LIFE AND SEDIMENTS : INTERACTIONS BETWEEN BIOLOGICAL ACTIVITY AND SEDIMENTS DURING GEOLOGICAL TIMES (PRE-CAMBRIAN AND PALEOZOIC)

Cl. MONTY

Laboratoire de Biosédimentologie, C.A.P.S., Université de Liège, B-4000 LIEGE (Bergique)

Many questions may come to the scientist's mind beside considering relationships between organisms and sedimentary features. Among these, two have been on my mind for quite a long time (Monty, 1979) : (1) do life processes significantly interfere with sedimentary processes and products ? Do the grains we presently dredge on the seafloor constitute objects which suffered a succession of biological impacts (2) The second question is : are we able to identify and recognize these impacts or at least to infer their eventual intervention? With this in mind, we directly face a third question : if there are close connections between life processes on the one hand, and particular sedimentary processes and products on the other, then some features of the later must have changed through time, following biological evolution; going a step further, some sedimentary suites are not haphazardeous but directly reflect the progression of life on earth and/or in the oceans. Although still debated, such conclusions appear clear to me in Precambrian times because of the progressive emplacement of basic and clearly distinct life processes over a time span of 3.5 Gyr (1 Gyr = 10^9 years). Things are more difficult to separate during Phanerozoic times as a result of the fantastic acceleration of evolution over about 500 million years and the increasingly complex integration of five kingdoms (procaryotes, protoctysts, fungi, plants and animals). A philosophical approach of this problem on a much global scale has been put forward by J. Lovelock (1979) in the "Gaia hypothesis" which postulate that up to now life has been able to regulate its global environments. Recently, P. Westbroek (1983) vulgarized this approach for geoscientists.

The purpose of this short note is to illustrate by casual examples some types of interaction life may have had with sediments. We may start the discussions on a large scale by following some important evolutionnary steps of Precambrian microbes at a time when they were the main inhabitants of planet earth and invented basic metabolical pathways.

Aside of early heterotrophic microbes (starting probably well before 3.8 Gyr) feeding on abiotic organic molecules, the first autotrophic organisms to appear (around of before 3.5 Gir) are the methanogenic and later the photosynthetic bacteria. Methane, which is biosynthesized in anoxygenic environments from CO_2, H_2 (or various organic compounds : lactate, acetate, ...), is poorly soluble in water;

it can thus constantly move through sediment rich waters; so doing, methanogenic bacteria may have been one of the first bioturbators originating the formation of fenestrae and various vugs in early archean sediments; furthermore, in the absence of sulfate reducing bacteria, much more competitive than methanogenic ones in harvesting available H_2 (or other organic electron donors), the intensity of methane production may have been particularly abundant to the point of inducing deep perturbations in the structure and texture of sediments, as well as on deposition of fine grained sediments disturbed by the turbulence resulting from rising bubbles. Also these first autotrophs started regulated interactions with CO_2 budget, a bio-impact that life will progressively increase and diversify. The rise of photosynthetic bacteria (3.5 Gir at least) will initiate interferences with the sulfur cycles as they use light to split H_2S molecules ($CO_2 + 2H_2S \rightarrow (CH_2O) + H_2O + 2S^{--}$) which where abundant in archean times due to absence of free oxygen and presence of high volcanicity. This type of interaction may have gone a step further with the oxydation of sulfide to sulfur and sulfate ($1/2\ H_2S + H_2O + CO_2 \rightarrow (CH_2O) + 1/2\ SO_4^{=} + H^+$); this last step might well have been recorded (3.5 - 3.4 Gyr) by the worldwide deposition if thick sulfate deposits (barite probably after gypsum; see Monty 1984) in anoxic environments (Australia, South Africa, Siberia). The last major microbial interaction with the sulfur cycle seems to have appeared around 2.7 - 3.0 Gyr with the evolution of sulfate reducing bacteria (Schopf, 1983). From then on, the world will be prevented from being progressively invaded by a crust of sulfates; from then on also the microbial world controls the sulfur cycle and its isotopic geochemistry (microbiological fractionztion). During this period of time (2.5 - 3.0 Gyr) new photosynthetic organisms were progressively rising i.e. the cyanobacteria, able to split the water molecules and liberate free oxygen. This type of metabolism, yielding much more energy than the previous ones will, among other things, ensure the fantastic success of cyanobacteria during the next eon (the Proterozoic). This free oxygen was instantaneously consummed by all the chemical accumulated up to then under a reduced state; once this achieved (first locally, then globally) oxygen started to accumulate; this transition towards and "oxygen-rich" hydrosphere and/or later atmosphere (Schidlowski in Schopf, 1983) could have been fossilized by the end of deposition of detrital uraninites and pyrites; such event could also have been recorded in the worldwide deposition of thick and extensive deposits of iron oxydes, extention probably facilitated by increased tectonic stability. Beside oxygen-releasing cyanobacteria, deposition of iron oxides may have been enhanced by iron-oxidizing microbes reminicent of present day "iron bacteria". The abundant precipitation of silica which accompanied the Iron Formation might have been triggered by the iron oxydes inducing disequilibrium in silica-rich waters fed by long lasting volcanic processes in the absence of silica fixing organisms. The origin of the huge iron deposits between 2.6 - 2.0 Gyr is still debated, although the associated silicification fossilized a diversified and well preserved cyanobacteria microflora.

The proliferation of cyanobacteria from about 2.0 and, before all, the fantastic bio-impacts they are going to impose, is bound to a conjunction of (1) biological factors including their growth potentials, the integration of the available range of microbes (from heterotrophic anaerobes to oxygenic photosynthesic producers) into efficient microecosyntems ("algal mats" and stromatolites; see Monty 1984), with (2) geotectonic factors : changes of tectonic patterns and stabilization of the earth crust, allowing the development of shelves and epicontinental seas. Resulting changes in creased chemical alteration of continents yielded a greater imput and proper recycling of nutrients and soluble chemicals s.l. These bio-geological features contributed to the appearence of new sedimentary types such as red beds, extensive deposition of carbonates (almost inexistant before 3 Gyr), as well as progressive spreading of biogenic build up ranging from stromatolitic sheets to bioherms and reefs piling up over tens or hundreds of meters. If on land, weathering patterns completely changed due to oxygen levels and microbial activity, sea floors became burried under new sediments both terrigenous and carbonates (included limestone muds, a unique abundance of dolomite, as well as new grains like peloids and ooids, which are of microbial origin to my views).

Although data are still scattered, significant phosphatic deposits became conspicuous between 1.6 - 1.2 Gyr under the form of stromatolitic deposits or reefs; careful examination generally reveals the close association between phosphate and microbial cells. This may reflect changes in particular benthic microbial recycling of phosphate, as well as in ocean productivity and circulation patterns under proper paleolatitudinal conditions. The most important jump in phosphate abundance will however occur later, after the Precambrian/Cambrian boundary. This roughly told story at least suggest close relationships between life evolution and particular types of sedimentary deposits resulting either directly from particular steps reached in microbial evolution, or indirectly from accumulation in the biosphere of by-products like oxygen that drastically changed the overall environmental conditions and hence sedimentary processes and products.

At the end of Precambrian times drastic changes intervene on earth which brought the essentially microbial world to an end, and allowed the radiation of new forms of life : animals, algae, and plants integrated with the already existing reigns (the procaryotes and fungi) into increasingly complex ecosystems; this increased biotic diversity will result into more complex recycling and ethologic pattens, hence more complex interactions between life and sediments.

The Precambrian-Cambrian transition corresponds to a big jump in production of phosphatic sediments, which will reach higher peaks yet in the Mesozoic anc Cenozoic. These post Precambrian phosphates differ basically from the Precambrian ones in being essentially pelletal instead of closely associated with microbial biotherms and reefs.

Also, development of skelettogenesis brought about two new types of rocks : (1) bioclastic or bioaccumulated siliceous deposits; siliceous sponges, radiolarians (and much later diatoms) will not only contribute to significant lowering of the silica dissolved in the oceans by concentrating it in their skeletton; during diagenesis these discrete opal particles will be converted into compact silicified sediments or cherts; (2) bioclastic or bioaccumulated carbonate deposits introduce a large new stock of grains; their mineralogy (calcite, low to high Mg-calcite, aragonite) is basically controlled by intrinsic metabolisms of the producers whereas their chemistry (Mg, Sr, content), although grossely dependant on water T° and salinity, is taxonomically controlled and not in theoretical equilibrium with seawater chemistry. As for physical features, the shape, size; durability and amount of primary particles shedded after death are pre-determined by the skelettal organization, (micro) architecture as well as by growth patterns. Some of these primary grains may be later microbially disintegrated into their constitutive units, to produce mud, like the aragonite needles of calcareous green algae. Accordingly the nature, as well as the greater or lesser complexity of biocenose covering the sea floor, will predetermine the original texture (grain size, polymodality etc...) - hence the initial porosity and permeability of the depsits and constitutive grains, their hydraulic behaviour and the overall chemestry of the resulting sediments.. When we combine these relationships with the plasticity of life we understand the potentially infinite variability of bioclastic carbonates.

Another new sediment bound to life evolution results from the progressive colonization of continent margins, then of significant continental areas, by plants; beside biodiagenetic features discussed below, this colonization will lead to the accumulation of deposits almost entirely composed of plant material, i.e. coal and peat.

Terrigenous sediments as well as carbonates will not be the same anymore as before Cambrian times. During Precambian times, continental rocks probably suffered limited microbial alteration and microboring. Eventual cover by microbial mats and films may have stabilized bare areas for some time although this process depends on available humidity and its persistance. Wind borne transportation was anyway a much more important process and should have conferred particular textures and surface feature to grains due to impacts during transportation. During phanerozoic times the extention of the plant cover, leading to the forest and then to the prairie in Cenozoic time, should have considerably changed patterns and depth of alteration and erosion. Changes in weathering would have also resulted from significant increase in carbon fixation and oxygen release, change of biological alteration by humic acids, and biochemical alteration in the vicinity of roots and rootlets with increased production of acid clays. One would also expect Phanerozoic sandstones to be increasingly more mature (richer in quartz and poorer in aluminosilicates and organics) than Precambrian ones as a result of deep weathering. Comparison is however difficult because we cannot compare the tremendous amount of Paleozoic data (500. 10^6 Yrs) with respect to those of Precambiran eon (scattered over 3 Gyr).

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