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ACTUALISM IN EPEIROGENETIC OCEANS

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Abstract:

Cayeux has described a regular and frequent alternation in time of sediments apparently formed in mid ocean, with layers showing evidence of shallow water conditions or even of temporary emergence. These sediments were formed in broad basins during periods of orogenetical quietness. In a booklet called "Causes anciennes et causes actuelles en géologie", Cayeux expresses the opinion that the formation of these sediments is due to processes which are no more active today. It is argued here, that this contention is erroneous, and caused by the aberrant nature of present-day oceans and continental shelves. These are influenced by two factors, viz. postorogenetic influences related to the alpine tectonical cycle, and eustatic phonemena related to the quaternary Ice Age. During long periods of the geological history comparable factors have not been active, and sediments formed during those periods exhibit characteristics peculiar to the environmental conditions prevailing during these periods.

In 1941, some years before his death, Cayeux published a booklet under the title of "*Causes anciennes et causes actuelles en géologie*". Written and edited wit a care otherwise reserved for editions of poetry, it is indeed poetry in a sense, in so far as it embodies the tune which forms the background of the entire scientific work of Lucien Cayeux. This has been rigorously concentrated upon a single theme, viz. the petrography and genesis of sedimentary rocks. Amongst a host of other publications, we may follow the trend marked by the well-known, extensively documented and illustrated volumes on sedimentary rocks of France and elsewhere. These began with his Lille thesis of 1897, treating of several siliceous sediments of northern France and Belgium, and of the chalk of the Paris Basin. Then follows a description of the sedimentary iron ores, published in two volumes, in 1909 and 1922, of which the second one, treating the liassic minette ores, is the most important. In 1929 appeared a volume on the siliceous rocks, followed in 1935 by a treatise on the calcareous rocks. The sedimentary phosphates form the subject of a last descriptive work, of which two volumes appeared in 1939 and 1941 respectively, whilst the last is to appear posthumously.

The ancient causes of Cayeux.

It is not my intention to review the detailed results of this work, as I may presume that the reader is himself well acquainted with the publications of Cayeux. A short survey may, moreover, be found in the obituary note by Leriche (1946). The minute examination of sections of various sediments, together with an intensive microscopical and chemical analysis, has convinced Cayeux that the facts governing the formation of many sediments, in the past were of an entirely different nature than at present. Time and again he tried but could not find any deposits in the present oceans, similar to those encountered in the mesozoic sediments of the Paris Basin, or in the various other fields studied by him. Nor did it seem possible to draw a satisfactory picture of the formation of these latter sediments, by studying their own characteristics. *Almost everywhere two conflicting sets of characters were found, one similar to those of recent pelagic sediments formed in mid-ocean, the other however indicating neritic conditions similar to recent near-shore coastal seas.*

This baffling situation was encountered by Cayeux in every group of sediments which he studied in detail. As more and more instances were found of sediments where pelagic and neritic characters are closely intermingled, Cayeux became more and more confirmed in his doubt as to the validity of actualistic theories for the determination of the sedimentation of these rocks. This doubt has crystallised in his small booklet on actualism, which forms the point of departure for this paper. I believe that actualistic principles may indeed be applied in explaining the origin of the sediments under discussion, and I do not agree with the ideas put forward by Cayeux. If, in doing so, I take a standpoint opposed to that taken by him, I wish to assert beforehand that this is in no way intended as a slight upon his scientific work. Firstly Cayeux has gathered an enormous mass of facts, all carefully studied and grouped together, on the petrography of sediments. He steadily continued this work, when other fields of study would perhaps have yielded quicker and more brilliant immediate results. Moreover, in putting down the essence of his deductions in his little book on actualism, he has provided us with a reliable guide through this factual wealth, where the salient points are conveniently grouped together, and highlighted as to their importance for problems of a more general character.

The peculiarities described are most evident in limestones and chalk, where we find an alternation with the normal rocks of numerous layers of a quite different nature. Thus the finegrained chalk may alternate with layers of limestone concretions. Or we may find an alternation of fine grained chalk or limestone with thin beds of flint. Of another kind, but closely related genetically, are the layers of oolithic iron ores and the sedimentary phosphates, enclosed in limestones or chalk. *In all rocks studied, the pecularities of the constituents were formed during sedimentation, and cannot be explained as the result of later, epigenetic influences.* Before the deposition of the next higher bed of limestone of chalk, the limestone concretions, the flints, the iron ore oolites, and the grains and concretions of phosphate, had already been formed as we find them at present. Their origin must be due to the peculiar characteristics of the contemporary ocean floor, where they were formed under the influence of chemical or biochemical reactions, which are indeed of rare occurrence on the present seabottoms. Moreover, all grains and concretions were disturbed by the action of waves or currents, between the time of their formation and the inclusion in the sediments where we find them at present. They have been sorted, worked, and redeposited on the ocean floor. Accompanying this sorting and redepositing of grains and concretions, are indications of reactions which have taken place at or about the sealevel. Under this heading come a frequent hardening of the underlying beds of limestone or chalk, and also the excavation of channels and pits in the underlying beds, filled with the redeposited grains, oolites or concretions, and capped by undisturbed beds of normal limestone or chalk.

These facts can be explained by assuming that the normal limestone and chalk were formed in an ocean of a certain depth, where no wave action, nor the influence of currents were felt. During the formation of the intercalated layers of concretions, of the flintbeds, the layers of oolitic iron ores and of the phosphates, the depth of the ocean must have been temporarily smaller. Consequently the influences operating near its surface could act upon the sedimentation, and also upon the sediments formed immediately prior to this moment. Cayeux thus found the indications for a continuous up and down movement of the seabottom, and he concluded that the earth's crust had been much less stable during those times than at present. He presumed that these alternations in the depth of the ocean must have been of about the same size, as the difference existing nowadays between seabottoms covered with pelagic sediments and those covered with neritic sediments. If this is true, then the sedimentation in those seas must indeed have been accompanied by a fluttering movement of the seabottom, which is contrary to the processes which we are familiar with, in an actualistic way of thinking.

The reader, who is familiar with the abundance of thin beds of flints in several horizons of the chalk, will feel nonplussed at this picture of continuous violent movements of the seabottom, upwards for the formation of flints — or iron oolites, or concretions, or grains of phosphate for that matter —, and downwards again for the formation of a bed of normal limestone or chalk.

Another possibility.

Although an alternation of deeper and more shallow water has certainly occurred during the formation of these rocks, I do not believe that it is necessary to postulate a difference in depth, in any way related in magnitude to that between the present pelagic and neritic sediments. The seas in question indeed always belong to a certain type of flat, extensive basins; moreover these sediments were formed during periods of general tectonical quietness. We may assume that there existed large and shallow bottomed seas, bordered by low-elevation continents. The orogenetic and postorogenetic mountain chains had been largely base-levelled, whilst the sedimentation in the adjoining seas had reached a point at which the latter had almost entirely been filled up. A state of erosional quietness ensued, when very few clastic products were derived from the base-levelled continents, and pelagic sediments were deposited almost everywhere in the flatbottomed seas.

It is of importance to note that, with the exception of the radiolarites, lydites and "cherts", almost all rocks described by Cayeux were formed during periods characterised by epeirogenetic movements only. For instance we may point to the iron ores of the Middle Devonian, and the limestones of the Lower Carboniferous of the Ardennes; to the liassic oolithic iron ores, the cretaceous flint beds and layers of limestone concretions and phosphate of the Paris Basin and to the north-african phosphates from the Eocene. They one and all originated during periods of tectonical quietness, which also happened a long time after the former orogenetic cycle, so that base-levelling of the former mountain-chains had already taken place to a large extent.

Under these circumstances, characterised by a base-levelled topography, by orogenetical quietness and by epeirogenetical movements of the seabottom and the adjoining continents, sedimentation must have been of a quite different nature than at present. Clastic material will have been rather rare, and as far as produced, it was deposited quite close to the shore. Almost everywhere the sedimentation in those seas must have been similar to that found at present only at a considerable distance off shore. Hence the uniform character of the "pelagic" sedimentation, as studied by Cayeux. His "pelagic sediments", and those formed today, have however only one trait in common, viz. the absence of detritical material. With the exception of the radiolarites and "cherts", which are considered true deep sea deposits by Cayeux also, the fossil fauna nowhere indicates a sedimentation depth comparable to the pelagic sediments of the present.

We may draw the following picture of these seas. *They were broad and shallow waterbodies, where the influence of continental material was negligible. Normally the sediments were "pelagic" in character, not influenced by wave action, by ocean currents or even by temporary emergence. Epeirogenetic movements of small size intermittently resulted in shallow water conditions, without influencing, however, the erosional equilibrium between the base-levelled continents and the oceans.* Consequently there was no increase of detrital material in the sediments formed during the shallow water conditions. The only effects were there upon the sediments of the seabottom itself, where the youngest beds, as yet only partially consolidated, were reworked to a certain extent. As long as the water remained fairly deep, the only result was a sorting out by wave action of the grains of phosphate, the iron oolites of the concretions. Only the material which by chance was at hand on the seabottom itself was affected, and no extraneous material was added. A slightly stronger rising of the sea bottom may have resulted in the formation of beds of flints, or in the excavation of small gullies or pits in the seabottom. Temporary emergence will have resulted in a hardening of the surface beds, which may have been beset by boring organisms, or on which may have developed reefs of oysters and the like. A longer emergence may have resulted in the formation of layers of gypsum or salt.

This picture is in accordance with the facts assembled by Cayeux. A simple sorting and redeposition of the coarser material on the seabottom is very common. In some formations similar conditions lead to the formation of flint beds. Excavations of the oceanfloor, coupled with sorting and redeposition of the coarser material in the gullies and pits, is less frequent. The same can be said of the superficially hardened beds, with the remains of boring organisms. Occurrences of oyster reefs, or layers of gypsum and salt are very rare indeed. Thus gentle movements of small size, which only result in a sorting of the material and which takes place beneath the sealevel, are most common, whilst the larger movements, resulting in temporary emergence, are of a much rarer occurrence.

Contrasting with the idea of very quick alternating movements of large size, we see these epeirogenetic oceans as gently undulating basins, with their bottoms always situated near the surface of the sea. They must have been very shallow at all times. Small size movements resulted in very marked differences of the facies of the sediments, when large areas of the seabottom came under the influence of wave action or currents or even showed partial emergence. Only in this way are we able to understand how these movements are confined in a narrow bathymetrical zone. If there really had been a regular alternation between deep see and littoral conditions, it seems preposterous to assume that these movements should always have stopped at sea level. Now and then they should have overshot their mark, and this would have resulted in continental sediments being intercalated in the series of marine sediments, or in the formation of small non-conformities. Gentle undulations of the shallow bottom of a wide sea basin can, however, result in the alternation of marine sediments of the different facies found, and the chance of a total regression of the sea becomes much smaller. In fact, these regressions have rarely taken place, as indicated by the scarce occurrence of gypsum, and normally the seabottom did not rise appreciably above the sea level.

A corroboration of this picture of gently undulating, wilde and shallow oceans, is presented by the fact that the phosphate horizons in the Paris Basin follow the synclinal axis of the shallow mesozoic folds. (Cayeux, 1939, p. 248, fig. 10). These folds nowadays do not exceed a difference of altitude of 50 m, which will have been even considerably smaller during the time of the deposition of the sediments. Altitudinal differences of ten or twently metres are thus sufficient to cause the difference between the formation of normal chalk or limestone and of a phosphate layer, characterised by sorting and redeposition of the coarser material. This is a strong indication, that the size of the vertical movements of these seabottoms has been very small indeed.

Oceans, former and recent.

Cayeux concludes that the oceans in the past were of a much more unstable nature, as the seabottom was characterised by constant movements upwards and downwards. To him, the past was a period of extreme unrest, contrasting with the stability of the oceans, of their depth and of their shorelines, at present.

It will always remain difficult to compare past movements with the present. Past movements are expressed in series of rocks whose formation took a long time to complete, whilst the short time available for the observation of movements at present, may easily suggest a stable condition, which may be only a flash light picture of strong movements going on at present.

All disturbances of equilibrium, as described by Cayeux of marine sediments, can be dated from periods of orogenetical quietness. This fact, to my mind, strongly suggests that the size of these disturbances must have been very small. Different facies do indeed follow each other in quick alternation in these sediments, giving the impression of far stronger movements than really might have taken place. Subconsciously our ideas are influenced by the rugged topography of ocean basins and continents of our days.

This view has already been expressed by Woolnough (1942) in a paper partly covering the same subject as the present one. Woolnough greatly stresses the fact that the present time only forms a momentary cross section of the continuous flow of processes active during geological history. Although every one of these processes may be compared to actual ones, actualism does not mean that the relative importance of individual processes has always been comparable to that during recent times. *Amongst the factors which, according to Woolnough, will have been of a far wider importance during past geological periods, "ultimate peneplanation", accompanied by a preponderance of chemical weathering, is mentioned explicitly.* Actualism ought to be taken in a wide sence, excluding processes which cannot take place anywhere at present, but including all actual processes, although in the past they might have been of a relative preponderance unheard of in our days.

These lines consequently form a corrollary to the thesis put forward by Woolnough. The reason why I have taken as a starting point the publication by Cayeux, is that the latter author, in denying point blank the possibility of an actualistic explanation of the facts marshalled by him, offers a better opening for a discussion on actualism. Moreover Woolnough centers his practical conclusions on radiolarites from the East Indies. Radiolarites are however held to be abyssal sediments by many writers, including Cayeux. Consequently it seems better to limit ourselves to those intercalations in a normal marine series, which show definite evidence of shallow water conditions. The admirable descriptions by Cayeux of the layers of nodular chalk, of the limestone and iron oolites, of the phosphate beds and of the flint layers, intercalated in normal calcareous sediments, thus make it desirable to use his work as a starting point.

I consequently suggest that these particular epeirogenetic oceans of the past were much more stable, than indicated by Cayeux. Although gently undulating during geological history, these movements will certainly not have been of the jumpy character as surmised by him.

In addition to this idea of small size movements in the epeirogenetic oceans in the past, we note the fact that the stability of the present day oceans and shorelines is not nearly so great as supposed by Cayeux. The number of raised and drowned beaches is sufficiently high everywhere to exclude the picture of a stable ocean during recent times. True be it, that, with the exception of some unstable portions of the earth, situated in the alpine orogenetic belt, these movements have been rather small. They have not resulted in large transgressions and regressions, or in the emergence of continental shelves.

Here we must not forget, however, that all continental shelves have been drowned since the last glaciation, and covered by a waterbody of up to 100 metres deep. I believe that this is indeed a second crucial point in comparing the present with the past. *We ought to keep in mind always, that we are at present in a very peculiar situation, as to waterlevels and continental shelves.* This condition is inhaerent to the Ice Age, with its alternation of lowlevel abrasion during glacial periods and the subsequent flooding of the shelves.

These conditions will certainly not have prevailed during any of the geological periods when those sediments characterised by regularly alternating equilibrium disturbances, were formed. Many seas during those periods of a temperate and ice-free climate will have been comparable to those covering our present day continental shelves, if we do not consider the upper layer due to recent postglacial flooding. All along the base-levelled continents of those epochs, very shallow seas must have existed, filled almost to capacity by detrital and chemical sediments. Small size movements, comparable to those indicated during recent and subrecent times by the raised and drowned beaches, will have a very great influence on a topography of that kind. In comparison, this influence is completely obliterated on our present day continental shelves, by the effect of the extra load of water added upon the lowlevel abrasion surface of these shelves. In postulating a marked stability of the present day oceans, I believe that Cayeux has been misled by the influences due to phenomena related to the quaternary Ice Age.

I therefore do refute Cayeux's postulate (1941, p. 75) that the oceans at present are much less mobile than in the past. It seems even very probable, that this mobility is much higher now, than during the past periods of marine sedimentation in epeirogenetic seas.

In comparing the "present history" during the Neogene and the Quaternary with that of the epeirogenetic seas in the past, another difference between the past and the present becomes apparent. We do not now commonly find wide, flat-bottomed and shallow oceans, bordered by base-levelled continents of gentle topography. This is, however, a purely temporary situation, as our present-day topography is the result of the orogenetic and post-orogenetic mountainbuilding forces of the alpine orogenetic period. In some 50 million years hence, a period of tectonical quietness will ensue, when most mountain-chains will have been completely eroded down, whilst their detritus has filled up wide areas of the oceans, converting them into shallow seas.

The present situation, with its emergence of vast areas of the continental shields, with its mountain chains, and with the formation of extensive coarse detrital continental sediments, is essentially of a postorogenetic character. It may be compared directly with other sediments from postorogenetic periods, such as the Older and Younger Red Beds of the Lower Devonian and the Permian. The marine sediments, studied in such great detail by Cayeux, have, however, not been formed during similar postorogenetic periods. Their origin dates from the later, epeirogenetic periods, which in turn follow the postorogenetic phases. In studying the formation of sediments from epeirogenetic periods, we must bear in mind that even if the causes of their formation are the same as at present, the ultimate result may be entirely different, owing to the difference of environmental factors, such as the topography of oceans and continents.

Only in those places where at present the topography is comparable to that which must have prevailed in the past, may we expect the formation of sediments at present which are comparable to those formed in the past.

Ancient causes and modern causes.

Cayeux is of the opinion, that the formation of marine sediments in the past can only be explained by the operation of ancient causes. In contrast to the modern causes from the present time, these ancient causes are totally non existant nowadays (Cayeux, 1941, pp. 8, 75, 79). In opposing these hypothetical ancient causes to the modern causes, he cites Lyell's Principles of Geology (Xth ed., 1867, I, p. 102—105). From the same text of the Principles of Geology, we may cite the following remarks on the gradual admittance of the theory of modern causes. Lyell thinks it strange, that: *"They* (the geologists) *still began, as each new problem assorted itself, to assume an original and dissimilar order of nature"*. Instead, according to his views, we ought to: *"strain analogy to the utmost limits of credibility"*, before: *"despairing of reconciling every class of geological phenomena to the operation of ordinary causes."*

To my mind, the opinions of Cayeux on the "causes anciennes" are a case in point. Before the enormous mass of carefully studied facts, on the origin of these sediments, the older views broke down. These chiefly operated with epigenetic influences acting upon the finished beds a considerable time after the sedimentation took place. No sediments of the same general characters are known to be formed in the present-day oceans, so that to Cayeux the conclusion seemed apparent that ancient causes must be held responsible for the peculiarities of these sediments.

It is easily seen that similar conditions to those which must have prevailed in the past during the formation of these sediments in epeirogenetic seas, are not of a general occurrence in the present oceans. This is due to two factors influencing present day oceans, which were not active during much of the past history. These are the drowning of the continental shelves as a consequence of melting of the icecaps, and the fact that we live today in a postorogenetic period, characterised by strong erosion, and not in a period of tectonical quietness and erosional equilibrium.

In trying to find modern causes for the formation of ancient sediments, we must therefore search the modern oceans for localities where these two influences are ineffective or non-existant.

For the oolothic limestones, several examples of this kind one known. Amongst these the Great Bahama Bank has been studied most thoroughly. The elucidation of the factors governing the formation of the oolithic calcareous mud in this region, will finally also answer the question of the formation of oolithic limestones in the past. It is of no importance that today this phenomenon is restricted to so small an area, whereas in the past it was widely distributed over extensive basins. The extent of these sediments is dependent on the prevalence of a proper depth of the seabottom and other environmental conditions. The crucial point is that we are lucky enough to find certains spots where local topography at present simulates the general topography during epeirogenetic periods. Although the oceans at present are quite different from those during the epeirogenetic periods in the past, local topography may in this way counterbalance the general dissimilitary. Thus the results of detailed oceanographical work on the Great Bahama Bank (Smith, 1940) and in similar localities will ultimately explain the formation of oolithic limestones in the past.

According to Cayeux, the formation of the oolithic iron ores only differs from that of the oolithic limestones, in the addition of iron during the genesis of the oolites. The iron is derived from mountains which are being eroded in the hinterland. No such mountains are available on the Bahamas, and consequently we only find calcite oolites on the Great Bahama Bank. We might however expect to find oolithic iron ores, actually in the course of formation, on the other side of the Florida Channel. The shallow sea along the North coast of Cuba, between the outlying keys and the mainland of the provinces of Santa Clara and Camaguey, is very similair to that on the Great Bahama Bank. Moreover, several of the small rivers emptying into this sea, drain parts of the serpentine areas on the Cuban mainland, and may consequently carry a considerable amount of iron. It seems worth the while, to explore this very badly known basin, with a view to find here, in the actual course of formation, beds of oolithic iron ore, similar to those of the past.

Out of the main groups of sediments from the past, not being generally formed now in the present day oceans, this theory still leaves unexplained the formation of the flintbeds and the layers of limestone concretions, together with that of the phosphates. The latter are largely formed by a biochemical process, according to Cayeux. I am convinced that a diligent search for similar recent sediments will ultimately yield the results desired. Provided only, that this search be excuted in localities with suitable environmental conditions, e.g. warm, shallow seas, bordered by low altitude coasts. *At any rate, it seems at present more probable that we shall find these sediments in the act of formation, once we know where to look for them, than that we shall ultimately have to revert to the influence of ancient causes, not known to us from anywhere today.*

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