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The Main Features of Global Photosynthesis and its Evolution in the Global Carbon Turnover

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ABSTRACT

Global photosynthesis is the key element of the recently proposed global carbon cycle model. It describes an integral action of ensemble of photosynthesizing organisms in large systems, like biosphere and global carbon cycle. At least two main features associated with the participation of global photosynthesis in large systems, differs it from conventional photosynthesis of individual organism. The first is the cyclic character of the photosynthesis evolution, and the second is spontaneous striving of global photosynthesis to the ecological compensation point that brings the carbon cycle to a stationary state. It is shown that the conventional photosynthesis equation should be modified to describe this process in the biosphere and in the global carbon cycle. The terms "living matter" and "sedimentary organic carbon" were used as an analog of biomass in the equation of global photosynthesis. Corresponding changes were made to describe the second product of global photosynthesis-atmospheric oxygen. Considering that the global carbon cycle reached the ecological compensation point that occurred in the Miocene, when the further accumulation of oxygen in the atmosphere and sedimentary organic matter in the earth's crust ended, the obtained approximate equations of photosynthesis were used to estimate the world's potential oil resources. To test the predictive capability of the model we compared the above characteristic with its analogue, the world's initial summary resources, calculated by independent geological methods. In spite of various assumptions a surprising proximity was found. It evidences that the model itself and underlying physical foundations are realistic and can be used as approximation in solving different problems in geology, evolution, climatology and related fields of knowledge.

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Global photosynthesis is the main element of the new global carbon cycle model [1,2]. It is impossible to understand its role in cycle functioning without considering the interaction of global photosynthesis with the other elements, including geological processes, because they form the common sequence.

In addition, it is important to consider what features of global photosynthesis are common with the conventional photosynthesis of an individual organisms and what features of global photosynthesis are linked with its functioning in large systems, such as the biosphere or the global carbon cycle. To assess carbon balance for global photosynthesis in large systems, it is necessary to derive the corresponding equations and justify them. But first it is necessary to consider the mechanism of the carbon cycle functioning and the role of global photosynthesis in it.

Global Carbon Cycle Model. General Considerations

Formally, redox model of the global carbon cycle can be represented as a closed loop consisting of two branches – reductive and oxidative ones (Figure 1). The loop has two key points. Point 1, where carbon from the oxidative state, represented by species of natural system (CO_2 - HCO_3- - CO_3=), passes through photosynthesis to the reduced state, represented by various forms of organic substances. The process uses the energy of the Sun. Point 2 another redox process that closes the loop. It illustrates the reverse transition from the reduced state of carbon to the oxidized one. The point includes numerous respiration processes in the biosphere, aerobic and anaerobic processes in the earth's crust, and the final oxidation of the residual sedimentary organic matter that reached the subduction zone (zone of lithosphere plates' collisions). The very important final oxidation occurs by means of thermochemical sulfate reduction. Energy, required for this reaction, is provided via collisions of the moving lithosphere plates.

The existence of sulfate reduction as an oxidizer of sedimentary organic matter in nature is recognized by many authors. But the overwhelming majority of them consider this process to be microbial, occurring in the anaerobic surface conditions, in the zone of activity of microorganisms [3-5].

Meanwhile, our assertion that the sulfate reduction oxidation of sedimentary organic matter is a thermochemical process has a fundamental sense, since it connects the periodic movement of lithosphere plates with the processes in the subduction zone. Moreover the process is bound to orogenic period. Hence it becomes time dependent. All other processes which are included in the common sequence of events turn to be time dependent as well. This assumption stems from the cyclic nature of climatic

and biotic events occurring in biosphere.

Indeed, in case of microbial sulfate reduction no temporal relationship of this process could exist, since microbial reaction depends only on the suitable conditions, but not on the time when it proceeds.

In addition, it should be noted that only biosphere carbon can circulate in a loop, shown on Figure 1. It means that carbon of carbonate sequences is excluded from chemical exchange between oxidized carbon species and, hence, from circulation in loop, since the rate of chemical exchange of solid carbonate is immensely less than the rate of other oxidized species. The implementation of this scheme in nature is described below. We deliberately simplified the model under consideration, highlighting those features that could play a role in the redox processes of the carbon cycle and can be confirmed by the available isotopic and chemical data.

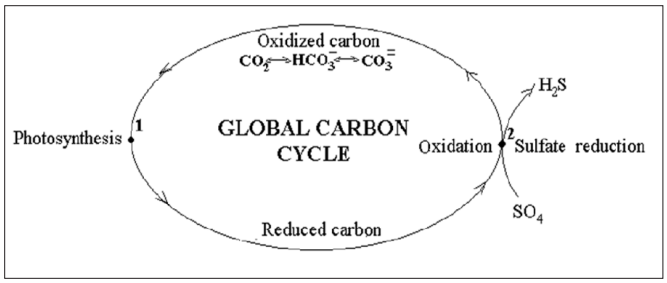

Figure 1: A formal diagram of the global carbon cycle in the form of a loop.
The loop has an oxidative and reducing branch. Point 1 corresponds to photosynthesis, that is, the transition of the oxidized state to the reduced one;
point 2 corresponds to the oxidation of sedimentary organic matter in the reaction thermochemical sulfate reduction, that is, the transition from the reduced state to oxidized form.

What makes lithosphere plates move? Lithosphere plates' motion is an experimental fact. The above question is problematic one. The most plausible appears to be the assertion that gravitational forcing of celestial bodies effect on the Earth motion around the sun. This forcing is transmitted via the magma convection streams. Since the lithosphere plates float on liquid magma surface gravitational forcing exerts an impact on the plates' movement as well. The movement is irregular and consists of short-term phase, called orogenic period, and long-term phase called geosynclynal period. They both form orogenic cycle. The moving plates collide. In the orogenic period the plates move faster and therefore collisions are more often. The orogenic period is characterized with intense volcanism, magmatism and mountain building. Energy of collisions is utilized to initiate thermochemical sulfate reduction which oxidizes sedimentary organic matter [6].

Participation in the redox loop of thermochemical sulfate reduction naturally binds the carbon cycle with the sulfur cycle. This relationship is proved by the conjugate changes in the chemical and isotopic characteristics of carbonate carbon and sulfate sulfur over a long period of geological history spanning Neoproterozoic and Phanerozoic. Of course, the model is only an approximate description of the real carbon cycle. The degree of this approximation can be judged from the way, how the model describes the long sequence of biosphere and climatic events established during the whole period of research. During the orogenic period of the cycle, CO_2, produced in organic matter oxidation due to sulfate reduction, goes up to the Earth's surface and fills the "atmosphere - hydrosphere" system. The increased CO_2 concentration provides warm " greenhouse " period on the Earth. Along with CO_2, H_2S and other volcanic gases, as well as the reduced metal forms, lift with magma onto the surface and, utilizing oxygen for oxidation, make anaerobic/low oxygen situation on the Earth.

In geosynclynal period, when tectonic activity slows down and the rate of lithosphere plates' movement reduces, development of photosynthesis and weathering become dominant. Due to photosynthesis, the oxygen content in the atmosphere increases whereas the concentration of CO_2 decreases. The atmosphere turns from anaerobic to aerobic. As a result, due to a decrease in CO_2 content, a cold snap occurs ending with glaciations.

The described sequence of events is confirmed by isotopic data. During the orogenic period, the entry of isotopically "light" CO_2 into the atmosphere is recorded. It causes the observed enrichment of organic matter and carbonates in ^{12}C. The source of CO_2 enriched in ^{12}C is an isotopically "light" sedimentary organic matter, which is oxidized in sulfate reduction [7]. By the end of the geosynclynal period, due to increased photorespiration of photosynthetic organisms and the Rayleigh effect associated with the depletion of CO_2, the biomass becomes enriched in ^{13}C isotope. Thus carbon isotope composition of sedimentary organic matter and carbonates, enriched in ^{12}C at the beginning of the cycle, become enriched in ^{13}C by its end.

Transitions between orogenic cycles play a special role in the mechanism of global carbon cycle since they are followed by dramatic changes in environmental conditions. Indeed, glaciations and high oxygen concentration in the atmosphere at the end of the previous cycle are replaced by an increased temperature of the "greenhouse" period and a sharp decrease in the oxygen content in the atmosphere at the beginning of the next orogenic cycle, not to mention other adverse external factors, accompanying intense volcanism and magmatism, such as the rise of toxic gases and increased radioactivity [8]. It causes mass extinction of organisms (up to 80%). Great masses of biogenic material after burial cause formation of sediments rich in organic matter [9]. Thus the end of the orogenic cycle is characterized by mass extinction and formation of black shales [10].

The additional evidence for the considered sequence of climatic events gives the biotic turnover observed by Gorican and colleagues [11]. They investigated the distribution in radiolarian species belonging to 69 genera in the course of transition from greenhouse to icehouse period and found a trend in radiolarian diversity caused by climatic changes. The ratio between number of originating and extinct species as well as diversity significantly changed over the studied period. Then the trend reversed throughout the extinction interval. Afterwards recovery started again and turnover resumed. Radiolarian diversity was in a fairly good agreement with that of other marine fauna.

Similar sequence of climatic events observed by many researchers indicated on the validity of the model [12,13]. The repeated orogenic cycles as a consequence of continues lithosphere plates' movement leads to one more conclusion, that the evolution of global photosynthesis occurred cyclically and each time it started with a higher level of oxygen and a lower level of CO_2.

The gradual increase in oxygen concentration in each new orogenic cycle affects the biochemical appearance of the biomass, which ultimately manifests itself in the observed chemical differences between sedimentary organic matter of different age. Some of

the features of the organic matter are inherited by oils produced by rocks containing this organic matter and are shown in their chemical appearance, which became the basis for the genetic classification of oils that are used in their search [14,15].

Having examined average carbon isotope composition of 504 oils, comprising interval from Precambriam to Neogene, Andrusevich et al. found 4 steps of ^{13}C enrichment of oil fraction C_{15+} [16,17]. This indicated that the above enrichment is associated with a 4-fold increase in oxygen content in the atmosphere and is explained by their connection with 4 orogenic cycles (Figure 2).

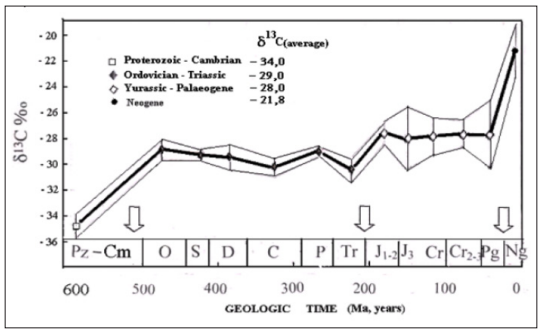

Figure 2: Thechange of the averagecarbon isotope composition ($\delta^{13}C$, ‰) for saturate fraction C_{15+} of crude oils. Vertical bars are standard deviations, which increase with decreasing age. Arrows indicate Cambrian– Ordovician,Triassic – Jurassic, and Paleogene –Neogene boundaries where ^{13}C enrichment occurs [16,17].

Another feature of global photosynthesis inherited from conventional photosynthesis is related to the ability of photosynthetic organisms to regulate their assimilation capacity by changing the ratio of assimilation and photorespiration in response to the change of CO_2/O_2 concentration ratio in the environment. The growth of CO_2 concentration stimulates the assimilation (carboxylase) function of Rubisco enzyme, the growth of O_2 concentration intensify its photorespiratory (oxygenase) function. Thanks to this ability, photosynthetic organisms have a compensation point that determines the limits of organisms survival. It determines the lowest level of CO_2 concentration in the environment, beyond which photorespiration cannot grow, i.e. the oxidation of biomass by means of photorespiration cannot exceed the amount of the assimilated carbon.

As applied to global photosynthesis, this means that the amount of reduced carbon formed during photosynthesis cannot be less than the amount of carbon oxidized in all respiratory processes occurring in the biosphere, the oxidative processes occurring with organic matter in the earth's crust, including the processes in the subduction zone. This moment is called ecological compensation point. The system spontaneously strives to it. When it is achieved, the global carbon cycle comes to a stationary state. There is no further accumulation of oxygen in the atmosphere and sedimentary organic matter in the Earth's crust.

It is high likely the appearance of a new type of photosynthetic assimilation, occurred in Miocene, seems to have been an indicator of the achievement of this point in the course of evolution [18-20]. The organisms of so-called C-4 type were capable to survive in habitats with so low CO_2 concentrations, where the preceding C-3 organisms could not exist [21].

Up to this point fluctuations in the CO_2/O_2 ratio in the environment, caused by the changes in the assimilation and photorespiration functions, affect biosynthesis accordingly. With emergence of C-4 type of assimilation, variations in the CO_2/O_2 ratio in the environment were regulated by the changes in the prevalence of plants of C-3 or C-4 type of assimilation [22].

Tolbert and colleagues conducted experiments with plants (tobacco and spinach) in a closed chamber, noticed that assimilation of CO_2 led to its relative exhaustion down to low concentration and to an increase of O_2 concentration [23]. They suggested that O_2 concentration at a constant concentration of CO_2, when the assimilation and release of CO_2 turned to be equal, doesn't change too. The work of Jahrens et al. who investigated fossil plant tissue led to the same conclusion [24]. Igamberdiev and Lea considering the changeability of CO_2/O_2 compensation ratio over photosynthesis evolution based on the rubisco kinetics determined limits of variations of CO_2 and O_2 for biosphere [25]. Later Ivlev spread the concept on ecological compensation point to global carbon cycle concluded, that not only CO_2/O_2 concentration ratio in the atmosphere, but sedimentary organic matter content in the earth's crust become stable [2].

Let's consider now the photosynthesis equations fit for description of the process in biosphere and in carbon cycle.

The Applicability of Formal Photosynthesis Equation to The Analysis of Global Carbon Cycle Balance

The similarity of the main features of conventional and global photosynthesis enables to assume that formal simplified description of conventional photosynthesis is valid for global photosynthesis as well. The traditional photosynthesis can be written as follows:

$$CO_2 + H_2O \xrightarrow{h\nu} (CH_2O) + O_2 \quad (1)$$

Here CO_2 and H_2O are the reaction substrates, taken from the environment, (CH_2O) is analog of biomass, produced in the reaction, and O_2 is another product of the reaction evolved into environment.

If to describe the equation (1) as kinetic equation for the first order chemical reaction, one can get the dependence of substrate (CO_2) and product (O_2) concentrations on the extent of reaction transformation [2]. In this case one can get two exponential curves and to conclude that both curves are of anti-phase character. The curve describing the decrease of CO_2 concentration should be followed by a synchronous mirror increase of O_2 concentration. As to "product – product" link, from the same mathematical analysis one can deduce that the above link is represented by two identical in-phase curves and that, at any moment, O_2 and CH_2O are formed according to stoichoimetry, i.e. in 1:1 ratio. Anti-phase nature of the relationship "substrate – product" during photosynthesis was proved in the works of Andre [26,27]

Photosynthesis Equation in Biosphere

Now let's see, how the conventional photosynthesis equation should be modified to describe this process in biosphere. At the time notable Russian geochemist V.I. Vernadsky introduced the concept of "living" matter to describe the interaction between biosphere and geological processes [28]. He defined "living" matter as the total biomass of all living organisms on the Earth. The terms "living" matter, and "global photosynthesis" are generalized integral characteristics. We used them to describe global photosynthesis in the biosphere. As known, "living" matter consists of two parts: photosynthetic and heterotrophic biomass:

$$\text{"living" matter} = \text{biomass}_{\text{photosynthesized}} + \text{biomass}_{\text{heterotrophic}} \quad (2)$$

The "living" matter as a whole can be presented as a photosynthetic product consisting of two parts: 1) the primary photosynthetic product, which is photosynthesized biomass, and 2) the secondary photosynthetic product, which is heterotrophic biomass.

Evidently, that a photosynthesis equation, describing this process in the biosphere, or in the global carbon cycle and taking into account a variety of individual organisms should look otherwise, than a conventional equation of photosynthesis for individual organism.

In case of biosphere the equation looks like that:

$$(CO_2 + H_2O)_{atmosphere} + {}_{hydrosphere} \xrightarrow{h\nu} \text{"living" matter} + O_2 \quad (3)$$

Indeed, equation (3) reflects the fact that CO_2 and H_2O are taken from the natural "atmosphere – hydrosphere" system, "living" matter corresponds to total biomass, including photosynthesizing and heterotrophic organisms, O_2 is a resultant oxygen, released into the atmosphere produced both by primary photosynthesizing organisms, as well as by photosynthesizing organisms, whose biomass had become a source of carbon for the consumers of food chains (Ivlev, 2020). Equation (3) can be regarded as the equation of global photosynthesis for biosphere.

Photosynthesis Equation in Global Carbon Cycle

Let's see now, what photosynthesis equation looks like for the global carbon cycle. Given the above said and the key role of photosynthesis as well as that getting into the sediment, biomass turns into a sedimentary organic matter, the photosynthetic equation can be presented as follows:

$$(CO_2+H_2O)_{atmosphere} + {}_{hydrosphere} \xrightarrow{h\nu} \text{"living matter"} + \text{COM} + O_{2\ atmosphere} \quad (4)$$

The left side of equation (4) is completely similar to that of equation (3), i.e. it denotes the substrates obtained from the environment. The right part of equation (4) is distinguished by the presence of the term COM which denotes the sedimentary organic matter of the Earth's crust. Both first terms "living" matter and Com are an analogue of the biomass in the photosynthesis equation. The first denotes the biomass of currently "living" matter, while the second denotes sedimentary organic matter, which is the buried and transformed biomass of all organisms that have inhabited the Earth since photosynthesis origin. The last term on the right side of equation (4) takes into account the total oxygen that was released in synthesis of the biomass of all organisms who ever lived on the earth currently and in the past. If to assume that biomass of currently living organisms is much less than the mass of buried organic matter in the Earth's crust, equation (4) turns into equation (5)

$$(CO_2+H_2O)_{atmosphere} + {}_{hydrosphere} \rightarrow \text{Com} + O_2{}^*{}_{atmosphere} \quad (5)$$

where the term, designated as $O_2{}^*{}_{atmosphere}$, includes both, the oxygen, released during photosynthesis of biomass of organisms that lived in the past, denoting as Com, as well as the oxygen, released during photosynthesis of the biomass of currently living organisms, which was neglected.

As one can see, the equations obtained for global photosynthesis in large systems are consistent in form with the equation which describes photosynthesis of individual organism and therefore should reflect the same links between the analogous characteristics of large natural systems that were shown for conventional photosynthesis, i.e. the counter-phase relationship between the substrate (CO_2) and the product (H_2O) of the photosynthesis, and in-phase relationship between reaction products (O_2 and H_2O) [1].

To apply photosynthesis equation (5) for balance estimates in global carbon cycle, one should keep in mind that the released oxygen, according to stoichoimetry of the reaction, is formed in parallel with the biomass, in a ratio of 1:1. This means that using the photosynthesis equation and knowing the amount of oxygen in the atmosphere it is possible to estimate the amount of sedimentary organic carbon in the earth's crust.

Indeed, the correlation between atmospheric carbon dioxide and oxygen, has counter-phase character and covering Neoproterozoic and Phanerozoic (Figure 3), as well as the correlation of atmospheric oxygen growth and burial rate of organic carbon, having in-phase character in the same range of geological time (Figure 4), illustrates the same character of dependencies as their analogues in conventional photosynthesis and gives additional argument in favor of application of the obtained equations of global photosynthesis to investigate natural systems.

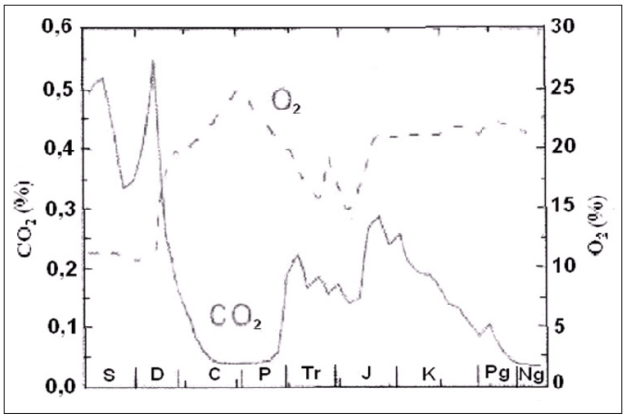

Figure 3: Changes in the atmospheric concentration of CO_2 (solid line) and O_2 (dashed line) during Phanerozoic eon. Abbreviation of the periods:
S – Silurian, D – Devonian, C – Carboniferous, P- Permian (Palaeozoic era); Tr – Triassic, J – Jurassic, K – Cretaceous (Mesozoic era); Pg – Palaeogene and Ng – Neogene (Cenozoic era). Given that the reaction is of the first order, one can expect an antiphase link between CO_2 and O_2. The first two periods of Palaeozoic era (Cambrian and Ordovician) are not shown because there is some uncertainty around establishing the CO_2 and O_2 concentrations. CO_2 estimates are from the Geocarb III model [26].

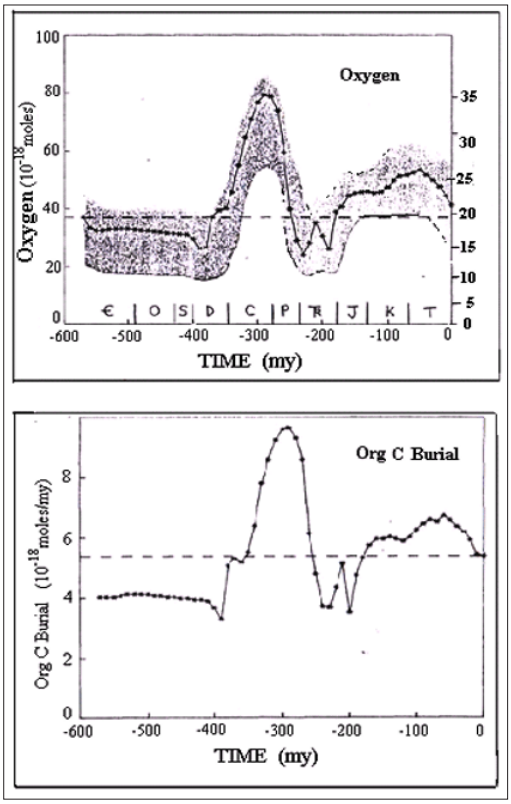

Figure 4: The in-phase changes of oxygen content in the atmosphere and burial organic matter rates in the sedimentary rocks in Phanerozoic. The shaded zone for oxygen designates the zone of possible errors based on sensitivity analysis [33].

Table 1 summarize the results obtained by different researchers who have modeled atmospheric evolution. All of them unambiguously show the oxygen accumulation in the atmosphere up to a certain point. However, despite this fact, some researchers have insisted that main consumer of the oxygen, produced in photosynthesis, is the oxidation reaction of bivalent Fe^{+2} iron to trivalent ion Fe^{+3} [29]. This ratio was presented as $Fe_2O_3/\Sigma Fe_{[Fe2O3]}$. They carried out the calculations for the time interval (ca. 2.22 to 2.06 Ga), when there was a steady growth of oxygen concentration in the atmosphere, confirmed by the appearance of extensive red beds, wide spread of evaporates (gypsum, anhydrite), disappearance of detrital pyrite, siderite, uraninite, and isotopic data. For these conditions, the amount of atmospheric oxygen, fixed in the above reaction, was evaluated.

However this results and the conclusions, relying only on balance estimates, cannot be regarded as reasonable, since balance approach can't be applied to "open" system. Because of geochemical cycles' coupling it is impossible to take into account the processes. in the points of coupling. Then the extent of the model's validity, as mentioned before, can be tested only by its ability to describe the sequence of biotic, climatic, and evolutionary events established as a result of thorough analysis of geological, paleontological data, supported by isotopic and other independent facts.

Table 1: Estimates of the Average Concentrations Of O2 in the Atmosphere during Geological Time According to Different Models

Eon / Era Numerical age Ma	Approximate Value	References
Precambrian/ Paleoproterozoic 2200 – 2000	~ 0,2 %	[30,31]
Precambrian/ Neoproterozoic 1700 – 570	2 – 3 %	[32]
Phanerozoic/ Cambrian– Devonian 570 – 350	< 15 – 17 %	[33-35]
Phanerozoic/ Carboniferous– Permian 350 – 230	25 – 30 %	[36]
Phanerozoic/ Mezozoic Triassic – Cretaceous 230 – 145	20 %	[36,37]
Phanerozoic / Cenozoic / Neogene / Miocene 23	23 %	[35,38]

The Possible Mechanism of the Oxygen Accumulation in the Atmosphere and Sedimentary Organic Matter in the Earth's Crust. It is known, that photosynthesis has born in the environment, where there was a high concentration of CO_2 and a very low concentration of oxygen [39]. With the appearance of the key photosynthetic enzyme, Rubisco, the concentration ratio of CO_2 to O_2 in the atmosphere began to change under enzyme control. As already said, Rubisco has the property with the increase of CO_2 concentration to intensify assimilatory function, while with the increase of O_2 concentration to intensify photorespiratory function.

From one orogenic cycle to another there was a stepwise growth of oxygen in the atmosphere. As a result, there was a continues decrease of the concentration ratio CO_2/O_2 in the atmosphere, i.e. there was O_2 accumulation. This trend continued until the achievement the ecological compensation point. At this moment the minimal concentration of CO_2 was achieved as well. This was manifested in the appearance of new C-4 type of CO_2 assimilation.

Then the ratio became stable and CO_2 and O_2 concentrations began to oscillate around some average meanings. In parallel with CO_2/O_2 ratio, and in accordance with the photosynthesis equation (5), the accumulation of sedimentary organic matter has taken place in the Earth's crust.

According to the model, the biomass, produced during photosynthesis firstly participates in respiration processes in the biosphere, then in form of buried organic matter undergoes numerous transformations in the earth's crust, where a part of it is lost in aerobic and anaerobic processes and finally the residual is completely oxidized in the subduction zone. Hence the reduced carbon, produced in photosynthesis, is preserved in this form only in the Earth's crust on its way to the subduction zone. The corresponding amount of oxygen in parallel accumulates in the atmosphere. At the ecological compensation point, when the ratio of CO_2 and O_2 concentrations in the atmosphere becomes stable, the further accumulation of sedimentary organic carbon in the Earth's crust ceases. Simultaneously the content of organic matter derivatives (oils) becomes stable as well.

Validation of the Global Carbon Cycle Model Based on the Global Photosynthesis Equation

For the stationary state of the global carbon cycle (at the ecological compensation point) a quantitative approach to balance evaluation is possible. Since the calculation was evaluative, the requirements for the accuracy weren't high. One of them is: the expected values shouldn't differ from the known parameters by more than one order of magnitude. The accuracy of the calculation was determined not only because of approximate initial expression (5) on the basis of which the calculation was performed, but also by the assumptions and approximations that are considered below.

One of the approximations was the following. In nature, sedimentary organic matter is represented by two forms – dispersed and concentrated. The source of the first is higher land vegetation, the second is plankton and other lower land vegetation. Higher terrestrial vegetation appeared on the Earth more than 2 billion years later than photosynthesis origin, and its contribution to the total mass of sedimentary organic matter can be regarded as insignificant.

The use of the photosynthesis equation (5) for the global carbon cycle balance is based on the statement that there is a proportionality of the amount of organic carbon accumulated in the earth's crust and the corresponding amount of oxygen released into the atmosphere. The violation of the proportionality may be only in case, if the photosynthetic products are used in side reactions. Partially we have touched the issue earlier. Now let's analyze such a case in detail.

According to the model, at the beginning of each orogenic cycle a part of the oxygen, previously accumulated in the atmosphere, is consumed in the oxidation of the reduced forms of sulfur, coming from the subduction zone, and the reduced elements of igneous rocks, lifting with volcanic and magmatic exhalations in the orogenic period. This results in the observed drop in the oxygen content in the atmosphere and in the emergence of a low-oxygen or anaerobic situation. A drop in the oxygen content is compensated at the expense of bound oxygen of sulfate in organic matter oxidation, proceeding in the subduction zone and due to close coupling of carbon and sulfur cycles. The remaining losses we consider as insignificant. It allows concluding that in case of steady state of the carbon cycle, the proportionality between the amount of oxygen in the atmosphere and the amount of sedimentary organic matter in the Earth's crust retains.

Two more approximations should be done. We assumed that 1) all organic matter in the Earth's crust is of photosynthetic origin. Organic matter of other origin is negligible; 2) the global carbon cycle is a "closed" system; oxygen, once formed during photosynthesis in the course of geological time is remained in the atmosphere. This point was discussed before.

After making the necessary comments, we proceed to the calculation based on the obtained photosynthesis equation (5). First we have calculated the number of moles of oxygen accumulated in the atmosphere. Multiplying the mass of dry atmospheric air, equal to (5.1 – 5.3) * 10^{18} kg, and the mass percentage of oxygen in the air layer, equal to 23.1% (Geological Encyclopedia on-line rus-geolog-enc.slovaronline.com), one gets the mass of oxygen in the atmosphere, equal to 1.2* 10^{18} kg. Dividing this figure by the molecular weight of oxygen M = 32, it easy to find the number of oxygen moles in the atmosphere n_{O2}. It turned to be equal to 3.75 1016 kg-mol. Using the relationship between oxygen concentration in the atmosphere and the amount of sedimentary organic matter, given by equation (5), one can get an estimate of the number of moles of organic matter for steady-state conditions. Considering they are formed in a stoichoimetry ratio of 1: 1, one gets n_{OM}. = n_{O2}.

Having determined the amount of organic matter in the Earth's crust, it is difficult to resist the temptation to find out what is the total oil generation capacity of the organic matter in the crust and at the same time to check the model's ability to make quantitative estimates. It is possible by comparing oil generation ability with its analogue, calculated by independent way. In the other words, it is interesting to know what percentage of the total organic matter of the source rock is made up of emigrated hydrocarbons. By hydrocarbons here and further we understand any liquid products of sedimentary organic carbon transformation that emigrate from organic matter in the main oil formation zone. If to denote the portion that emigrating hydrocarbons make up of the total mass of organic matter of the source rock, generating in the main oil generation zone as k_1 and M_{oil} as the molar mass of hydrocarbon approximating oil, then oil generation capacity of the organic matter in the crust, called by world oil resource R, can be presented by the expression (6).

$$R = n_{OM} * k_1 * M_{oil} \quad (6)$$

The first 2 multipliers on the right side denote the numbers of moles of oil hydrocarbons, emigrated from dispersed organic matter. Multiplying it by molar mass of the hydrocarbon, approximating oil M_{oil} ($C_{10}H_{22}$), we get the mass of oil generated by dispersed organic carbon in kilograms. Before using expression (6), a few more explanations should be done.

It is known that the portion of emigrated petroleum hydrocarbons depends on the type of organic matter and on the range of it transformation [40]. From the previously carried out balance calculations, it follows that k_1 varies within 10% for any type of organic matter and any range of organic matter transformation [41]. Accounting of the adopted low accuracy of the calculations, we accepted that the emigration coefficient is equal to 5% regardless of organic matter type and of catagenesis range, i.e. k_1 is equal to 0.05. Then using the expression (6) and substituting the numerical meanings of included values, we get R is equal to 2,68*10^{15}kg.

Geologists have long developed a method for estimating the socalled initial summary resources (ISR), which include proven reserves of oil, indicated (probable) reserves and speculative (hypothetical) resources of oil. Though the structure of the world's initial summary resources in different countries is different, the main items are the same. Moreover, the items are calculated with different accuracy. The proven reserves are most reliable. Speculative (hypothetical) resources are the least accurate and for many countries are unknown.

However, a direct numerical calculation of the ISR for the world is impossible, since for the most of the countries detail structure of ISR is unknown. But for some cases, where this information is available, we found that the most reliable item, the proven oil reserves, were about 20% of the ISR. Assuming that the ratio of the proven reserves and potential resources $(ISR)_{world}$ is approximately the same like for the individual countries (Russian Federation), and taking from the Internet the value of the proven oil reserves for the world, which found to be 2,34* 10^{14} kg, we estimated $(ISR)_{world}$ as follows:

$$(ISR)_{world} = 5* 2,34* 1014 = 1,17*10^{15}kg$$

Comparing the values R = $2,68*10^{15}$kg and $(ISR)_{world}$ = $1,17*10^{15}$kg, one can see proximity between results obtained by using photosynthesis equation in the frames of global carbon cycle model and the estimate obtained by geological methods. This evidences that the suggested global carbon cycle model, in spite of numerous assumption and approximations, is reasonable. It gives us right to consider that equation (5) is valid and our assumption that atmosphere can be regarded as oxygen storage. Nevertheless, the search for new arguments must continue.

The Conclusions

Global photosynthesis describes the functioning of ensemble of photosynthesizing organisms within biosphere or global carbon cycle. The main features of global photosynthesis that distinguish it from the conventional photosynthesis of an individual organism are related to its participation in the functioning of large natural systems, such as the biosphere and the global carbon cycle. They are the cyclical nature of evolution and its spontaneous striving to a stationary state, due to the increase in the concentration of oxygen in the atmosphere that occurs during evolution

As a key element of the previously suggested global carbon model cycle, global photosynthesis allows estimating such important characteristics, like the accumulation of sedimentary organic matter in the Earth's crust and the oxygen in the atmosphere.

To do this, the equation of conventional photosynthesis was modified to make it suitable for description of photosynthesis in biosphere and global carbon cycle. For this objective such characteristics as "living matter" and "sedimentary organic matter" as analogues of biomass were introduced. The corresponding changes were included in the term, designating the other photosynthetic product - oxygen. To investigate the organic matter content in the Earth's crust and to estimate oxygen accumulation in the atmosphere the obtained equation for global carbon cycle was used for the case when the cycle achieves the ecological compensation point.

To test the validity of the global carbon cycle model and its underlying assumptions, and using the resulting expression for global photosynthesis, we calculated the value of world oil resources, which according its physical sense are the analogue to the value of the so-called the initial summary oil resources, which are calculated using independent geological methods. The obtained values turned out to be close. and in spite of numerous approximations, although indirectly, indicate the validity of the model and confirm the reasoning of the accepted assumptions.

References

1. Ivlev AA (2015) Global redox cycle of biospheric carbon: interaction of photosynthesisand earth crust procsess. BioSystems 137: 1-11
2. Ivlev AA (2019) Formation of sequences rich in organic matter in the light of new model of global carbon cycle. Geologiya Nefti i Gasa (russ.) N 5: 83-90.
3. Schobben M, Stebbins A, Ghaderi A, Strauss H, Korn D, et al. (2015) Flourishing ocean drives the end-Permian mass extinction. Proc. Natl. Acad. of Science Early Edition 1-6.
4. Algeo TJ, Henderson CM, Tong J, Feng Q, Yin H, et al. (2013) Plankton and productivity during the Permian–Triassic boundary crisis: An analysis of organic carbon fluxes. Global Planet Change 105: 52-67.
5. Meyer KM, Kump LR, Ridgwell A (2008) Biogeochemical controls on photic-zone Geology 36: 747-750.
6. Torres MA, West AJ, Li G (2014) Sulfide oxidation and carbonate dissolution as a source of CO2 over geological timescale. Nature 507: 347-349.
7. Franceschi M, Corso JD, Posenato R, Roghi G, Masetti D, et al. (2014) Early Pliensbachien (Early Urassic) C-isotope perturbation and the diffusion of the Lithiotis Fauna: Insights from the western Tethys Palaeogeography, Palaeoclimatology, Palaeoecology 410: 255-263.
8. Neruchev SG (2007) Uranium and Life in the Earth History. L. VNIGRI https://world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/what-is-uranium-how-does-it-work.aspx.
9. Ivlev AA (2019) The Global Carbon Cycle and the Evolution of photosynthesis. Cambridge Scholars Publishing https://www.cambridgescholars.com/resources/pdfs/978-1-5275-3730-9-sample.pdf.
10. Yudovich Ya El, Ketris M (2015) Geochemistry of Black Shales. Moscow, Berlin. Direct MEDIA file:///C:/Users/SRC/Downloads/Chapter3.pdf.
11. Goričan Š, Carter ES, O'Dogherty GL, Wever P, Paulian D, et al. (2013) Evolutionary patterns and palaeobiogeography of Pliensbachian and Toarcian (Early Jurassic) Radiolaria http://dx.doi.org/10.1016/j.palaeo.2013.06.028.
12. Korte Ch, Hesselbo SP (2011) Shallow marine carbon and oxygen isotope and elemental records indicate icehouse/greenhouse cycles during Early Urassic. Paleoceanography 26: A 4219.
13. Chen R, Sharma Sh (2017) Linking the Acadian Orogeny with organic-rich black shale deposition: Evidence from the Marcellus Shale. Marine and Petroleum Geology 79: 149-58.
14. Maksimov SP (1964) The Regularities of replacement and formation conditions of oil and gas fields in Paleozoic sediments (on the examples of South regions of Volgo – Ural oil-gas province) Nedra. Moscow.
15. Botneva TA (1987) Genetic Basis for Petroleum Classification. Nedra. Moscow.
16. Andrusevich VE, Engel MH, Zumberge JE, Brothers LA (1998) Secular, episodic changes in stable carbon isotope composition of crude oils. Chemical Geology 152: 59-72.
17. Andrusevich VE, Engel MH, Zumberge JE (2000) Effects of paleolatitude on the stable carbon isotope composition of crude oil. Geology 28: 847-850.
18. Cerling TE (1991) Carbon dioxide in the atmosphere: evidence from Cenozoic and Mesozoic paleosls. American Journal of Science 201: 377-400.
19. Cerling TE, Wang Y, Quade J (1992) Expansion of C4 – ecosystems as an indicator global ecological change in late Miocene. Nature 361: 344-348.
20. Cerling TE, Harris JM, Mac Fadden BJ, Leakey MJ, Quade J, et al. (1997) Global vegetation change through Miocene/Pliocene boundry. Nature 389: 153-158.
21. Chihua W, Guoqing X, Wagreich M, Rodriguez- Lopez JP, Xiaoming S, et al. (2019) Early Miocene Expansion of C-4 vegetation on the Northern Tibetan Plateua . Global and Planetary Change 177: 173-185.
22. Huang Y, Street-Perrott FA, Metcalfe SE, Brenner M, Moreland M, et al. (2001) Climate change as the dominant control on glacial – interglacial variations in C_3 a nd C_4 plant abundance. Science 293: 1647-1651.
23. Tolbert NE, Benker C, Beck E (1995) The oxygen and carbon dioxide compensation points of C_3 plants: Possible role in regulating atmospheric oxygen. Proc. Natl. Acad. Sci 92: 11230-11233.
24. Jahren AH, Arens NC, Harbeson SA (2008) Prediction of atmospheric δ13CO2 using fossil plant tissues. Rev. Geophys 46: (RG 1002. P. 1 - 12)

25. Igamberdiev AU, Lea P (2006) Land plants equilibrate O2 and CO2 concentrations in the atmosphere, Photosynthesis research 87: 177-94.
26. Andre MJ (2011) Modelling ^{18}O and ^{16}O unidirectional fluxes in plants: 1.Regulation of preindustrial atmosphere. BioSystems 10: 239-251.
27. Andre MJ (2011) Modelling $^{18}O2$ and $^{16}O2$ unidirectional fluxes in plant: II. Analysis of Rubisco evolution. BioSystems 103: 251-264.
28. Vernadsky VI (1926) Isotopes and "living" matter. Dokl. AN SSSR December 215-220.
29. Bekker A, Holland HD (2012) Oxygen overshoot and recovery during the Early Paleoproterozoic. Earth and Planetary Science Letters 317-318: 295-304.
30. Holland HD (1965) The history of ocean water and its effect on the chemistry of atmosphere. Proc Natl. Acad. Sci. USA 53: 1173-1182.
31. Bjerrum CJ, Canifield DE (2004) New insight into the burial history of organic carbon on the early Earth. Geochim. Geophys. Geosyst. V.P Q08001.
32. Canfield DE, Teske A (1996) Late Proterozoic rise in atmospheric oxygen inferred from phylogenetic and sulphur-isotope studies. Nature 382: 127-132.
33. Berner R.A., Canfield, DE (1989) A new model for atmospheric oxygen over Phanerozoic time. Am J. Sci 289: 333-361
34. Berner RA, Petsch ST, Lake JA, Beerling DJ, Popp BN, et al. (2000) Isotope fractionation and atmospheric oxygen: implications for Phanerozoic O2 evolution. Science 287: 1630-1633.
35. Berner RA (2003) The long-term carbon cycle, fossil fuels and atmospheric composition. Nature 426: 323-326.
36. Lenton T (2001) The role of land plants, phosphorous weathering and fire in the rise and regulation of atmospheric oxygen. Global Change Biol 7: 613-629.
37. Bergman MJ, Lenton TM, Watson AG (2004) COPSE: a new model of biogeochemical cycling over Phanerozoic time. Am. J. Sci 304: 397-437.
38. Berner RA, Kothavala Z (2001) GEOCARB III: a revised model of atmospheric CO2 over Phanerozoic time. Am. J. Sci. 301: 184-204.
39. Rutten MG (1971) The origin of life by natural causes Amsterdam, London, New York Elsevier Publ. Co https://catalogue.nla.gov.au/Record/1898934.
40. Rogozina EA (1969) on the balance question of the process of coalification of dispersed organic matter of rocks. Proceedings of VNIGRI, 1969, issue 279: 3-19.
41. Ivlev AA, Chetverikova OP (1983) Modified method of balance calculation for the purpose of separate accounting of gaseous and liquid products of emigration in the catagenesis of dispersed organic matter. Geologiya nefti i gaza № 3: 28-34.
42. Geological Encyclopedia on-line rus-geolog-enc.slovaronline.com
43. Ivlev AA (2020) Global Photosynthesis is an Instrument in Large Natural Systems Studies. Geology, Earth & Marine Science 1: 1-4
44. KM Meyer, LR Kump, A Ridgwelleuxinia (2008) during the end-Permian mass extinction. Geology 36: 747-750.
45. Uspensky VA (1970) Introduction into oil geochemistry. Leningrad. Nedra