ALCIDE D'ORBIGNY AND THE STAGES OF THE JURASSIC

by

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Summary

The work and ideas of Alcide d'Orbigny (1802-57) in the formulation of the concepts of stratigraphy, and especially in their application to the Jurassic, are examined in their historical context and reconsidered in the light of modern knowledge. It is shown that to regard d'Orbigny simply as an advocate of the long-abandoned theory of catastrophism is to severely undervalue his work: his studies, in fact, anticipated many of the ideas today current in stratigraphy. In a postscript, the recent assessment of d'Orbigny's work by a Belgian writer, C.L.V. Monty, is critically examined.

(Translators' Preface. This paper was presented, and distributed in preprint, in the original French, to the 2nd International Colloquium on the Jurassic, held in Luxembourg, 1967. It is considered to be of great potential interest to English readers, in view of d'Orbigny's importance in the history of stratigraphical palaeontology and in view of the fact that the Jurassic has come to be the test-case for the establishment of internationally acceptable stratigraphic subdivisions. England has perhaps the World's finest, and faunistically richest, series of exposures of the Jurassic; and fully half of the stages proposed by d'Orbigny have English stratotypes. Two of these, the Kimmeridgian and Portlandian, remain a cause for dispute even after two International Colloquia. Since the "Comptes rendus" of the 2nd International Colloquium have not yet appeared, M. Rioult's work is here published for the first time.

This translation attempts to follow the French text as closely as possible, but a number of passages have needed to be rephrased as a result of differences between French and English idioms or for purpose of clarification. The final text has been checked and approved by the author: it appears by permission of M. P.-L. Maubeuge, Chairman of the two Luxembourg Colloquia).

> "ALCIDE DESSALINE D'ORBIGNY, born on the 6th September, 1802, at Couëron (Loire Inférieure), received his early education in La Rochelle, and devoted himself very early to zoological and palaeontological studies. In 1826 he was sent to South America by the Museum in Paris, and brought back with him splendid collections of zoological, geological, ethnographical, historical and archaeological interest. The results of this journey were afterwards published in a comprehensive work. His later works deal with palaeontological and stratigraphical subjects. In 1853 d'Orbigny was appointed Professor of Palaeontology at the Museum in Paris, the Professorship being established especially for him: died on the 30th June, 1857, at Pierrefitte near Saint Denis".
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> K.A. VON ZITTEL, 1901:
> "History of geology and palaeontology to the end of the Nineteenth Century". London: Walter Scott, 562 pp. (footnote to p.506).
> [Date and place of death here corrected].

Introduction

In 1962, the first International Colloquium on the Jurassic, held in Luxembourg, provided the occasion for a large-scale bringing-together of the results acquired during the study of the Jurassic. What characterised the spirit of that international meeting was, without question, the constant search for understanding, which led to numerous agreements and a few compromises. The desire to progress only with caution, in order to avoid enclosing stratigraphy prematurely in a too rigid framework, was expressed by the expounding of very diverse conceptions and the postponement of decisions regarding the limit of certain stages, together with those of subsidiary divisions, the proposed delimitation of which brought about a confrontation between the German, English and French schools of geologists in particular. The extremely rich and positive balance-sheet from the working sessions of this meeting, and the numerous papers presented, served to form the basis for the preparation of the second Colloquium.

However, after reading the contributions to the first Colloquium and on the point of resuming discussions relative to the stages of the Jurassic, it seemed to me vital to return briefly to the sources and to focus attention on certain aspects of the work of Alcide d'Orbigny which are unknown, misunderstood or else forgotten and which constitute, whatever one may think of them, the basis of the first attempt to formulate a general stratigraphic scheme for the Jurassic.

The small divergences which exist between the different national delegations present at Luxembourg express conceptions of stratigraphy different from those expounded by d'Orbigny. I wholeheartedly repudiate any chauvinism, polemics or exclusivism. I will stress only the original characteristics of Alcide d'Orbigny's method, placing it into its historical context; and I hope to show in conclusion that the diverse points of view expressed, far from being incompatible, are to be placed on two planes which are different, but subordinate one to another, and finally, that these conceptions are complementary.

The place of d'Orbigny's work in the history of the geological sciences

At the beginning of the nineteenth century, in Europe, two of the great geological disciplines - stratigraphy and palaeontology - were developing in parallel fashion at an accelerated momentum.

Between 1794 and 1817, William Smith, working in the region of Bath, focussed attention on a classification of the Jurassic strata, when he rediscovered the principle of the superposition of strata and the fossils they contained; these principles he used for the first time in the simultaneous elaboration of a stratigraphical scale and a geological map. Very quickly, the English geologists applied this method in the study of the strata of diverse regions; for example, Roderick Murchison in the Palaeozoic of Wales, John Phillips in the Jurassic of Yorkshire, and Richard Fitton and Gideon Mantell in the Cretaceous of southeast England. The travels of William Buckland and Henry de la Bèche on the Continent, the exchanges between European geological societies and between the great national museums, combined to make the results obtained in Great Britain better known.

During this period, France and Germany were not inactive. Alexandre Brongniart and Georges Cuvier studied the succession of the various Tertiary beds of the Paris basin, extending step by step the horizontal and vertical correlations. In Germany, the schools of Fuchsel and Werner developed the study of mineralogy and applied geology, whilst Alexander von Humboldt and Leopold von Buch respectively subdivided the Jurassic beds of Württemburg and Swabia. F.A. Quenstedt was beginning his geological and palaeontological researches.

At this same period, France was witnessing the Golden Age of palaeontology. At the Natural History Museum in Paris, J. -B. de Lamarck was formulating the broad outlines of transformism, sustained and developed by E. Geoffroy Saint-Hilaire. On the other hand, Cuvier was establishing

vertebrate palaeontology on the solid bases of comparative anatomy, whilst Adolphe Brongniart undertook the publication of his palaeobotanical studies.

This ferment of natural sciences was fostered in England and in France by actualism, which was a new scientific mentality rather than a new doctrine; its roots were very ancient, but it seems to have taken form, in France, as a consequence of the Revolutions, the social upheavals which they brought about and the shaking of Christian dogma. In Austria, the actualist outlook had known a period of favour in geological circles, but it was above all in Britain that James Hutton, John Playfair, Charles Lyell and their pupils, and, after Buffon, in France, Constant Prévost and his disciples, perceived certain analogies between past worlds and living Nature. Little by little, they came to realise that certain natural phenomena, observable in our time, could explain a large number of phenomena of the past, without need for recourse to mysteries and catastrophes. This fecund hypothesis, which had already given birth to comparative anatomy, yielded equally good results in geology.

It is at this crossroads of ideas, and in this current of renewal of concepts and scientific methods, that the work of Alcide d'Orbigny must be placed. Initiated very young into the natural sciences by his father, a learned scholar of Charente, and by his elder brother Charles d'Orbigny, Alcide d'Orbigny was always to be both zoologist and actualist. His work, poorly understood by his contemporaries, remained unfinished, cut short by an early death. His successors very quickly placed his "doctrine" in the shadow of that of the great Cuvier and preserved only two important ideas: the theory of "global revolutions" (catastrophism) and that of "successive creations" (creationism). Branded by these two "tags", Cuvier and d'Orbigny have been represented to posterity as the two principal adversaries of Lamarck's transformism; this does not entirely express the truth. This very cursory view of the work of d'Orbigny is, in fact, merely a very schematic reflection of the ideas of this visionary, forever contemplating both the present and the past, both space and time. His principal stratigraphical publications are the "Prodrome de Paléontologie stratigraphique universelle des animaux Mollusques et Rayonnés" (1850-1852), the volume "Céphalopodes" of the "Paléontologie Française - Terrain Jurassique" (1842-1851) and in particular his "Cours élémentaire de Paléontologie et géologie stratigraphiques" (1849-1852).

But these "classic" works were only a small part of his scientific output; he in fact added to them numerous palaeontological and zoological studies on the Foraminifera, crinoids, cephalopods, etc., and a certain number of less well-known works, among which one may mention the 9 large volumes and 500 plates relating to his "Voyage en Amerique méridionale" and his important natural history monographs dealing with the Canary Islands, the Antilles, Cuba, Colombia, the Argentinian Pampas, and Patagonia and with the margins of the Caspian Sea, the Caucasus, the Crimea and European Russia. The majority of his works were published between his return to France and the year which preceded his death, when he fell ill with a cardiac disease. With his collections, his classes and his travels in France, his scientific writings combine to bear witness to 22 years of exceptionally frantic work, in which d'Orbigny sought consolation from the mockery, the jealousies and the lack of understanding, even the hostility, of the contemporary scientific world.

What appears to me essential, in any examination of the conclusions presented by d'Orbigny, is the necessity of accommodating our twentieth-century minds to the realities of his epoch, to the ideas which served as bases for his thinking and which have necessarily changed and developed, from the very meaning of the vocabulary to the whole scientific outlook. Moreover, it is not always easy to take into account this shift of meaning and outlook, brought about by the development of the sciences and the scientific world, when trying to obtain a conception of the work of a scientist. However, I have striven my utmost to keep as close as possible to his texts and to continually distinguish between d'Orbigny's own thoughts and the ideas I might personally have of his work.

Alcide d'Orbigny, actualist

In his zoological and geological researches, Alcide d'Orbigny was very broadly receptive to all concerning the present-day marine domain. On the philosophical plane, there can be no doubt, from the reading of his works, that the theory of natural causation orientated his researches - as much the "actualist" principles of his colleague Constant Prévost as the ideas expounded by Charles Lyell and Charles Darwin, to which he makes allusion several times.

But, first of all, what does one understand by actualism? Prévost defines the theory himself.

> "The doctrine of actual causes ("causes actuelles") does not assume, according to my interpretation and contrary to the ideas of many geologists, the identity and eternity of the same causes and the same effects, but instead the necessary and natural connexion between causes and effects which mutually modify each other in such a way that the successive facts produced, not only may, but must vary; that new things may manifest themselves whilst others cease to be produced, without one having the right to suppose, for this reason, any alterations in the great immutable laws of Nature or any upheavals, cataclysms or revolutions which would not be the consequences of these same laws."

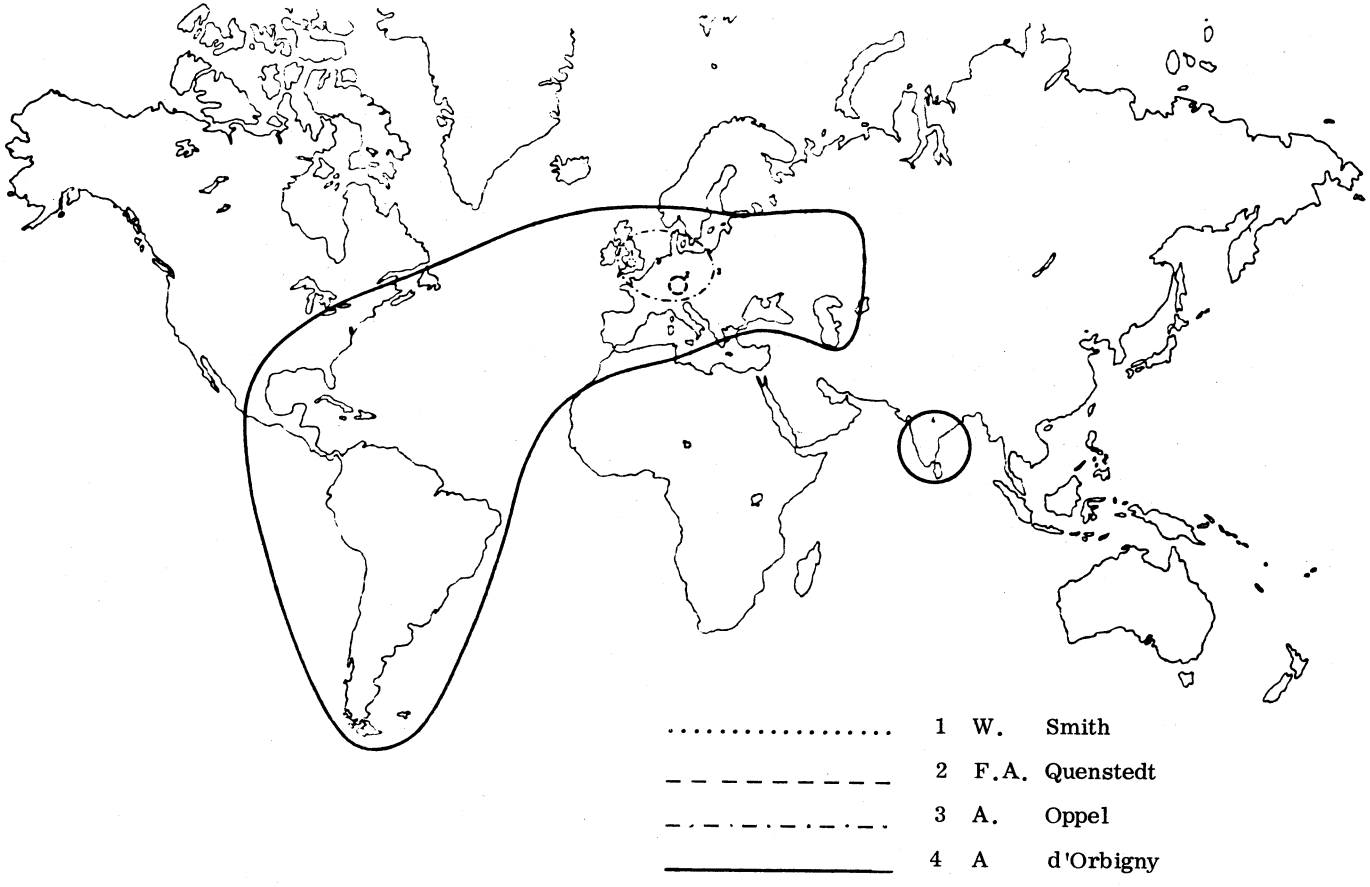
It would be more exact to speak of the doctrine of "natural causes".

From the beginning of his researches, Alcide d'Orbigny visualised geology and palaeontology on a universal scale ("Cours élémentaire," II, 1851, pp. 264-6), invoking great planetary phenomena governing the oceans, the atmosphere, and the crust of the earth (currents, rotation of the earth, the tectonic theories of Elie de Beaumont and of Cordier, etc.). Several times, he writes that "present-day causes may alone explain many past events." From his youth onwards, d'Orbigny accumulated observations on natural phenomena and living organisms. From the Atlantic coasts of Charente to the remote shores of South America, he constantly enriched his understanding of the marine and terrestrial environment.

As zoologist and palaeontologist, he studied the invertebrates, from the coasts of the Atlantic, the Pacific, the seas of the Antilles and the English Channel. Their systematics, their modes of life, the conditions of death, decay and burial were examined turn by turn. As a consequence of the researches of Alexander von Humboldt, he studied the geographic distribution of organisms as a function of currents, climates and remoteness from coasts, in the coastal, littoral, pelagic and deep-water zones. The meticulous study of the fauna of molluscs from the Atlantic and Pacific shores of South America showed him the differences between two oceanic basins, whilst that of the invertebrates from the shores of Charente, Cuba, the Antilles, the Canary Islands, etc., made evident to him the variation in the population of the marine bottoms in the same ocean. He did not study only the distribution of living animals, but also devoted special attention to the distribution of dead organisms floated or shifted along the bottom. These researches dealt with the distribution of terrestrial organisms as a function of Continental configuration, latitude, altitude, and the living environments, as well as those of the marine organisms as a function of the morphology of coasts and sea bottoms, latitude, depth and environment. Finally, the influences of environment and mode of life on the organisms themselves were considered ("Cours élémentaire", I, 1849, pp. 5-7).

As geologist d'Orbigny studied present-day sediments, their composition, their provenance and their distribution in the sea according to the relief of the Continents and the outline of the coasts, the hydrodynamic conditions and the shape of the sea-floor.

> "Molecules and sediments animated and deposited by the waters which overlap



Text-fig. 1 Comparative fields of geological experience for some pioneers in stratigraphy.

> the land and which, in all the ages of the World, have tended to level the irregularities of the terrestrial and marine surface".

He treats equally with sediments as a milieu for life and for fossilisation. He is concerned with textures of mechanical origin (horizontal and oblique stratification), ripples and imprints of raindrops, and textures of biological origin, such as footprints, borings and impressions of diverse character. To cite some examples of observations which would not be repudiated by modern sedimentologists: he described the cross-stratifications in the sandy levées of a delta, he was the first to note the constant direction of the cross-stratification in the Pierre de Langrune (Upper Bathonian of Normandy), as well as the orientation of floated logs and of shells parallel to the line of the Bathonian shore in Normandy. He wrote on this subject that one found "in scrutinising the bottoms of the shores many points capable of being applied in geology" and further noted:-

> "We should also recognise that the mineralogical character of the beds has served only to deceive observers little acquainted with the elements of stratigraphy drawn from present-day causes, which often made them see quite erroneous parallelisms".

The factors of disturbance of sedimentation, contemporary to or later than its deposition, were attentively examined - waves, tempests and tides, but also earthquakes, tectonic movements, tiltings, foldings and dislocations.

Like Alexander von Humboldt, he treated both with climatology and comparative geography, from Primary to Tertiary, and considered the role of currents and of isothermal zones ("Cours élémentaire" 1851, II, pp. 239-43). As early as 1852, d'Orbigny wrote with regard to the Jurassic (ibid., 1852, II, pp. 432-3):

> "The presence, in this period, of the same genera and the same species of animals, from the Torrid Zone to the Polar Circle, would prove that the temperature was uniform on the globe, in consequence of the central heat, and that no isothermal line yet existed on the globe. The composition of these faunas would show also that they were analogous to the present-day tropical faunas".

Volume 1 of his "Cours élémentaire de Paléontologie et de Géologie stratigraphiques" (1849) contains a second section (pp. 70-157) which is, in fact, a veritable précis of actualist ideas.

This zoologists' outlook, very receptive to observations of the earth, and this wide experience with present-day Continental and marine environments, confer a great originality on the works of Alcide d'Orbigny and show a marked contrast with many of his contemporaries and successors, in particular with those who were to critize his work.

Alcide d'Orbigny, zoologist and palaeontologist

Already very advanced in the study of the different branches of the natural sciences, d'Orbigny began to complete his learning, as soon as he arrived in Paris, in particular at the Museum of Natural History, where he followed the courses given him by E. Milne-Edwards and met the specialists of the period. He studied anatomy, physiology, embryology and the ecology of marine invertebrates, as Cuvier had studied the vertebrates. Ontogenetic development, ecology and systematics held his attention longest. He fixed his attention, first of all, on those characteristics of living organisms which do not disappear in fossilization. He experimented on the environmental conditions disadvantageous to marine organisms, showing in particular that cuttlefish and squids die rapidly in turbid waters and even in

waters charged with black produced by their own ink-sacs.

The conchological observations made on the rich collections of the Museum gave him a wide experience with living invertebrates, an experience increased and renewed in the course of a long journey which he undertook in America, from north to south, from east to west (1828-36);and from which he returned at the same time as Darwin, who had left for America in 1831.

In his palaeontological researches,d'Orbigny was able to put into practice all his zoological knowledge. He personally studied almost all classes of marine invertebrates.

His admirable work on the Foraminifera made him the foremost micropalaeontologist and represent a considerable addition to our knowledge of these organisms, which have acquired such a great place in stratigraphical studies since the nineteenth century. He studied them from the Jurassic, Cretaceous, Tertiary and Recent. He imposed his own classification and showed, for the first time, the stratigraphical value of the Foraminifera.

He treated in the same degree the sponges, the coelenterates, the molluscs (pelecypods, gasteropods and cephalopods), the Bryozoa, the brachiopods and the echinoderms (crinoids and echinoids). He always made his own original contributions, notably in the domain of their systematics and stratigraphical distribution.

In the phylum of sponges, he noted the importance of tissues and of spicules for the fossil forms.

In the classification of the pelecypods, he laid stress on the variation of the pallial line and introduced the distinction between integripallial and sinupallial, explicable in terms of the particular modes of life.

He applied geometric methods to the gasteropods, inventing the helicometer for measuring the spiral angle of the shells; he stressed the ontogenetic variations of the ornamentation and the systematic value of the characters of the peristome.

For the cephalopods, he took count of the different ontogenetic stages, gerontic degeneration, sexual dimorphism, the teratological cases and the ecological variations ("Cours élémentaire" 1849, I, pp. 266-7). He tried to define, for each class of molluscs, the limits of variation according to the zoological knowledge of the time (ibid., 1849, I, p. 269).

He did not neglect ichnology and the conditions of fossilization in their chemical aspects (diagenesis, favourable environments) and mechanical aspects (deformation of the fossils).

His method of comparative anatomy of invertebrates, inherited from Cuvier and Alexandre Brongniart, caused him to revise the systematic criteria and to introduce a new spirit into stratigraphical palaeontology.

On a more elevated plane, he attempted to define statistically, following the tremendous systematic revision undertaken in the "Prodrome", the periods of "growth" and of "decline" of the various groups of fossil invertebrates,just as the modern evolutionists are doing once more.

Not only did he study the rich French and foreign palaeontological collections in the official Parisian and provincial establishments, but also he collected fossils in the field, himself, from the classic localities, guided by the best regional geologists. He thus explored all the provinces of France, in addition examining the local collections. Foreign material at his disposal came from Europe

(England, Germany, Norway, Sweden, Russia from north of the Urals to the Crimea, Italy and Spain), Asia (the Indies, Cutch and Pondicherry) and South America (notably Colombia, Chile, Peru and the Magellan Strait).

In brief, he amassed a quantity of observations in the field, and palaeontological documents which, together with bibliographical compilations comprising the summation of all the zoological and geological literature at his disposal, were to constitute the basis for his revisions and his syntheses.

As zoologist and palaeontologist, he was always to show the double concern of the systematist and the stratigrapher.

Alcide d'Orbigny, systematist

After the work of the Encyclopaedists and that of Lamarck, Alcide d'Orbigny entered palaeontology at a time when, throughout Europe and in America, the great catalogues of fossils for each region were being undertaken; most often hampered by territorial considerations, these voluminous inventories, rarely illustrated, were arranged sometimes in geological order, sometimes in zoological order, sometimes even in alphabetical order. In the course of his travels in America, he discovered the American and Canadian geological work: the fossils collected in these regions, only newly accessible to geology, added further to the nomenclatural chaos which had not ceased to build up in every country of old Europe.

Confronted by this state of things, d'Orbigny reacted immediately and undertook the revision of the nomenclature of living and fossil invertebrates, from the base of the Silurian to the present day; he hoped to find a solution leading to systematic unity and stability. He thus attacked the most urgent problem, taxonomy. Not only was he the first palaeontologist to give family names a uniform and euphonious suffix, -idae, and to resume the critical definition of names of genera and species, but also he introduced detailed lists of synonyms and applied the principle of priority. He founded his critiques on examination of figures and of topotypes (i.e. specimens obtained from the type locality of the species in question). Unfortunately, he incorrectly applied the principle of priority to the genus as well as to the species; this is expressed in his studies by the substitution of his name for that of the first describer of the species which he is redescribing and classing, and it drew upon him lasting enmities. D'Orbigny refused to adopt the precedent advocated by contemporary English systematic zoologists, which consisted of adding the word species or the abbreviation sp. after the name of the author of the genus, to clarify the fact that the latter was not the author of the species (which procedure is today replaced by the writing of the name of the author in parenthesis).

The strict application of the Linnaean binomial nomenclature and of the rule of priority; the employment of uniform and euphonious suffixes for higher systematic categories; the precise diagnosis of genera and species, their resemblances and differences; the discussions of the history of taxonomic terms; details of the place of lodgement, the place of collection and of the stratigraphical horizon; usable illustrations; all this mass of data demanded by the modern palaeontologist truly commenced to appear in palaeontology through Alcide d'Orbigny and the "Paléontologie Française". Certainly, not all is perfect in the realisation of these ideas, but the concept, the spirit and the plan of the undertaking are beyond criticism.

Fourteen years of researches into zoological and geological literature, in collections and in the field, were necessary for him in order to understand the value of the stratigraphic, as well as geographic, distribution of the different species of fossils. D'Orbigny compiled a list of 200,000 species names, of which 40,000 were those of fossil species. A stringent critical revision reduced the number to 18,000 names of species, distributed into 1,440 genera. The spirit which guided d'Orbigny in the systematic chapters of his "Cours élémentaire de Paléontologie et de géologie stratigraphique" (I, 1849,

pp. 158-294; II, 1851, pp. 1-258) is identical to that which guided the elaboration of the treatises of Karl von Zittel, Jean Piveteau and Raymond C. Moore. In the wearisome labour which is represented by the "Prodrome", d'Orbigny attempted to formulate a language, a code for an international nomenclature, universal in application, internally consistent, with its own rules and units.

Above all, he was plainly aware that fossils represent only a part of the living organisms ("Prodrome", 1850, p. XXVIII) and that their classification can only be attempted on the basis of the palaeozoological study of their remains, i.e. essentially their morphology and internal structure - from this he drew his ideas regarding the generic form and specific form.

In his studies of invertebrates, he advocates the acquisition of a thorough knowledge of these organisms in present-day Nature, in order to use the method of comparative palaeontology. He warns against morphological groupings proposed without appropriate examination of the tests and skeletons.

For him, the classification of fossil invertebrates is important at the level of genera and species. But it must be stressed that in relation to our present-day knowledge, the systematic categories of d'Orbigny are much larger - for example, most ammonites were still grouped into the genus Ammonites Bruguière and the single species Ammonites margaritatus (d'Orbigny) contained the whole extent of the genus Amaltheus de Montfort, as it is understood today.

[The genus (or the generic form) was, for d'Orbigny, a systematic division of order higher than the species, but it was not just any kind of grouping of species (in the sense which he understands them), for in his definition, stratigraphical distribution plays an essential role, alongside external similarities. For him, the attribution of a generic name needed to be thoroughly discussed in a determination, because of the importance of the genus in stratigraphy. The generic name must be treated in the same way as a species name, according to the principle of priority, with a concern for fairness and stability. In subdividing an older genus, one must take care to religiously preserve the original name for one of the divisions established, whatever the number of divisions, and as far as possible for the species which combines the most distinctive characters indicated by the proposer of the original genus. D'Orbigny also emphasises the necessity of knowing precisely the age of appearance and disappearance of the genera.

The species (or the specific form) is a concept which d'Orbigny allies to the notion of the species in zoology.

> "The natural division of species, based on extended studies, on the minute examination of many specimens of all ages, collected in the best geological conditions, accords in every respect with the most stringent zoological requirements and leads to the most positive geological results, when applied to the recognition of the age of stages". (Cours élémentaire", 1849, I, pp. 5-6).

And again:-

> "When one has no other guide than the conchological characteristics, which is the case for all fossil species (of molluscs), it is advisable to compare a large number of individuals collected from the same horizon, in order to make sure of the diverse variations, so as not to erect species that are based simply on growth stages, on varieties, on deformations or on states of fossilization. In general, with regard to the Cephalopods, one must take especial account of age and of pathological cases. For the gasteropods, age differences, pathological cases, and local influences are even more important in their effects. For the bivalves and brachiopods, age and local influences must above all be studied with care". (Cours élémentaire", 1849, I, p. 269).]

D'Orbigny lays stress on the range of variation of the species in the molluscs in particular; with regard to the ammonites, one must not confuse true species with the various phases of individual growth (ontogeny) with morphological modifications of the shell determined by the environment (ecophenotypes), by sex if these organisms prove to be separated into sexes (sexual dimorphism), or by simple accidents of mechanical, pathological or teratological origin ("Cours élémentaire", 1849, I, pp. 267-9; "Prodrome", p. XLIX). The limits to adopt in specific determinations vary according to the organisms considered: they are proportionately more restricted as the organism is more advanced in organisation and "as it enjoys more liberty in its existence, and conversely, proportionately wider as the organism is less free in its movements and as it is more sedentary" ("Cours élémentaire", 1849, I, p. 6).

> "The name of the species must be as sacred as that of the genus. It must be, likewise, always the oldest and, in this respect, it is good to go back as far as 1757, that is to say to the works of Adanson and Linné, who instituted the specific name and placed it as adjective to the genus. Starting from the same principle of justice and fairness as for the generic name, species must invariably bear the oldest name with which a description was published." ("Prodrome", p. L.).

Alcide d'Orbigny was a supporter of the binomial nomenclature of Linné and an adversary of the trinomial nomenclature utilised by J.A. Eudes-Deslongchamps for varieties:

> "If these so-called varieties are constant, if they have well-defined limits, if, in a word, they may be always circumscribed and distinguished, then these are no longer varieties but veritable species ("Prodrome", p. XXVIII).

In systematics, d'Orbigny thus introduced and applied a method of classification whose concept and broad principles are still vigorously surviving in our own age.

Alcide d'Orbigny and the "global revolutions"

In the course of his researches, Alcide d'Orbigny ascertained that each of the characteristic faunas, which he recognises as a stable unit across numerous countries, is separated from the subjacent and superjacent fauna by two lines of demarcation, representing two natural upheavals. As these lines of demarcation are constantly found at the limits of the same faunas, he concludes from them that "catastrophes" have affected the whole surface of the globe and that they have quickly made the rounds of the earth. He thus arrived at the idea that the succession of living beings were intercalated into a succession of planetary upheavals, the "global revolutions".

In our Jurassic series, a hiatus occurs periodically between the successive stages, which may be more or less important and well marked according to whether one is in the epicontinental or geosynclinal regime. This discontinuity is often made manifest, either by an angular discordance, or by an erosional surface, or by a conglomerate or a condensed deposit, which may be glauconitic, phosphatic or ferruginous. Alcide d'Orbigny speaks only of "discordance", but he distinguishes three types ("Cours élémentaire", 1849, I, pp. 148-157):-

> discordances of stratification or discordances of isolation, suggesting a dislocation between the deposition of the beds.
>
> discordances of denudation, with a phase of erosion between the the deposition of the beds.
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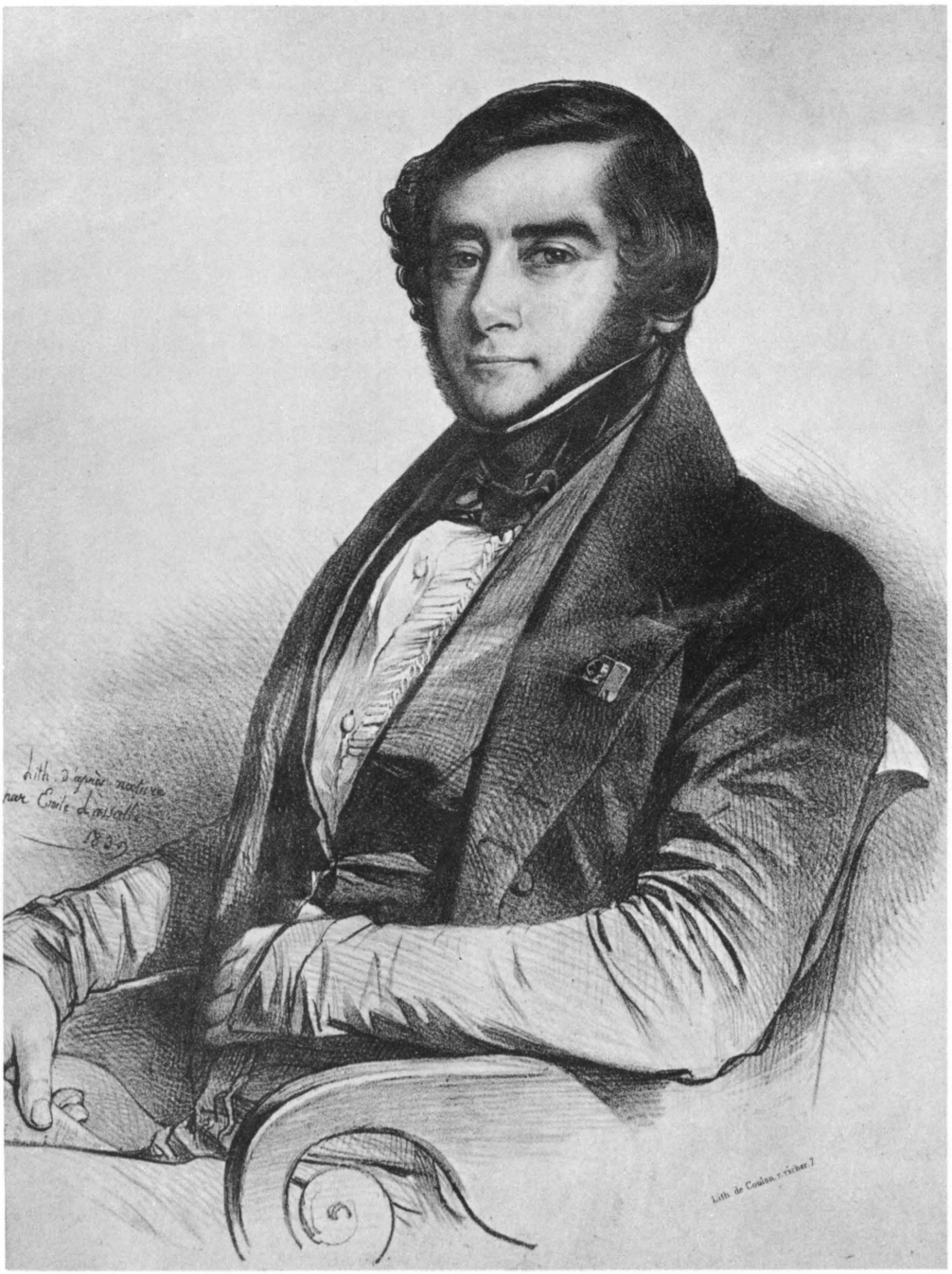
> discordances of superposition, when two inshore deposits, separated by a line of demarcation, are superposed at the same point; this indicates epeirogenetic movement between the two.



Alcide D' Orbigny (1802 - 1857)

"The line of demarcation between two stages is, let us say, marked by a discordance of stratification in the beds, by denudations, by polishing, attrition of the surface of the older stage of the two, by ferruginous deposits, by beds of pebbles, by surface inequalities of the ground, finally by differences in colour and mineralogical composition of the succeeding rocks". ("Cours élémentaire", 1849, I, p. 152).

However, the relative importance of these lines of demarcation must be confirmed by study of the faunas. In order to illustrate these phenomena, d'Orbigny cites as examples "the ferruginous bed at the base of the Bajocian stage of Bayeux, Moutiers and Sainte-Honorine" - and "the small pebbles which one finds often at the base of a stage, as for example at Thouars (Deux - Sèvres) in the Toarcian Stage". ("Cours élémentaire", 1849, I, p.151).

These discontinuities are thus marked in sedimentation by a change of facies and in the fossil population by a change of fauna, one fauna disappearing to be replaced by another that is quite different.

"The oscillations of the Earth's surface are exceptionally well marked in the Jurassic system. Their traces are particularly discernible by littoral deposits superposed at several points. On ten successive occasions, geological disturbances of greater magnitude than the oscillations came to interrupt the life of land and seas, and destroyed almost all living beings. After each of these great world catastrophes, calm returned once again; the whole of Nature was repeopled by her plants and her animals. On each occasion, if the genera in part remained the same, the species changed entirely, as one can see from the respective systematic categories represented". ("Cours élémentaire, 1852, II, p. 433). [NOTE: It is necessary to remember here that d'Orbigny's "genera" would now be systematic categories of the order of families, or larger, and that his "species" would now be subgenera or even genera.]

For d'Orbigny, it was necessary to establish the hierarchy of tectonic phenomena, to differentiate between general disturbances, global revolutions and simple oscillations.

The observations obtained on the occasions of the earthquakes and tidal waves on Peruvian and Chilian coasts and at Lisbon in 1755, and the memory of a "deluge" common to almost all the ancient civilizations, gave to d'Orbigby an idea of destructive phenomena capable of identification with the catastrophes that he invoked, in particular regarding their speed of propagation, their distribution and their incidence in coastal regions. In contrast, the recent movements of depression and elevation on the coasts of the Netherlands and South America, Colombia in particular, illustrated the oscillations. ("Cours élémentaire", 1852, II, pp. 834-5)

D'Orbigny discussed the origin of global revolutions on the basis of study of the Anglo-Parisian, Aquitaine and Rhodanian Basins of the Jurassic, as well as on the history of the Russian Platform of the Upper Jurassic. For him, it was not possible to invoke a vertical movement of a continent. Starting from a simple experience, he showed that the sudden retreat of the sea could result from a sinking of the ocean bottom (sinking linked with a contraction of the globe caused by cooling, as visualised in the theories of Elie de Beaumont and Cordier), whilst any upheaval of a part of the bottom could produce the inundation by marine waters of the continental margins, in proportion to the continental area upheaved. Thus d'Orbigny found in this eustatic hypothesis, controlled by geosynclinal evolutions, a mechanism for the changes of faunas. ("Cours élémentaire" 1852, II, pp. 430-2).

As an actualist d'Orbigny recognised, in the events of contemporary geology, two great classes of phenomena:-

a) Passive, constantly operative conditions, during which continental and marine sediments are deposited slowly to form stratified beds, except when their effects are modified by (b).

b) Other chance, momentary circumstances, which, as a result of dislocations of the terrestrial crust, cause plutonic rocks, or rocks of subsurface igneous origin, to appear on the surface of the earth. There is thus synchronism between stratified rocks and plutonic rocks, in the sense that these latter, according to their nature and chemical composition, appear to have arisen at distinct epochs, corresponding to the relative age of the sedimentary rocks. ("Cours élémentaire," 1851, I, pp.262-3).

Here one finds ideas expressed earlier by James Hutton. D'Orbigny considers that each suite of crystalline or volcanic rocks has its own special characters, permitting correlations with the sedimentary rocks. In the Jurassic, he instances notably suites of basalts, pyroxenic porphyries and even granites ("Cours élémentaire", 1852, II, p.433).

The global revolutions are thus reference points for d'Orbigny, dates in the history of the Earth. Between these lines of demarcation, the faunas have sufficiently well-marked characteristics to enable the identification of a clear-cut period in the history of the planet.

This discovery of the existence of relationships between the geological phenomena, involving the entire terrestrial globe and the history of life, is presented in an original and detailed fashion by d'Orbigny; it is the basis for his concept of the stage.

Alcide d'Orbigny and the "Successive creations"

For the majority of zoologists and palaeontologists, Alcide d'Orbigny is, together with Cuvier, merely one of the principal representatives of the "fixist" school, opposed to the "transformist" school of J.B. de Lamarck. However, he was unaware neither of the researches of Lyell nor of those of Darwin, to which he refers in his works; he questions certain conclusions of Lamarck and, in his fashion, he supports the idea of a certain degree of improvement, which is not without certain common features with the modern doctrine of evolution.

From the outset, one must note that Cuvier, d'Orbigny, Lyell and Darwin all employed the term "creation" to designate the totality of organisms populating the continents and seas at a given time; moreover, d'Orbigny uses, in the same sense, "peuplement" (peopling) and "animalisation". The biblical sense of "creation" was reserved for the first populating of the earth. Alcide d'Orbigny, recognising that, at the very base of his Silurian stage, the fauna was already very diversified, concluded that this first fauna was "created" and that the subsequent faunas were "renewed". The distinction had the merit of taking into account both the origin of life on Earth and the appearance of new populations on the planet, which subsequently succeeded one another during the diverse epochs of the Earth's history. Moreover, Cuvier himself made, in this context, a very interesting remark when he wrote:-

> "Besides, when I maintain that the pebble beds contain the bones of several genera, and the unconsolidated beds, those of several species which do not now exist, I do not claim that there must have been a new creation to produce the species existing today; I say only that they did not exist in the places where one sees them now and that they must have come here from elsewhere". [From "Discours sur les révolutions de la surface du globe et sur les changements qu'elles ont produits dans le régne animale"; quoted by A. Lacroix in his speech to the Academy of Sciences on the centenary of the death of Cuvier, 12 July 1932 (C.R. Acad. Sci., Paris, p.6.).]

In these words, he expresses two important facts; first, he introduces a distinction of time between the evolution of genera and that of species, comparable with the time taken for lithification of the sediments; secondly, he states that the new fauna which replaces the fauna of a given place, in the course of geological time, has not been 'created' by special divine intervention, but that it had come from elsewhere to replace the pre-existing fauna. This proposition is the key to the theory of Cuvier and d'Orbigny.

As a matter of fact, Alcide d'Orbigny states that few common points exist between the successive faunas of ammonites at the different periods of Jurassic history, each of these periods having its characteristic fauna, the observation valid for the ammonites being equally valid for the remainder of invertebrates and the flora. Considering only the ammonites, and working from the lists quoted by d'Orbigny, one can show, by reallocating the species according to the principles of present-day systematics, that each stage is characterised by distinct groups:-

Sinemurian:	Psiloceratacеae (Psiloceratidae, Schlotheimiidae, Arietitidae, Oxynoticeratidae, Echioceratidae).
Liasian :	Eoderoceratacеae (Phricodoceratinae, Coeloceratinae, Polymorphitidae, Liparoceratidae, Amaltheidae).
Toarcian :	Hildoceratacеae (Harpoceratinae, Hildoceratinae, Grammoceratinae, Graphoceratidae, Hammatoceratidae, Sonniniidae).

Bajocian :	Stephanoceratidae, Sphaeroceratidae, Parkinsoniidae, Morphoceratidae, Leptosphinctinae.
Bathonian :	Oppeliidae (pars), Tulitidae, Zigzagiceratinae, Clydoniceratidae.
Callovian :	Macrocephalitidae, Proplanulitinae, Kosmoceratitidae, Reineckeidae, Pachyceratidae.
Oxfordian :	Cardioceratidae, Perisphinctinae.
Corallian :	Aspidoceratinae.
Kimmeridgian :	Ataxioceratinae, Pictoniinae, Aulacostephaninae.
Portlandian :	Gravesia, Virgatosphinctinae, Dorsoplanitinae.

The replacement of the fauna of a given stage by a new fauna, in the following stage, is readily intelligible in terms of the 'global revolutions", explaining both the abruptness of the disappearance and appearance of faunas in the regions where the marine pulsations were felt, on the one hand, and, on the other hand the very wide distribution of ammonites in harmony with the great world-wide marine transgressions, in the Bajocian and in the Callovian, for example.

But let us examine more profoundly d'Orbigny's ideas on the mechanism of "improvement". D'Orbigny systematically opposes his arguments to the theory of Lamarck. He states firstly that the "improvement", observable in the faunas of a stage, is not comparable to the transformations of the animal world brought about by the global revolutions. During the stages, there are often only "improvements", not progressing beyond the level of the genus (in the sense which he understands it); they are expressed by a multitude of slight modifications of organisation, such as changes in position or form of the elements of the skeleton or of the organs, etc. However, d'Orbigny recognises that there is occasionally a true filiation of species (in the sense of Lamarck) when, in an interval of geological time, one can establish the direct connexion of morphological relationships; but he adds immediately that certain morphological characteristics may well be repeated at different epochs, without it being possible to find any interconnexion whatsoever ("Prodrome", pp. XXXVII - IX):

> "Why does one want to preclude Nature from repeating similar faunas several times over in the ages of the World, if they are not identical and especially when space and time separate them?" (Prodrome, 1850, p. XXIX).

These remarks clearly show that he was no fixist, in the sense that one normally understands the word; indeed, his "improvement" is akin to the ideas developed by Darwin and he shows that he was, in the domain of the invertebrates, one of the first to recognise what we now term the phenomena of convergence and of homeomorphy.

At the limit of stages defined by global revolutions, there are on the other hand phenomena of greater magnitude, which the geologist comes across; the annihilation of species and of genera (in d'Orbigny's sense) and their replacement by new forms. Clearly, d'Orbigny distinguishes between a slow improvement, within the limits of stages, and a parallel, accelerated improvement recurring at the confines of two stages; was this not an early recognition of the distinction now made between micro- and macro- evolution? Thus, d'Orbigny takes a census of the great changes interposing in the history of the molluscs, annelids, Radiata and vertebrates. For him, as for Buffon, Lyell and others, species are doomed to disappear; there is only transition between one and another within stages, whereas, on either side of a line of demarcation between two stages, there is parallel improvement affecting "bodily organs, species and classes". "Nowhere does one encounter a transition from one specific form to another, at the contact of two successive ages".

D'Orbigny charges the Lamarckian theory with a too marked finality and anthropomorphism. Progress or regression of organisation may each be favourable to the species, in particular environmental conditions. For d'Orbigny, as an actualist, the majority of the natural environments known in our day existed also during the geological past. Such environments were not able to exert direct influence on the extinction and the renewal of successive faunas. In contrast, the changes of environment following the global revolutions, the general regressions and transgressions, have played a primary role in this direction, for the great systematic breaks, like the great stratigraphic breaks, are tied up with the major crises in the history of the Earth. In a sense, d'Orbigny attributes a place in "improvement" to natural selection brought about by the upheavals of the marine and continental domains, at the time of tectonic crises. D'Orbigny brought together observations on these drastic environmental changes, and he experimented in this field ("Cours élémentaire", 1849, I, pp. 132-4). Almost all organisms disappear at the time of these catastrophes. The breathing of air, commencing in the earliest times of our planet's biologic history (in the Primary), appears to him as a particular instance of adaption to environment : "In short, it is a new mode of existence, which is related, not to true improvement, but to special circumstances" ("Cours élémentaire", 1851, I, pp. 232-8). Thus, global revolutions control adaptions.

To summarise, the stage, in its palaeontological expression, is, for Alcide d'Orbigny, a period of biological equilibrium between two tectonic disequilibria.

Alcide d'Orbigny and the concept of the stage

"In brief, stratigraphical geology, which is of the greatest importance since it is the positive part of this science and since it comprises the chronological history of the terrestrial globe, was most certainly born on the soil of England". Alcide d'Orbigny thus pays homage to English geologists who were the first to discover the essence of stratigraphy ("Prodrome", p.XXXI). But, confronted by the chaos of stratigraphical nomenclature at the beginning of the 19th Century, d'Orbigny attempted to restore order. As he had proceeded for systematic palaeontology, so also he attacked the matter of a stratigraphical nomenclature for the Jurassic in the selfsame spirit, seeking a clear, practical and universal language (ibid., p. XXIV : "Cours élémentaire", 1852, II, p. 418). He does not set himself up as a reformer, but as an interpreter of nature : "It is from nature itself that one must obtain the general bases of a stratigraphical solution".

After having travelled over America for 8 years and roamed through France for 6 years, after having studied palaeontological material in innumerable collections derived from the greater part of the regions of the World known at that period, after having widely analysed geological and palaeontological literature, d'Orbigny concludes that faunas everywhere succeed one another in the same order and that "discordances" everywhere separate them at the same levels.

> "The partial facts which I unceasingly study in all details lead me inevitably to general facts, to the consequences of the whole. I seek to present them methodically by laying down firm guidelines for the application of zoological types to the recognition of beds".

Taking as his basis both the sequence of global revolutions and the sequence of successive invertebrate faunas, d'Orbigny comes to form the concept of the stage, of which he gives several definitions which do not permit of any ambiguity.

Stages are "the expression of the boundaries which Nature has drawn with bold strokes across the whole globe", boundaries which are not arbitrary ("Paléontologie française, Céphalopodes", p.603). He studies ammonite faunas and takes into account particularly the vertical distribution of these organisms, from their appearance to their disappearance : he shows that their horizontal

distribution is independent of lateral variations of facies, which conforms with observations made of living nature ("Prodrome", p.XXXIV).

> "It is certain that such stages as present exact superposition, and the limits of the faunas they contain, are as clear-cut in the Jurassic formations as are, for example, the Silurian, Devonian and Carboniferous stages in the Palaeozoic formations".

This comparison serves well to throw light on the importance which d'Orbigny accorded to tectonic crises, in the subdivision of geological epochs.

The study of the Jurassic of countries as far apart as France, Russia, India and Chile had led d'Orbigny to claim not only common characters in the ensemble of faunas, but even the presence of identical species which attested to their contemporaneity.

> "These confirmations from afar which, for the Jurassic formations, came to corroborate my observations, at the same time made me certain that all the causes of separation of stages have been universal."

> "A stage is, for us, an epoch exactly the same as the present epoch; it is a state of rest in Nature's past, during which there existed, as in present-day Nature, continents and seas, marine plants and animals: and, in the seas, pelagic animals and neritic animals in all depth zones". ("Cours élémentaire," 1851, II, pp. 256-7).

Two principal elements thus interpose in the definition of his stages; firstly, a characteristic fauna which always enables the stage to be recognised, in whatever facies it is represented, and secondly, definite limits which separate this fauna from those subjacent and superjacent.

> ". . . . I take for starting-point, with the limits of the zoological types, the annihilation of a series of organisms to be replaced by another. I proceed solely according to the identity in composition of the faunas, with the extinction of genera or of families".

The definition of each one of his Jurassic stages comprises:-

a. The naming of the stage, with an explanation of the origin of the name.

b. The list of genera which appear therein; the reign or period of predominance of the dominant groups, both marine and continental; information on the "growth" or "degeneration" of certain other groups; and, finally, the list of species constituting the zone or zones.

c. A synonomy of the formations according to the fossils or mineralogical composition.

d. The designation of types, in general, in the vicinity of localities renowned for their richness in fossils, chosen in France or in Europe.

e. D'Orbigny mentions afterwards a whole series of localities or regions in France, in Europe or outside Europe, whose sections or fossils he had studied and which he classes in this stage. He gives some details of the contacts with the stages above and beneath, of lithology, sedimentology (bathymetry of the deposits), the thickness of the beds, the fauna and flora and, finally, palaeogeographic conclusions on the European and global scale.

There are thus few aspects left obscure; and afterwards, few stratigraphers were to take as many precautions before defining a stage.

The stage is a generalisation, but d'Orbigny was in a position to generalise; this was the result of twenty-five years of personal researches, palaeontological and stratigraphic studies, effected in very widespread geographical regions, on very important collections and which took into account a very extensive bibliographic documentation.

The stage, according to d'Orbigny, is a tangible unit, accessible to the hammer, founded both on biological evolution and on the tectonic history of the globe. It is the materialisation of geological time, although sedimentation or evolution vary with time. Nevertheless, its general applicability still makes it the best tool for long-distance correlations, after more than a century of application.

Conclusions

Since d'Orbigny's time, geological researches have greatly developed. What is our opinion, nowadays, of the fundamental data used by d'Orbigny in his definition of the "stage"?

a) D'Orbigny's stratigraphic units and global revolutions.

In reconsidering the stratigraphic units distinguished by d'Orbigny, in the Jurassic of the northwest of the Paris Basin, one remarks that the boundaries which he invokes correspond frequently to orogenic phases or to major transgressions linked to these latter. Thus, below the Purbeckian, whose middle part is denoted by the Osterwald (Dorset) phase, one finds:-

THE PORTLANDIAN of the Pays de Bray, the Boulonnais and Dorset (from the Gravesia gravesiana Zone to the Titanites giganteus Zone) shows a tendency to regression in its upper part; and its transgressive base is a continuation of the Deister phase (the Nevada and Pre-Tithonian phases are parallel with this latter). Within the stage, two minor divisions exist: the lower, below the Pectinatites pectinatus Zone, characterised by the arrival of the species of Pavlovia and the deposition of a conglomerate, whilst the Upper is marked by the appearance of the large Perisphinctids (Titanites, Glaucolithites) and a second conglomerate.

THE KIMMERIDGIAN of Normandy (from Decipia decipiens to Aulacostephanus autissiodorensis) begins with an important transgressive phase, but the Pictoniinae appear at the very base. The major phase occurs higher, following the regression of the Ringsteadia frequens Zone, with the transgressive Pictonia baylei beds. Above, the ammonite fauna is renewed with the successive arrival of the species of Rasenia, then of Aspidoceras. Amoebites disappears in the upper part.

THE CORALLIAN of Normandy (Perisphinctes cautisnigrae) is a more or less well-marked unit according to locality, intimately linked with the Oxfordian. It is likely that in the choice of this stage, d'Orbigny had been strongly influenced by the development of this "stage" in Charente, his home area.

THE OXFORDIAN of Normandy (from Cardioceras cordatum to Perisphinctes plicatilis). The C. cordatum Zone shows an important condensation of the sedimentation and the fauna. Above, a ferruginous and oolitic horizon is present at the base of the P. plicatilis Zone; then, a minor oscillation is marked by an intraformational conglomerate. In the course of the Oxfordian, foldings have been recorded in other regions.

THE CALLOVIAN of Normandy and Maine, France (from Clydoniceras discus to Quenstedtoceras mariae). At the base, the argillaceous facies of the Cornbrash is sharply

transgressive on the western border of the Paris Basin: the lower part, with C. discus, is only locally developed – sometimes, as in Maine, condensed at the base of the Macrocephalites macrocephalus Zone, which oversteps the Upper Bathonian in this region. Everywhere, an erosional phase and a regression mark the top of the calcareous Bathonian. Within the stage, the principal pulsations are marked by the zones of Proplanulites teysseiri and of Sigaloceras calloviense, Kosmoceras (Gulielmites) jason, Peltoceras athleta and Q. mariae. In other regions, the American Agassiz orogeny and the Yaila orogeny of the U.S.S.R. are accompanied by transgressions in the upper part of the Callovian, whilst the base is generally marked by a great Callovian transgression (M. macrocephalus Zone) which brings in a number of new forms.

THE BATHONIAN (from Procerites [Gracilisphinctes] progracilis to Clydoniceras hollandi). The transgression becomes more marked in the Bathonian, covering a maximum area, with sediments of the Tulites subcontractus zone which may rest on the Palaeozoic. Accessory pulsations mark each zone of this stage. A tectonic phase is known at the very top of the Bathonian in Tunisia (Matmatian phase).

THE BAJOCIAN of Normandy (from Stephanoceras humphriesianum to Oppelia yeovilensis) begins with the Bajocian transgression: the humphriesianum Zone rests on eroded Toarcian and on Palaeozoic. The paroxysms of the Cotswolds and Donetz phases occur at this level. The subfurcatum-garantiana and parkinsoni zones continue the transgression and small pulsations coincide with the convergens and zigzag zones.

THE TOARCIAN of Normandy (from Dactylioceras tenuicostatum to Otoites sauzei) oversteps the Pliensbachian (i.e. the Liasian of d'Orbigny). At the base, the transgression of the tenuicostatum zone follows a slight regressive tendency in the upper Pliensbachian and corresponds to the American Dunlap phase. There are subsequently pulsations associated with the mulgravium, variabilis, Dumortieria and opalinum beds, after concava, after discites, and after Witchellia; these horizons are marked by erosion surfaces and by reworked fossils and pebbles.

THE LIASIAN of Normandy (from Uptonia jamesoni to Pleuroceras spinatum) oversteps the limits of the Sinemurian onto the Palaeozoic basement quite sharply in the jamesoni beds; then a secondary transgressive phase is marked by the davoei beds and a conglomerate marks the base of the spinatum zone (the margaritatus subzone is eroded to a greater or lesser degree). In England, there is a transgression at the base of the Pliensbachian onto the Palaeozoic.

THE SINEMURIAN of Normandy (from the top of Psiloceras planorbis to Echioceras raricostatum). At the base, the first marine beds have the fossils of the pre-planorbis beds. The topmost Valognes Limestones, containing Caloceras torus, are truncated by an erosion surface; and at Osmanville, a slight angular discordance has been reported below the Coroniceras rotiforme beds. Generally there is a lacuna in the upper Hettangian. In England, the bucklandi zone may rest on the Rhaetian (uppermost Triassic) in the Mendips. Above this discontinuity, the Sinemurian spreads widely over the Primary basement, with two stronger pulsations, one associated with semicostatum and one with oxynotum. At the Rhaetian-Hettangian boundary, a transgression takes place in the Salghir or early Cimmerian phase.

Sedimentation has thus recorded a certain number of water movements and it is a question of classifying them. Alcide d'Orbigny advocates that one make use of the fauna in order to determine, among these movements, those which are of major importance, the revolutions which involve the whole surface of the globe and which bring in train destruction of the fauna, whereas local oscillations cause only minor changes.

A certain number of orogenic "phases" have been recorded in the Jurassic System of Europe (Alps, U.S.S.R., and England), America (Nevada, Texas and Canada), and China; and

attempts have been made at world correlation. [Important volcanic phenomena were developing at the same period, particularly in America (from Patagonia to Canada).]

The data from geophysics show that certain seismic waves, engendered during earthquakes, make the round of the earth several times; they generally produce tsunamis, which profoundly affect the littoral populations and, more significantly, they are the prime cause of important redistributions of material by turbidity currents and give rise to phenomena of resedimentation. Earthquakes also set in motion great faults, which can slowly continue their development before our very eyes. There certainly thus exist, in present-day Nature, sudden, paroxysmal phenomena which affect the whole surface of the Earth and also slow, much more localised phenomena, as d'Orbigny observed.

The transmission of series of orogenic waves in the Earth's crust and waters evidently occurred in different directions, according to the particular period of the Jurassic. Whilst at the beginning, in the Hettangian and Sinemurian, the general tendency of transgressions in Normandy was from west to east, it seems that from the upper Pliensbachian, S.E. - N.W. directions, from Boreal to Tethyan, were predominant until the Lower Callovian; boreal N.E. - S.W. influences then briefly appeared, to take the place, temporarily in the Upper Callovian and above all in the Kimmeridgian, of Tethyan influences.

The Dunlap, Donetz, Agassiz and Nevada paroxysmal orogenic phases were relatively swift and took place, according to Crickmay (1933), during a lapse of time that did not exceed a single ammonite zone. This is very important, for the crystalline or volcanic synorogenic episodes may provide absolute dates. These orogenic phases have left traces in the Jurassic formations and, from a general point of view, the correlation of these traces, whether diastrophism or orotaxy, has given rise to very interesting researches on the part of Anglo-Saxon (T.C. Chamberlin and Umbgrove) and German (H. Stille) geologists. As far as stratigraphers in particular, are concerned, following the work of E. Hebert (1857), the researches of W. Klupfel, H. Frébold, W.J. Arkell, P.L. Maubeuge and A. Hallam have shown the vast horizontal extent of the phenomena of erosion and condensation in the whole European area.

The orogenic crises always show paroxysmal phases, which give rise locally to folds and to displacements of considerable volumes of sediments and marine waters; they are preceded and followed by periods of instability of sea level. The universality and amplitude of the great Jurassic transgressions onto numerous epicontinental regions express eustatic rather than epeirogenic causes; regressions are associated with the periods of expansion and subsidence, transgressions associated with lateral compressions, raising up the sea bottoms or reducing the marine basins and thus bringing about a phase of overflow by the oceans, according to the utterances of Pierre Pruvost.

Epeirogenic deformations and localised vertical movements occur regionally to complicate the phenomena and, for example, give rise to minor transgressions in a regressive regime, or the converse.

In this regard, d'Orbigny recommended with good reason the categorisation of the diverse traces recorded by sedimentation, in the course of movements by crust and waters: the disturbances marking the ending of a stage and the beginning of another being more important than the oscillations observed within the stage. I will add that, on a larger scale, the limit of subdivisions of systems must be even more marked than the limit between two stages; the Middle Jurassic is well delimited by the lower boundary of the Bajocian and the upper boundary of the Bathonian. Only the echoes of these major dynamic phenomena in the marine and continental populations can indicate the scale of the phenomena.

b) D'Orbigny's stratigraphical units and the "successive creations"

At the boundary of two stages, the hiatus which is materialised by the sedimentary lacuna bears witness to a lapse of time, short or long, during which sediments were not deposited. For modern palaeontologists, the discontinuity observed between the characteristic faunas of successive stages need not be misleading, for the ammonites continued to evolve in the calmest regions However, if the ammonite faunas were widely distributed in all marine environments in the course of transgressions, it certainly seems that these free-swimming shallow-water organisms living in our epicontinental basins were swept away like the unconsolidated sediments, far from the platforms, at each major regression and that the subsequent population was brought in during a new phase of oceanic inundation (Tethyan, Boreal, Atlantic, Indo-Pacific, etc., according to the region). The variation of the limits of the marine domain may have played a motive role in the selection of the forms best adapted to the new conditions of life offered in the course of a transgression or regression. The abruptness of the dynamic phenomena eliminated the forms too closely tied to particular environmental conditions.

It seems that one can henceforward define some tendencies in the ammonites.

The study of the composition of the entire fauna of ammonites from a given horizon shows that the development of families is not synchronous and that there is displacement in space and time of the period of their dominance, in the fauna, as a function of the general or local transgressions or regressions. For example; the Parkinsoniids travelled apparently from the west to east, the Cardioceratids from north to south, and the Perisphinctids from south to north. The Hammatoceratids appear earlier in Italy than in Normandy and the acmes of the various genera are not synchronous in the two countries. At each level, each region contains an assemblage which, in its composition, is different (the works of B. Ziegler are very interesting in this respect). Regressions tend to force back the vagile marine faunas towards the ocean depths, whilst transgressions push back the vagile continental faunas towards the high land; the theory of "refuges" is based on this.

In the epicontinental basins, one frequently notes, at the limits of two stages, the following facts; in the upper part of the lower stage, alongside numerous representatives of Family A, there exist a small number of forms - emissaries of Family B which arrived in these regions in the course of the earliest phases of a revolution, before the orogenic paroxysm and the great eustatic variations with which it is associated; whilst in the lower part of the upper stage, Family A is no longer represented except by a few rare specimens, whereas Family B evolves explosively in its turn. Some examples: Xipheroceratinae - Eoderoceratinae play a subsidiary role in the Upper Sinemurian, whilst the Eoderoceratidae dominate the Pliensbachian; it is the same for the Dactylioceratidae and Hildocerataceae in the Pliensbachian and the Toarcian. Numerous Sonniniidae and rare Stephanocerataceae in the Upper Toarcian give place to rare Sonniniidae and numerous Stephanocerataceae in the Bajocian. Let us in addition cite the Tulitidae and Macrocephalitidae of the Upper Bathonian and Lower Callovian; the Cardioceratidae, Peltoceratinae and Aspidoceratinae of the Upper Callovian and Oxfordian; the Cardioceratidae and Aspidoceratinae of the Upper Oxfordian and Kimmeridgian; the Perisphinctids of the Upper Kimmeridgian and Portlandian.

The emissary forms were not able to enter into competition with the populations there already, but at the time of the regression and transgression, they rapidly attained dominance over forms too closely tied to littoral conditions.

Within the stage, the phenomena are in proportion identical, but occurring at the level of species rather than at that of genus; thus H. Frébold has pointed out that the zonal ammonites do not cross the "Dachbänke" (the last beds of a sedimentary cycle) and R. Brinkman has demonstrated that the Kosmoceratidae evolved slowly between the "Dachbänke" and "Sohlbänke" (first beds of

the next cycle): similarly one may add that, at the scale of the sub-system, these phenomena are placed at the level of the superfamily. The hierarchy and the proportions are inscribed in Nature, as d'Orbigny has well said.

In the vicinity of these discontinuities, condensed beds or sedimentary lacunae, one finds frequently associated with the dominant ammonite faunas, shells with a certain number of special characters:-

i) Either shells of small size, the representatives of whose family in the lower horizon showed, if anything, a tendency to increase in size. These small shells are globular or carinate, or exhibit a scaphitoid or spiroceratoid mode of coiling, or again they may exhibit an aberrant ornamentation with a complex aperture funished with apophyses, a rostrum, a collar, with ventral crenulations, with a degenerate suture-line, etc.

ii) Or shells with little ornamentation or quite smooth, when the members of the family showed, in the lower horizon, a rich ornamentation made up of ribs, tubercles, spines, etc. Here again, the suture-line is degenerate, simplified and inconstant in form.

These two morphological types seem to relate to troubles in metabolism. These forms would simply be degenerate branches of the family represented in the lower horizons, which had survived upheavals of the sea-bottoms on which they lived, which would have developed alongside species well adapted to the new environment and which would have been the prelude to the elimination of the family by vital competition. If it were a question of sexual dimorphism, one does not see why the males should only have been represented in certain populations and by forms whose development could only lead to the disappearance of the branch. Again, does one have to be sure that the sexes were separate in the ammonites ? It is more probable that dimorphism, if it exists, is marked by small differences in the height or thickness of the living chamber of the shell; these animals having to lodge in their shells the appendages of their reproductive apparatus, If one takes account of the anatomy of living Cephalopods.

The new forms which appear at the time of transgressions and occupy the different ecological niches, often belong to two associated morphological types, which are: either oxycones with a solid, strongly carinate shell, reinforced by undulose septae and having a "hydrodynamic form", or cadicones and sphaerocones with a floating globulous shell, with large chambers filled with gas. These two solutions to the mechanical problem of transport in the aquatic environment (reduction to a minimum or augmentation to a maximum of the effects of friction) are the result of a "mechanical" selection in the oceanic stock. The serpenticones are also good floating shells and appear in same conditions. One may thus cite: Oxynoticeras of the Upper Sinemurian; Becheiceras and Amaltheus of the Upper Pliensbachian; Nodicoeloceras and Orthodactylites of the Lower Toarcian; Oxycerites and Tulites of the Bathonian; Macrocephalites and Cadoceras of the Lower Callovian; Lamberticeras and Eborariceras of the Upper Callovian; Cardioceras and Goliathiceras of the Lower Oxfordian; or Balticeras and Prionodoceras of the Upper Oxfordian; Orthaspidoceras of the Kimmeridgian or Gravesia of the Portlandian, etc.

Involute, flattened forms, with sides converging ventrally, tend to be dominant at the maximum period of agitation of the waters, giving place to more evolute forms in more stable conditions; for example Psiloceratidae, Amaltheidae, Graphoceratidae, Sonniniidae, Kosmoceratidae, and Cardioceratidae. Finally, the arrival of new forms with Tethyan affinities is generally accompanied by the arrival of Phylloceratidae and Lytoceratidae. The first appear in the Middle Pliensbachian in Normandy, the last in the Upper Callovian.

In summary, it certainly seems that, as d'Orbigny noted, the changes of faunas, at the boundaries of stages as at the boundaries of other stratigraphical subdivisions, are sufficiently marked to serve as reference points, if one also takes count of the major revolutions. The displacement of the vagile faunas at the time of regressions and transgressions obliges the palaeontologist to envisage evolution both in space and in time. [Note: Archaic organisms which have scarcely evolved are either sedentary, intertidal forms with a great capacity for resistance to changes of the external environment (e.g. Cyanophyceae) or "refugee", geographically restricted forms. The organisms which are the most evolved are those which live on either side of the strand line, those of the continental maritime regions and those of the infra- and circa- littoral regions]. As the majority of types of ornamentation were developed amongst the ammonites as early as the Trias, it would be interesting to examine the relationships between morphology, hydrodynamic conditions and environmental conditions; it certainly seems that the morphology of the whole of a fauna is strongly influenced by a sort of "mechanical" selection at the time of transgressions. The living world is in equilibrium with the environment which encloses it; each modification of this equilibrium inevitably brings readjustments in its train. During stable periods, marine and continental organisms evolve slowly in a particular direction. The monographs of genera, advocated by d'Orbigby, thus have great stratigraphic interest (R. Brinkmann, M.K. Howarth, B. Ziegler, H. Tintant, etc.) If an upheaval takes place, the organisms introduced into these new conditions will disappear if the conditions are too unfavourable or sometimes will survive, enfeebled, until eliminated by competition; or in contrast will occupy all ecological niches if they are well adapted. Variations within populations widely distributed by transgressions could be fixed by geographical or physiological isolation. The role of natural selection, under eustatic control, accounts for the palaeontological facts. If there is a finality in evolution, this can only be a planetary finality.

The concept of the stage is thus primarily a zoological and actualist idea. This chronological division of the geological history of our planet was essentially worked out on the basis of stratigraphical analyses of the Jurassic of Europe. Unfortunately, a premature death prevented Alcide d'Orbigny from developing his work with all the fullness that it demanded.

The contemporaries and successors of d'Orbigny have accorded a variable reception to his conclusions. Three principal attitudes have been adopted with regard to d'Orbigny's system; that of French-speaking geologists, that of German and Slavic geologists, and that of Anglo-Saxon geologists.

a) The first-named believed that progress consisted in the creation of new stages (very often with no more justification than to make known a regional, lithological or palaeontological stratigraphic unit), allotted a name ending in "-ien" or "-in". The "recipe" found favour, but rare are those who consulted the scale given by d'Orbigny to see whether there was any synonymy. Fortunately the endeavours of A.de Lapparent and E. Munier-Chalmas, of E. Renevier and of E. Haug have brought the necessary clarifications; but these authors have not truly adopted the concepts of d'Orbigny; rather, they have been influenced in their conclusions by the work of Oppel and of S.S. Buckman. Each wished to create his own "standard" and the stages were extended, or shortened, at the inclination of each particular author.

b) The German geologists reacted first. In "Der Jura", F.A. Quenstedt stigmatised, in scoffing terms, the conclusions advanced by d'Orbigny. His principal complaints were taken up and expounded with more rigour and less passion by one of his pupils, Albert Oppel. The long and patient researches of Alexander von Humboldt and Leopold von Buch, carried further by Quenstedt, had led to a very detailed knowledge of the Jurassic of Swabia and Württemburg. D'Orbigny, in discussing

these geological researches, showed that the divisions adopted by the German geologists, although accurate and useful, were not readily applicable outside their country of origin and were inadequate for a universal stratigraphy. Oppel, accompanied by Edward Suess, had travelled and studied in certain regions of France and England between 1854 and 1855. He visited mainly the periphery of the Paris Basin; and met d'Orbigny. Following these travels, he published his classic "Die Juraformation Englands, Frankreichs und des südwestlichen Deutschlands, nach ihren einzelnen Gliedern eingetheilt und Verglichen", in which he attempted to make a synthesis of the researches of German, English and French geologists. He opposes to the concept of the stage his idea of the zone, without however taking the trouble to define it. Now, for d'Orbigny, the zone is constituted by the faunal content, chronologically delimited, of the stage. With regard to the 4,000 species of Jurassic invertebrates, d'Orbigny states precisely:-

> ". . . . that this number is divided into ten superposed zones, forming, throughout the Jurassic terrains, as many chronologic faunas or epochs which regularly succeed one another. That, further, each zone showed a particular fauna distinct from those of the zones above and beneath, which constitutes a stage, a well-characterised epoch, as well defined as the present epoch". ("Cours élémentaire, 1852, II, p.426).

In his definition of the aims of palaeontology, he writes also:-

> "It is necessary to study these beds in their order of superposition, in their relative age, in their geographic and geologic circumscription, in the composition of the faunas they contain, so as to follow the organisms across different deposits and to recognise the points at which they cease to exist, to be replaced by others". ("Cours élémentaire", 1849, I, p.7).

But yet, for d'Orbigny, it is difficult to imagine stratigraphic units of universal value smaller than a stage:-

> "There is, regarding the limits of the stage, a trap that one must be careful to avoid; it is that of attaching too much importance to the local distribution of fossils by bed, before being certain whether these details are the same in all parts of the world. Most frequently, in fact, when one finds, in a geological basin, that a certain bed contains a certain series of species, one is naturally inclined to regard this as a fact important to stratigraphy, as constituting a special distinct epoch, when it is most often, as we have perceived by comparison, only a purely local feature, which enables no generalisation whatever and which results solely from the composition of the sediments or local oscillations of the crust, as we will try to demonstrate for stages in particular".

Thus d'Orbigny stresses the geographically restricted value of possible subdivisions of the stage.

Oppel in contrast puts the accent on the value of zones for correlation between the Anglo-Parisian Basin and southwest Germany; that does not mean that the comparison may extend further, for even in the two basins, the zones may not be the same in the north and in the south, in the Upper Jurassic, for example. Oppel has no time for global revolutions; for him, geological disturbances are purely local. What he calls "zones" are, in fact, biostratigraphic units within sedimentary formations. He maintains, for the easy manipulation of the zones, groups of zones; he thus adopts the Semur-Group, the Pliensbach Group, the Thouars Group, the Bayeux Group, the Bath Group, the Kelloway Group, the Oxford Group, the Kimmeridge Group, rejecting Liasian, Corallian and Portlandian.

For him, the stage is convenient because it permits the parallelising of groups of zones, containing poorly determined or poorly described fossils. Never did Oppel regard his stratigraphical scale as definitive, but, like the English geologists, he sought to adapt his zonal analyses to the stages rather than to analyse the zonal content of d'Orbigny's stages. He did not hesitate to modify the boundary of the Thouars Group and of the Bayeux Group, without knowing the geology of the region of Thouars, using as basis only German work. The "zone" of Oppel brought progress in the field of regional stratigraphic analysis. Furthermore, his palaeontological revision, illustrated in 1862-1863, and the creation of the Tithonian Stage (1865), subsequently completed his writings on the Jurassic. He too was prevented by a premature death (1865) from carrying his work further.

c) Finally, taken as a whole, the English geologists preferred to retain their traditional lithostratigraphic units, until William J. Arkell, in 1933, then in 1946 and 1956, adjusted certain of the conclusions of d'Orbigny to accord with very detailed stratigraphic analyses made in England, following close upon the work of S.S. Buckman, A.E. Trueman, W.D. Lang, L.F. Spath and others. Arkell possessed very great experience in the palaeontology and geology of the Jurassic. His discussion takes into account only two of the works of d'Orbigny ("Paléontologie française, ... Céphalopodes", 1842-1851 and "Cours élémentaire," 1852, II). His principal criticisms are those of Oppel, but, without alluding to d'Orbigny, he accords more credit to diastrophism. Firstly, he deplores the fact that the types for stages chosen in England, were selected when d'Orbigny knew the stratigraphic data of the type localities only through study of English geological publications and fossil collections; and secondly, the fact that the faunal assemblages which serve to define these stages were derived in part from northern France. D'Orbigny himself conformed to priority by using certain stratigraphic terms published by Brongniart in 1829 in order to name his stages; in so doing, he paid homage to the English geologists by taking five types in France and five in England.

The criticisms directed at d'Orbigny have never, to date, taken account of the whole of his work.

The fact that he connected tectonic and biologic data proves that he was conscious that neither the one nor the other, taken separately, would be sufficient to define his subdivisions. The geographical distribution and evolution of marine organisms are dependant upon eustatic phenomena,

affecting the whole globe. The types of the stages, chosen deliberately in regions on the edge of the ancient massifs, recorded in better fashion the variations in level of the sea, complementary types being present to enable the possible specification of the biostratigraphic and diastropic data. In designating the faunal content characteristic of each stage under the name "zone", d'Orbigny conferred on these assemblages the value of a tool in correlation. That it might be possible, regionally or locally, to distinguish smaller units within the stage is not incompatible with the concept of the stage, but is subordinate to it. Finally, in the choice of the majority of index-species, d'Orbigny has made it clear that his selection was at least as strict as that of Oppel and that he accorded a greater value to the ammonites.

In the quantity of precautions with which he surrounded his work, I do not think he has ever been surpassed.

Finally, it seems to me that the differences of opinion which subsisted at Luxembourg, arose from three fundamentally different concepts of stratigraphy:-

i) That set forth by d'Orbigny, which is the quest for a clear, intelligible, rational and universal language, based upon geological data and observations on living Nature.

ii) That of Quenstedt and Oppel, the detailed and laborious analysis of geological facts, but too particularist and which does not aim at an immediate generalisation.

iii) That of William Smith, Sidney S. Buckman and William J. Arkell, the assembling of definite facts, independently of any "system".

There is no opposition between those methods, there is only a difference in scale, and all the observations are complementary, the zones of Oppel and Arkell being subordinate to the stages of d'Orbigny. Just as d'Orbigny indicated, if one takes into account the hierarchy of phenomena periodically interrupting sedimentation and the results of modern biostratigraphy, it seems possible to use, as regional basis, the replacement of species in order to establish sub-zones and that of sub-genera and genera to establish zones; thus also, on a more general plane, the replacement of certain subfamilies or families would serve to define stages and that of certain families or superfamilies to provide limits for sub-systems.

Postscript (1968)

In a recent paper (J. Paleont., May 1968), C.L.V. Monty, a Belgian geologist working at Princeton University, U.S.A., examined d'Orbigny's concepts of stage and zone. Successively employing several of d'Orbigny's definitions, he focuses attention on the stage as an uniformitarian approach, a sort of "paleo-today" (p.690); as a natural chronological division of the Earth's history (p.690); an accumulation of rock strata (p.691); and as a part of a biostratigraphical unit (p.692). Monty considers that, in the definition of stages, the physical criteria are regarded by d'Orbigny as subordinate to the palaeontological ones: each stage starts from the appearance of newly created organisms and finishes with their catastrophic extinction in a geological "revolution". On the other hand, the zones are chronological indices, characterised by given species selected from among the fossils of the stage on the basis of their palaeoecological significance, their wide geographical distribution, and their vertical range in the strata. After his analysis of d'Orbigny's definitions of these two stratigraphical concepts, Monty concludes that "attempts to read very precise meanings

into his terminology and religiously follow certain subsequent interpretations of his concepts are scarcely justifiable in view of inconsistencies in his writings and in the light of progress in stratigraphic understanding since his day" (p.699).

Monty assigns importance more to the form than to the spirit of d'Orbigny's stratigraphical researches; never does he consider d'Orbigny in his historical context. At the beginning of his paper, he emphasises that one should not be misled by the traditional judgement on d'Orbigny's works; and yet subsequently he is himself unable to forget this caricature of the truth.

After such an attentive reading of A. d'Orbigny's works, it seems to me equally difficult for Monty to claim (p.689) that this geologist stood aside from the current of scientific thought in the first half of the 19th century, as it is for him to represent d'Orbigny as the last obstacle to the rise of Evolutionism. D'Orbigny did not ignore the studies of James Hutton, Charles Lyell, Charles Darwin and John D. Hall - he quoted and discussed them; he was fully conversant with J.B. de Lamarck's transformism before ever he read J.B. d'Omalius d'Halloy's publications on this theory.

I believe that Monty did not take into account d'Orbigny's attempts to arrive at a synthesis of catastrophism and uniformitarianism and to consider stratigraphical concepts in their historic and taxonomic perpectives. Moreover Monty separates out each aspect of the concepts of stage and zone, without attempting to show how closely they are linked and how they are classified together by A. d'Orbigny.

Personally, I don't like the term "paleo-today", as it is presented by Monty. I agree with Monty that uniformitarian, ecological and geographical approaches were used by d'Orbigny, but I am sure that the duration of time, and especially the historical epoch characterised by a relative equilibrium in natural conditions at the world scale, was more important to d'Orbigny than the pictures, landscapes or frescoes visualised by Monty. In brief, I believe that the historical concept was basically prevailing over the geographical aspect in d'Orbigny's writings.

D'Orbigny's concept of stage is essentially of a chronological division of the Earth's history, delimited by two dates marked by cataclysms (i.e. inundations) which modified the mutual relations between continents and seas. During these intervals of geological time, stratified sedimentary deposits incorporating organic remains, were forming; the fossils they contain are historically and geographically characteristic. But all these natural, simultaneous phenomena are just so many aspects of a single reality, the chronological history of the Earth.

Never did d'Orbigny suggest that physical criteria should be subordinated to biological ones: he claimed emphatically that both criteria are strictly dependent upon cataclysmic changes (i.e. transgressions). These are what he termed "global revolutions". He observed a lateral gradation in the sedimentological and palaeontological evidences of these changes.

Because of its palaeoecological and palaeogeographical basis, the zone concept is much more limited in space and time. The value of a zone is restricted by the distribution of organisms in "provinces". D'Orbigny conceded a regional value to the zone, but never a general value as a universal standard. But a yet more important aspect of this concept is neglected by Monty: it is the conclusion reached by d'Orbigny that, in the selection of biological indices for zones, one should not descend below a certain systematic level; beneath such a level, the differentiation encountered is too geographically limited to be stratigraphically meaningful on a world scale. In these stratigraphical correlations, it is necessary to fully recognise the geographical limits of the distribution of each systematic unit. The true content of the "genus" and of the "species" in d'Orbigny's time, much larger than today, is forgotten by Monty.

At no stage does Monty in fact make a thorough analysis of d'Orbigny's concepts "in the light of progress in stratigraphic understanding"; this I regret. I fear even that Monty found in d'Orbigny's writings nothing other than what he sought - arguments to confirm his conviction of d'Orbigny's recognition of three separate stratigraphical fields, comparable to those visualised in the works of Dr. Hollis D. Hedberg. Thus Monty intentionally separates the chronological, lithological and biological aspects of the concepts of stage and zone to reinforce his demonstration. Unfortunately, however, d'Orbigny never separated these aspects of his concepts; he defined only one stratigraphy, chronostratigraphy, resulting from the natural expression of the (wholly interdependent) tectonic, lithologic and biologic histories of the Earth's surface. In conclusion, I concur with Monty's assertion that d'Orbigny's stratigraphical concepts are richer than is generally assumed in geological literature; and I hope that these concepts will be reconsidered in the light of modern geological knowledge.

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