AAPG and AAPG European Region Energy Conference and Exhibition
“CHALLENGE OUR MYTHS”
18-21 November 2007, Megaron Athens International Conference Centre, Athens, Greece

TASSOS, STAVROS, Institute of Geodynamics, National Observatory of Athens, Athens, Greece; and SEAN PHILLIPS, Curtin University of Technology, Perth, Australia.

HYDROCARBONS IN THE CONTEXT OF A SOLID, QUANTIFIED, GROWING AND RADIATING EARTH.

The Conventional Organic Origin of Hydrocarbons

Traditionally coal, oil and gas, are considered to be biogenic in their origin. However it is acknowledged that the processes by which fossil fuels evidently formed are not totally understood. Coal and gas are thought to originate from the organic matter of dead plants (ferns, trees, grasses and phytoplankton), and oil from dead animal matter (mainly zooplankton). In this context the plants and animals from which fossil fuels were formed, lived and died 300-400 m.y.a. in primordial swamps for coal and gas, and oceans for oil, where stagnant water prevented the oxidation and total decomposition of organic matter. Assuming prevailing anoxic conditions and a depositional basin setting it is then thought that continual deposition and subsequent burial provided pressure and exposed the confined organic matter to high temperatures. For example, terrestrial plant material on the bottom of swamps was compacted into peat, and finally into anthracite by compaction to 10% of the original volume of the peat, and heating to ~200 ^{o}C. Bacteria attacked the cellulose in the plant and phytoplankton cell walls leading to significant biodegradation and producing methane gas. In the final conventional stage many of the seas receded and left dry land with coal, oil and gas buried underneath it.

Chemically, coal, oil, and gas are a complex mixture of hydrocarbons, mostly alkanes of various lengths, with no two deposits chemically identical. Naturally occurring methane gas, CH_4, represents the simplest possible alkane and parent molecule. Longer chains, in the range of C_5H_{12} to $C_{18}H_{38}$, are the liquid petroleum form, and the longest, but hydrogen deficient form is the solid coal. Hydrocarbons frequently contain other elements such as sulfur, oxygen, and nitrogen. The sulfur content in some cases can reach very high concentrations.

Fundamental Issues that Question the Organic Origin of Hydrocarbons

- *The accumulation, preservation and transformation of organic matter:* In conventional terms, abundant supply of organic matter, rapid accumulation of both coarse grained and fine grained sediments to reserve oil and gas and block their escape, and anoxic conditions to prevent the oxidation of organic matter are the four fundamental requirements that favor the accumulation and preservation of organic matter and its transformation into oil and gas. But the abundant supply of organic matter as well as the supply of sand require near shore and well oxygenated turbulent waters. In turn, the fine grained sediments and the anoxic conditions required to prevent decomposition are typical of stagnant and/or deep waters that exclude abundant life.
- *The sedimentary sequence and tectonic setting:* Conventionally the sediment and tectonic setting sequence is the following: first, fine-grained material into which organic matter is adsorbed in a shallow setting, i.e., lagoon, or swamp, to form the source rock. Second, coarse grained sediments to serve as the pressure load for coal and as the reservoir for oil and gas, in a sufficiently deep but near shore environment, and, finally on the top of the source and reservoir rock and in an offshore setting, clay material lithified to shale to serve as sealant. There is nothing that can be confidently said about the sediment source and tectonic associations in all three stages, but it is the last stage that presents the greatest degree of uncertainty. The formation of shale requires high temperatures and/or pressures; but these conditions are incompatible with it being offshore an on the top.

- *Pressure:* In the conventional context for the formation of anthracite a temperature of the order of 200 °C, ten times higher than the estimated temperature for the formation of peat, and a pressure of $>10^8$ Pa are required. Physically, pressures of this magnitude require more than 7 km of overlying sediment. Given that the volume of the compressed peat to form anthracite is 10% of the volume of uncompressed peat if the temperature is kept at 20 °C, the required pressure then has to be one order of magnitude higher, i.e., $>10^9$ Pa, or >70 km of overlying rock. In both cases, and more so in the 70 km case, the source of this sediment needs to be identified.
- *Temperature:* The incompressibility of the crustal basement rock, e.g., granite, is of the order of 10^{10} to 10^{11} Pa and that of sandstone $\sim 10^{10}$ Pa. Thus the 10^8 to 10^9 Pa of the overburden weight cannot result to a yield and subsidence of the loaded basement and to a subsequent burial and exposure to higher temperatures of the compressed peat. Provided a sediment source and the proper tectonic setting exist i.e. fault throw of >10 km, adding sediments on the surface of the Earth increases altitude and decreases depths of the loaded areas. But, the relative position, and therefore the temperature of the sediment–basement rock interface is the same as before the emplacement of the sediment, since this interface did not sink to a greater depth relative to proximal unloaded areas. Moreover it is thought that periods of mass volcanism existed after the initial dispersal of Pangaea. This mass volcanism would destroy any reserved organic matter at the continental margins.
- *Sulfur:* Petroleum is a complex mixture of many hydrocarbons, primary of the alkane group, the general composition of which is C 83-87%, H 11-15%, and traces of Oxygen, Nitrogen, and Sulfur. The Sulfur content, either as free S, and/or H_2S, and/or as S compounds, like thiols/mercaptans, in petroleum is on the average ~1.5 (0.1-5.5) wt%, and it can be more than 31%. In coal is higher, av. ~1.7 wt%, and in the Illinois coal is >3 wt %. In natural gases is usually lower, traces to 0.2 wt%, and gas is considered sour if the H_2S content exceeds 5.7 milligrams per m^3 of natural gas (~0.0007 wt%), but in some cases, e.g., Texas, Arkansas, and Wyoming, the H_2S content of gases can be as high as 42.4 %. On the other hand the composition of organic matter is: C 52-71%, H 5-10%, O 5-20%, N 4-6%, and no Sulfur (Levorsen 1967). Also the total C content in the C-rich shales of Central India is up to 6.44%, whereas that of S 16.5% (Banerjee et.al., 2006).
- *Trace elements:* Nickel and vanadium (Ni, V) found in all oils as well as trace-elements such as Zn, Pb, Cu, Cd, Cr, Co, As, Sb, Te, Hg, Au, Ag cannot be of organic origin and are typical of mantle rocks, like dunite/peridotite and serpentinites.
- *Carbonaceous chondrites:* Carbonaceous chondrites, thought to be a type of meteorites that never melted or even heated above 50 °C, are mostly small, black, friable, very low density and high porosity rocks. Visually they are almost indistinguishable from kerogen or coal. They contain amino acids and polycyclic aromatic hydrocarbons, a class of very stable hydrocarbon compounds with multiple benzene rings, typical of asphalts, fuels, oils, and greases.
- *Bitumen nodules in Archean rocks:* Bitumen nodules preserved, for example in sandstones from the ~3.5 Ga old Pilbara Craton, Australia, are thought to have formed in situ around uraninite from kerogenous sediments, due to radiogenic heating (Buick et al., 1998). But, the lack of oxygen and the absence of extensive sedimentation during the Archean do not favour the production of organic matter, and its burial and preservation, and give merit to the inorganic origin of these nodules.
- *Depth of oil and gas discoveries:* Almost *all* oil giants are found between 1 and 2 km; shallower than the ~3 km of the gas giants. If the force is from above and given the greater mobility of gas, the order should be opposite. Oil should be found at greater depths and gas closer to the surface. The greater depth gas is found is a consequence of higher temperatures at depths where microcracks-resonant cavities and electrons radiating at thermal frequencies coexist.
- *Dissolved to particulate Carbon ratio:* In mangrove and seagrass systems in Gazi Bay, Kenya, the ratio of dissolved organic carbon (DOC) to particulate organic carbon (POC) is between 3 and 15, i.e., the DOC is 65 to 95% of total organic carbon (Bouillon et.al., 2007). The direct implication is that the carbon dissolved in water could very well be of inorganic origin, and if it is of organic origin is excluded from the oil transformation process.

- *Lack of biodegradation:* Despite all expectations, oil found in Barents Sea in a depth as shallow as ~1000 m was not biodegraded. Since biodegradation, the process by which organic matter is broken down, aerobically or anaerobically, by micro-organisms is not observed in the Barents Sea, the great gas reserves in the area cannot be attributed to the action of methanogenic bacteria. Therefore, we can with good reason argue that the generating mechanism for oil and gas is common, and biodegradation does not play any major role in their formation processes.

Excess Mass Stress Tectonics and Hydrocarbons

In the context of Excess Mass Stress Tectonics – EMST, Earth is a quantified solid black body, the size of which appears to increase with time at an exponential rate. About 200 m.y.a. Earth's diameter was about 60% its present size, and its whole surface was covered with granitic continental crust, representing Pangaea, with narrow and shallow epicontinental seas. The Fe-rich mantle, the also mafic oceanic crust, and the deep and wide oceans formed during the last 200 m.y. or so.

Earth's inner core is considered as an equilibrium high-tension/high-frequency location, wherein energy–unpaired standing waves transform into paired standing waves–matter, so that the conservation principle is not violated, and form new elements, i.e., Excess Mass. Earth's outer core, being 'looser' space than that of the inner core, in correspondence to the electron cloud of an atom, has the characteristics of a plasma state. The order which elements form depends on their nuclear binding energy. Hydrogen with the lowest nuclear binding energy of ~1.15 MeV per nucleon should be the first element to form, and iron, with its ~8.8 MeV, the last and most stable. Thus, the absence of Fe-rich rocks and oceanic crust older than about 200 m.y. finds its physical explanation. The nuclear binding energy of U^{238} is ~7.7 MeV, about the same as that of C^{12}, implying that uranium from the fission sequence to the right of the Fe peak, and carbon, from the fusion sequence to the left of iron, started to form about the same time in the Earth's evolution from low to high energies/frequencies.

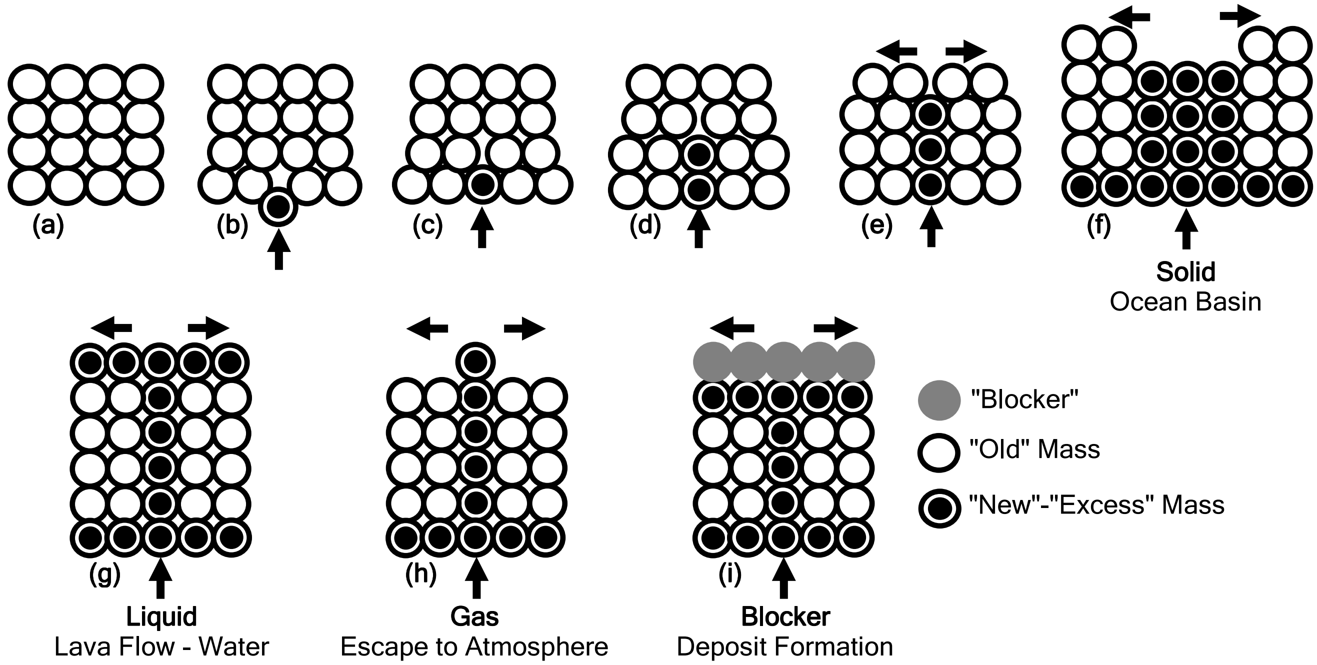


FIGURE 1. The atom-by-atom emplacement in solid state of 'New'-'Excess' Fe-rich Mass during the last 200 m.y. oceanized, rifted and up-lifted the pre-existing Fe-poor granitic continental crust, (a) through (f), and resulted to the formation of deep (av. ~3.8 km) and wide ocean basins. Melting temperatures and lava flows is a surface phenomenon and lava floods the surface, the same way as water fills the ocean basins (g). So if the rising mass is in a liquid or gas states it will stay on or escape from the Earth's surface (h), unless stopped by a 'blocker' (i).

Excess Mass, is added in a solid state and atom-by-atom around the core; enters into the crystalline structure of the pre-existing and overlying Fe-poor minerals and rocks, e.g., feldspar and granites, respectively (Fig. 1). Thus causing their 'oceanization', and transforming them into andesites, and forming the banded iron formations (BIFs) of the greenstone belts in the Archean cratonic masses. The greater bulk of Excess Mass is added atom-by-atom concentrically and chaotically whereas the 'active' part ascends through radial micro-fracture pathways, as solid 'wedges' in the cold and increasingly rigid with depth mantle. Upon encountering an obstacle accumulates due to its blockage (Fig. 1i). Iron rises as reduced high pressure Fe^{2-}, and upon decompression-oxidation releases its 4-5 'excess' electrons to become $Fe^{2,3+}$. The released 'excess' or 'new' electrons following the least resistance path enter into the tiniest microcracks and enlarge them proportionally when their concentration exceeds the threshold of $>10^{18}$ electrons/m^2 and their internal pressure builds up. Microcracks also serve as resonant cavities for 'old' electrons from $Fe^{2,3+}$, or from the radioactive decay of U^{238}, Th^{232}, and K^{40}, and 'new', or, 'excess' electrons from Fe^{2-}, radiating at the thermal infrared frequencies, of the order of 10^{14} Hz.

In a solid, quantified, growing and radiating Earth (EMST) a black body is an object in which the thermal frequencies ~10^{14} Hz do not develop in preference to all other frequencies (Fig. 2). In order for that to occur resonant cavities – microcracks of ~10^{-6} m, i.e., the wavelength of thermal radiation, that lower the bulk rigidity by 2 to 3 orders of magnitude to 'thermally proper' rigidities are required.

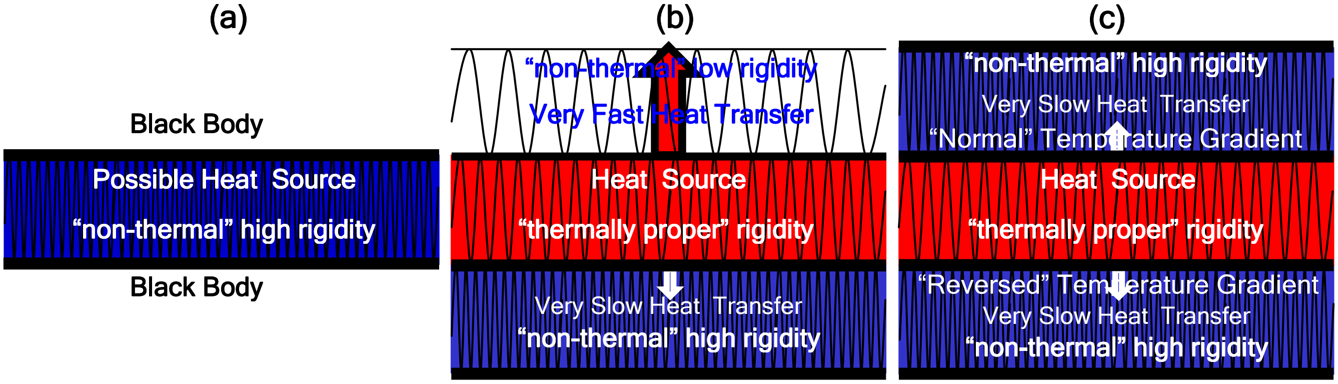


FIGURE 2. In the context of a solid, quantified, growing and radiating Earth (EMST) a black body is an object in which the thermal frequencies ~10^{14} Hz do not develop (a). Thermal radiation, i.e., resonance of electrons inside ~10^{-6} m microcracks-resonant cavities at ~10^{14} Hz frequencies, is the source of heat inside the Earth at 'thermally proper' rigidities. Thermal frequencies cannot develop when the rigidities/frequencies are either too high, e.g., solid rock, or too low, e.g., air. Radiative cooling, from a 'free' surface to the very low rigidity atmosphere, is very fast, at rates of the order of °C/sec to °C/day. In the high rigidity rocks, the cooling rates are extremely low, of the order of °C/billion years (b). If a heat source is sandwiched between two high rigidity layers an upward 'normal' and a downward 'reversed' temperature gradient will develop (c).

Within resonant cavities lossless reflection of resonating electrons at the thermal frequencies of ~10^{14} Hz occurs and when the resonance seizes the free surface of an object quickly cools. So the only source of heat inside the Earth is thermal radiation, and except for some minor radiogenic heating is due to the resonance of 'new' electrons inside ~10^{-6} m microcracks at ~10^{14} Hz. At higher (X-rays and higher) and lower (radio waves and lower) frequencies the amount of thermal radiation decreases rapidly. In that context radiative cooling, at rates of °C/sec to °C/day, is the most efficient way of heat transfer from the 'free' surface to the very low rigidity atmosphere. In high rigidity media unfavorable for thermal frequencies, heat is conducted at rates of the order of °C/billion years, i.e., 10 to 15 orders of magnitude slower than the cooling rates of lava. Thus if a heat source is sandwiched between two high rigidity layers (Fig. 3c) an upward 'normal' and a downward 'reversed' temperature gradient will develop. In that context, whatever high temperatures might develop in the plasma state outer core, are confined there due to the very high rigidity of the overlying mantle and the underlying inner core.

There is experimental evidence that complete closure of microcracks is expected at a depth greater than 5 km (Kern, 2005). The EMST explanation is that at depths less than ~5 km, microcracks form at the interface between the rising Excess Mass and the overlying layers of rock and can remain permanently open, thus acting as 'resonant cavities' for 'old' and 'new' electrons liberated from the reduced Fe, i.e., Excess Mass. As a result of electron resonance at ~10^{14} Hz in these microcracks radiant heat is released. Direct borehole and indirect infrared methods, measurements indicate that temperatures inside the Earth do not exceed ~300 ^{o}C at the rock to rock interfaces, and the 'hot lenses' usually are found at depths shallower than 5 km. Melting temperatures require a 'free' surface, thus they can only occur at the Earth's surface in lava flows, or near the surface in cracks and fissures. In that context the Earth's average heat flux of ~60 mW/m^2 should be attributed to a lower concentration of microcracks that give a temperature of 150 ^{o}C at 5 km depth, i.e., ~30 ^{o}C/km. Otherwise according to the Stefan-Boltzmann law for a black body the ~60 mW/m^2 is equivalent to a temperature of ~33 K, i.e., –240 ^{o}C!

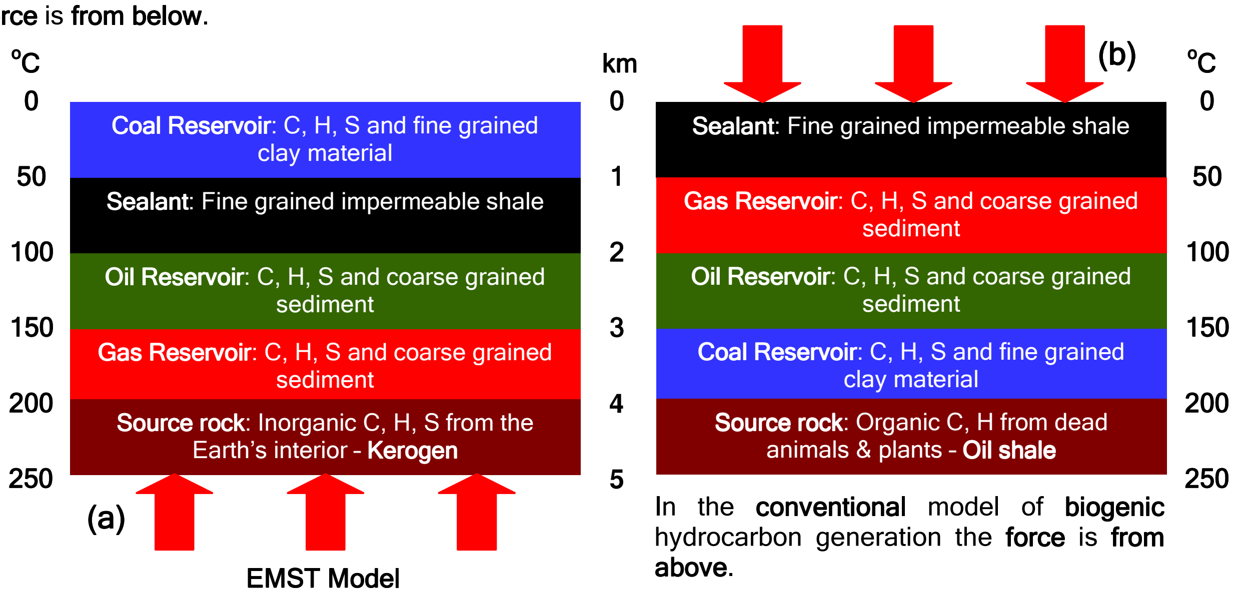
The formation of all elements in a sequence that depends on their nuclear binding energy has several very important implications that directly relate to the formation of hydrocarbon deposits. Among others:

- Earth's evolution and growth can be divided into the: 1. Pre-Fe phase, when all other elements except Fe were formed. Their nuclear binding energies vary from the 0 of H^1 to ~1.1 MeV of H^2 in the fusion side, and from the ~7.6 MeV of U^{238} in the fission side, about the same as that of C^{12} (~7.7 MeV) in the fusion side. These two opposite processes converge to the limit of ~8.8 MeV per nucleon of iron. 2. Meta-Fe phase which started ~200 m.y.a. and still goes on today.
- All elements form in the Earth's core; are emplaced atom-by-atom around it and depending on structural constraints form compounds, crystals, minerals and rocks. The first rocks to form on the Earth's surface were the Li, Be, B-rich proto-pegmatites. Almost concurrently with U^{238}, C^{12} started to form and to enter into the crystalline structure of proto-pegmatites, thus forming the proto-kerogen that later gave the nearly H-free anthracite. Carbon upon its association with H gave CH_4, the parent molecule of oil. At this early stage most of methane was released in the atmosphere, the same way as it is released from Titan's surface today. Some of the CH_4 entered into the proto-pegmatites, and later, with the formation of O, Na, Mg, Al, Si, S, K, and Ca the proto-pegmatites gradually transformed into pegmatites and finally into granites, and the proto-kerogen into kerogen. Due to the weathering of feldspars, kaolinite was formed in situ. At the end of the pre-Fe stage an all encompassing felsic pegmatitic/granitic crust covered the surface of a smaller, ~$0.6R_{present}$, Earth.
- During the meta-Fe era the last 200 m.y., the solid emplacement of Fe into the crystalline structure of minerals of granitic rocks led to their 'oceanization', the formation of the intracratonic greenstone belts, BIFs and komatites, e.g., the Jack Hills belt in W Australia. The emplacement of Fe was associated with a rise in temperature and the initiation of the pyrolysis process of kerogen into oil and gas, the enrichment of kaolinite with iron, its 'baking' into shale, and the formation of various types of coal. New Fe-rich minerals, such as the platy micas and the granular olivine, and rocks (e.g., gabbro), started to form splitting the all encompassing granitic continental crust, filling the space beneath it and in between the split, like a solid wedge, thus forming the mantle and the oceanic crust, and resulting to the Earth's exponential growth to its present size (Fig. 1).
- An important property of Fe under high pressure/tension is the coincidence of the s- and d-orbital electronic states. Thus the reduced Fe^{2-} anion is formed, which upon decompression acquires its oxidized low pressure configuration of $Fe^{2,3+}$, and releases its 4-5 'excess' electrons. It is these 'new' electrons that enter and resonate into microcracks-resonant cavities at thermal frequencies that provide the heat capable to cause the pyrolysis of kerogen into oil and gas, the in situ 'baking' of kaolinite into shale, the formation of coal from proto-kerogen, but also volcanism and lava flows.
- The temperature window for the formation of coal-lignite is from 0 to 50 ^{o}C. At the oil window between ~50 and ~100 ^{o}C, thermal depolymerization breaks up the kerogen molecules into the straight-chain hydrocarbons that make up most of petroleum. At the gas window, 100 to 200 ^{o}C, any oil is converted into natural gas by thermal cracking. At temperatures above 200 ^{o}C porphyrins are destroyed, and

kerogen is fully oxidized to CO_2 and H_2O. Thus oil and gas cannot exist at temperatures higher than about 200 °C, but the almost H-free anthracite requires such temperatures.

- In the presence of micro- and/or macro-cracks as a result of very high seismic and tectonic activity, and in the absence of the impermeable cap rocks oil, and especially CH_4, is released from the Earth's surface and cannot be reserved.
- Due to the emplacement of iron during the last 200 m.y., the tectonic activity intensified, wide and deep oceans and a complex pattern of uplifts and near shore sedimentary basins developed, thus providing the coarse grained reservoir sediments, the necessary heat, and the structural and/or stratigraphic traps for the formation and preservation of oil and gas. These temperature and geodynamic prerequisites explain why oil and gas deposits are found in basins adjacent to deformed precambrian shields and platforms, and associate with moderate seismic and volcanic activity, free-air gravity, geoidal, and heat flow anomalies, and large igneous provinces (LIPs), i.e., Excess Mass.
- In the EMST model the 'force' comes from below (Fig. 3a). That way there is no need for clay sediment source and transport and for overburden pressure and heat for its lithification after deposition. The same applies to the coal formation. In contrast in the conventional model the 'force' is from above (Fig. 3b), including organic matter, pressure and heat. In that case an identifiable and sufficient source of the organic matter, of the coarse- and fine-grained sediment, and of the necessary load and/or heat for the lithification of clay into shale, and the transformation of peat into anthracite, and afterward a quantifiable removal process of this load are required.

FIGURE 3. In the Excess Mass Stress Tectonics - **EMST** model of **abiotic** hydrocarbon generation the **force** is **from below**.



In the **conventional** model of **biogenic** hydrocarbon generation the **force** is **from above**.

- Provided all other conditions that designate the relationship of hydrocarbons with "excess mass" are met, in the context of EMST and in compliance with direct measurements and indirect estimates, locations with a "virtual" temperature gradient of ~50°C/km, i.e., ~200°C at 4 km depth, and surface heat flow values of ~100 mW/m^2 are the most preferable ones to look for oil and gas.
- In the case of 'normal' temperature gradient, coal should be found at or close to the Earth's surface, oil at 1-3 km, and gas at 3-4 km depths. In the case of 'reversed' temperature gradient (Fig. 2c), gas should be found on the top, oil in between, and coal in the bottom.