Determination of the cosmological parameters from the Earth-Moon system evolution

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Abstract. We have obtained empirical laws for the variation of the Earth parameters with geologic time that are in agreement with coral fossil data obtained by Wells and Runcorn. Our model predicts that the day is lengthening at a rate of 2 ms/century at the present time. The length of the day when the Earth was formed is found to be 6 hours and the synodic month to be 56 days. The angular momentum of the Earth-Moon system is found to be increasing with time. The origin of the presently observed acceleration of the Moon is explained. It is predicted that the Moon is approaching the Earth at a present rate of $1.5 \text{ cm/year}$ and with an acceleration of $20.6 \text{ arc sec/yc}^2$. It is shown that the Moon has never been close to the Earth in last $4.5 \text{ million years}$.

1. Introduction

The Einstein General Theory of Relativity (GTR) is one of the most fascinating theories that people have come to know. Einstein himself, after the overwhelming success of his theory when applied to the Sun, constructed a model for the whole universe. The Einstein model was a static model, in which stars (or galaxies) do not move, as appeared to him at that time. After the universe was found to be expanding with time, Einstein abandoned his model. Obtaining a static model of collection of matter alone is not possible, and this led Einstein to hypothesize a repulsive force (later known as the cosmological constant ($\Lambda$)) to hold his universe from collapse. Einstein regretted the addition of this constant when it appeared to him that the expansion plays the role of repulsion ($\Lambda$). Later, Einstein and de Sitter constructed a model for the universe (now known as the Standard Model) in which matter and radiation are distributed homogeneously and isotropically. That model is successful in many regards: it predicts an existence of a cosmic background radiation and a primordial synthesis

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of helium and hydrogen in the earliest stage of expansion of the universe. Such predictions are now well established facts about the present universe. However, the Standard Model is fraught with other problems which could not be solved in the framework of the Einstein-de Sitter model. An idea that the universe had once expended at an enormous rate was brought by Guth [1980] and Linde [1981] which is known as the Inflationary Scenario. This scenario solves, most if not all, of the standard model puzzles. The Standard Model gives an age for the universe of \( t = \frac{2}{3} H^{-1} \), where \( H \) is the Hubble constant. This value is smaller than those obtained by astronomers. Cosmologists have found that if one still retains the concept of the cosmological constant the age problem can be resolved. However, a pure constant might pose a problem, from the point of view of particle physicists who estimated its value at the Planck time to be 120 orders of magnitude smaller than its present one.

In fact, the idea of a variable is associated with Dirac [1937] who noticed some puzzling coincidence between atomic and cosmic scales. He found the age of the universe in terms of atomic time to be about \( 10^{40} \), the ratio between the electric and gravitational forces of an electron and a proton (e.g., in hydrogen atom) to be about \( 10^{40} \) and the ratio of the Hubble radius (observable radius of the universe) to the classical radius of electron to be about \( 10^{40} \). He thought that the coincidence of these dimensionless huge numbers is not accidental, but must have a physical origin. In order that this coincidence to hold at all times, and not just for the present time, he proposed that the gravitational constant has to change with time inversely, i.e., \( G \propto t^{-1} \). Therefore, to Dirac, the expansion of the universe lead to a weakening of the gravitational constant. Later, Brans and Dicke [1961] (BD) formulated a field theoretic model in which \( G \) is related to a scalar field (\( \phi \)), that shares the long range interaction with gravity, viz. \( G \propto \phi^{-1} \). Their theory predicts a decreasing \( G \), as in Dirac model, but with a lesser rate. For conformity with the present observations regarding the solar system, BD theory becomes indistinguishable from GTR. The BD theory is set to satisfy Mach principle which asserts that our local physics is affected by the presence of distant matter in the universe.

The variation of \( G \) with time would have numerous geological and astronomical consequences. For instance, the luminosity of the Sun depends on \( G \). The distance between the Earth and the Moon, the length of the month, the Earth’s surface temperature, the length of the day and the Earth’s radius would all be affected. Shapiro et al [1971] have set an upper limit to the present variation of \( G \), viz., \( |\frac{\Delta G}{G}|_0 \leq 4 \times 10^{-10} y^{-1} \). A comprehensive investigation of the effect of the variation of \( G \) can be found in Wesson [1978].

The idea that gravity increases with time was proposed by several authors [Abdel Rahman, 1990, and references therein]. Canuto [1976] suggested a variation of the form \( G \propto t \). In line with that, we have recently proposed a cosmological model and have found that the gravitational constant has to increase in order to resolve the cosmological contradictions of the Standard Model with observations. This represents a minimal change of the Standard Model to fit the current observational data. We have found that \( G \propto t^2 \) in the early universe, but generally evolves as \( G \propto t^{(2n-1)/(1-n)} \), where \( n \) is related to viscosity of the cosmic fluid.
We have shown in that work that many non-viscous models are equivalent to viscous models with variable gravity [Arbab, 1997]. Our model does not determine \( n \) exactly but rather imposes a constraint that \( \frac{1}{2} \leq n \leq 1 \) in order to comply with the present observational data. All of our cosmological quantities depend only on the parameter \( n \). Very recently, a similar variation of \( G \) (without viscosity) in terms of another parameter \( \beta \), whose value determines the whole cosmology is also considered [Arbab, 1999]. The universe is consequently shown to be accelerating at the present time. This acceleration requires \( n > \frac{2}{3} \) (or \( \beta > 3 \)) [Arbab, 1999].

The purpose of this paper is to determine \( n \) from a different source of data that was not tried before. We remark that the evolution of the universe affects the Earth-Moon system indirectly, by allowing the gravitational constant to change with time at the present epoch. A fixed value for \( n \) (or \( \beta \)) is found from studying the evolution of the Earth-Moon system, viz. \( n = 0.7 \) (or \( \beta = 12 \)). This immediately implies that the Moon must be accelerating in its orbit while approaching the Earth. The same effect should be observed in the motion of the Earth around the Sun.

2. The Sun-Earth-Moon System

Kepler’s second and third laws governing the Sun-Earth-Moon system can be written as

\[
G^2[(M + m)^2 \cdot m^3]T = 2\pi L^3, \quad G[(M + m)^2 \cdot m^3]r = L^2, \tag{1}
\]

\[
G^2[(M + M_s)^2 \cdot M^3]Y = 2\pi N^3, \quad G[(M + M_s)^2 \cdot M^3]R = N^2, \tag{2}
\]

where \( m \) = mass of the Moon, \( M \) = mass of Earth, \( M_s \) = mass of the Sun, \( L \) = the orbital angular momentum of the Moon, \( N \) = the orbital angular momentum of the Earth, \( r \) = the Earth-Moon distance, \( R \) = Earth-Sun distance, \( Y \) = the number of days in a year and \( T \) = the sidereal month.

It is believed that \( N \) has remained constant throughout the Earth history while \( L \) changes with time. The synodic month, \( T_{sy} \), is related to the sidereal month by the relation

\[
T_{sy} = \frac{T}{(1 - \frac{T}{T'})}, \tag{3}
\]

From the above equations one can write

\[
\frac{Y}{Y_0} \frac{T_0}{T} = \left(\frac{L_0}{L}\right)^3, \tag{4}
\]

(hereafter, the subscript ‘0’ refers to the value of the quantity at the present time).

Based on the slowing down of the Earth’s spin with time, the conservation of total angular momentum of the Earth-Moon system dictates that the Moon angular momentum has to increase. It is evident from eq.(1) that if \( G \) increases then so will \( L \). It can also be inferred
from eq. (1) that if $L$ increases then $r$ must increase. In this case the Moon will lose its kinetic energy as it goes away from the Earth. However, observations show that the Moon is accelerating in its orbit [Dickey 1994], which, in turn, means that the Moon is gaining kinetic energy. Here lies the conflict and this is why this acceleration is called anomalous acceleration. In the present approach the variation of the Earth parameters with time is related to that of $G$. For instance, the acceleration of the Moon is a consequence of the increase of $L$. This would require the distance $r$ to decreases in such a way that $L$ increases. Therefore, our model predicts, rather than conflicts with, the presently observed acceleration of the Moon. Our prediction is well within the observational limits. Moreover, as a very close approach of the Moon in the past did not occur, this model resolves the problem of the short age of the Moon.

3. Coral and Bivalve Fossil data

Data about the past rotation of the Earth was obtained from fossil coral by Wells [1963], who concluded that the day was shorter in the past. In his systematic study of coral fossils, Wells was interestingly able to relate the number of ridges recorded by the corals to the number of days in a year, during the time when that corals had lived. He could go back with this analysis up to 600 million years ago. Investigations that employed coral fossils and related to the synodic month were done by Panella [1968], Munk [1966] and Scrutton [1964]. Barry and Barker [1975] employed bivalve fossil data and obtained a similar conclusion about the length of month in the past times. It has thus become clear that these corals can be used as chronometer, where changes in a length of day can be noticed. This method is clearly advantegous to radiometric dating, where only a time passage of million years can be differentiated. Wells’s data is shown in Table 1 and our corresponding data is shown in Table 2. Using Wells and Scrutton data, Runcorn [1962, 1964] concluded that the ratio of the angular momentum of the Moon 400 million years ago, to the present one ($L_0$) to be

$$\frac{L_0}{L} = 1.016 \pm 0.003. \quad (5)$$

4. The Earth-Moon system and the cosmological parameters

Using the results of Wells and Runcorn, one finds the variation of $G$ with time to be as follows

$$G = G_0 \left(\frac{t}{t_0}\right)^{1.3}, \quad (6)$$

where $G_0$ is the present value of Newton’s constant and $t_0$ the present age of the universe. Wells and Runcorn data require that the age of the universe to be $11 \times 10^9$ years. Hence, our model predicts that

$$\left|\frac{\dot{G}}{G}\right|_{t_0} = 1.1 \times 10^{-10} \text{y}^{-1}. \quad (7)$$
This age is found to be in agreement with the present astrophysical estimates. However, ages obtained from astronomical data usually involve some uncertainties (10 – 15 billion years). This constraint on the age of the universe implies that the universe is accelerating at present with an acceleration parameter of $-0.1$. This means that the contribution of ordinary matter to the total energy density in the universe is 60%.

Equation (6) can be viewed as representing an effective value for the gravitational constant ($G_{\text{eff}}$). Thus all gravitational interactions couple to matter with this effective rather than ‘bare’ constant ($G_0 = 6.67 \times 10^{-11} \text{Nm}^2\text{kg}^{-2}$). The introduction of the effective gravitational constant should leave our physical laws intact (form invariant). In effect, all old quantities have to be replaced with their corresponding effective ones (see below). With this prescription one can employ the old equations of Kepler, Newton, etc. for describing the present phenomena without any further complications.

Equation (6) can be written as follows

$$G_{\text{eff}} = G_0 f(t),$$

with $f(t) = 1$, for $t = t_0$. The idea of dealing with an effective quantity rather than a ‘bare’ one has already been applied for the motion of the electron in a solid, where it was shown that the electron moves with a different (effective) mass that is related to its ‘bare’ one.

In the present study, this ansatz will have lot of implications on the motion of celestial objects. One of the immediate consequences of this assertion for Newton’s law of gravitation is that a system in equilibrium tends to exhibit an apparent acceleration towards its center. The other physical (effective) quantities can be expressed only in terms of their present values and the past time (measured from the present time epoch backward). The number of days in a year and the length of the day are given by

$$Y = Y_0 \left(\frac{t_0 - t}{t_0 - t_0}\right)^{2.6}, \quad D = D_0 \left(\frac{t_0 - t}{t_0}\right)^{2.6}$$

In fact, the time duration of the year has not changed, but the number of days in a year changes because the day is getting longer as time goes on due to tidal effects of the Moon on the Earth. This means that in the past, the number of days in the year was bigger than now.

Recently, McNamara and Awramik [1992] have concluded, from the study of Stromatolites, that at about 700 million years ago the number of days in a year was 435 days and the length of the day was 20.1 hours. In fact, our model predicts this value to correspond more accurately to 715 million years ago. This indicates that this approach is reliable and can be used safely to get some clues about the nature of life that was prevailing at a particular time in the past. In this manner, one can use these Stromatolites as chronometer for dating geological rocks in which they are found.

Sonett et al [1996] have used laminated tidal sediments to determine the number of days in a year some 900 million years ago and inferred from these records that the number of
days in a year was 456 days, and that the length of day was 19.2 hours, considering only the lunar component. They also concluded that the sidereal month to be 23.8 days (present epoch day). This is in agreement with the value we obtain for this period (see Table 2). In fact, Stromatolites are believed to be dated back to the earliest stage of the Earth formation (3.5 billion years ago—see McNamara and Awramik).

Hannu [1991] made a statistical formula from the data of the corals and bivalve and found that 3.556 billion years ago the year contained 1009 days. All these results are in agreement with our model predictions.

Our model predicts that when the Earth was formed the length of the day was 6 hours, the year having about 1434 days and the synodic month being about 56 days. This is because the Moon orbited the Earth with rather a smaller velocity and at a larger orbit. Studies indicate that billion of years ago, the length of the day was between 5 and 6 hours. These results have been confirmed by an unexpected finding [William, 1994]. Moreover, Schopf [1983] has found the length of the day 4.5 billion years ago to be 5-7 hours. As it difficult to find fossils that dated back to 4.5 billion years ago, the information about the primitive Earth can only be extrapolated from these data. For this reason our model becomes a very useful tool for those who are keen to know about the early evolution of the Earth-Moon system.

5. The Moon’s Acceleration

The orbital angular momentum \((L)\), the length of the sidereal month \((T)\), the Moon orbital velocity \((v)\), and the Earth-Moon distance \((r)\) are given by

\[
L = L_0\left(\frac{t_0 - t}{t_0}\right)^{0.44}, \quad T = T_0\left(\frac{t_0 - t}{t_0}\right)^{1.3},
\]

\[
r = r_0\left(\frac{t_0}{t_0 - t}\right)^{0.44}, \quad v = v_0\left(\frac{t_0 - t}{t_0}\right)^{0.88}.
\]

It is shown by Dicke [1962] that the Earth radius \((d)\) is related to \(G\) as \(d \propto G^{-0.1}\), hence

\[
d = d_0\left(\frac{t_0}{t_0 - t}\right)^{0.13}.
\]

The lunar and Earth angular velocities are given by

\[
\omega = \omega_0\left(\frac{t_0}{t_0 - t}\right)^{2.6}, \quad n = n_0\left(\frac{t_0 - t}{t_0}\right)^{1.3},
\]

where \(\omega = \frac{2\pi}{D}\), \(n = \frac{2\pi}{T}\), \(n_0 = 2.661699 \times 10^{-6}\) rad/sec, \(\omega_0 = 7.2921 \times 10^{-5}\) rad/sec.

It is evident that an increasing gravitational constant leads to a contraction of the Earth radius. Such a variation can be tested with observation. In fact, the idea of a contracting Earth was once favored by geologists, as it helps interpret the process of mountain building.
Bursa [1987] has shown that the resonant condition between the Earth and Moon is such that the length of the month is 50.7 days, a distance of 581098 km, which corresponds to a time of 3.2 billion years ago. According to our model the Earth had once a similar condition, viz., at a time of 4.16 billion years ago when the Earth-Moon distance was 473774 km. If that was the case, our model may provide the answer to the question of the origin of the Moon that preoccupied scientists for several decades.

According to our model the Earth is contracting at a present rate of 0.1mm/year. A contraction in the Earth will result in an apparent increase in the sea-covering water areas.

Equation (12) implies that the Moon is approaching the Earth at a present rate of 1.5 cm/y, while Apollo mission to the Moon suggests a recession of the Moon of 3.8 cm/y [Dickey et al, 1986]. This result is the only disagreement that our model has with the present observational data. The present recession obtained from the Apollo mission when extrapolated backward (to 1.4 – 2.3 billion years) would imply that the Moon was almost touching the Earth’s surface. However, the age of Earth-Moon system is believed to be more than this time (about 4.5 billion years ago). This is a real difficulty to Apollo data regarding the origin of the Moon. However, there is so far no geological evidence for such a situation.

Slichter [1963] remarked that “if for some unknown reason the tidal torque was much less in the past than in the present (where ‘present’ means roughly the last 100 million years), this would solve the problem”. He concluded that “the time scale of the Earth-Moon system still presents a major problem.” The Moon could not remain an intact body much closer to the Earth than about 18000 km. Brosche [1984] remarked that “from the results of paleotides, it seems probable that the Moon was not in a ‘narrow’ state, especially if there were no oceans during the first billion years.”

In fact, the increasing angular momentum does not necessarily imply that the Moon is receding (as immediately taken by many people). We could resolve this situation even with a Moon approaching the Earth (a decreasing $r$). That is because the Moon is accelerating in its orbit and this acceleration takes into account the decrease of the Earth-Moon distance. This is evident from our eq.(11).

While our model predicts a lunar acceleration of (20.6 arc sec/cy²), the present estimate of lunar acceleration from lunar laser ranging amounts to (−24.9 ± 1.0) arc sec/cy² [Dickey et al, 1986]. Christodulidis et al [1988] have found the total contribution from tidal effects to be −21.4 arc sec/cy². This result is very close to our prediction. Spencer and Jones [1939] found the acceleration to be −22 ± 1.1 arc sec/cy². Lambeck [1980] has shown that the rate of change of the lunar and Earth angular momenta to be related by

$$ \dot{\omega} = (51 \pm 4) \dot{n} . $$

Lambeck [1980] and Stacey [1977] argued that “tidal dissipation must have been lower in the past”. Equation (13) gives the following

$$ \dot{\omega} = -54.8 \dot{n} . $$

(15)
This represents another agreement with observation. Equation (13) implies

\[
\dot{\omega} = -5.47 \times 10^{-22} \text{ radian/sec}^2.
\]  

(16)

where it is shown by Christodulidis [1988] to give

\[
\dot{\omega} = (-5.98 \pm 0.22) \times 10^{-22} \text{ radian/sec}^2.
\]

(17)

which shows how our prediction is closed to the observed one. In fact, Lambeck [1980] has found \( \dot{\omega} = -5.48 \times 10^{-22} \text{ rads}^{-2} \) to be his consensus value from astronomical observations. Murray [1957] has shown that the deceleration derived from ancient lunar eclipse is in an excellent agreement with that deduced from Hipparchus’s observations. He combined the two independent determinations and adopted that the Moon acceleration to be \((-21 \pm 3) \text{ arc sec/cy}^2\). Calame and Mulholland [1978] considered the possibility of the time variation of \( G \) in inducing any tidal acceleration. They pointed out that \( \dot{n} \) is supposed to be constant in nearly all discussion pertaining to it, as no geophysically plausible mechanism can account for a significant variation over historic time. They observed that all of the various solutions lay in the range \(-22 \) to \(-26 \) arc sec/cy\(^2\). They concluded that “it will require several more years before the cosmological question of \( G \) can be resolved with any confidence”. Calame and Mulholland [see Brosche and Sundermann (1978)], when correcting Williams [1974] data for the origin of longitude, obtained an acceleration of the Moon of \(-20.7 \pm 1.6 \text{ arc sec/cy}^2\). It is speculated that as the Moon recedes far away from the Earth the tidal effects become unimportant and the length of the month and that of the day will be both equal to about 55 days (present epoch days). We have found that the month in the beginning was 56 days and the Moon was in its farthest point from the Earth. This picture on one hand resembles the situation that our model predicts.

One of the competing scenarios about the origin of the Moon is the fission theory by Darwin. This requires the Earth to have rotated at a period of 2.5 hours in the past. As this was not the case, our model rules out this scenario.

The rapid rotation of the Earth in the beginning led to tremendous geologic effects on the Earth’s motion. It gave rise to various geologic activities: volcanos, earthquakes, mountain building,..., etc. Since the Earth adjusts itself so as to be in equilibrium, the slow-down of Earth rotation would have its influences on the evolution of the Earth-Moon system. The continental drift suggested by geologists would have its causes in the ever-changing rotational motion of the Earth and the tidal forces exerted by the Moon. The rapid rotation of the Earth in the past must have affected our past climate.

We notice from Fig.1 that the number of days in a year decreased uniformly in the beginning but curved during some time and again decreases steadily. The time when this curvature occurred could be due to a significant emergence of water on the Earth. This is because as water became abundant, tidal forces would have slowed the Earth rotation at a bigger rate. However, this period, which lies between 1.1 – 3.8 billion years ago, is the time that life was first appeared on the Earth as suggested by scientists. Researchers in oceanography have to
set the proper limits for this an outstanding event in the Earth past history.
The escape velocity and the thermal velocity of a gas molecule are related by
\[ v_{es.} = \sqrt{\frac{2GM}{R}}; \]
\[ v_{th.} = \sqrt{\frac{3kT}{m}}, \]
where \( k \) is the Boltzman constant. For the gas molecules to immigrate from
the Earth gravity it must have \( v_{th.} \gg v_{es.} \). The luminosity (\( L \)) of the Sun is related to the
Earth’s temperature by the black-body formula, \( T^4 = \frac{L}{\pi^2} \). But \( L \propto G^8 \) [Weinberg, 1972].
Therefore, the evolution of the escape velocity and the temperature of the Earth can be
written as
\[ \theta = \theta_0 \left( \frac{t_0}{t_0 - t} \right)^{3.25}, \quad v_{es.} = v_{es.}^0 \left( \frac{t_0}{t_0 - t} \right)^{1.56}. \quad (18) \]
The escape velocity for the gases making the atmosphere was not enough to leave the Earth
since the Earth started cold at a temperature of 54 K. This is why a cold origin of the
Earth is favored over the hot one. Hence the Earth, most likely, has retained its primordial
atmosphere. A cold start of the Earth would have facilitated the development of life on the
primitive Earth. The appropriate conditions prevailing at that time suggest that life could
have originated inside the sea, where the temperature was higher, originating from rapid
frictional motion between Earth’s plates that provided sufficient heat inside the sea. And
when the outside conditions have changed life gradually moved to the surface, where light
was abundant to trigger the essentials of life.

6. The Future of the Earth-Moon System

As the Earth gradually heats up, the ice caps on the poles will start to melt. This would in-
crease the tidal effects on the Earth while the Moon approaches it. Thus, in the distant future
the tidal effects will become very strong and the Moon will enter a region of destabilization
(Roche limit). As the tidal forces increase the rotational velocity of the Earth will decrease
until it reaches a stage when the Earth can no longer remain in equilibrium. This will lead
to big disturbances in the Earth’s interior allowing the molten hot core material to come
to the surface. This disruption will result in many geologic activities, such as, volcanoes,
earthquakes, etc. The Earth’s temperature will become higher and life will again be pushed
back to the sea, as it once started in!

7. Conclusion

We have developed a model that describes the evolution of the Earth-Moon system from
its inception to the present. This system, which dates back to 4.5 billion years, had encoun-
tered various conditions that finally shaped the present Earth-Moon system as we observe
today. The history of this system is not lost, but embedded in different forms, in biologi-
cal samples that had punctuated clocks and the rocks that embodied and preserved them.
Our important prediction is that the Moon is approaching the Earth at a rate of 1.5cm/y
thus causing the Moon to accelerate. The consequences of this model may have important
impacts on geology, astronomy, theology, religion, arts, geography, biology, archeology, etc. The full data pertaining to the Earth in the past is tabulated and the necessary graphs are plotted. Data from paleontology and geology can not go back to the first instances of the formation the Earth. As there is no rock available more that 3.8 billion years ago. This justifies the necessity of having a model that can extend these data. For these issues we have to recourse to theories about the formation of the celestial objects to know the initial parameters describing our Earth-Moon system and other similar system. We have developed a complete and consistent simple mathematical method for handling the tidal dissipation, that agrees well with observations. The present model can be applied to other coupled systems in the solar system. The expansion of the universe is found to affects the evolution of the Earth-Moon system by imparting a small change in the gravitational constant. Further investigations are going on to ravel other hidden subtleties.

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References

Abdel Rahman, A.M.-M., Gen. Rel. Gravit. 22, 655, 1990
Arbab, A.I. Gen.Rel. Gravit. 29, 61, 1997
Arbab, A.I., [http://xxx.lanl.gov/abs/gr-qc/9905060]
Barry, W.B.N., Baker, R.M. (in Rosenberg, G.D., and Runcorn: Growth rhythms and the history of the Earth’s rotation, Willey Interscience, New York, 1975)
Brans, C, Dick, R.H., Phys. Rev. 124, 1961
Brosche, P., Phil. Trans. R. Soc. Lond. A313, 71, 1984
Bursa, M., Bull. Astron. Inst. Czechosl. V. 38, 321,1987
Calame, O. and J.D. Mulholland, Science 199, 977,1978
Canuto, V et al, Nature 261, 438, 1976
Christodulidis, D.C., and Smith, D.E., J. Geophys. Res. V93 6216, 1988
Dicke, R.H., Sience, 138, 653, 1962
Dickey, J.O. et al. Science 265, 482, 1994
Dirac, A.P.M., Nature 139, 323, 1937
Frank, D., Physics of the Earth, John Wiley & Sons,1977
Guth, A., Phy. Rev. D23, 347, 1981
Jeffreys, H, The Earth: Its origin and physical constitution, 1976
Lambeck, Kurt, The Earth’s Variable Rotation - Geophysical causes and consequences, Cam-
bridge University Press, 1980
Linde, A., Phys. Lett. B108, 389, 1982
McNamara, K.J, Awramik, S.M., Sci. Progress 76, 345, 1992
Munk, WJ, The Earth-Moon system, New York, Plenum, 1966
Murray, C.A., Mont. Not. Roy. Astr. Soc. 117, 478, 1957
Pannela G., et al. Science 162, 792, 1968
Runcorn, S.K., Nature 204, 823, 1964
Runcorn, S.K., Nature 195, 1248, 1962
Runcorn, S.K., Nature 193, 311, 1962
Runcorn, S.K., Paleogeophysics, Academic Press, London, 1970
Schopf, J.William, Earth Earliest Biosphere: Its origin and Evolution, 1983, Princeton University Press, New Jersey, U.S.A.
Scrutton, C.T., Paleontology. 7, 552, 1964
Shapiro, I.I., et al, Phys. Rev. Lett. 26, 27, 1971
Slichter, Louis B. J. Geophys. Res. 68, 14,1963
Sonett et al, Science 273, 100, 1996
Spencer and Jones (see Brosche, P., and Sundermann, J., Tidal friction and the Earth rotation, Springer-Verlag, Berlin 1978)
Weinberg, S, Gravitation and Cosmology, Wiley & Sons, 1972
Wells, J., Nature 197, 948, 1963
Wesson, P.S, Cosmology and Geophysics, Oxford University Press 1978
William K. Hartmann and Chris Impey, Wadsworth, Inc. HTML by Guy K. McArthur, 1994
Williams, J.G, private communication, 1974 (see Brosche and Sundermann, pp.43, 1978)
Table 1: Data obtained from *fossil corals and radiometric time*

| Time*  | 65  | 136 | 180 | 230 | 280 | 345 | 405 | 500 | 600 |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| solar days/year | 371 | 377 | 381 | 385 | 390 | 396 | 402 | 412 | 424 |

Table 2: Data obtained from the *principle of increasing gravity*

| Time*  | 65  | 136 | 180 | 230 | 280 | 345 | 405 | 500 | 600 |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| solar days/synodic month | 29.74 | 29.97 | 30.12 | 30.28 | 30.45 | 30.78 | 31.22 | 31.58 |
| solar days/sidereal month | 27.53 | 27.77 | 27.91 | 28.08 | 28.25 | 28.48 | 28.69 | 29.02 | 29.39 |
| synodic month/year | 12.47 | 12.59 | 12.66 | 12.74 | 12.82 | 12.93 | 13.04 | 13.20 | 13.38 |
| sidereal month/year | 13.47 | 13.59 | 13.66 | 13.74 | 13.82 | 13.93 | 14.04 | 14.20 | 14.38 |
| solar days/year | 370.9 | 377.2 | 381.2 | 385.9 | 390.6 | 396.8 | 402.6 | 412.2 | 422.6 |
| length of solar day (hr) | 23.6 | 23.2 | 23.0 | 22.7 | 22.4 | 22.1 | 21.7 | 21.3 | 20.7 |

Table 3:

| Time*  | 715 | 900 | 1000 | 1200 | 1400 | 1600 | 2000 | 3000 | 3500 | 4500 |
|--------|-----|-----|------|------|------|------|------|------|------|------|
| solar days/synodic month | 32.00 | 32.72 | 33.11 | 33.93 | 34.79 | 37.63 | 43.48 | 47.09 | 56.26 |
| solar days/sidereal month | 29.81 | 30.53 | 30.92 | 31.75 | 32.61 | 33.46 | 41.33 | 44.90 | 54.14 |
| synodic month/year | 13.59 | 13.94 | 14.13 | 14.54 | 14.96 | 16.35 | 19.23 | 20.99 | 25.49 |
| sidereal month/year | 14.59 | 14.94 | 15.13 | 15.54 | 15.96 | 17.35 | 20.23 | 21.99 | 26.49 |
| solar days/year | 435 | 456 | 467.9 | 493.2 | 520.3 | 615.4 | 835.9 | 988.6 | 1434 |
| length of solar day (hr) | 20.1 | 19.2 | 18.7 | 17.7 | 16.8 | 14.2 | 10.5 | 8.8 | 6.1 |

* Time is measured in million years before present