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Half-Lives of balanced Hydrocarbon Systems

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Abstract: *Ever since there is life on earth, dead organic material is being deposited and, in consequence of geologic processes, gets into regions of higher temperature and higher pressures by subsidence. Under these conditions, fluid hydrocarbons, which - due to their low weight and mobility - try to migrate towards the earth's surface where they return to the circle of nature as changed organic material, evolve from the subsided bio mass. In a first analysis, the processes below the earth's surface are assumed to be balanced. Generation, storage, migration to the earth's surface, and thermal "cracking" of the hydrocarbons are part of this balancing process. In the past, the balance might not have always applied, but this attempt enables an integral approach of the global hydrocarbon balance over time. The following processes, averaged over time and space are important issues:*

- *The sedimentation of organic material as a significant global cycle,*
- *The temperature-dependent generation of crude oil and natural gas of the sedimented organic material,*
- *The observed half-lives of storage,*
- *The balance assumptions.*

This way, one gets the mean rates of the hydrocarbon generation and the cumulative values deducible from them. With the half-life derivable from the age structure of the global crude oil reserves the "oil generation rate" of the earth and, in this process, the time-dependent entry into the biosphere can be determined assuming that half-life is about 30 million years. There is no global data for natural gases yet, but a half-time of 60 million years can be estimated for the natural gas fields in the Weser-Ems region in Northern Germany from the ratio of Zechstein (Upper Permian) to Buntsandstein (Lower Triassic) reserves if one classifies the Buntsandstein reserves as a result of degasification of the Zechstein fields below and assumes comparable half-lives for both storage systems. For regions on earth that are tectonically active for a longer period of time, like the Circum-Pacific zone or the Alpine deformation belt, it should well be allowed to fall below this value.

Keywords: *hydrocarbon systems, half-lives, oil-fields, gas-fields, Upper Permian, Lower Triassic*

1. Introduction

For a better prediction and, this way, a risk minimization of drilling projects, the complex correlations of the processes of crude oil and natural gas generation and storage taking place in the subsurface have to be examined more and more extensively in the context of the evaluation of the hydrocarbon systems to be tested. These time- and position-dependent processes are, amongst other things, the deposition of reservoir rocks and biomass, their subsidence into greater depths, the generation of hydrocarbons from organic material and their migration upwards to the reservoir rocks as well as their accumulation there in the context of the indispensable structure formation, which is the consequence of predominantly tectonic causes. These processes partly happening continually, but primarily occurring episodically, have to have gone on in a certain context without which the accumulation of economical amounts of crude oil and natural gas is hardly possible. In the evaluation of the risk linked to hydrocarbon generation it is important if or when the source rocks have yielded crude oil and natural gas and since when they are "overmature", i.e. "burnt out". Below, the attempt is made to mitigate the conditions of the temporality of generation and storage that are limiting to the risk evaluation via the analysis of half-lives.

2. Crude Oil and Natural Gas Generation as Function of Temperature and Time

After sedimentation and the ensuing subsidence and heating, hydrocarbons are generated as a product of a geochemical breeder reactor e.g. in mudstones that contain a sufficient amount of organic material, be it distributed dispersedly or also as coal layers. In this case, the generation rate is basically a function of the percentage TOC (total organic carbon) and temperature. For a crude oil and natural gas source rock of the so-called Type II with a TOC of 1%, which consists of marine algae and low contingents of terrestrial plant residues and – to simplify matters - is assumed as representative under general global viewpoints, a temperature-dependent generation rate is the result like presented in Fig. 1 [1].

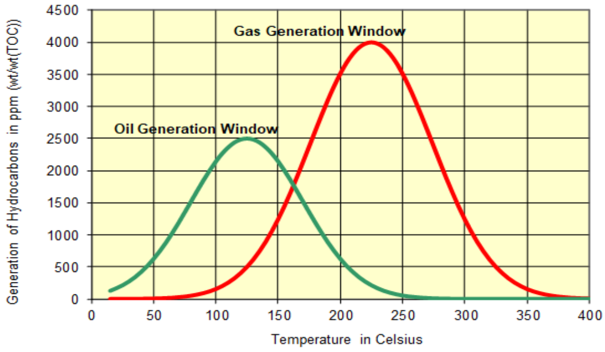

Fig -1: Generalized Generation of Hydrocarbons of a standardized Source Rock with 1% TOC (Total Organic Carbon) after [1]

2. The Global Hydrocarbon System

The generation of crude oil and natural gas is accompanied by a global oil expulsion and degasification rate as they are observed at natural seepages on land and underwater (Fig. 2) [2, 3]. The distribution of these seepages correlates noticeably with global seismicity [4] and, in the process, with the current global tectonic activity (Fig. 3).

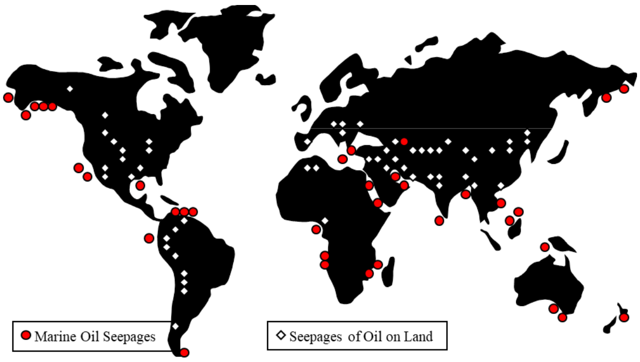

Fig -2: Globally Distributed Locations of Seepagesof Oil [2], [3]

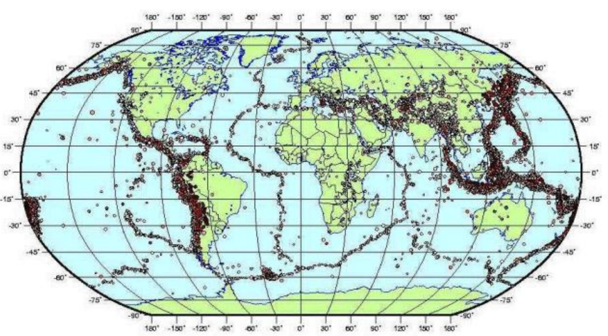

Fig -3: Seismicity of the Earth [4]

The crude oil generation, its seepage rate at the earth's surface, the filling and storage in the reservoir rocks of the sedimentary basins, and the thermal "cracking" at ultra-large heating were integrated into a model of the global crude oil system by Miller [5], which he deducted for the conditions currently existing assuming that these processes are balanced (Fig. 4).

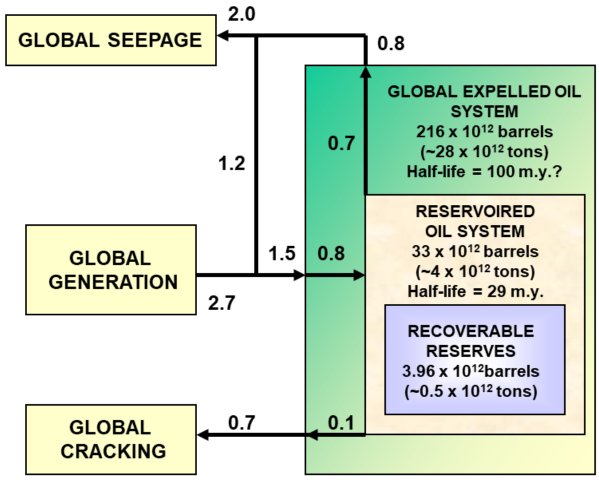

Fig -4: The Global Oil System, Flowrates in Mio bbl/yr [5], 1 bbl = 159 l, Density of the Oil ~ 0.8 gr/cm^3

According to Miller for example, 2.7 million bbl/yr are currently generated globally, 1.2 million bbl/yr of which exit directly at the earth's surface and 1.5 million bbl/yr remain underground for the time being. The observation that the age distribution of the globally stored crude oils points to a half-life of ca. 30 million years for a stay in the reservoir (Fig. 5), forms the basis of this model as well.

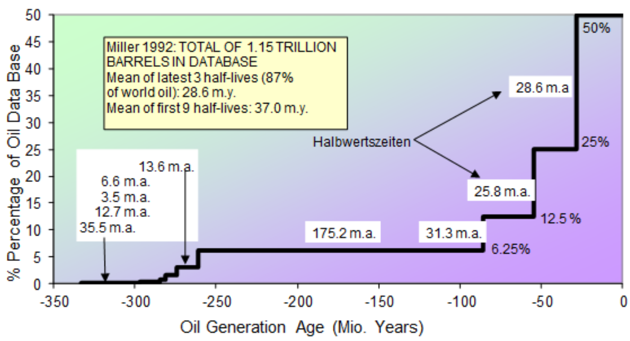

Fig -5: Age Distribution and Half-Lives of Reservoired Oil [5]

The oil fields of the earth lose 50% of their respective reserves in steps of 30 million years in average this way, which can be depicted via an exponential decay curve. At the same time, the entry into the biosphere subsides exponentially because of the exits at the earth's surface as well. As it is, the generation rates were not constant during the course of subsidencs in the past due to the temperature-dependency. Also, the sedimentation of the original organic material is subject to a global cycle with distinctive maxima and minima that is also related to sea level fluctuations and climatic changes [6]. Via a time-dependent TOC distribution (Fig. 6) [7] that can be regarded as the polished sequence of the sedimentation of hydrocarbon source rocks [8], a hydrocarbon generation rate as specified in Fig. 1, and the assumption of half-lives of 30 million years, the crude oil and natural gas generation rates as well as the amount of the crude oil currently stored globally in reservoirs can be estimated now (Fig. 7).

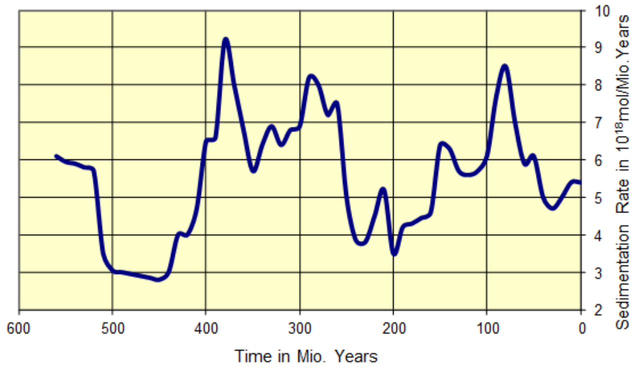

Fig -6: The Sedimentation Rate of Organic Carbon as Function of Time[7]

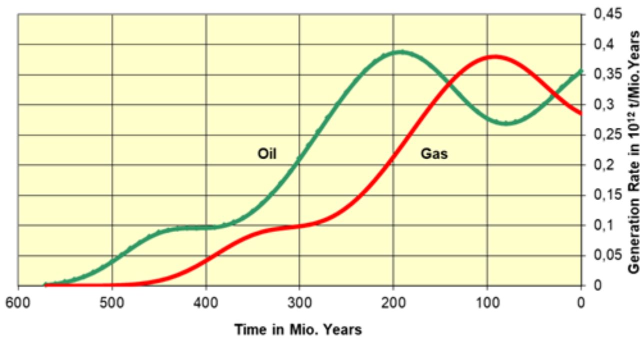

Fig -7: Estimated Global Generation Rates of Oil and Gas as Function of Time (Mean Heating Rate: 10°C/Mio.Years (~Subsidence: 33m/Mio.Years for 30°C/100m)

One proceeds on the assumption that the global average heating rate is 1°C/million years [5], which equates to a medium subsidence rate of ~ 33 m/1 million years for a temperature gradient of 3°C/100 m. According to these assumptions, the gas generation with its maximum ~ 100 million years ago lags behind the crude oil generation by ~ 100 million years. Needless to say, these time-dependent generation rates would have to be taken into account in the determination of a global half-life, something that exceeds Miller's approach [5]. Especially during the time from the beginning of the generation to ~ 250 million years ago the generation should have been the determining process in the hydrocarbon balance essentially. Because the generation rate of crude oil has fluctuated around the value 0.33 x 10^{12} t/million years in the last ~ 250 million years however, its influence on the half-life is being neglected in this case. Via the balance relations and the determined half-life the filling rates and exit rates as well as the cumulative complete generation of crude oil can be calculated. The present global crude oil generation rate by Miller with 0.35 x 10^{12} t/million years (= 2.7 million bbl/yr) [1] is chosen as standardisation value (Fig. 8), which consequently leads to a 20% higher value for the world crude oil reserves than declared.

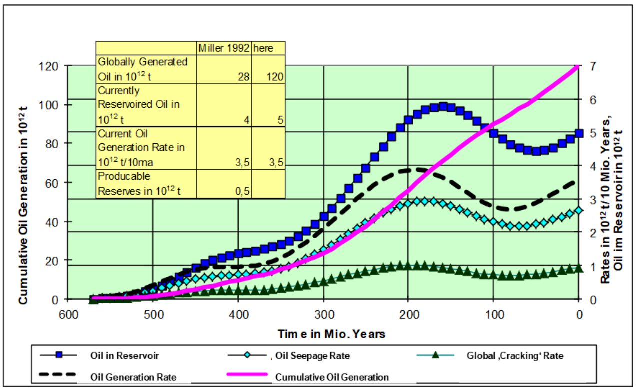

Fig -8: Estimated Global Generation Rates of Oil and Gas as Function of Time (Mean Heating Rate: 10°C/Mio.Years(~Subsidence: 33m/Mio.Years for 30°C/100m)

Measured by the abundance of the limiting assumptions on the method applied, the achieved accuracy of this value is quite remarkable. There is, however, one significant difference in the estimation of the complete globally generated crude oil, which is with a value of ~ 120 x 10^{12} t about 4 times as big as with Miller. One can gather from the curves in Fig. 8 that there was a maximum of the crude oil exit rate ~ 180 million years ago that is almost being reached again today. The delay of ~ 20 million years as opposed to the crude oil generation maximum is the result of intermediate storage in the reservoir whose previous maximum occurred ~ 160 million years ago.

4. The Natural Gas Fields in North-West Germany

Miller's approach only applies globally and for crude oil only. Nevertheless, it is attempted below to confer this model to natural gas and then only for North-West Germany as well. Between the Ems and Weser rivers in North-West Germany, natural gas is exploited from the two reservoir rocks of the basal Zechstein carbonate

(Upper Permian) and the Middle Buntsandstein (Lower Triassic) lying on top of each other (Fig. 9) whereat the location of the fields is nearly congruent (Fig. 10) [9].

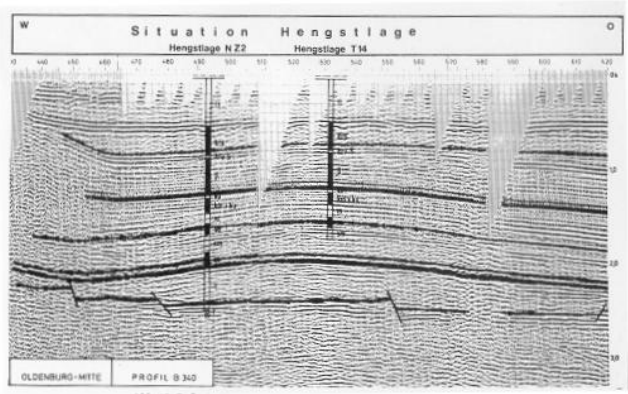

Fig -9: Reflection Seismic Profile across the gasbearing Hengstlage Anticlinal Structure of the Middle Buntsandstein (Lower Triassic) and the underlying gasbearing Main Dolomite (Ca2) Fault Block of the basal Zechstein (Upper Permian) [9]

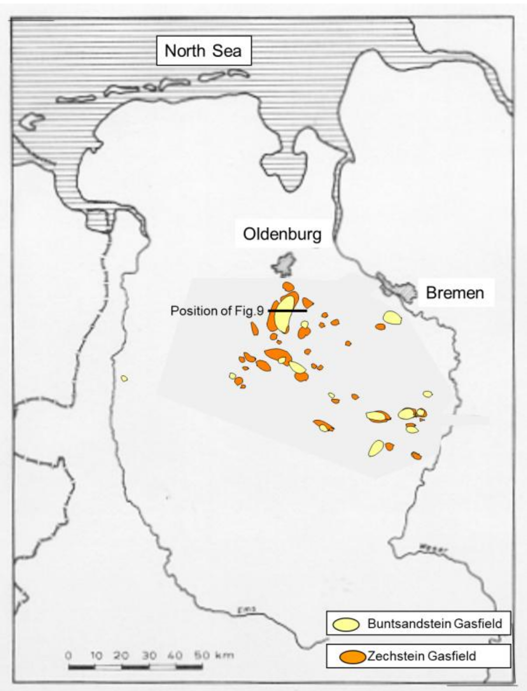

Fig -10: Locations of the Zechstein and Buntsandstein Gasfields

between the Weser and Ems rivers in North-West Germany [9]

Here, a genetic connection appears obvious, even if the natural gas is contaminated by sulphurous compounds in Zechstein but not in Buntsandstein. Both reservoirs are sealed up by superimposed salt layers. The natural gas stored in them comes mainly from the coal beds of the Carboniferous (see [10, 11] among others), which have experienced a subsidence history in North-West Germany as portrayed in Fig. 11 in a generalised manner [11, 12].

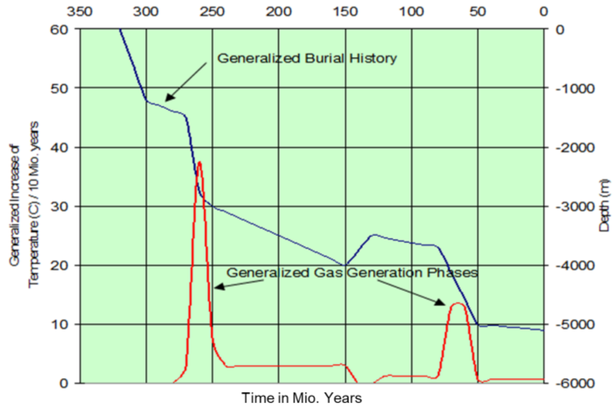

Fig -11: Generalized gas generation phases of the North German Basin [11, 12]

The details of this subsidence history are the causes of the bimodal distribution of two nearly synonymous natural gas generation phases whereat both phases can be characterised by their differences in the amounts of carbon and nitrogen isotopes (see [10, 11] among others). From the amounts of natural gas already produced in the meantime (until ~1998, Zechstein > 120 billion m³, Buntsandtein> 80 billion m³ [13]), added to the estimated remaining reserves (Zechstein ~ 130 billion m³ (~ 39% of the total reserves), Buntsandstein ~ 30 billion m³ (~ 10%) [14]), separately for both reservoirs in each case, a Zechstein – Buntsandstein ratio of ~ 2.3 of the total reserves can be calculated. On the assumption that the yield factors are comparable for both reservoirs this value also applies to the total amounts of the stored natural gas.

5. The Zechstein-Buntsandstein Hydro-carbon System

If you proceed on the assumption of a relatively fast proceeding natural gas generation phase in the coals of the Upper Carboniferous and an almost immediately following filling of the Zechstein reservoirs, the Zechstein will subsequently degasify exponentially according to the Miller model, whereas the half-life is still unknown for the time being. This degasification certainly will not proceed continually, but will be geared to tectonic processes as it is also observed today in the Circum-Pacific zone and the Alpine foldbelt of the Earth [2]. Even if it does not completely give consideration to the processes probably running episodically, it is being attempted here, in a generalising manner, to depict a discontinuously proceeding degasification analytically via an exponential curve mathematically and cumulatively. The degasification of the Zechstein will lead to the filling of the Buntsandstein reservoirs lying above it, whereby a part neglected here possibly reaches the earth's surface directly. The loading of the Buntsandstein does not happen in a short time for this reason, but drags on for a longer period of time. The degasification process of Buntsandstein starts simultaneously with the loading. To keep the possible mathematical complexity limited, it is to be assumed that the Middle Buntsandstein (because of its sealing by the salt as well) has a half-life comparable to the Zechstein. The mathematical approach for the Zechstein degasification, the Buntsandstein filling rate, the Buntsandstein reserves, and the Buntsandstein degasification is portrayed in Fig. 12.

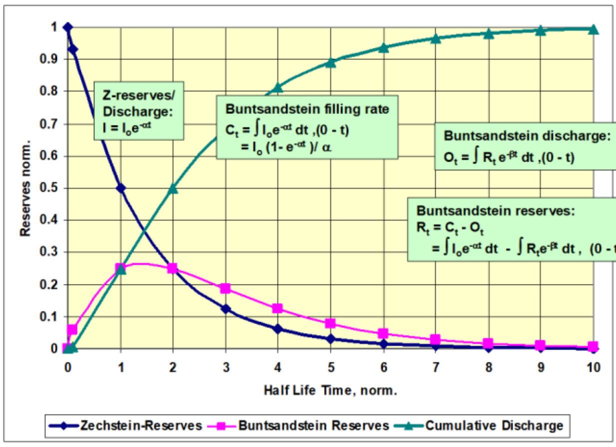

Fig -12: Normalized gas reserves, Zechstein discharge, Buntsandstein charge/discharge

The curves were calculated numerically as function of the half-life and interpolated for the values lying in between. From the ratio of the time-dependent filling quantities of Zechstein and Buntsandstein one can determine how today's value and the half-life of the Zechstein-Buntsandstein system relate to one another (Fig. 13). From the observation presented above, that the last generation phase and filling happened in North-West Germany about 50 million years ago, one can conclude a half-life of about 60 million years. This value is twice as much as the global value of 30 million years for crude oil. In this case, the larger fugacity of natural gas probably gets more than balanced through the excellent properties of the salts in North-West Germany in covering fluid deposits. If the deduced value also applies to the first generation phase of ~ 240 million years ago, there would only be remainders of the first methane filling of less than 10% contained in the Zechstein reservoirs. The value for the Buntsandstein reservoirs would probably be ~30%, which might contribute to the slightly different gas and isotope composition of these gases. If the reserves specified above get reduced by the amount of the first filling phase, a proportion between Zechstein and Buntsandtein gas of 225/80 = 2.8 results for the second filling phase, which would only cause an insignificant change of the half-life according to the analysis of Fig. 13. If the Buntsandstein fields genetically relate to those of the Zechstein lying below, as it is posited here, and if one regards them as multiplicative system in their entirety, sorted by size, their field size distribution has to point to a higher complexity compared to Zechstein as well, because additional parameters dependent on the Zechstein degasification define their reserve amounts [15]. The field size distributions of both reservoirs presented in Fig. 14 confirm this assumption, because, compared to Zechstein, the Buntsandstein indicates a considerably higher, complexity symbolising slope in the log-normal presentation – here in a selection of larger fields [13].

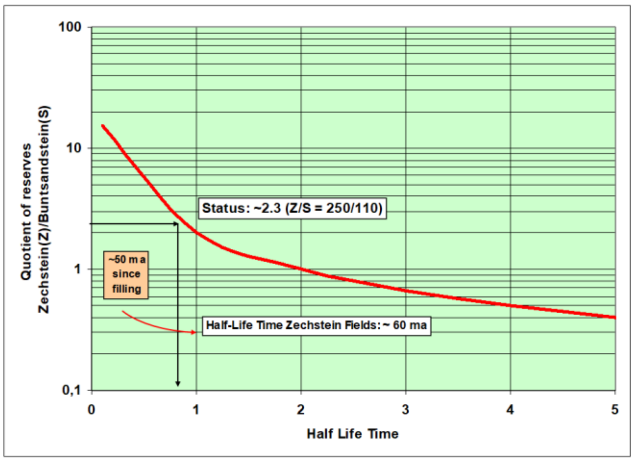

Fig -13: Quotient of Zechstein and Buntsandstein reserves vs. Half-Life Time

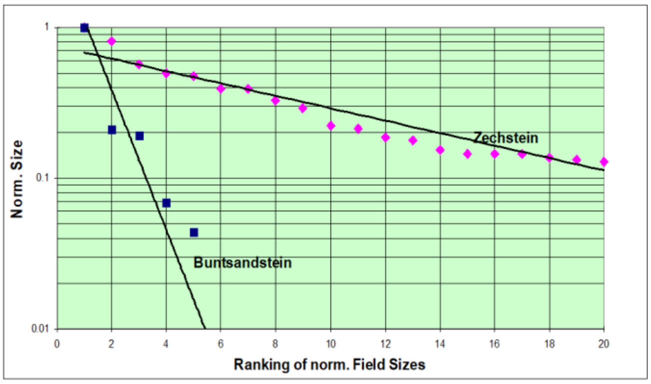

Fig -14: Field Size Distributions of Zechstein and Buntsandstein Gas Fields in North-West Germany

6. Conclusion/Future Prospects

Since comparable half-lives of hydrocarbon reservoir systems lying above each other, as described here, lead to a "smearing" of the temporality of generation and accumulation, there might still exist attractive exploration possibilities in the higher levels for hydrocarbon provinces, whose source rocks are either classified as overly mature in the meantime or whose reservoir rocks lying in greater depth have already been explored all over. This applies especially, if a lateral migration of hydrocarbons in the higher level was not necessarily conductive for their discovery during the exploration phase in the lower level up until now. If one wants to make detailed statements about past eras in regards to the entry of hydrocarbons into the biosphere, the applied method does not suffice however. Then, all major sedimentary basins of the Earth should be treated individually and the total effect should be regarded cumulatively as function of time.

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