# The January 2018 M7.5 offshore North Honduras earthquake: its possible energy link to the New Madrid Seismic Zone, Mississippi Valley

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**Abstract:** The great M7.5 earthquake on 10 January 2018 in the Caribbean offshore north Honduras occurred at the junction of the global-scale Archean-origin North and South American Superanticline (NSAS) and the E-W trending Cayman Fault. The seismic energy of this quake is considered to have derived from the outer core through gigantic fracture systems developed in the mantle deep under the Caribbean.

Seismo-tomographic images show a conspicuous 400 km wide low velocity lens with two small peaks developed in the axial area of the NSAS at the 400-500 km depth under the Caribbean. This lens is considered a porous zone filled with electromagnetically-charged fluid and gas which plays a role as an energy transmigration channel or surge channel. An anomalously low velocity lens is also recognized in the New Madrid Seismic Zone at the 25 to 50 km depth at the top of the mantle on the axis of the NSAS. Although further support of deep structural information is needed, it is likely that these velocity anomaly lenses in two remote areas are connected. The surge channel has been repeatedly reactivated since the Proterozoic, which altered the mantle and crustal composition to form a collapsed axial structure; Caribbean dome and the Mississippi Valley as we see today.

It has been well established that the energy release from the outer core dramatically increases during the major solar low cycles. This is confirmed by suddenly increased earthquake activity since 1990 when the solar cycle 22 peaked and a longer solar cycle (which includes the 11-year solar cycles 23, 24 and possibly 25 and 26) started. It has also been found that seismic energy transmigrates northward during the declining solar cycle in the Central America-Caribbean area. A combination of these facts well explains the historic devastating New Madrid earthquakes that occurred during every solar minimum, four in a row, since 1400 AD. The arrival of another solar low period, or Eddy Minimum from 2007, is in harmony with the increased seismic activity in the Caribbean since 1990, especially since 2007, as represented by the gigantic January 2018 earthquake.

The physical processes that determine the solar cycle influence on geodynamics, seismicity, volcanism and climate can be explained. In addition, a physical explanation can be envisaged for the location of the Caribbean Sea and the New Madrid seismic region, and for energy transmigration.

Owing to those several reasons, we can reasonably expect another cycle of strong earthquakes in the New Madrid region during the current solar hibernation period. Further studies on deep geological/geophysical structure and monitoring of precursor signals are urgently in order.

***Keywords:*** *New Madrid Seismic Zone, energy transmigration, Caribbean Sea, low velocity lens, N-S American Superanticline, solar cycle and hibernation*

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## 1. Introduction

The International Earthquake and Volcano Prediction Center (IEVPC) has been studying large earthquakes since its establishment in 2012. Our studies have shown the link between deep and shallow earthquakes, which was originally established by Blot (1976) as the energy transmigration concept, or ET concept or law (Grover, 1998). The ET concept allows to forecast strong shallow quakes, magnitude 6.5 or greater, several years in advance, based on the appearance of deep strong earthquakes. Many of the IEVPC's successful predictions have validated the ET concept.

On the other hand, our studies on deep Earth structure have clarified the important role of deep fracture systems particularly in the lower mantle which play a role as conduits for outer-core derived energy to rise to shallow Earth. Almost all of the deep earthquakes (300 to 700 km) are related to deep structure, particularly fracture systems developed in the lower mantle (660-700 km or deeper). In the upper mantle, energy flow takes place in two modes; one surfaces through inclined fracture zones (Wadati-Benioff zone mainly developed in the Circum Pacific region; Kamchatka, Choi, 2017b for example), and another enters porous zones (low velocity lenses or surge channels by Meyerhoff et al., 1996) and transmigrates laterally which finally rises through deep fracture zones (Tonga-New Zealand, Choi, 2017a, for one of documented cases).

Another major discovery we have made is anti-correlation between the solar cycle and earthquake frequency (Choi and Maslov, 2010). This fact has been typically demonstrated in the New Madrid seismic zone, **Figs. 1 and 2**; there, devastating earthquakes have occurred exclusively during the solar low cycle or minimum four in a row since 1400. Historic records show convincingly the increased earthquake and volcanic activities during the solar low cycles throughout the globe (Choi, 2013b; Choi and Tsunoda, 2011; Casey and Choi, 2017; Casey et al., 2016, to cite only few).

Bearing the above in mind, a very strong earthquake in the offshore north Honduras (M7.5) on 10 January 2018 caught our attention, because of its possible link to the New Madrid Seismic Zone, **Fig. 2**.

Both regions are structurally connected by one of the most fundamental Earth's geanticlinal structures, North and South American Superanticline, NSAS (**Fig. 3**). The authors studied the significance of this January 2018 shallow quake from various angles. This article describes our findings focusing on the energy link between the Caribbean and the New Madrid Seismic Zone.

All aforementioned evidences are derived from objective inference based on observations. Observations are matters of fact. In the present case, there is no warning or concern about error bars or mistakes. In addition, some reasonable guess can be proposed for the physical explanation of processes and mechanism. Thus, an explanation in terms of a possible model further supports the effectiveness of the interpretation – and also the credibility of some forecast of the evolution of phenomena.

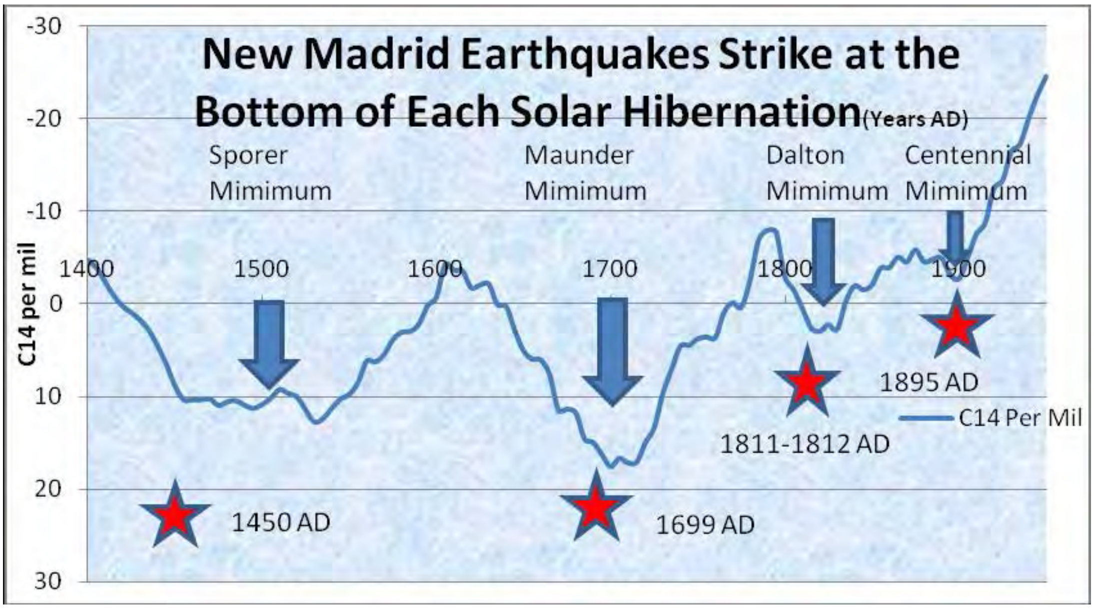


Fig. 1. Recorded strong earthquakes and solar cycle. The chart tracks the global temperature using Carbon-14 as a proxy for temperature. Cited from Choi and Casey, 2015. See also Casey et al., 2016 for details.

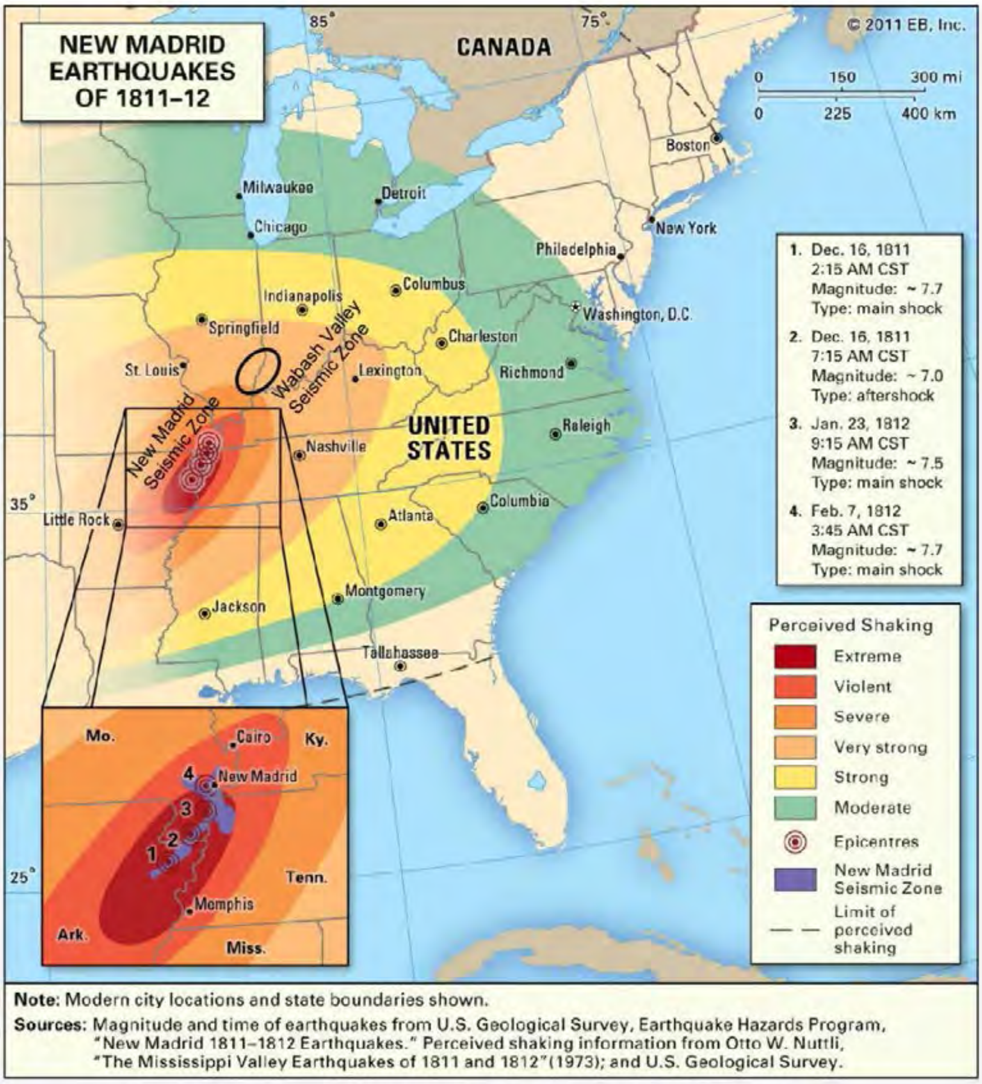


Fig. 2. Map of the New Madrid earthquakes of 181-12. Base map cited from Encyclopedia Britannica, Inc. (http://www.britannica.com/EBchecked/topic/1421133/New-Madrid-earthquakes-of-1811-12). Wabash Valley Seismic Zone is added. Note the listing by date of the past NMSZ quakes, especially the historic 1811-12 series of quakes.

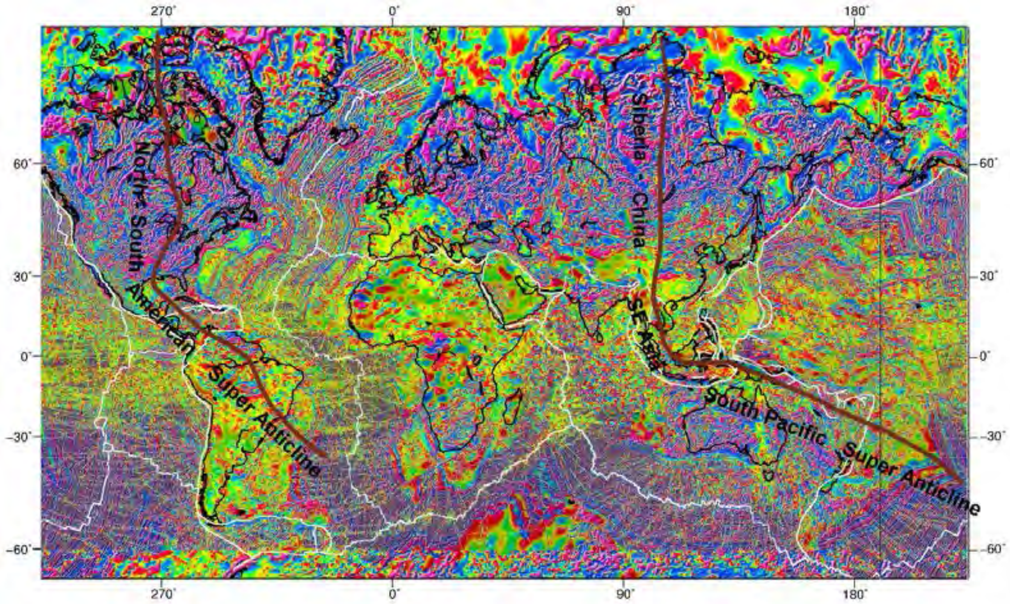


Fig. 3. Antipodal Archean-origin geanticlines or super anticlines on the globe (Choi, 2013a; Choi and Kubota, 2015). These anticlines have been repeatedly reactivated during Proterozoic and Phanerozoic. The Caribbean, the Gulf of Mexico, and the Mississippi Valley are developed on the axis of this anticline.

## 2. The 10 January 2018 offshore north Honduras earthquake

The 10 January M7.5 offshore North Honduras earthquake was an unusually strong earthquake to occur in the Caribbean since 1970, **Fig. 2**. According to USGS NEIC, its parameters are;

44km E of Great Swan Island, Honduras. 2018-01-10 02:51:31 (UTC). Depth = 10.0 km. (https://earthquake.usgs.gov/earthquakes/search/)

It was the second strongest earthquake since 1970 in the Caribbean region; the largest being 7.6 in the Pacific coast in 2012. Note that six out of the eight 7.0+ quakes occurred 2007 or after; the year 2007 is the starting year of the modern solar minimum, or Eddy Minimum (Casey et al., 2016), which will be discussed later.


Fig. 4. The 10 January 2018 offshore north Honduras earthquake. It occurred on the axis of N-S American Superanticline and its junction with the Cayman Trough. Quakes with magnitude 7.0 or greater in 2017 and 2018 (February) are indicated.

Geologically speaking, the quake concerned occurred on the axis of the North-South American Superanticline where it meets with the E-W deep-seated Cayman Fault that forms the southern wall of the Cayman Trough (Choi, 2010 and 2013a; Choi and Kubota, 2015; **Figs. 4 and 5**). The Cayman Trough is an oceanized horst structure that continues to Hispaniola (Choi, 2010).

## 3. Deep structure of the Caribbean Sea

In considering the earthquakes in the New Madrid region, a right understanding of the structure of the mantle under the Caribbean is essential, because the seismic energy manifested in the former is derived from the latter on various grounds as described in this article. Mantle structure of the Caribbean can be understood by analysing seismo-tomographic images. There are several tomographic images available at our hand. They are; Widiyantoro (1997), Romanowicz (2003), van Benthem et al. (2013), see **Fig. 6**.

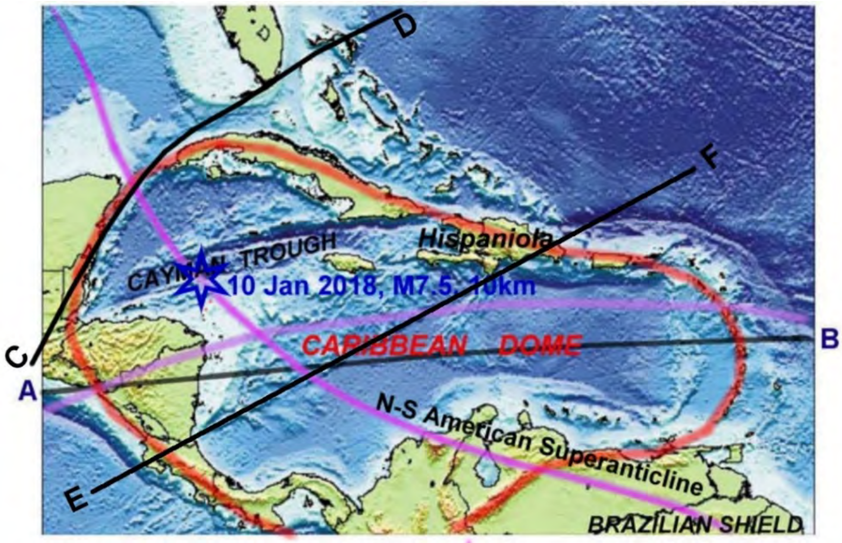


Fig. 5. Outline of the Caribbean dome, major tectonic trends. The January 2018 earthquake is superimposed. Line C–D, tomographic profile by Romanowicz (2003) and Line E–F by van Benthem et al. (2013), see Fig. 6. Line A-B is by Widiyantoro (1997) which is not shown here (see Choi, 2010). C-D line, Romanowicz, 2003; E-F line, van Benthem et al., 2013.

The Caribbean Sea occupies the axis of a globe-encircling Archean geanticlinal system. The Sea has a dome structure that has been oceanized since the Mesozoic (Choi, 2010). This is primarily in agreement with James (2016 and 2018; James et al., 2009) and Pratsch (2008 and 2010), who also consider the in-situ origin of the Caribbean. This is the simplest interpretation that well explains most of the geological/geophysical features of the region, rather than introducing a chaotic subduction mechanism as represented by van Benthem et al. (2013), **Fig. 6.**

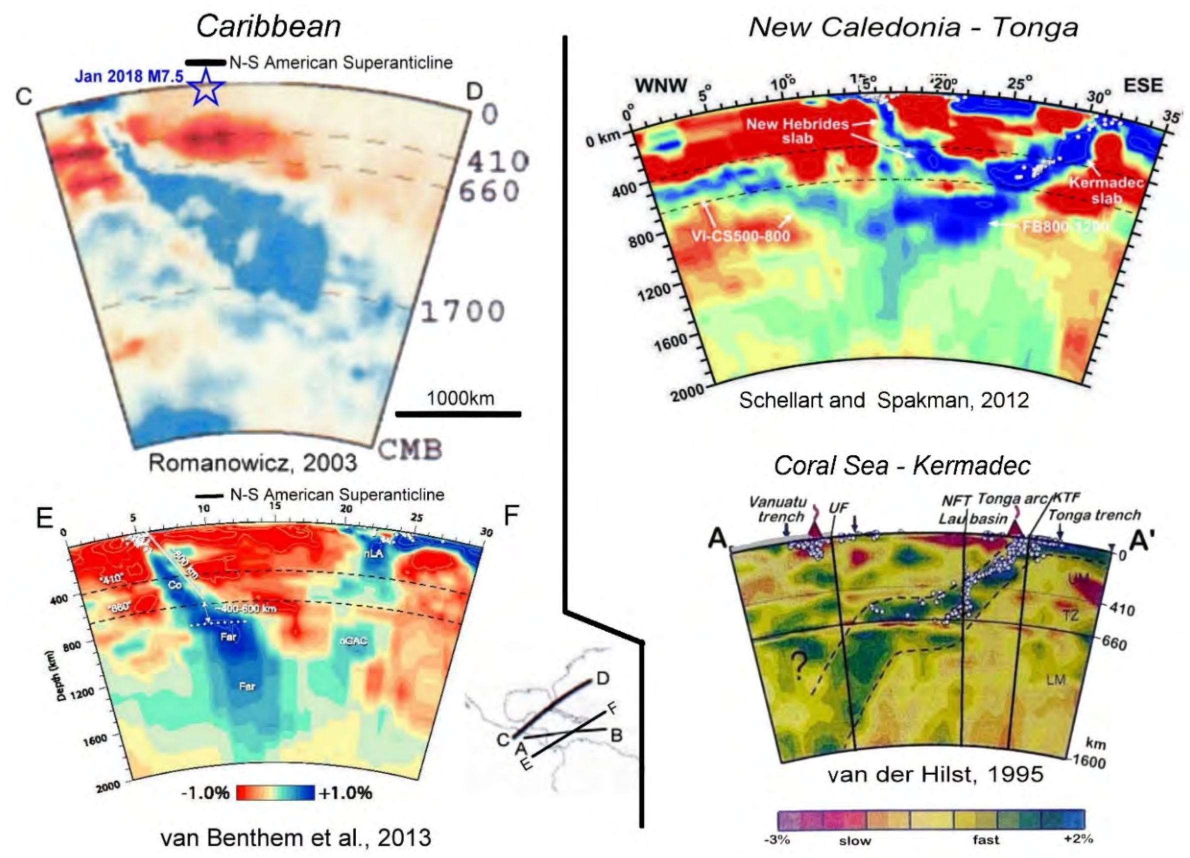


Fig. 6. Tomographic images of the Caribbean (left figures) and Southwest Pacific (right figures). Abbreviations in the van Benthem et al. profile (left bottom): Co = Cocos; Far = Farallon; nLA = northern Lesser Antilles; nGAC= northern Great Arc of the Caribbean.

As illustrated in the northern Caribbean line (C-D line, **Fig. 6**), the tomographic profile shows; 1) the January 2018 quake occurred above a notable low velocity lens developed at the 410 to 450 km depth which has two small peaks inside the envelop, and 2) the low velocity lens is situated where anticlinal axis runs. These facts indicate the close relationship between the January 2018 quake, geanticline, the low velocity lens at 410-450 km, and the deep Cayman fault system. The presence of low velocity lenses under the ancient and modern orogenic belts was emphasized by Meyerhoff et al. (1996); they were termed "surge channel", an endogenic energy flow channel.

***Northward shallowing of the low velocity mantle***

In both Caribbean profiles (left figures, **Fig. 6**), the low velocity mantle, which is considered porous filled with liquid/gas (Choi, 2015), is developed mainly in two horizons, 660-700 km, and 300 to 500 km. The southern profile (E-F line) has well developed slow mantle, reaching much deeper than the northern profile (C-D line). Another tomographic image by Widiyantoro (1997), although not cited here, also shows a major low velocity lens at around 300 to 700 km depths in the central Caribbean.

These three tomographic images show unequivocally the shallowing of the low velocity mantle northward to the Gulf of Mexico (**Fig. 7**). This northward shallowing of the slow mantle seems to continue further north, which is confirmed in velocity/density profile in the New Madrid Seismic Zone at the top of the mantle, 25 to 50 km (Ervin and McGinnis, 1975; **Fig. 7**), although deeper geophysical data in the Gulf of Mexico and the lower Mississippi Valley are needed to confirm this assertion.

***Comparison of the Caribbean deep structure with other areas***

As stated above, the tomographic profiles reveal very intriguing mantle structure of the Caribbean, the primary characteristics of which are commonly observed in other earthquake-prone areas in the Pacific; Southwest Pacific (Choi, 2017a), Kamchatka (Choi, 2017b) and around Japan (Choi et al., 2017). In all areas, similar velocity distribution patterns are recognized: High angle fast zone in the lower mantle below

700 km, thin slow lenses at the top of the lower mantle, from 660 to 700 km, and inclined fast zone with earthquakes in the upper mantle. Note here that deep earthquakes appear as if they are emanating from the low velocity lenses (Coral Sea – Kermadec profile), **Fig. 6**. This is also seen in the Sea of Japan and Kamchatka (Choi, 2017b; Choi et al., 2017).

What available information tells us is that earthquake energy rises from the outer core through deep fracture systems (fast mantle) in the lower mantle, which generate partial melt lenses at the top of the mantle (660-700 km). This low velocity layer is ubiquitously observed throughout the globe (Choi et al., 2017). Almost all of the earthquakes are related to this low velocity lenses which are underlain by deep fracture systems (expressed as linear fast zones) in the lower mantle.

***Branched fracture system in the lower mantle under the Caribbean***

Another conspicuous feature seen in the tomographic images is the inclined fast velocity zone in the lower mantle, see the van Benthem E-F line, **Fig. 6**. The same branching of the fast mantle at about 1200 km was depicted in the Widiyantoro's Caribbean profile (1997). The fast mantle is considered open to the surface, many of them representing fracture zones or connected to fracture zones; they are considered a dry and less porous portion of the mantle in contract to the slow mantle which is porous filled with liquid or gas (Choi, 2017a).

It expands laterally below 700 km and branches at about 1200 km depth towards the eastern Caribbean. Energy flowing along this eastern branch of fast mantle is considered responsible for earthquakes in the eastern Caribbean and Hispaniola (Choi, 2010), and for forming the eastern chain of islands of the Caribbean.

A similar profile was presented by Schellart and Spakman (2012) in the New Caledonia – Tonga profile, Southwest Pacific (top right figure, **Fig. 6**). The area is bounded by the Kermadec Trench in the east and arched submarine ridge and the North Fiji Basin in the west. Here again plate tectonic subduction model is irrelevant to the region; It is simply explained by a branched deep fracture system that carries deep Earth energy to the surface and generates shallow earthquakes and arc-trench structure. A similar case, "double subduction" in the Molucca Sea (Cardwell et al., 1980; Choi, 2005), can be explained by the same mechanism.

## 4. Solar cycle and earthquakes in the Caribbean

***Seismic energy movement in relation to solar cycle***

The senior author (DRC) found that earthquake and volcanic energies in the Central America come from the outer core under the Caribbean Sea and transmigrate to the Pacific coast through the oceanized horst structures, one of which now forms the Cayman Trough (Choi, 2014). The direction of energy movement is controlled by the level of thermal energy input into the Caribbean dome from the outer core, which is inversely correlated with the solar cycle; during the declining solar cycle, earthquake and volcanic swarms move northward, but during the rising cycle, southward **(Fig. 8).**

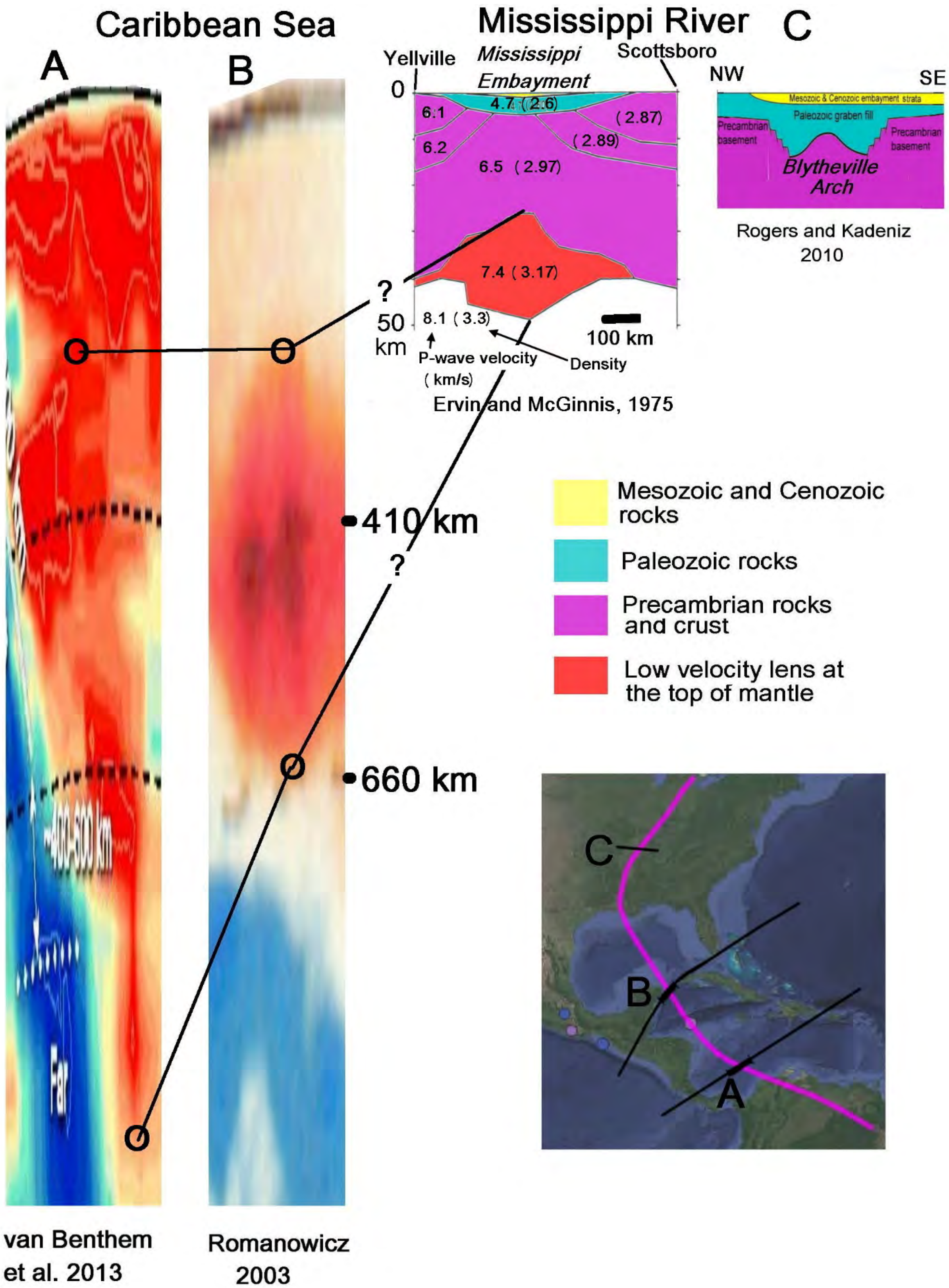


Fig. 7. Low velocity zones in the Caribbean and the Mississippi Valley, showing their northward shallowing. The Mississippi Valley profiles indicate that the Valley was formed by an anticlinal structure which collapsed before the Paleozoic. Note the mantle with decreased velocity and density (7.4/3.17) under the Mississippi Embayment, suggesting that it served as an energy transmigration channel during the time of tectonic activity, that formed the present-day Mississippi Valley.

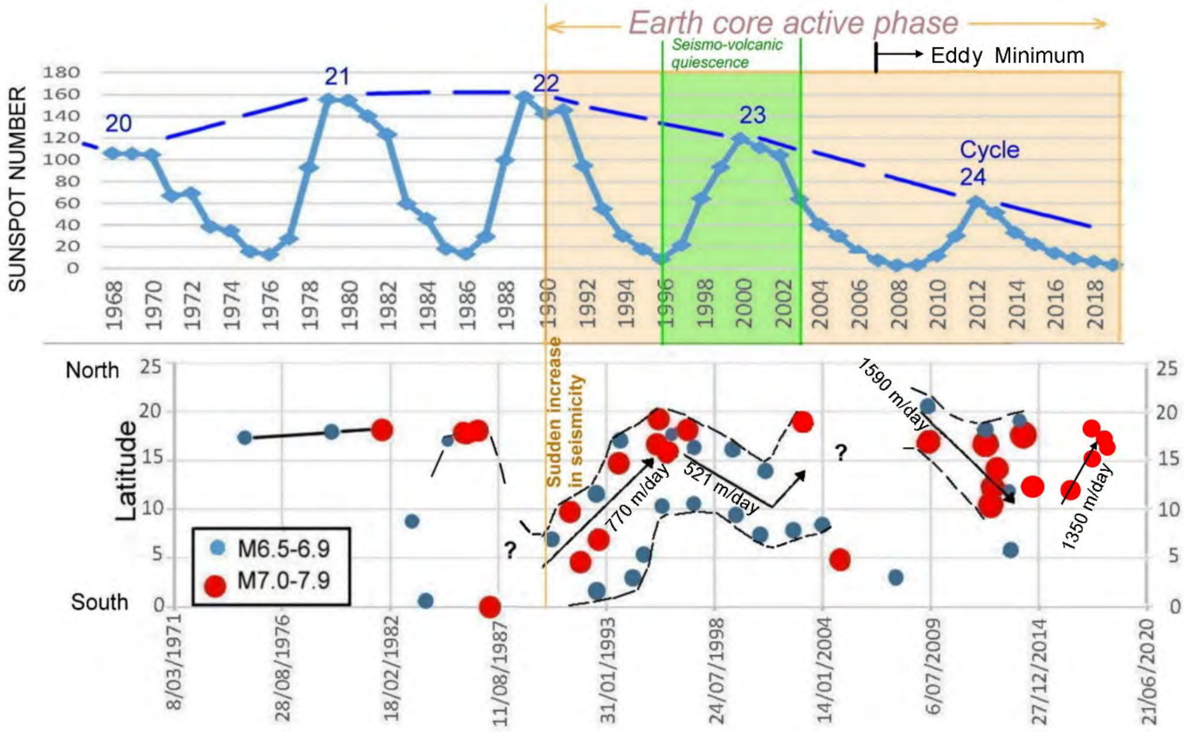


Fig. 8. Solar cycles and earthquake propagation trend in Central American Pacific coast (Choi, 2014, new data added). Note a general trend in which earthquakes move northward when the solar cycle is in decline, but southward when the solar cycle rises, except for the period from 2005 to 2009 for which no data are available. The sudden increase in seismic activity from 1990 coincides with the start of a declining period of a longer cycle obtained by tying the peaks the 11-year cycle, 23 and 24. Seismo-volcanic quiescence cited from Choi (2010) and Tsunoda et al. (2013), and the “Earth core active phase” from Choi and Maslov (2010).

The seismic energy transmigration speed shown in **Fig. 8** is only approximate. However, it is worthwhile to note a large increase in propagation speed after the cycle has entered the Eddy Minimum.

This energy transmigration cycle pattern explains why the catastrophic New Madrid earthquakes have occurred exclusively during the major solar minimums.

***Increased seismic activity since 1990, particularly since 2017 in the Caribbean***

The IEVPC group’s study (Choi et al., 2014; Choi and Casey, 2016) has found that world-wide earthquake and volcanic activities have increased dramatically since 1990, which is the start of declining longer cycle after the peak of the 11-year cycle (Schwab cycle) no. 22. This longer cycle is obtained by tying the peaks of the 11-year cycles, 23 and 24, which covers, along with the coming cycles 25 and 26, the current major solar hibernation period. This increased trend has been accelerated after 2007, which is the starting year of the Eddy Minimum or Modern Minimum (Casey et al., 2016).

The above worldwide trend is validated by earthquake–solar cycle correlation for the Caribbean, **Fig. 9**. The figure was made for large earthquakes with magnitude 6.0 or greater in the Caribbean dome. In harmony with other regions, seismic activity has dramatically increased from 1990-1992 onwards in the region (listed in **Table 1)**.

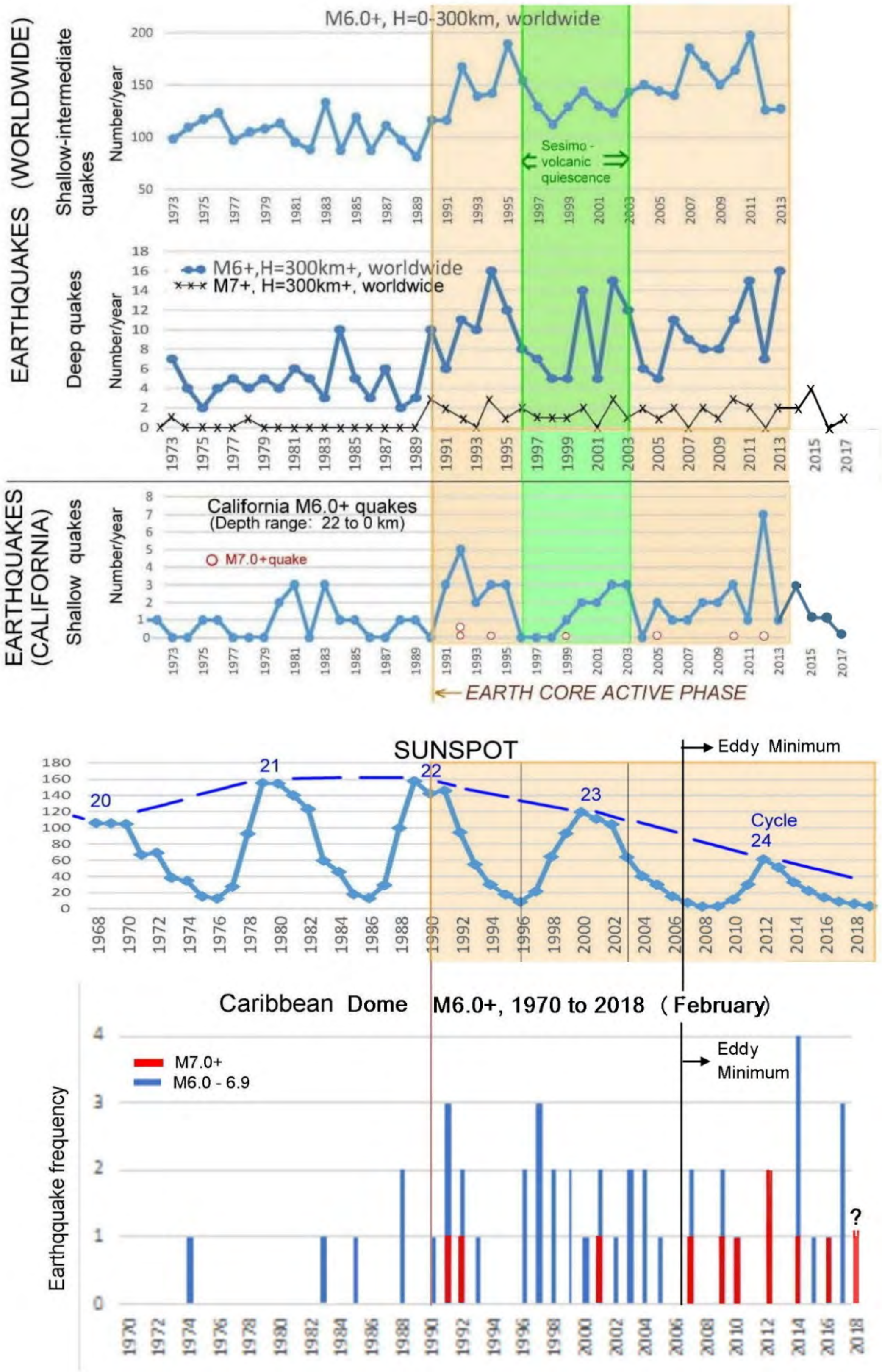


Fig. 9. Solar cycle and strong earthquakes since 1970. Caribbean earthquakes (bottom) are compared with Californian and worldwide quakes, and the solar cycle. The overall trend in the Caribbean which shows a dramatic increase in M6.0+ earthquakes is harmonious with that of other regions. The Earth's core has entered an active phase in accordance with the declining solar cycle from 1990. Upper figures modified from Choi et al., 2014 (added new data). The seismo-volcanic quiescence from Choi and Maslov (2010). Eddy Minimum from Casey et al. (2016).

Table 1. Magnitude 7.0 or greater earthquakes in the Caribbean dome from 1970 to 2018 (February)

| M7.0, 1970 - 2018 (Feb), Caribbean | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Month | Day | Time UTC | Mag | Lat | Lon | Depth km | Region |
| 2018 | 1 | 10 | 2:51:31 | 7.5 | 17.47 | -83.52 | 10 | NORTH OF HONDURAS |
| 2016 | 11 | 24 | 18:43:48 | 7 | 11.96 | -88.84 | 10.3 | OFF COAST OF CENTRAL AMERICA |
| 2014 | 10 | 14 | 3:51:37 | 7.3 | 12.59 | -88.07 | 63.9 | OFF COAST OF CENTRAL AMERICA |
| 2012 | 9 | 5 | 14:42:07 | 7.6 | 10.02 | -85.39 | 20.7 | COSTA RICA |
| 2012 | 8 | 27 | 4:37:19 | 7.3 | 12.13 | -88.66 | 16 | OFF COAST OF CENTRAL AMERICA |
| 2010 | 1 | 12 | 21:53:10 | 7 | 18.38 | -72.59 | 15 | HAITI REGION |
| 2009 | 5 | 28 | 8:24:48 | 7.3 | 16.81 | -86.24 | 29 | NORTH OF HONDURAS |
| 2007 | 11 | 29 | 19:00:19 | 7.4 | 14.99 | -61.22 | 147.3 | WINDWARD ISLANDS |
| 2001 | 1 | 13 | 17:33:34 | 7.7 | 13 | -88.73 | 82.9 | OFF COAST OF CENTRAL AMERICA |
| 1992 | 10 | 18 | 15:11:59 | 7.2 | 7.15 | -76.84 | 10 | NORTHERN COLOMBIA |
| 1991 | 4 | 22 | 21:56:51 | 7.3 | 9.7 | -83.07 | 4 | COSTA RICA |

Note: List from IRIS. No M7.0+ earthquakes prior to 1991 have been registered in the Caribbean dome.

This increase was accelerated since 2007, which is witnessed by the fact; eight out of the eleven 7.0+ quakes in the Caribbean since 1970 occurred 2007 or after; the year 2007 is the starting year of the Modern solar minimum, or Eddy Minimum (Casey et al., 2016), **Fig. 9**. Please note the M7.0+ shocks occurred every two years except for 2009-2010.

As stated above, we now have on the table; 1) northward movement of seismic energy during the solar low cycle, 2) dramatically increased seismic activities since 1990, particularly from 2007 onwards in the Caribbean, 3) the latest January 2018 M7.5 quake offshore north Honduras which occurred exactly on the axis of major anticline, 4) the axis of the anticline is underlain by a low velocity lens or surge channel, and 5) the surge channel under the anticlinal axis shallows towards the New Madrid region. These facts suggest active energy flow through this surge channel has started already.

On the basis of the above-described factual evidence, it is reasonable to expect another cycle of large earthquakes during the current solar minimum, or Eddy Minimum, probably within three to five years, or between 2021 and 2023.

## 5. Physical interpretation: Deep Earth processes

The most intriguing geological/geophysical feature as displayed in tomographic images of the study region is deep structure of the Caribbean Sea. In this section we will briefly present its physical interpretation, focusing on electric nature of its formation – "sea urchin spike" model (Gregori, 2002 and 2009).

Consider the electric currents that ought to exist according to the so-called energy spectrum of the geomagnetic field that (see e.g. Gregori, 2002 or 2009) can be better expressed in terms of the Nevanlinna-Lowes plot. That is, we do know that some intense electric currents flow at the core-mantle boundary (CMB). If a lesser bump occurs at the core-mantle boundary (CMB), owing to Hamilton's the electric currents concentrate on the tip of the bump. Thus, owing to Joule heat, currents can propagate upward like the tip of an electric welder [this is the electric soldering iron (ESI) mechanism]. This process generates a "sea-urchin spike" (**Figure 10a**).

The sea-urchin spike experiences a self-focusing effect. It shrinks due to two effects, i.e. by the Cowling dynamo (**Figure 10b**; see the Appendix), and by a process that can be proved (not here shown) similar to what occurs - according to classical plasma physics - to a so-called field-aligned current (Scott et al., 2015).

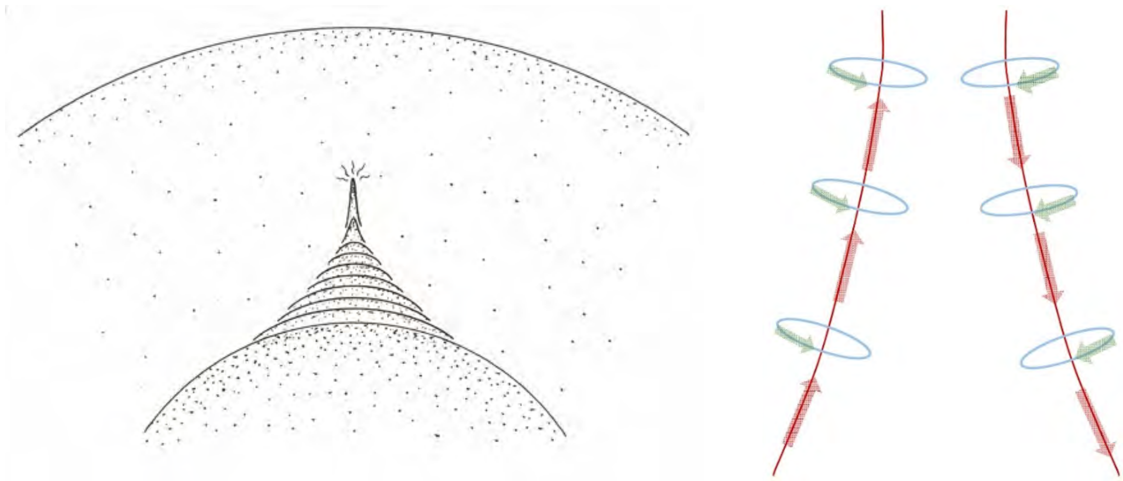

Figure 10. (a) [left] Consider the core-mantle boundary (CMB), and some minor bumps with respect to perfect spherical symmetry. Owing to Hamilton's, the electric currents tend to concentrate on the top of such a bump, where they release a comparatively larger amount of Joule heat. Since the thermal conductivity is very low, such a local heating cannot propagate. Hence, the local temperature increases, and also the local electrical conductivity σ. Hence, owing to Hamilton's, an additional and ever-increasing amount of electric currents occurs. The process is self-amplifying. The result is that the mechanism looks much like in the case of an "electric soldering iron" (ESI) that is pushed into a block of ice. It ought to be stressed that such a propagation strictly implies no transport of matter (no magma, no ions, etc.), rather only and strictly only of conduction charges (electrons). The process is merely electrodynamic, rather than thermodynamic. After Gregori (1993 and 2002).
(b) [right] Owing to the Cowling dynamo, but also to plasma physics, a self-collimation occurs of the electric current that flows on one given side of a sea-urchin spike.

Different spikes can be shown to tend to coalesce into one unique spike. No details can be here given. The explanation derives either from the Cowling dynamo or also from the aforementioned analogy with field-aligned currents.

In any case, the final result is that the Earth - which for mathematical convenience in terms of rheology is usually represented in terms of roughly concentric layers like an onion – in terms of electrical phenomena is rather crossed by a huge number of sea-urchin spikes.

The regions that are crossed by a larger number of spikes are thermally expanded. Hence, huge uplifts are originated at the Earth’s surface. Comparison of deep geological structure and locality of sea urchin spikes indicates that sea urchin spikes are often located at the junction of two or more deep-seated fault zones and/or anticlines. These facts explain the formation of the Caribbean dome structure and the New Madrid Seismic Zone.

To stay on the main theme of this paper, further discussion on the physics of endogenous energy will not be given here. Readers are asked to refer to Gregori (2002, 2009, 2014 and 2015) and Gregori and Dong (1996) for further details.

But, as far as the New Madrid seismicity is concerned, a few conclusions are to be emphasized. A rationale relates the Caribbean to the New Madrid area. The rationale fits with the transmigration envisaged by **Figures 4 - 7**. A sound physical explanation exists for the solar cycle modulation of global geodynamic and volcanic activity (**Figures 1, 8 and 9**). At present, an anomalous huge release is in progress of endogenous energy, which is modulated by solar cycle, with the obvious impact on climate fluctuation. However, as soon as the endogenous energy budget will be exhausted - and while waiting for the recharge of the energy reservoir – a comparatively rapid and large drop of global temperature has to be expected. These cyclic phenomena happened many times during the history of the Earth. It is however impossible to make precise evaluation of the timing of the present event, which is fast on the geological scale although comparatively slow on the human time scale.

It can be shown that several sound reasons support the whole aforementioned scenario. Hence, the explanation of the New Madrid seismicity is not a simple academic exercise. Rather, it relies on realistic consideration of several sound matters of fact.

## 6. Conclusions

This paper documented scientific grounds for linking deep geological structure of the Caribbean Sea to its northern area, the New Madrid Seismic Zone. The following points were documented here:

1) The latest gigantic earthquake, January 2018 magnitude 7.5 offshore north Honduras, occurred at the junction of the Earth's most fundamental geanticlinal structure, North-South American Superanticline and the E-W Cayman deep fault.

2) The quake occurred above a major low velocity lens at 400 to 500 km depth, which is considered filled with liquid and gas. It is an energy transmigration channel or surge channel.

3) The low velocity lens shallows northward to Gulf of Mexico and appears to extend to the New Madrid Seismic Zone, where a distinctive low velocity lens is developed at the top of the mantle.

4) Seismic activity has dramatically increased since 1990, especially since 2007. These years are significant, because the former is the starting year of a one-order longer solar cycle, and the latter the starting year of the current solar minimum, or Eddy Minimum.

5) A comparison of Central American earthquakes and solar cycle shows that during the declining years of solar cycle, seismic energy transmigrates northward, and during the rising period southward.

6) The above facts explain the damaging New Madrid earthquakes that exclusively occurred during the last four major solar minimums.

7) There are strong scientific grounds to forecast another series of major earthquakes in the New Madrid Seismic Zone during the current solar minimum.

8) A tentative explanation is proposed of the planetary tectonic scenario aimed to explain the formation of the Caribbean by the "sea urchin spike" model.

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**Appendix – The Cowling dynamo**

Remind about the old classical debate about the Cowling theorem that can be briefly illustrated by a few historical notes.

In 1919-1920 Larmor, following the discovery by Babcock of the magnetic field B of the Sun, envisaged the existence of a dynamo inside every star. A violent endogenous heat determines a huge motion of its strongly ionized medium. At present, this is called an MHD process. That is, in this way the thermal energy supplies a strong dynamo process, which transforms kinetic energy into e.m. energy.

In 1934 Cowling showed his renown theorem. It claims that no physical system - if it has a perfect cylindrical symmetry - can self-sustain a dynamo. This theorem originated serious difficulties for all solar physicists, and also some eventually harsh debate. Several proofs were proposed, although it is authoritatively claimed that no proof is strictly rigorous. The controversy remained essentially unresolved, almost until nowadays.

In 1953 the Chandrasekhar-Fermi's virial theorem for plasmas was published. Consider an ionized medium, i.e. a "plasma", with no internal energy source, and suppose that it is characterized by internal dynamics. This theorem shows that this physical system cannot be self-contained. That is, no "magnetic bottle" can be self-generated that should confine the plasma inside some finite volume. Rather, the system must expand as much as possible. That is, no dynamo is possible that ought to generate a "magnetic bottle" suited to self-contain the plasma.

In 2002 almost unconsciously, the solution for the controversy was found (Gregori, 2002), in terms of the "*generalized Cowling theorem*", which can be briefly explained as follows (the formal proof, not here given, is only a lengthy analysis of all possible case histories).

It can be explained as follows. Consider a plasma inside a given volume, and eventually having some endogenous energy source. In general, this system certainly generates some e.m. field. That is, it is a dynamo that, in any case, can only display either one of two possible topological configurations shown in **Figure 11**.

It can be shown – in a fully rigorous way with no approximation - that the case of toroidal **E** and poloidal **B** (figure 17a) represents an equilibrium state that, however, is *unstable*. In contrast, the case of toroidal **B** and poloidal **E** (**Figure 11b**) represents a state of *stable* equilibrium. Therefore, every observed dynamo *must* generate a toroidal **B** and a poloidal **E**.

However, if the system has a perfect cylindrical symmetry, the field that is generated is shown to have null energy, i.e. the dynamo cannot be operative, giving thus justice to the original Cowling's theorem.

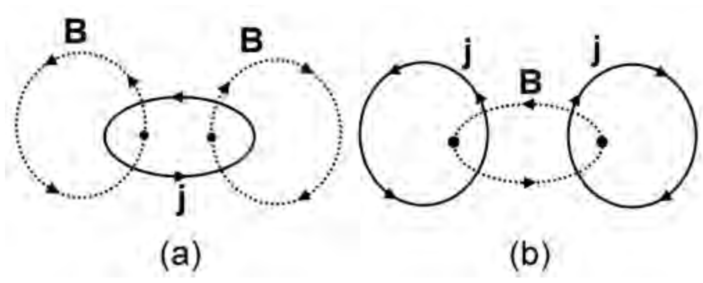


Figure 11 – (a) Idealised scheme, with merely poloidal **B** and merely toroidal currents **j**. (b) The same with merely toroidal **B** and merely poloidal **j**. The generalized Cowling's theorem proves that configuration (a) is an *unstable* equilibrium, unlike configuration (b) that is *stable*. However, in the case of perfect cylindrical symmetry, the **B** generated by configuration (b) has null energy. After Gregori (2002).

The dynamo that generates a toroidal **B** and a poloidal **E** can be briefly called "*Cowling dynamo*".

The Cowling dynamo is universal and ubiquitous. It applies everywhere and on several different spatial scales. On the microscopic scale it can be shown to justify water condensation and precipitation. On an intermediate scale it explains the microphysics either of a spark or of a lightning discharge. On a larger scale it shows that convection inside clouds determines the electrostatic charging of the ionosphere, and – in case of violent convection – it provides the so-called "seed **E**" that is needed to trigger the "runaway breakdown" (RB) process that generates the TGFs (terrestrial gamma-ray flashes). It also explains the self-collimation inside the solar wind, and the filamentary patterns of stars inside galaxies, or of galaxies inside super-galactic clusters. No details can be here given.