt.

Crater timescale. The older craters are obvious because they have been rounded off by bombardment, they are covered in regolith, and may be cut by younger craters. The newer caters are much fresher, sharper features, with fresh rays radiating from the centre. Another piece of evidence used is "the higher the crater density, the older he feature"

Very profuse – but many more on the highlands than the Maria – suggesting the Highlands had been around longer.

The next major advances in our understanding of the Earth-Moon system came when scientists left the earth. Visiting is believing: a lot of information and understanding have been gained relatively recently with space exploration programmes (see Box. 2).

Box. 2
Sputnik – USSR, sent the USA into the space race, thus spurring the explosion of scientific achievement
Ranger series – with our first close pictures of the Moon
Surveyor series – gave us our first information on the chemistry and the strength of the surface materials on the Moon, indicating that something could land on the Moon without sinking into it.
Orbitor series – gained the necessary information for selection of landing sites, which had to be safe and of scientific merit.
Apollo Series – Apollo 8 orbited the Moon, but Apollo 11 will always be remembered for putting the first man on the Moon in July 1969 – Neil Armstrong. There were 6 landings on the moon. Apollo 17, noted for being, the last landing, put the first scientist on the Moon, "a geologist on the Moon" – a full crew member

The astronauts collected about 400kg of rock material from the surface of the Moon.
Many questions were being asked and now we had a chance to answer some
The samples are the most studied in the World.

We had suspected that the term maria was not appropriate, because the dark smooth areas named by Galileo were not oceans. In fact, there appeared to be neither water nor atmosphere on the Moon.

Study of the rock samples determined that the largest craters were filled with **layer upon layer of basalt lava**, solidified into rock. These were very fluid flows, that flooded the depressions. We can actually see the forward edges of flows, 'frozen' in space from satellite pictures. Individual lavas are often > 30m thick, and the total thickness of lavas that fill the Maria is thousands of metres. The basalts are similar to those found on Earth, except that they were formed under dry conditions, and have remained under dry conditions. Those on earth can contain up to 2% water, chemically combined with the minerals such as amphibole. On Earth the mineral feldspar would have been decomposing to more stable clay minerals......at much younger ages. The first observation by any geologist is that the Moon material appears breathtakingly fresh. Further, geochemical evidence suggests that these Mare basalts were produced by partial melting of the Moon's underlying mantle.

The Highland areas make up most of the lunar surface. They are the most heavily crated areas of the Moon. We can see the lavas have overlapped onto the Highlands, therefore the highlands are an older feature than the basalts.
The highland rock is similar to a rather rare rock we find on Earth – anorthosite – a rock rich in the feldspar, anorthite, together with small amounts of pyroxene and olivine.

The highland anorthosites are less dense than the basaltic maria, and for this reason the highland areas stand 2.75 km higher than the maria.

What else do we know? We know that the first astronauts to walk on the moon made footprints! All lunar terrains are covered with a layer of mostly grey, unconsolidated sediment. This has been derived from billions of years of meteoritic bombardment.
This soil like layer is called lunar regolith. It is composed of fragments of igneous rocks, breccia, glass beads, and fine particles, commonly called lunar dust. The regolith varies in thickness from about 3m to 30m.

Jack Scmidtt, took a core of this of this material. It showed fine layering, each layer being caused by the dust and debris of a meteoroid impact. He saw an area of orange soil, and got quite excited, thinking this represented recent volcanic activity. The ‘soil’ turned out to be more than 3billion years old.
The regolith has a **stratigraphy**, it is showing us a sequence of events which has been recorded over millions of years.

The chronology built up by relative dating of events could now be calibrated with actual dates.
Absolute ages : Basalts 3.2-3.8by
Anorthosites 4.4by (slide with dates.)

All of these observations have allowed detailed debate on the origin and geological history of the Moon.

There are several widely held hypothesis on the origin of the Moon.

1. **The Moon formed at the same time as the Earth**, from fragments that condensed out of the solar nebula
2. **The Moon was captured into the Earth’s orbit** as it passed close to the Earth. The similarity in composition is difficult to explain.
3. **The Earth was fluid, and spinning so fast** that part of the earth detached and went into orbit. Explains similarity in composition.
4. **The favoured hypothesis** at present is that very early in the Earth’s history, a giant body, the size of Mars and travelling at 20-30 km/sec, collided with the Earth. The resulting explosion is thought to have ejected huge quantities of mantle material from the primitive Earth, into orbit.
   Moonlets formed, and gradually accreted. On collision all gravitational energy would have gone into heat energy, and caused melting. The material would have lost volatiles. Moon material is particularly depleted in volatiles. This giant impact occured after the Earth had segregated into iron core and silicate mantle. The data we have tell us that the composition of the moon is similar to that of the Earth’s mantle. The material thrown into orbit was mantle

material. This explains the lower average density of the Moon. The radiometric dates tell us this was only about 100my after the formation of the Earth.

What happened next?
The bombardments caused heating up of the Moon and **substantial melting**. >1200°C (heat of accretion). The **lighter elements floated** to the top to form the feldspar rich crust, anorthosite, and the **heavier elements sank** forming a small iron rich core. The remnants of this crust have been dated at 4.5by and form the densely cratered highlands. This is the Moons primary crust.

Bombardment continued, with the last major period around 4by ago.
The craters known as the Maria basins were formed at this time. The impacts ejected quantities of loose rock, sometimes forming breccia ridges 5 km high. How do we know the age of bombardment? Small fragments of glass (melted rock) have been collected from the ejecta rings, and and they all date at about 4 by .

Subsequently the Maria filled with basalt lava, dates between 3.2 and 3.8my.(Youngest maria are equivalent to some of the oldest rocks we find on earth.) The lavas were formed by partial melting of the underlying mantle rocks. – heated by the energy generated by the impacts. In places lavas overflowed the margins of the craters. So it is believed that the basalts formed from shock melting of rocks deep within the Moon.

Most, if not all of the Moon's tectonic activity ceased about 3by ago.

So the first billion years of the Moons history is still on show, and provides evidence for the history of the Earth. This is very useful because very little trace can be found in the geological record, of the Earths History at that time.

Why is the moon not like the Earth, with its abundance of water ad gases that make up our hydrosphere and atmosphere? **Did the Moon not experience outgasing?** Outgasing of the Earth occurred in its early history, and still occurs today, when water vapour and gases were thrown out of the Earths interior, to form the oceans, and the atmosphere. This process continues today though at a much slower rate.

If you compare the 2 planets. The average density of the Moon is only **3300kg/m3**. Compare the Earth **at 5,500kg/m3**. This small planet with its low density would not have had the gravitational pull to keep the lighter elements. We all know that an astronaut can jump 6 times higher on the moon. – because gravitational accelerastion is only $1/6^{th}$ that experienced on the Earth.

The lack of water and atmosphere has a very important implication. The processes which shape the Earth, - weathering and erosion, are virtually lacking on the Moon. (that chip away at our mountains and wear them down.
(see crater on Earth). There are no sedimentary rocks, of the type formed by flowing water.

In addition – tectonic events, such as earthquakes, and volcanic eruptions, are not occuring on the moon at present. There are no plates, no plate margins. – with their associated dramatic activity. – no san andreas, fault, no volcanic iceland or japan.

There are some small **moonquakes** . These are due to tidal forces, with focal depths deeper than on Earth. So it seems that there is not much happening on the moon at present. Why should it behave so differently to the Earth?

Well there are a few small changes. Micrometeoriods, continually bombard the moon. Over very long periods they can gradually cause smoothing of he landscape. Occasionally a larger meteoroid causes the formation of a crater.

It is thought that the footprints of the astronauts will remain fresh for 1 or 2 million years, before they lose clarity from the build up of lunar dust.

Seismicity and Magnetic rocks give us information about the Moon's interior.

The modern method is Laser Ranging. And the current distance is approx
384, 000 kilometers
(Elliptical orbit – you will still read in some books "apparant size of the Moon does not change , so distance between the Earth and the Moon must be constant"!!!)
Galileo. Clementine, and Lunar Prospector continued the exploration, and a good review can be found in Science 1994

PART TWO

But has the Moon always been at the same distance from the Earth?
No. The geophysicists have been telling us for a long time that the Moon is receding from the Earth. It is moving further and further away from us, and may have been since its origin.

Let us look at the Theory

Variations in the rate of rotation of the Earth cause changes in the length of day. Short term changes can be attributed to a number of things, such as changes in sea-level.
For long-term variations, the most widely accepted mechanism is tidal friction. Both the sun and the moon contribute to the Earth's tides. The effect of the Sun is much smaller than that of the Moon.

What is happening? The gravitational attraction of the Moon on the Earth causes tidal bulges. These occur in the solid Earth, and in the oceans.
See slide – tidal bulge if there is no friction and oceans perfectly non-viscous fluid (strong attraction at near side, weak attraction at far side)
But this is not the case. The actual tidal bulge occurs as in second figure.
Accurate tidal measurements are important, and show the lag in response is 50minutes. So, tidal friction delays the tidal bulge.

This produces a couple on the Earth, slowing down rotation about the spin axis. If we ignore the solar tide, then the E-M system can be considered a closed system. It must obey the laws of conservation of angular momentum. As the Earth's velocity decreases, the Earth's angular momentum is decreased.
But the total angular momentum of the E-M system must be conserved.
If we assume the mass of the Moon is a constant, then the Moon must swing into a wider orbit to increase its angular momentum.

So, the loss of angular momentum as the Earth slows down is balanced by an equal increase in the angular momentum of the moon's orbital motion, which means the moon progressively recedes from the earth.

To a small extent the 'tides' in the solid earth add to this process.
It takes energy to overcome the friction in shallow seas, and to deform the solid earth.
A small amount of heat is generated by the process.

(Tidal interaction between the Sun and the Earth, contributes a further increase in length of day, but much smaller than that of the moon)

What happens if the Earth's rotation slows down? - increases the length of day.

Using records of ancient eclipses, during the past **3000years**, it has been estimated that the Moon is retreating from the Earth at a rate of about 6cm/yr.
The estimate for the increase in the length of day over the 3000years is quoted in different ways, but Martin Bott quotes it as 2.7 milliseconds per century.
Atomic clocks were stopped for one second on New's Eve about 12 years ago, to allow the spinning earth to catch up with the clocks!

Apart from these records of ancient eclipses
<u>Are there any other messages left for us on Earth as the Moon recedes?</u>
The Moon has left evidence for us to find and interpret.

The story of the earth's rotation and the moons recession can be carried back much further into the past **using fossil clocks**. Some corals secrete calcium carbonate on a daily basis. In the 1970's Palaeontologists had tentatively recognised daily, monthly and annual banding, in rugose corals, suggesting there were 400 days in the year in the middle Devonian. (ie approximately 400million years ago), divided into 13 lunar months. Note: length of solar year was the same.
Now we have evidence from Corals and brachiopods and stromatolites. Give us information on the length of day, and number of days in a solar

In 1987 I began to incorporate this into a course on Geodynamics.
My question at the end of the class to the students was
"If the Moon was closer to us in the geological past, what was the effect on the worlds tides, (were they much bigger – with more energy), were the intertidal zones much bigger, -what was the impact on intertidal habitats in the past (were they more extensive), and could their have been a greater evolutionary forcing factor in the past. (The intertidal habitats are very important – fairly hostile environments - where life left the oceans and took to dry land)"

I asked eminent sedimentologists. They said 'was the moon nearer in the past?'."hmmmm". I began to take more notice of their sedimentary logs. Intertidal sediment was very often featured. **This has evidence of tidal action, and therefore records the past activity of the orbiting Moon**. **The moon has left messages for us of its past activity.** But could we look to see if it was more or less in the past? An impossible task - erosion, alteration, quantity of data to be collected and analysed.

I asked physicists, and oceanographers, some who said 'was the moon nearer?', "hmmm". and all got excited about the prospects/possiblilities of new patterns of wave oscillation in the oceans in the geological past. I asked biologists who were interested in intertidal habitats. The said 'was the moon nearer?" "hmmm".
All of that did not get me any nearer answering my qusestion.

I was fortunate in that a student who was interested in sedimentolgy and mathematical modelling. After some discussion with staff he took on a project to try to throw some light on the above questions.

First of all we wanted to get some idea of just how big were those tides in the past.
Looking into the physics of the problem, Paul found that the tide raising force was inversely proportional to the distance cubed. So the nearer the Moon was, the bigger were those tides.

We began by assuming a linear model for the Moon's recession.
6cm/yr and 3.8cm/yr
Paul worked out the tidal force and devised a sliding scale so that you could take any date and predict the tidal force at any time in the past. This was neat! (Examples)
We could say something about the tidal range, and therefore for a particular coastal geomorphology, the size of the intertidal zone.
The numbers were not huge, but the conclusion was demonstrated that all things being equal, there was a greater tide raising force in the past, and we had gone a small way to understanding and quantifying this change. Because of the cubed function, tides didn't really start getting big until we go back as far as the Precambrian. (the first creatures may have been on land in Silurian/Devonian – plants slightly earlier – but life was in the oceans 3 billion years ago at least)

So, This turned into the question – "Where <u>was</u> the Moon in the geological past?"

I initially thought that the recession was not linear, but would have actually been faster in the past, when the moon was nearer, and there was greater friction in tidal environments. So a curved graph, with the moon nearer than our linear models allowed?

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Theoretical work by physicists bring the Moon back to 2.7 Earth Radii 4.5 billion years ago. This is within the Roche limit, which is 3 Earth radii. If this were the case, the Moon may have been broken up by the Earth's gravitational pull, and would not have survived for long. (For this reason we should assume there was some factor keeping the moon from such a close approach**). At 3 earth radii we're talking about**

a 5 or 6 hour day. (The earth spins once every 5 hours or so). **The tides at any time in the Precambrian period would certainly have been huge.**

But as we searched the literature, to try to get a better handle on just where the moon was in the past, we found that there were estimates of the Earth-Moon distance which were at odds with each other. The models proposed by the scientific community varied greatly. This became an interesting puzzle in its own right. **(By trying to answer one question, more questions arose!).**

The conflicting evidence came from geological observations!
In the process of this research, we came across a sedimentologist in Australia, George Williams who had done some very interesting work.

The Moon has left messages for us to interpret in the form of tidally influenced sediment. The energy of the tide will vary through the day. The character of tidally influenced sediment is that coarse grains are deposited as the tide comes in, and fine grained material is deposited as the tide turns. More than this, the allignment of the Sun and moon causes higher tides, and the thickness of the sediment deposited will be greater. The tides at perigee and apogee can be recognisable.
Sediments – The neap/Spring Cycles are recognisable (Present day) And can be preserved /recognisable in ancient rocks.
We discovered that during the 1990s, a geologist in Australia had been doing some very interesting work. George Williams, had analysed samples which were 600my old, and extracted information about the position of the Moon in the geological past. His results indicated that there were about 400 days in the solar year.

More recently he analysed the banded Ironstone formation of dubious origin, but possibly tidally influenced, and acquired >500 days in the year.

This puts the moon, in an orbit not much different to the one today, in the Precambrian. Other workers have tried similar methodology, and results are summarised here. Very little data to go on.

Williams is claiming that the fossil clocks are unreliable, due to the difficulty in counting the banding. He says the banding in Corals may reflect a lunar day rather than a solar day. However 400 lunar days in a year would have the Earth spinning faster in the Middle Devonian than 400 solar days.
So we have conflicting evidence.
George recognised that he could extract information on the Moons position from these tidally influenced sediments. He came up with the following figures.
Other workers used similar techniques. So we have approx. 3 dates by this method. Are they accurate ? Is this meaningful? We should try it ourselves.

So we looked at the extremes in an attempt to restrict the possibilities for our modelling.

Then Paul realised something that was missing from their work. Neap Spring Cycles occur because of the interaction of the motions of the Sun and Moon.

No-one had taken into account, the ratio of lunar to solar influence would have been different in the past. Paul constructed graphs of the Neap-Spring influence in the past. If the Moon was half the distance it is now, the neap/spring graph would look like this.

Looking at these both together shows that they would be hardly recognisable. There may be some critical limit to them ocurring at all.

This would help to illuminate the catastrophe model, predicted by the physicists. If we can go back billions of years and find sediments showing neap/spring cycles, then we will be favouring the conservative estimates.

All this is a bit of a shame for my gigantic waves, and extensive intertidal habitats. But they have not disappeared altogether, and are still receiving attention. They may yet prove to be significant.

In the meantime we are collecting samples from Silurian and Devonian rocks of Ireland, which have been classified as intertidal by sedimentologists. We are experimenting with methods of digitising the layers and analysing them. Counting the laminae can be problematic. We produce a sort of bar code which can be read automatically. In these 2 samples we have used fourier analysis to look for patterns.

The fourier analysis tells us there is no pattern. My eye can see cyclic sedimentation.
We are not seeing exact numbers of laminae per lunar month. We can recognise periods of erosion, and so not continuous undisturbed sedimentation.

With this methodology it will be possible to analyse a large number of the tidally influenced sediments preserved in the Silurian/Devonian/Carboniferous of Ireland. Our results can be added to the data pool.

When we have perfected this technique, we will be looking to sample some of oldest tidally influenced sediments in the world, to see if we can put more figures on the graph.

So this work has thrown up even more questions. I think this work has helped the scientists we have worked with to ask slightly different questions about the moon in relation to their own work, ..and I hope it has done the same for you. Thankyou.

(To fit in somewhere: The fossil clocks fell out of favour a little, because more detailed work showed that the patterns were slightly more irregular than was first observed. However, the Earth's spin is now thought to have speeded up at least twice in its history. This may explain the disrepancies in the fossil clocks, and quieten the sceptics.)

Concluding remarks
".......Up to the present, a very small fraction of the total amount of tidal deposits formed during the geological Past has been discovered and studied, which leaves ample opportunity to the elucidation of a number of features, which are still enigmatic at present".

We are developing a methodology, using Devonian and Silurian tidally influenced rocks in S. Ireland. These will give us data about the position of the Moon in the past, which we can compare directly with the fossil clocks of similar age.
We would then intend to study older sedimentary rocks wherever we can find them.

Also, we can discriminate between different parts of the tidally influenced system, by studying the disturbance of the Neap-Spring pattern.

(Somewhere: - But we realised this was an oversimplification – There are many cycles affecting the forces). Predictions of tidal height/range and intertidal zone in low relief coastlines. (GIS type cartoon)

Reasons why the theoretical considerations may come up with **too** close an approach:
There may have been no oceans.
Volcanic activity has added water to the system, but water is lost in the upper atmosphere.
Water lain sediments over 3 billion years old are certainly preserved in the geological record, but some researchers say that we may not have had the same area of shallow seas as we have today.
Could the continual differentiation of the earth have had an influence. As denser material sinks, and lighter material is brought to the surface??
Recent work has suggested that large chunks of rock can sink through molten rock in the earths mantle, and cause a temporary speeding up of the earth rotation.

It is interesting to note where the theoretical predictions place us in the future.
The Moon will cease receding when the earths spin rate is 48present earth days. So we would get 24 days of sunlight and night will last for 24 days, and
The moons orbit will be 88 earth radii. But take heart, this is unlikely to happen. it is likely that we will be involved in a supernova explosion before that.

Then we will have synchronous rotation.
The influence of the Sun in the system will then dominate, and cause the Earth/Moon system to recede from the Sun, and the Moon to approach the earth again.

The Millennium edition of the Irish Scientists Year Book.

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