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CRETACEOUS OCEANIC ANOXIC EVENTS: CAUSES AND CONSEQUENCES

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ABSTRACT

Organic carbon-rich sediments are globally developed in pelagic sedimentary sequences of Aptian-Albian and Cenomanian-Turonian age. They formed in a variety of paleo-bathymetric settings including oceanic plateaus and basins, continental margins and shelf seas. The widespread nature of these deposits suggests that they were not strictly controlled by local basin geometry but were a product of "Oceanic Anoxic Events". We interpret these events as the result of the interplay of two major geologic and climatic factors: firstly the Late Cretaceous transgression which increased the area and volume of shallow epicontinental and marginal seas and was accompanied by an increase in the production of organic carbon; and secondly the existence of an equable global climate which reduced the supply of cold oxygenated bottom water to the world ocean. This combination of climatic and hypsographic conditions favoured the formation of an expanded oxygen-minimum layer and where this intersected the sediment-water interface, organic carbon-rich deposits could be formed, these being records of "Oceanic Anoxic Events".

INTRODUCTION

The discovery of carbonaceous sediments of Barremian – Aptian and Cenomanian – Turonian ages at Deep Sea Drilling Project (DSDP) sites in the south Central and western North Pacific during Legs 32 (M o b e r l y and L a r s o n, 1975) and 33 (S c h l a n g e r, J a c k s o n et al., 1976) greatly extended the known geographic range of such deposits.

On Leg 33, which took place during November and December 1973, a section of greenish-black, waxy volcaniclastic sediment of Barremian – Aptian age containing 28.7% organic carbon was cored on the Manihiki Plateau – a broad topographic high in the south Central Pacific Basin. This occurrence suggested to the writers that the wide geographic distribution of previously drilled carbonaceous sediments, as discussed below, indicated such layers "....may therefore be the record of some 'event' related to poor oceanic mixing" (J e n k y n s, 1976) and that this "....event may have been a very widespread, perhaps worldwide oceanographic phenomenon" (J a,c k s o n and S c h l a n g e r, 1976).

We now propose that certain stratigraphically restricted carbon-rich horizons are more the result of the development of widespread and thick O_2-minimum zones in the world ocean than the result of the structural-topographic isolation of relatively local basins. Because such stratigraphic horizons are widespread and transcend local basins we herewith refer to them as the result of "Oceanic Anoxic Events".

ATLANTIC AND CARIBBEAN BASIN DSDP DATA

Since the coring, on Leg 11 (L a n c e l o t et al., 1972) of carbonaceous clays and shales of late Neocomian to Cenomanian age in the western Central Atlantic, strata of similar age and lithology have been found at a number of DSDP sites in the eastern Central Atlantic, the eastern and western South Atlantic and also in the Caribbean Sea (S a u n d e r s et al., 1973; B o l l i, R y a n et al., 1975; L a n c e l o t, S e i b o l d et al., 1975; P e r c h-N i e l s e n, S u p k o et al., 1975; K a n e p s, 1976). Detailed analyses of Leg 14 material (B e r g e r and v o nR a d, 1972) from the eastern North Atlantic revealed that much of the carbonaceous material in the black Cretaceous sediments is of terrestrial plant origin but that some strata are characterized by organic carbon of marine planktonic origin; late Cenomanian sapropels containing pyrite cored at site 137 (B e r g e r and v o n R a d, 1972) just east of the Canary Islands are an example of the latter.

The abundance of terrestrial plant remains in these smaller proto-Atlantic basins is not surprising considering that the Cretaceous transgression, beginning in Barremian – Aptian time and extending to Turonian – Coniacian time, resulted in submergence of low-lying coastal plains that were being rapidly populated by dense forests of the newly arrived angiosperms; by Albian time this flora had virtually taken over this low-land habitat (D u n b a r and W a a g e, 1969). The source of the marine planktonic component of the

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organic carbon fraction of certain of these sapropels has been ascribed to material that passed downward through the oxygen minimum zone below a region of high surface productivity (B e, r g e r and v o n R a d, 1972).

In general the accumulation and persistence of the organic matter in these Atlantic and Caribbean Cretaceous strata has been explained in terms of local basin topography and geometry (see review by K a n e p s, 1976). According to this topographic-geometric argument sills and submarine ridges are credited with preventing 0_2-rich bottom waters of the world ocean from entering these basins during the early opening phases of the Atlantic.

INDIAN OCEAN BASIN DSDP DATA

In the Indian Ocean, particularly in the continental margin region west of Australia, there is some evidence of organic-rich deposits of Cretaceous age. At site 258, cored on Leg 26, Albian to Cenomanian black and olive-black clays were discovered; these locally contain pyrite crystals and abundant fish remains. Organic carbon levels rise to 2.7%. The foraminiferal faunas in these deposits are of restricted diversity (D a v i e s, L u y e n d i j k et al., 1974). Similar lithologies of probable Aptian age were recorded at site 263 on Leg 27; organic carbon contents locally reach the 2% range in these sediments (V e e v e r s, H e i r t z l e r et al., 1974).

PACIFIC BASIN DSDP DATA

On Leg 32 (M o b e r l y and L a r s o n, 1975), in the western North Pacific, bituminous shale of early Cenomanian to early Turonian age was cored at site 305 on the Shatsky Rise; foraminiferal nannofossil chalk and chert were cored above and below this shale. At site 306, also on the Shatsky Rise, Barremian – Aption carbonaceous radiolarian shale (9.3% organic carbon) was cored. At site 310 on the Hess Rise in the north Central Pacific, black, carbonaceous, pyritic and sideritic pelagic shale of Cenomanian – Turonian age was recovered; this unit also is bounded by chalks and cherts. On Leg 33 at site 317 atop the Manihiki Plateau, in the south Central Pacific, a thin layer of black, volcaniclastic, waxy sediment with an organic carbon value of 28.7% was cut in strata of Barremian – Aptian age (J a c k s o n and S c h l a n g e r, 1976; J e n k y n s, 1976). On Leg 17 at site 171 on Horizon Guyot in the eastern Mid-Pacific Mountains Turonian sediments are characterized by pyritized foraminifera (W i n t e r e r, E w i n g et al., 1973). These Pacific Basin carbonaceous sediments did not accumulate in isolated barred basins cut off from presumably oxygenated bottom waters of the world ocean. Indeed the environmental settings were the opposite of deeps. The Manihiki Plateau has a large eastern sector that lies at a depth of 2.5 to 3 km rising above the surrounding basins that lie at depths of 5 to 5.5 km. The sediment-water interface on the part of the Manihiki Plateau drilled at site 137 was probably shallower at times but never deeper than the present 3 km throughout the history of the Plateau.

The Plateau itself has probably been close to 10°S. Lat. since its origin (W i n t e r e r et al., 1974). The Hess Rise, drilled at site 310, has a flat top at a depth of 3.5 km, elevated about 1.5 km above the surrounding basin; it passed under the equator some 90 to 100 myBP (L a n c e l o t and L a r s o n, 1975), during which time (Cenomanian) carbonaceous sediments were deposited. The shatsky Rise has a broad top approximately 3 km deep and rises some 2 km above surrounding deeps; this plateau crossed the equatorial zone, between 10°S.Lat. and 10°N.Lat., some 110 to 65 my ago (L a n c e l o t and L a r s o n, 1975) and was also near the equator when the Barremian – Aptian and the lower Cenomanian carbonaceous sediments were deposited. Significantly the Pacific equatorial zone is and was a locus of high plankton productivity (e.g. B e r g e r and W i n t e r e r, 1974). All of these rises and plateaus have a stratigraphy indicating that their tops were at or above the carbonate compensation depth during their entire postvolcanic histories.

OUTCROP DATA

In discussion of the Leg 15 carbonaceous deposits S a u n d e r s et al. (1973) referred to the presence of similar strata on land around the Caribbean. Bituminous pyritic sediments are present in the deepwater Turonian globigerinid limestones of the Querecal Formation, Venezuela (H e d b e r g, 1973, 1950); they furthermore occur in the Gautier and Lower Naparima Hill Formation of Cenomanian – Turonian – Coniacian age of Trinidad (K u g l e r, 1953).

Similar deposits also occur in Cretaceous Tethyan facies of the Alpine – Mediterranian region. Perhaps the most famous of these is the so-called "Livello Bonarelli", a band of bituminous marls that, although discontinuous, occurs in the same stratigraphic position over a wide area in the Umbrian Apennines of Italy.

The enclosing rocks are early Turonian in age and are developed as deep-water pelagic nannofossil limestones of *Scaglia* facies (B e r n o u l l i and J e n k y n s, 1974). According to B a r n a b a (1958) the bituminous layer contains 18.5% organic material, plus quartz, illite, pyrite, rutile, haematite and calcium and magnesium carbonate. This horizon, unlike the planktonic foraminiferal-rich *Scaglia*, is dominated by Radiolaria.

Similar bituminous levels (*scisti neri*) occur in the pelagic nannofossil carbonates of the Cretaceous in the Venetian Alps; they occur locally in the Albian, at Mollaro, and in the Lower Turonian, at Covelo (F u g a n t i, 1964). These levels are relatively enriched in uranium. The bituminous horizon at Mollaro extends for some 8 km^2, its thickness varies between 30 and 150 cm, and it comprises sapropelic material plus pyrite, glauconite, phosphate and dolomite (F u g a n t i, 1961, 1964). The sample analysed by B i t t e r l i (1963) from the Mollaro deposit contains some 3.3% organic carbon; F u g a n t i (1961) quotes 30.53% organic carbon plus carbon dioxide. In the Breggia Gorge, Canton Ticino, Switzerland, organic-rich levels occur in the *Biancone* of Barremian age, the Aptian – Albian *Scaglia variegata* and also in higher Cenomanian red and white *Scaglia* and flysch. The Aptian – Albian "fish shales" are particularly rich in organic matter (max. 17% — 13.6% organic carbon). This level is highly siliceous, contains apatite and clay minerals and is laminated. A higher bituminous level contains pyrite, phosphatic fragments and a little silt-size quartz (B i t t e r l i, 1975).

Bituminous levels are also recorded from similar pelagic facies from the Cenomanian – early Turonian of the Subbetic of Spain; these levels contain Foraminifera and Radiolaria (D ü r r, 1967). They also occur in the Cretaceous of the Sclafani Zone of Sicily (M a s, c l e, 1970). In all the above cases deposition of the bituminous horizons took place in deep water on the continental margin of the Tethyan Ocean (B e r n o u l l i and J e n k y n s, 1974). By "deep water" depths of a few kilometres are implied. However, even in shelf-sea chalks, bituminous levels occur. For example in Yorkshire and Lincolnshire, England, the so-called "Black Band" is developed at the Cenomanian – Turonian boundary of the Chalk: this level is bituminous, and contains pyritic nodules and complete fish while lacking benthos (J e f f e r i e s, 1960).
Chemical analysis of this material shows 1.1% organic carbon in a smectitic clay matrix. In the Western Interior and Big Bend (Texas, Mexico) regions of North America the dearth of benthonic faunas in the upper Cenomanian limestones and shales has been linked to widespread oxygen depletion in the bottom waters (F r u s h and E i c h e r, 1975).

Oceanic deposits, presently preserved as the sedimentary cover of ophiolites, also reveal a record of mid- to late Cretaceous anoxic events. In the Ligurian Apennines of north-west Italy, for example, the Albian – Cenomanian *Scisti di Val Lavagna* are developed in black-shale facies (D e c a n d i a and E l t e r, 1972). These deposits are similar to coeval sediments cored in the central Atlantic (B e r n o u l l i and J e n k i n s, 1974). In California the ophiolite-bearing Franciscan Formation contains probable lower Cenomanian bituminous pelagic carbonates (Lower Black Calera Limestone); in this facies contents of organic matter are usually greater than 2% (W a c h s and H e i n, 1974). Unlike the overlying Upper White Calera Limestone, the organic-rich facies lacks planktonic foraminifera; Radiolaria and nannofossils are common to both sedimentary units.

We suspect that organic carbon-rich sediments will be found in mid- and upper Cretaceous sections throughout the world.

DISCUSSION

From the above data it is clear that two "Oceanic Anoxic Events" stand out from the welter of such phenomena in the Cretaceous: one in the Aptian – Albian, the other in the Cenomanian – Turonian. Particularly significant, in the case of the Cenomanian – Turonian event, is the fact that its record is found in a great variety of settings, including broad rises and plateaus in the open Pacific, the Tethyan continental margins and the shallow shelf of northeastern Europe where the Black Band of Yorkshire and Lincolnshire was deposited within a chalk sequence probably laid down in water as shallow as 300 metres (S c h o l l e, 1974; K e n n e d y and G a r r i s o n, 1975). Yet the terrestial record at least is laterally discontinuous. Nevertheless the geographic range and stratigraphic restriction of the Aptian – Albian and Cenomanian – Turonian Oceanic Anoxic Events suggests that an explanation should be sought that goes beyond the invocation of local submarine topography to restrict the inflow of oxygenated bottom water of the world ocean to the basin. H a l l a m (1967) stated that the "barred basin" model was inadequate to explain numerous bituminous shale occurrences and pointed out that equable climates and widespread epicontinental seas could foster such deposits.

We suggest that the two events documented in this paper are directly related to the Late Cretaceous transgression well-known to stratigraphers (Fig. 1) and recently quantified and placed in a plate-tectonic framework (G i g n o u x, 1955; H a y s and P i t m a n, 1973; P o m e r o l, 1975).
In the Hays-Pitman model a pulse of rapid sea floor spreading during Cretaceous time was accompanied by an increase in the volume of the mid-ocean ridge system; this in turn led to a major transgression of the sea over the low-lying Cretaceous coastal plains. During this period the climate was mild and equable; in high latitudes plants characteristic of warm temperature and subtropical environments were abundant. The higher latitudes were probably not as abundant sources of oxygenated sinking cold water as they were in Cenozoic time and are now. Furthermore the central tropical belt was quite wide. According to the Hays-Pitman model, between Barremian – Aptian and Cenomanian – Turonian time or between 112-115 and 86-88 my BP respectively (v a n H i n t e, 1976) 35 $\times 10^6 km^2$ of new epicontinental seas less than 300 metres deep were formed. This was in addition to the 33 $\times 10^6 km^2$ of the present continents that were already covered by shallow epicontinental seas. At the present time the area of all small mediterranean seas, such as the Baltic Sea, is 2.33 $\times 10^6 km^2$ and their collective mean depth is 172 metres; the area of all marginal seas such as the North Sea and East China Sea is 8.1 $\times 10^6 km^2$ and their collective mean depth is 874 metres (S v e r d r u p, J o h n s o n and F l e m i n g, 1942). The present surface area of the oceans, including adjacent seas, is 360 $\times 10^6 km^2$. Ninety million years ago the oceanic area was 430 $\times 10^6 km^2$, 68 $\times 10^6 km^2$ of which was probably less than 500 metres deep (H a y s and P i t m a n, 1973). The ratio of surface area of all small

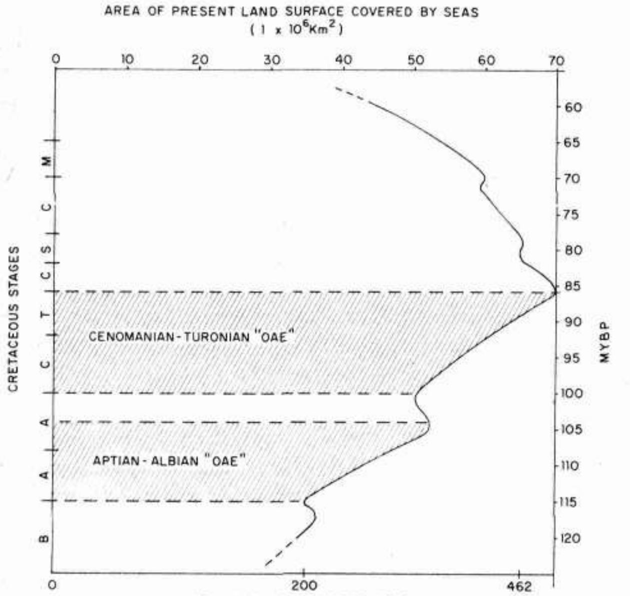

Fig. 1.
The Aptian-Albian and Cenomanian-Turonian "Oceanic Anoxic Events" and the Cretaceous transgression. The "OAE" boundaries dashed lincs are shown to coincide with the two major transgressive pulses that took place between the beginning of the Aptian stage and the end of the Turonian stage. The boundaries themselves should be thought of as enclosing a period of time during which Oceanic Anoxic Events were frequent and prolonged;we do not mean to imply that during the whole of Cenomanian – Turonian time the entire worls ocean war undergoing a pringle, continuous "OAE". Date on the ages in myBP for the Cretaceous stages are from van Hinte Pomerol (1975) and Hays and Pitman (1973) as are the data on land surface area and sea level.

mediterranean and marginal seas to the surface area of the world oceans is 0.03:1 whereas at 90 myBP it was at least 0.16:1.

We suggest that under these climatic and hypsographic conditions the absolute amount of organic carbon produced per year in the world ocean increased (assuming no limiting factor such as nutrient supply) the amount of 0_2 renewal in the bottom waters decreased and therefore the potential for development of thick, widespread 0_2-minimum zones increased independently of local basin geometry. Of the 23 x 10^9 tons of carbon formed in the upper illuminated layer of the world ocean 8.7 x 10^9 tons, or 37% of the total, is produced in that part (13.6% surface area) that is classified as inshore or neritic (K o b l e n t z-M i s c h k e et al., 1970; M e n z e l, 1974). Thus the change in the ratio of small mediterranean plus marginal seas to world ocean surface area from 0.03:1 to 0.16:1 would greatly increase the organic carbon produced per year.

production. Even though only approximately 3% of the organic carbon produced reaches the sediment-water interface (M e n z e l, 1974) the total escaping recycling in the upper layer would have increased. At the same time this higher carbon input to the deeper water masses would encounter lower dissolved 0_2 concentrations due to the relative paucity of new oxygen-rich bottom water being formed in the world ocean. This would tend to allow vertical and horizontal expansion of the 0_2-minimum layer. At the present time thick widespread water layers with marked 0_2 minima exist under regions of high surface productivity in the eastern tropical Atlantic and Pacific.

Dissolved oxygen concentrations of 0.1 – 0.2 ml/1 are known to persist from within less than 100 metres of the surface to depths of as much as 1200 metres; along coasts affected by strong upwelling the top of the minimum layer can be as shallow as 40-50 metres (B or o n g e r s m a-S a n d e r s, 1971; R i c h a r d s, 1965).

We suggest that during significant periods within Aptian – Albian and Cenomanian – Turonian time large regions of the world ocean were characterized by strongly developed oxygen minimum layers that reached to within less than 300 metres of the surface (in order to account for the Black Band of Yorkshire and Lincolnshire in the shallow shelf-sea chalk) intersected oceanic plateaus and extended downward to continental margins (ca. 2000 – 3000 m). S c h o l l e and A r t h u r (in press) note that a major carbon isotopic fluctuation took place near the Cenomanian – Turonian boundary and relate this fluctuation to a change in oceanic circulation in the Atlantic which produced an expanded oxygen minimum layer. This chemical evidence supports the stratigraphic argument presented here for an Oceanic Anoxic Event during Cenomanian – Turonian time. According to our model (Fig. 2) any sediment-water interface in the world oceans that lay within this depth range had a high probability of being exposed, at least intermittently, to reducing conditions brought on by the lack of dissolved 0_2; organic carbon-rich sediments could then accumulate and be preserved.

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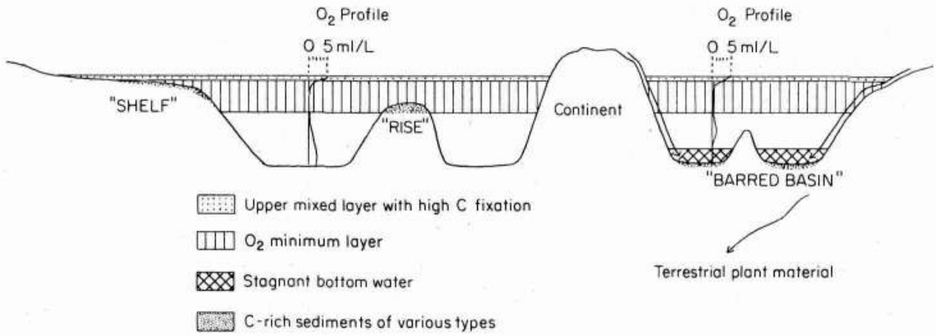

Fig. 2.
Stratification during an "Oceanic Anoxic Event". The 0_2 minimum layer (schematically shown) is widespread and more continuous and thicker than at present-reaching down to the tops of oceanic rises such as the Manihiki Plateau. Three types of organic carbon-rich sediments accumulate: a SHELF TYPE such as the Black Band of Yorkshire and Lincolnshire (these may be locally intensified by the introduction of terrestrial organic material from large rivers); a RISE TYPE such as described from the Hess and Shatsky Rises and the Manihiki Plateau (these should be relatively free of terrestrial plant debris); and a BARRED BASIN TYPE such as is found in the Atlantic and Caribbean Basins (these contain abundant terrestrial plant debris delivered to these basins in thier early opening stages by rivers and turbidity currents).

REFERENCES

Barnaba, P.F. (1958) – Geologia dei Monti di Gubbio – Boll. Soc. geol. Ital., 77/3, 39-70.

Berger, W.H. and U. von Rad (1972) – Cretaceous and Cenozoic Sediments from the Atlantic Ocean, in: Hayes, D.E. and A.C. Pimm et al., Initial Reports of the Deep Sea Drilling Project, v. 14 (U.S. Government Printing Office, Washington), 787-954.

Berger, W.H. and E.L. Winterer (1974) – Plate stratigraphy and the fluctuating carbonate line, in: Hsü, K.J. and H.C. Jenkyns, eds., Pelagic Sediments: in Land and under the Sea – Spec. Publi. Int. Assoc. Sedimentol., 1, 11-48.

Bernoulli, D. and H.C. Jenkyns (1974) – Alpine, Mediterranean and central Atlantic Mesozoic facies in relation to the early evolution of the Tethys, in: Dott, R.H. Jr. and R.H. Shaver, eds., Modern and ancient geosynclinal sedimentation – Spec. Publ. Soc. econ. Paleont. Miner., 19, 129-160.

Bitterli, P. (1963) – Aspects of the genesis of bituminous rock sequences – Geol. Mijnb. 42, 183-201.

——, (1965) – Bituminous intercalations in the Cretaceous of the Breggia River, S. Switzerland – Bull. Ver. Schweiz. Petrol. -Geol. u. -Ing., 31, 179-185.

Bolli, H.M. and R.W. Ryan et al. (1975) – Basins and margins of the eastern south Atlantic – Geotimes, 20,6, 22-24.

Brongersma-Sanders, M. (1971) – Origin of major cyclicity of evaporites and bituminous rocks: an actualistic model – Marine Geology, 11, 123-144.

Dürr, St.H. (1967). – Geologie der Serrania de Ronda und Ihrer Südwestlichen Ausläufer (Andalusien) – Geol. Romana, 6, 1-73.

Davies, T.A., B.P. Luydenijk et al. (1974) – Initial Reports of the Deep Sea Drilling Project, v. 26 (U.S. Government Printing Office, Washington), 1129 pp.

Decandia, F.A. and P. Elter (1972) – La "zona" ofiolitifera del Bracco nel settore compreso fra Levanto e la Val Graveglia (Appennino Ligure) – Mem. Soc. geol. Ital., 11, 503-530.

Dunbar, C.O. and K.M. Waage (1969) – Historical Geology. J. Wiley and Sons, New York, 556 pp.

Frush, M.P. and D.L. Eicher (1975) - Cenomanian and Turonian Foraminifera and palaeoenvironments in the Big Bend region of Texas and Mexico, in: Caldwell, W.G.E., ed., The Cretaceous System in the Western Interior of North America – Spec. Pap. Geol. Assoc. Canada, 13, 277-301.

Fuganti, A. (1961) – Ricerche geologiche e giacimentologiche sugli "scisti bituminosi uraniferi" de Mollaro (Val di Non-Trentino) – Studie Trentini Sci.nat., 41/1, 73-110.

Gignoux, M. (1955) – Stratigraphic Geology. Freeman, San Francisco, 682 pp.

Hallam, A. (1967) – The depth significance of shales with bituminous laminae – Marine Geology, 5, 481-493.

Hays, J.D. and W.C. Pitman (1973) – Lithospheric plate motion, sea level changes and climatic and ecological consequences – Nature, 246, 18-22.

Hedberg, H.D. (1937) – Stratigraphy of the Rio Querecual section of northeastern Venezuela – Bull. geol. Soc. Am., 48, 1971-2204.

——, (1950) – Geology of eastern Venezuela – Bull. geol. Soc. Am., 61, 1173-1215.

Jackson, E.D. and S.O. Schlanger (1976) – Regional Synthesis, Line Islands Chain, and Manihiki Plateau, Central Pacific Ocean, DSDP Leg 33, in: Schlanger, S.O. and E.D. Jackson et al., Initial Reports of the Deep Sea Drilling Project, v. 33, (U.S. Government Printing Office, Washington), 915-927.

Jefferies, R.P.S. (1963) – The stratigraphy of the *Actinocamax plenus* subzone (Turonian) in the Anglo-Paris Basin – Proc. Geol. Assoc., 74, 1-31.

Jenkyns, H.C. (1976) – Sediments and sedimentary history of the Manihiki Plateau, South Pacific Ocean, in: Schlanger, S.O. and E.D. Jackson et al., Initial Reports of the Deep Sea Drilling Project, v. 33 (U.S. Government Printing Office, Washington), 873-890.

Kaneps, A. (1976) – Deep Sea Drilling Project – Geotimes, 21,1, 16-17.

Kennedy, W.J. and R.E. Garrison (1975) – Morphology and genesis of nodular chalks and hardgrounds in the Upper Cretaceous of southern England – Sedimentology 22, 320-321.

Koblentz-Mischke, O.J., V.V. Volkovinsky and J.G. Kabanova (1970) – Plankton primary production of the world ocean, in:

Wooster, W.S., ed., Scientific Exploration of the South Pacific, Nat. Acad. Sci., Washington), 183-193.

Kugler, H. (1953) – Jurassic to Recent sedimentary environments in Trinidad – Bull. Ver. Schweiz. Petrol.- Geol. u. – Ing., 20, 27-60.

Lancelot, Y, J.C. Hathaway and C.D. Hollister (1972) – Lithology of sediments from the western north Atlantic, Leg 11, DSDP, in: Hollister, C.D., J.I. Ewing et al., Initial Reports of the Deep Sea Drilling Project, v. 11 (U.S. Government Printing Office, Washington), 901-949.

Lancelot, Y. and E. Seibold et al. (1975) – The eastern north Atlantic – Geotimes 20,7, 18-21.

Lancelot, Y. and R.L. Larson (1975) – Sedimentary and tectonic evolution of the northwestern Pacific, in: Larson, R.L., R. Moberly et al., Initial Reports of the Deep Sea Drilling Project, v. 32 (U.S. Government Printing Office, Washington), 925-941.

Mascle, G. (1970) – Geological sketch of western Sicily, in: Alvarez, W. and K.H.A. Gohrbandt, eds., Geology and History of Sicily – Petrol. Explor. Soc. Libya, Tripoli, 231-234.

Menzel, D.W. (1974) – Primary productivity, dissolved and particulate organic matter and the sites of oxidation of organic matter, in: Goldberg, E.D., ed., The Sea 5, 659-679 (Wiley, New York).

Moberly, R. and R.L. Larson (1975) – Mesozoic magnetic anomalies, oceanic plateaus, and seamount chains in the northwestern Pacific Ocean, in: Larson, R.L., R. Moberly et al., Initial Reports of the Deep Sea Drilling Project, v. 32, (U.S. Government Printing Office, Washington), 945-957.

Perch-Nielsen, K., P. Supko et al. (1975) – Facies changes in the south Atlantic – Geotimes 20,3, 26-28.

Pomerol, Ch. (1975) - Stratigraphie et Paléogéographie, v. 2, Ere Mésozoïque (Doin, Paris), 383 pp.

Richards, R.F. (1965) – Anoxic Basins and Fjords, in: Riley, J.P. and G. Skirrow, eds., Academic Press, New York, 611-655.

Saunders, J.B., N.T. Edgar, T.W. Donelly and D.W. Hay (1973) – Cruise Synthesis, in: Edgar, N.T., J.B. Saunders et al., Initial Reports of the Deep Sea Drilling Project, v. 15 (U.S. Government Printing Office, Washington), 1077-1111.

Schlanger, S.O., E.D. Jackson et al. (1976) – Initial Reports of the Deep Sea Drilling Project, v. 33 (U.S. Government Printing Office, Washington), 973 pp.

Scholle, P.A. (1974) – Diagenesis of Upper Cretaceous shalks from England, Northern Ireland and the North Sea, in: Hsü, K.J., and H.C. Jenkyns, eds., Pelagic Sediments: on Land and under the Sea – Spec. Publ. Int. Assoc. Sedimentol., 1, 177-210.

Scholle, P.A. and M. Arthur (in press) – Carbon isotopic fluctuations in Upper Cretaceous sediments: An indicator of paleo-oceanic circulation (abstract) – Bull. geol. Soc. Am.

Sverdrup, H.V., M.W. Johnson and R.H. Fleming (1942) – The Oceans, their Physics, Chemistry and general Biology. (Prentice-Hall, New Jersey), 1087 pp.

Van Hinte, J.E. (1976) – A Cretaceous time scale – Bull. Am. Ass. Petr. Geol., 60, 498-516.

Veevers, J.J., J.R. Heitzler et al. (1974) – Initial Reports of the Deep Sea Drilling Project, v. 27 (U.S. Government Printing Office, Washington), 1060 pp.

Winterer, E.L., J. Ewing et al. (1973) – Initial Reports of the Deep Sea Drilling Project, v. 17 (U.S. Government Printing Office, Washington), 930 pp.

Winterer, E.L., P.F. Lonsadale, J.L. Matthews and B.R. Rosendahl (1974) – Structure and acoustic stratigraphy of the Manihiki Plateau – Deep Sea Research 21, 793-814.