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Possible Sun's Gravity Influence in Seismology

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ABSTRACT

Motivated by the lack of a unified theory for the driving force that causes plates movements on Earth and based on the success of some simple models to predict general features of Earth's seismic development we introduce outer gravitational fields as the possible energy providers for such enormous and permanent phenomena. Some known results on faults preferential orientations might give support to the hypothesis. Further experimental base for the consideration of external gravitational fields is supplied by the almost nule tectonic activity nearby Earth's poles.

Key-words: earthquakes, self-organized criticality, Sun's gravitational field

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I. INTRODUCTION

Earthquakes are one of the most explored phenomena in Earth nature because of their intrinsic interest and fundamentally because of the threat that they represent for the human kind.

However, the motor force of seismic activity is far from being clearly stated. The common factor to all the explanations that have been forwarded as possible driving forces for plate tectonics appears to be the gravitation [*Hobbs, Means and Williams*, 1976]. Gravitation coming from the Earth is supposed to be the cause in the case of plates pushed from ridge, pulled from trenches and dragged from beneath by the mantle. The same is the case for plates sliding downhill from ridges. Earth gravity is still involved in some theories on the pressure driven phase transitions from basalt rocks (of approximate density $3g/cm^3$) to eclogite (density $\sim 3.6g/cm^3$) that would cause some plates to sink into another. Moon's gravity has been advanced as a possible force to drag plates from above.

Here we attempt to introduce the possible gravitational effects, but now from the Sun (and also from the Moon), on the seismic activity on the Earth. The Sun gravitational force on a piece of ground is about 150 times the force that the Moon exerts on the same piece in the average.

Interdisciplinarity is a consequence of modern science where the aborded problems are so complex that scarcely we could say that they are contained in a single classical science realm. One of the more typical examples of interdisciplinarity is the theory of non-linear dynamical systems and, more particularly, self-organized criticality. Bak, Tang and Wiesendfeld (BTW) [1987] introduced, in 1987, the new concept of self-organized criticality to explain the behavior of large interactive systems. Many systems that at a first glance could appear totally different, share the tendency to a stationary state without a typical length scale and without a typical time scale. Avalanches, the name that bursts of activity in those systems receive, of all sizes are observed. According to the BTW theory the mechanisms that lead to minor events are the same that lead to major events.

The paper is organized as follows: in the next section the seismic characteristics of the Earth crust are described as a critically self-organized phenomena. To do this we compare it to some relatively well established models. Section III is dedicated to a simple analysis of gravitational forces on plates and of the type of fault pattern to be expected from these facts. Finally, section IV describes experimental findings that might give support to the hypothesis here advanced. It contains references to Earth structure, Moon's more active seismic zone (obtained during the Apollo program) and other planets' moons obtained along the Voyager program.

II. SELF-ORGANIZED CRITICALITY AND EARTHQUAKES

Self-organized criticality appears to underlie the global behavior of systems very unlike at a first look. Experimental evidence has been found in superconducting vortex avalanches [*Field, Witt, Nori and Ling*, 1995], sandpiles [*Held et al*, 1990], the brain [*Papa and da Silva*, to appear in Theory in Biosciences, 1997], ^{4}He [*Moeur et al*, 1997] and earthquakes [*Bak, Tang and Wiesenfeld*, 1987].

There are some general characteristics common to systems that self-organize critically: their single components are able to store potential energy (there are other self-organized systems in which it is not obvious what kind of magnitude is stored, an example is the stock market, however we will refer always to potential energy) in a more or less local way and just to a more or less well defined threshold; the systems are continuously supplied with energy not necessarily in a local way. When the accumulated energy in a single element surpasses the threshold it is released in part to other single elements related to the former and in part out of the system. Eventually some of the related elements will be close enough to the threshold in such a way that the energy supplied by the neighbor is sufficient for this element to surpass the threshold. In this way, a single element can initialize a chain reaction that will stop only when all the elements are below the threshold.

This chain reaction is what receives the name of avalanche in clear reference to sandpiles and snow barriers.

The continuous supply of energy has to be small if compared with the maximum power that the system can support because if not there would be no sense in speaking about avalanches. A simple example that can help to understand this is a sandpile. When we throw sand on the pile it has to be done grain by grain. If we try to put a quantity of sand similar to the greater avalanche that we observe when the sand is thrown grain by grain, we will not observe avalanches because the external perturbation is not more a slight one, instead we observe sand falling off the pile in approximately the same rate at which it is thrown on the pile.

Models for earthquakes also present self-organized criticality. We will describe in a bit of detail the Burridge-Knopoff (BK) [1967] model and mention the model of Olsen, Feder and Cristiensen (OFC) [1992]. The BK is a two dimensional dynamical system of blocks and springs. All the blocks rest on a single plate that interacts frictionally with them. All the blocks are also connected to other single plate by a set of springs and, finally, each block is connected by springs to the four nearest neighbors. The driving forces on the blocks come from the relative movement of the two plates. When the force on a given block surpasses some threshold F_{max} (nothing but the maximal static friction) the block slides. The movement of this block changes the total force on each of its neighbors. Eventually, some of the neighbors will also surpass the threshold and slide, and so on. An earthquake is taking place.

The OFC model is a mapping of the B-K model into a cellular automata. They obtained exponents for the Gutemberg-Richter law in accordance with experimental results $(0.8 - 1.05)$ when isotropic elastic ratios were assumed between blocks.

While the real counterparts of springs between blocks and of the frictional force are more or less well defined (plastic deformation of plates and frictional force between superficial and deeper plates, respectively), the elastic forces represented by springs between blocks and the superior plate (and that represent, in last instance, the motor mechanism of earthquakes) remain a mystery.

If some model gives results that agree reasonably well with experiments this is the fingerprint that something in the model contains some of the fundamental features of reality. We try then to extract the possible content that models like those described above can give to us about earthquakes features and, fundamentally, about earthquakes predictions.

III. A NEW POINT OF VIEW

Earth rotation defines a privileged direction on space for phenomena that take place on Earth: the rotation axis direction. The other special "direction" is the Earth surface: plates are forced to move in directions more or less "parallel" to this surface.We present the problem here in the simplest (but at the same time a very pictorial) way.

In Figure 1a we represent the equatorial section of the Earth as seen from the North pole. We also represent the section on this plane of four hypothetical plates, two on the line that joins the centre of the Earth and the centre of the Sun (or Moon) and two on the line perpendicular to the first that passes by the centre of the Earth. There are also represented in Figure 1a the instantaneous forces that a celestial body, not the Earth, exerts on each block.

In Figure 1b the surface components of forces on plates A, B and C in Figure 1a along a whole day are represented. As plates are forced to move on the surface, block C (as well as the others) experiments periodically indirect forces coming from plates A and B. Note that this implies that near the Equator line, there should be a preferential orientation North-South for Earth surface defects as ridges and trenches owing to the hit-stretch sequence at which plates are submitted. This appears to be the case [*Clark*, 1996], for example, in the central Atlantic ridges an in the American border of the great Pacific plate. An exception to this rule will happen when there are stronger forces involved in that regions as is the case, for example, of very rigid plates.

Another interesting observation, that permits to do the direct connection with B-K and OFC models, is that in the neighborhood of Earth, the Sun's gravitational force has approximately a constant value. However, as a consequence of Earth rotation the component parallel to the Earth surface of the force on a plate has, during an important part of the day, a linear increase with time that is analogous to a constant relative velocity of plates in the models and then, to a linear increase of force with position. A possible representation of this is a spring with some elastic constant K.

Figure 2 shows a side view of the Earth and the forces that act on two near equatorial hypothetical plates A and B. The force on each of them are also represented. The surface component of the aceleration (force/mass ratio) is the same for both plates. However, the movement possibilities for regions on the Equator should be greater than, for example, regions near Tropics. This fault could cause sliding regions. Near the Equator then, there should be also expected a concomitant fault pattern parallel to the Equator, they should be preferentially sliding regions. This type of pattern is observed also in the near-equatorial part of the central Atlantic and through the whole eastern part of the Pacific.

Closer to the poles both effects are weaker. To reinforce this idea it is shown in Figure 3 a section of the Earth containing the two poles. There are represented four hypothetical polar semi-plates A, B, C and D. For the sake of clarity we have represented the force on two of them only but on the other two act similar forces also. The important fact from this point of view is that the forces on all the semi-plates are practically equal and, more important, they are all in phase. The rapid conclusion of this is that in polar regions there should be expected almost zero earthquake activity because of the lack of fault production. A polar plate is maintained as a single unit by its own position. The extension of the integral unbroken polar plates can be stimated to extend for about 25 degrees from each of the poles: the extremal points where the superficial component of the force does not differ in more than 10 percent of its maximum value. There is an amazing coincidence with this prediction in South and North poles.

Both polar plates act as a hammer for subpolar regions. In those regions there should be Earth surface defects of the type ridge or similar. In contrast with the equatorial regions now this type of defect should be observed in east-west orientations as is the case in practically all the extension of the south regions of Pacific, Indian and Atlantic oceans. On the other hand the movement of polar plates on the subpolar regions is similar to the roll of a wheel: at each instant the polar plate exerts a force on a narrow north-south streep. This "wheel-effect" will cause sliding regions oriented approximately in the north-south direction. Contrary to what is observed in equatorial regions such patterns are observed in the western side of the South Pacific and, principally, along the Indian ocean.

To close our simple analysis we depicted in Figure 4 a section of a cone containing the centre of Earth an a piece of the surface. Two regions of different depths A and B are represented together with the forces that act on them. By the same arguments as before, this could cause plate over plate sliding and could increase or decrease locally the effects of all what was explained above for plate movement on the surface.

IV. DISCUSSION AND CONCLUSIONS

The singular characteristics of the Earth surface described in section III can be considered as a first experimental evidence of the hypothesis here introduced. They include, among others, the almost null fault activity in polar regions, the preferential orientation of ridges and trenches (north-south in equatorial regions and east-west in subpolar regions), and the preferential orientation of sliding regions depending on their position on Earth's surface. In regions not to close to the poles or to the Equator the patterns observed for defects are not so clear because in those regions several factors act simultaneously and without preference for any of them. However, the patterns observed in equatorial and polar regions (when not disturbed by extremely rigid plates) as well as the almost perfect integrity of polar regions gives a serious experimental support to the hypothesis here presented.

The weak perturbation (as needed in self-organized critical systems) that outer gravity represents for the plate structure of the Earth might have organized along millions and millions of years the Earth structure in the critical state we observe nowadays. Earthquakes are not only the consequence of such state but they are also believed to be the way through which Earth crust was organized [*Sornette and Sornette*, 1989]. It could seem for a non-expert that owing to the slow variation of Earth structure it could be expected a weak periodicity for equal intensity earthquakes and that as a consequence of the almost perfect periodicity of forces acting on plates there could be some preferential periods of the day in which earthquakes would occur. However, this picture is wrong: earthquake activity is known to be a weakly chaotic process (this is the name with which some authors identify self-organized criticality) and as a consequence of this, for a large enough system, there is always an element of it sufficiently close to the threshold as to initiate a chain reaction under the action of any force without mattering how little this force could be.

The ideas in this work were introduced in the simplest possible way: we have not considered the inclination of Earth rotation axis nor the separation of actual Earth shape from an ideal sphere. Consideration of both effects could give a more detailed general description but at the same time will lead to a much less instinctive picture.

Depending on the involved forces and on the constitution of planets the fault pattern should become apparent on planet surfaces. More or less regular striped patterns have been found along the Voyager program in Jupiter moon Europa [*Soderblom*, 1980] and in Neptune moon Triton [*Kinoshita*, 1989]. An extreme case is Jupiter moon Io, where a special combination of extremely strong forces and an extremely maleable constitution of the planet lead to what are believed to be gravity forced vulcanoes eruptions.

As shown during the Apollo program [*Latham et al.*, 1971], moonquakes exist. The motor force of moonquakes have to be searched mainly on Sun's gravity. Owing to the similarity between the period of rotation and the orbital period of the Moon (approximately 30 days), it presents always the same face to the Earth. With this, the dynamical process on possible Moon plates (as a consequence of Earth's gravitational field) is extremely weak and is exclusively due to the radial variation Moon position with respect to Earth. Since it is observed a correlation between moonquakes occurrence and the perigee period of Moon [*Stacey*, 1977] we are bent to think that the Moon crust has not been driven yet to a critical state. The extremely interesting fact is that the region responsible for almost all (about 80 percent) moonquake activity, is located near the center of the side that always face the Earth (*i.e.*, the region where the greater hit and stretch effects should be expected from the Earth) and oriented in an almost perfect north-south direction as should be expected from all that was explained above.

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FIGURE CAPTIONS

Figure 1-. a)Schematic representation of the equatorial section of the Earth as seen from North pole. We have represented four hypothetical tectonic plates. As Earth rotates the Sun's gravitational force on each plate changes creating alternatively stress among different plates as well as drag forces oriented perpendicular to the Earth's surface. See text for a more detailed explanation. b)Temporal dependence of the surface component of the force for plates A, B and C in a). The total compression on plate C is given by the difference between the curves for plates A and B.

Figure 2-. Schematic representation of two idealized plates near the Equator. Equal force/mass ratios on neighbouring plates could lead to different east-west and/or west-east displacements giving rise to sliding regions. Above and below the Equator the slidings directions should be the opposite of each other. See text for a more detailed explanation.

Figure 3-. Schematic representation of a pole-pole section of the Earth. Two parts of a hypothetical plate were depicted. The forces on them are approximately the same. The surface components of those forces are also similar and pointing to the same direction. The same is true for the other two "quarters" with centers on the plane perpendicular to the one presented and that contains the line south pole - north pole. All of them move approximately "in phase". See text for further comments.

Figure 4-. A piece of "pie" of the equatorial section of the Earth. Equal force/mass ratios at different depths could cause plate-over-plate slidings.

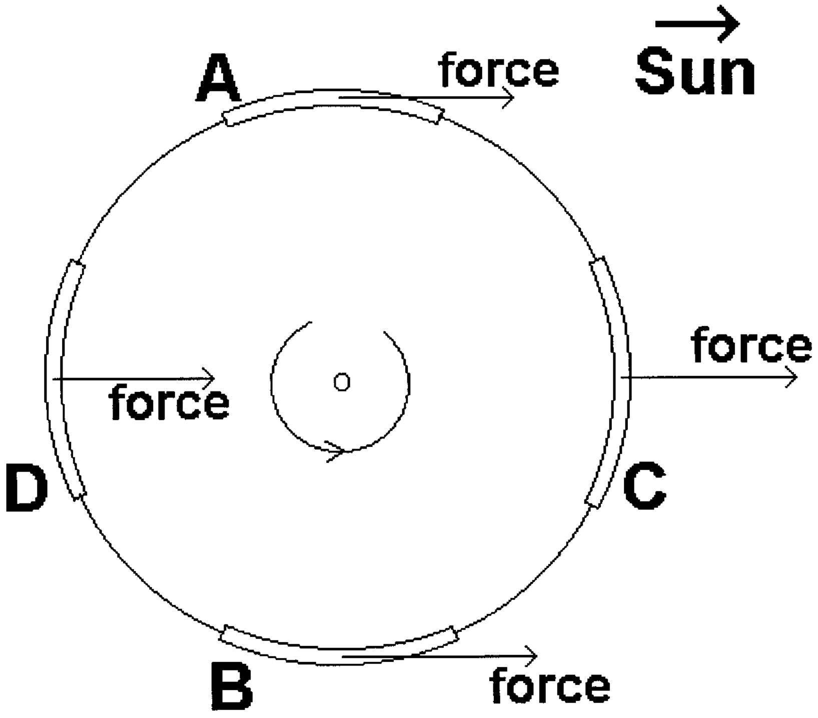
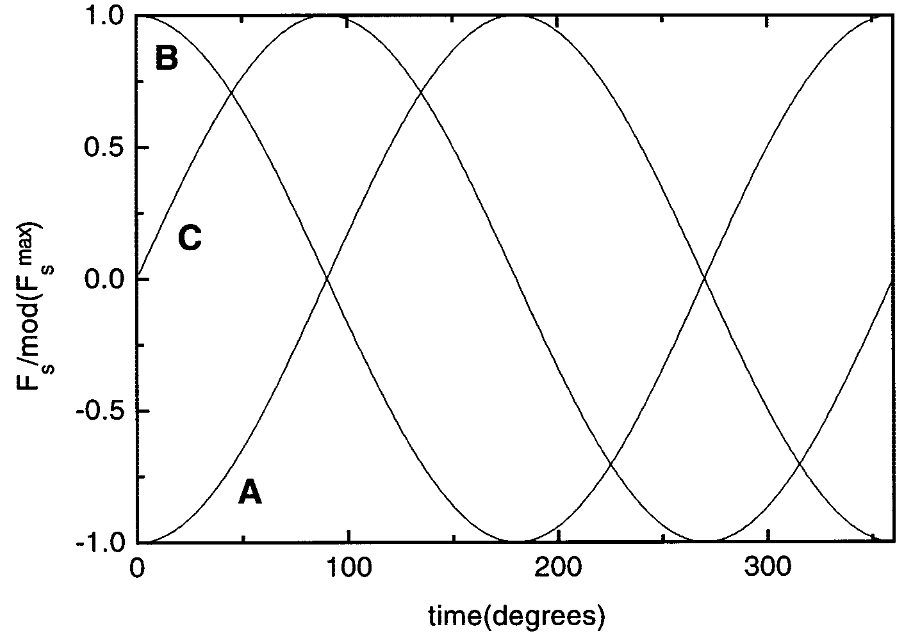


Figure 1a


1.0
0.5
0.0
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$F_s/\mathrm{mod}(F_s^{max})$
time(degrees)

Figure 1b

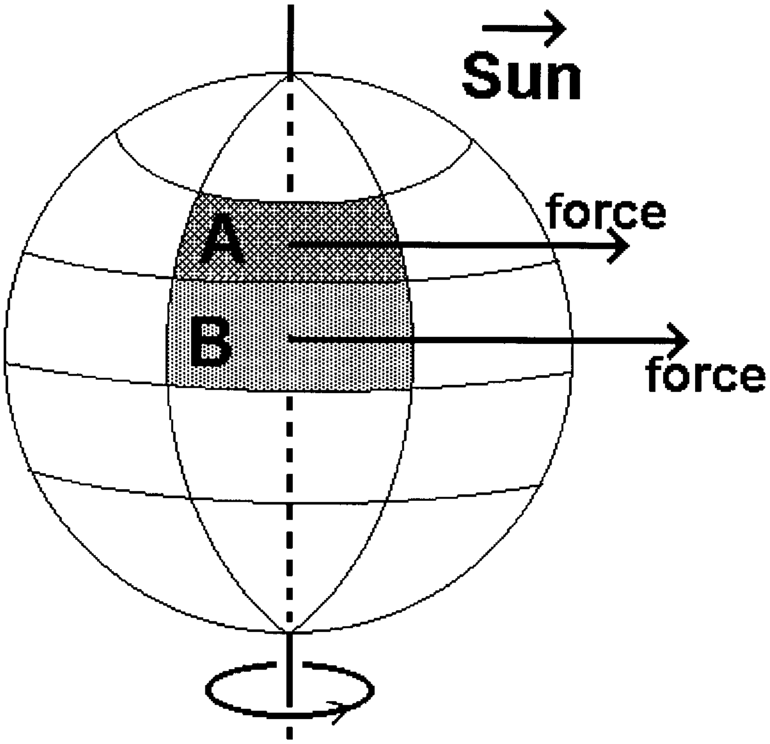

Figure 2

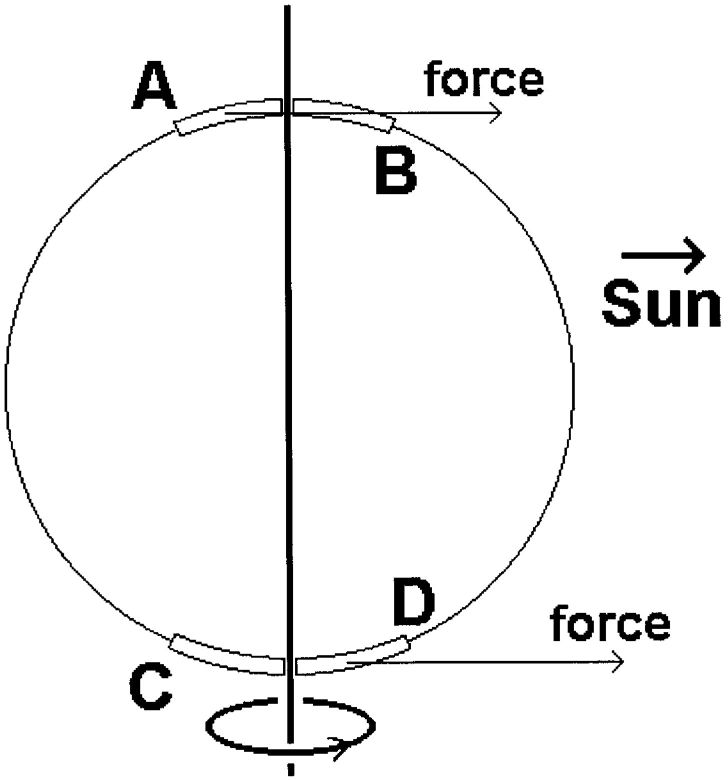

Figure 3

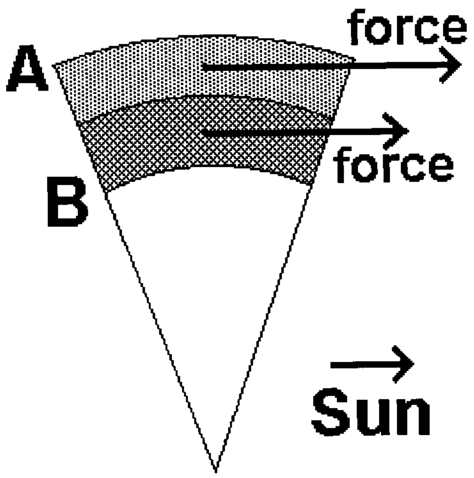

Figure 4