Cretaceous Oceanic Redbeds: Implications for Paleoclimatology and Paleoceanography

WANG Chengshan[1,3], HUANG Yongjian[1], HU Xiumian[2] and LI Xianghui[1]
1 *State Key Laboratory of Oil/Gas Reservoir Geology and Exploration, Chengdu University of Technology, Chengdu, Sichuan 610059; E-mail: wcs@cdut.edu.cn*
and *College of Earth Science, Chengdu University of Technology, Chengdu, Sichuan 610059*
2 *Department of Earth Science, Nanjing University, Nanjing, Jiangsu 210096*
3 *China University of Geosciences, Beijing 100083*

Abstracts The Cretaceous is among the most unusual eras in the geological past. Geoscience communities have been having great concerns with geological phenomena within this period, for example carbonate platforms and black shales in the Early and Middle Cretaceous respectively, during the last decades. But few people have paid any attention to the set of pelagic redbeds lying on the black shales, not to mention the applications to paleoclimatology and paleoceanography. It is shown by the sedimentary records of redbeds, that they were deposited around the CCD, with both a higher content of iron and much lower concentrations of organic carbon, which implies conditions with a relatively high content of oxygen. Such redbeds occurred in the global oceans, mainly in the Tethyan realm, with different durations of deposition and a climax from the late Santonian to early Campanian. Global cooling and dramatic changes in ocean currents might help to increase the oxygen flux between the atmosphere and ocean, after the large scale organic carbon burial during the Middle Cretaceous, and therefore lead to the oxygenation of deep ocean and so the occurrence of late Cretaceous oceanic redbeds.

Key words: Cretaceous, oceanic redbeds, paleoclimate, paleoceanography

1 Introduction

It is thought traditionally that a greenhouse climate predominated in the Cretaceous world, and the related geological phenomena, for example carbonate platforms and black shales, have been paid much attention to by the international geoscience communities, during the past tens of years (Berrera and Johnson, 1999). There is still a big progress to be made in understanding the evolutionary mechanisms of paleocean and paleoclimate at that time, although a series of geological programs and projects has been conducted which increase our understanding about the Cretaceous greenhouse climate (Bice et al., 2002). The discovery of Cretaceous oceanic redbeds (CORBs) allows us to extend our studies of the Cretaceous paleocean and paleoclimate (Wang et al., 2000a, 2003; Hu et al., 2003), which is the aim of the two newly founded IGCP projects, i. e. IGCP 463/494. From an earth system science prospective, and within the framework of IGCP project, this research will correlate the global CORBs, elucidating its genesis and applications to paleoclimatology and paleoceanography, which is of much importance for understanding the evolution of the paleoceanic/ atmospheric system after the occurrence of oceanic anoxic events (OAEs).

2 Question: Why CORB ?

The complete Cretaceous stratigraphic section is exposed near the Chuangde Village, Gyangzê region, southern Tibet (Fig. 1, Wang et al., 2000b; Li et al., 1999). In the Gyabula Formation of the Berremian-Santonian stage, the black shale of Cenomanian-Turonian Boundary (CTB) can be found and was proved to be the product of global oceanic events (Wang et al., 2001b).

The Chuangde Formation lies on the top of the Gyabula Formation with an age from the Santonian to Campanian (Hu, 2002; Wan et al., 2003), and a thickness of 40 m (Fig. 1), composed of amaranth, maroon lime and marls intercalated with layers of amethyst shales and siliceous shales. Calcirudite and slump rocks with heterogenous glauconite appear above the boundary between the Chuangde and Gyabula formations, implying deposition within a debris flow. Neither are there any signs of shallow-water structure in the rock layers, nor terrigenous silty debris. The assemblage of planktonic foraminifora and radiolarian suggests a pelagic deposition environment, which would be in the lower slope-basin around the CCD. This deposition depth is also proved by such phenomena, for example, the erosion of foraminiforan fossils in the siliceous shales, and the deposition of gravity flux in the upper part of the Chuangde Formation.

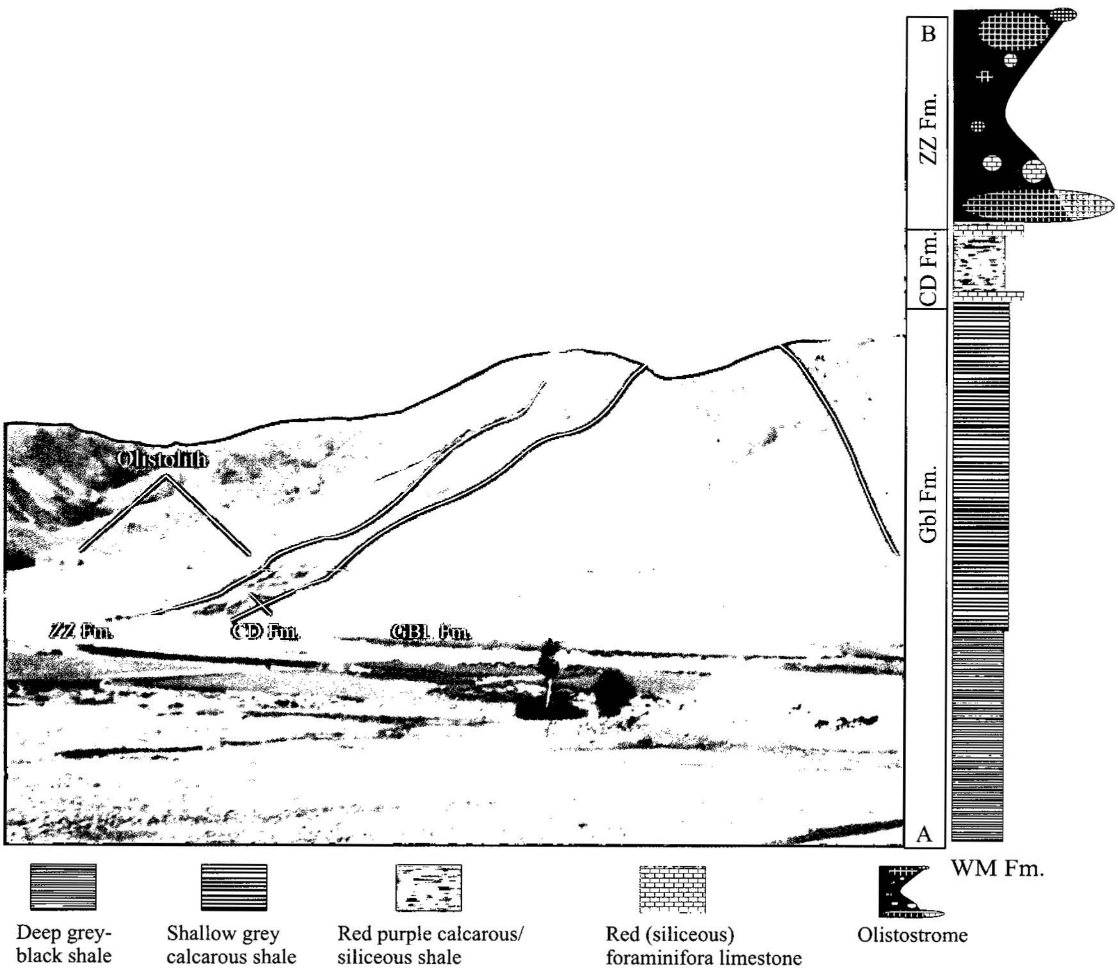

Fig. 1. Cretaceous outcrop and its stratigraphic interpretation in Chuangde, Gyangzê, southern Tibet. CD Fm. – Chuangde Formation; GBL Fm. – Gyabula Formation; ZZ Fm. – Zongzhong Formation; WM Fm. – Weimei Formation of the Upper Jurassic.

Petro-geochemical data indicate a rather dramatic change with the increase of the $Fe^{3+}/(Fe^{2+}+Fe^{3+})$ratio from 0.51 to 0.99, corresponding to the transition from black to red shales. It is the existence of hematite that makes the rock become red. X-Ray diffraction results demonstrate that hematite occurred as minute non-crystal particles dissipated in the redbeds, a product of the early diagenesis around the interface of water-sediment, suggesting high oxygenation conditions in the bottom water. The abundance of organic carbon also shows dramatic reduction from 0.5 (22 samples) to 0.1 (8 samples) percent, even less, during this black to red bed transition. When one considers the modern ocean, very few pelagic red carbonates occur, except for the aeolian red clays in the northern Pacific. Earlier researchers preferred other explanations, such as the "short oscillation of reduction-oxygenation in the bottom water caused by turbidites " or "paleogeographic change in local area", for the occurrence of CORB (Gorur et al., 1993), which is not the case (Tuysuz and Yikilmaz, 2003). Thus, why did these special oxygenized sediments occur? Did they occur only locally, or on the other hand, globally? If the latter is the case, then what is the paleoclimatological and paleoceanographic significance of CORBs?

3 Characteristics of Global CORBs and Their Temporal and Spatial Distribution

After a comprehensive collection of data on CORBs from different parts of the world (Sarti and Hu, 2002; Tuysuz and Yikilmaz, 2003; Table 1), CORB have shown signs of global distribution (Fig. 2, Norris et al., 2001; Hu, 2002; Bralower et al., 2002; Shipboard Scientific Party, 2002, 2003; Hu et al., 2003), compared to that of Middle Cretaceous black shales.

It seems that CORB appeared predominantly in the later Cretaceous, after the occurrence of OAEs, and were affected by local tectonism and deposition of turbidites

Table 1 Comparison of the typical characteristics of the CORBs from seven typical areas in the world

Area	North Atlantic	Italy	Austria	Poland	Turkey	Tibet	Exmouth, Australia
Upper Cretaceous Red beds	Plantagenet	Scaglia Rossa	Nierental	Pustelnia marl Macelowa marl	Kapanboğazi	Chuangde	Upper Cretaceous carbonate
Color	varicolored, yellow-olive, pink, red	red, white	red, gray, white	red, gray	red	red	red-olive, gray-green
Thickness (m)	92.3	200–400	400	–	40	~30	93.5
Age	early Turonian - Paleocene	early Turonian-middle Eocene	late Campanian-Maastrichtian	early Cenomanian - early Campanian	late Cenomanian-Campanian	Santonian-Campanian	early Campanian-early Maastrichtian
Lithology	mudstone	limestone, marlstone, shale, chert	shale, marlstone	marlstone, shale	limestone, marlstone	shale, marlstone, chert	mudstone, marlstone
Sedimentation rate	1–3 mm/ka	5–12 mm/ka	6–26 mm/ka	1–4 mm/ka in shallow water, 8–23 cm/ka in deep water	–	2–10 mm/ka	18.2 mm/ka
TOC (%)	0.3	0.07–0.17	–	–	–	0.11	0.00–0.005
CCD	below	above	near	above	above	near	above
Turbidity current	none	frequent	frequent	few	few	few	none
Red beds in strata	all	all except turbidite	all except turbidite	all	all	all	high-frequency cycle with shale
Sedimentary environment	deep basin below CCD	pelagic basin to slope	slope	pelagic	pelagic	pelagic slope to basin	outer shelf to hemipelagic

Note: Please see the text for the data sources.

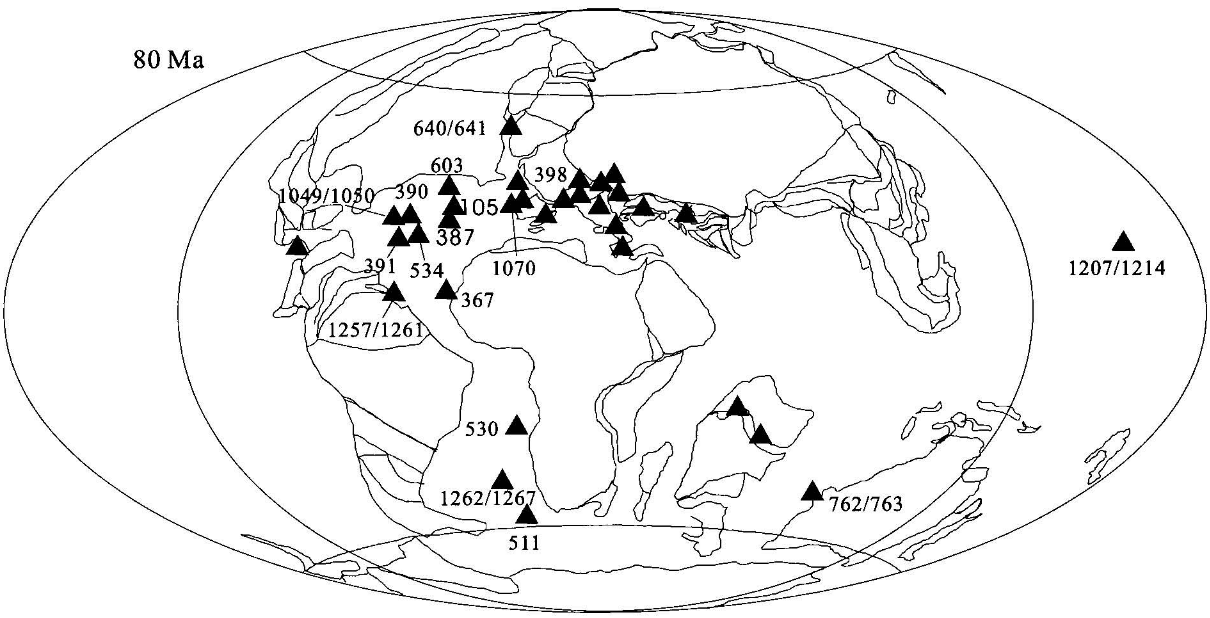

Fig. 2. Paleogeographic localities of CORBs in the Late Cretaceous.

Note: Please see the text for data sources. The base map is a paleogeographic map of 80 Ma in the Campanian stage, downloadeded from http://www.odsn.de/odsn/services/paleomap/paleomap.html.

(Gorur et al., 1993). Both the start and end of CORB deposition in different parts of the world were not synchronized, with a notable global climax during the late Santonian-early Campanion. CORBs are mainly distributed in deep-water environments of low-latitude regions in the global oceans, including the Tethyan, Atlantic, Indian and Pacific Oceans. Oceanic domains involved include the continental slope, oceanic basin, outer shelf and seamount. Because of difference in the degrees of influence imposed by tectonism, much of the CORBs can be found in the western Tethys and North Atlantic, while less remains in the orogenic zone of the eastern Tethys and on the seamounts of the Pacific Ocean. Red shales, red marls and limes, and red siliceous shales compose the litho-types of the CORBs.

According to the outcome of the global correlation, the most significant geochemical characteristics of global CORB are of low levels of organic carbon, less than 0.1%, and of high contents of hematite, 10% in the red shales at most, as the product of in-situ oxygenation in the early diagenesis (Eren et al., 2001), suggesting high levels of oxygenation during deposition.

4 CORBs and Their Ipplications to Paleoceanography and Paleoclimatology

It is suggested by various lines of evidences that the Cretaceous experienced three stages of evolution of greenhouse climate, i.e., the warm, hot and cool greenhouse, approximately corresponding to Early, Middle and Late Cretaceous. With the highest temperature at the Cenomanian-Turonian Boundary, it generally became colder from the Coniacian to Maastrichtian (Barrera and Johnson, 1999; Stoll and Schrag, 2000), which favored the increase of dissolved oxygen contents of oceans. The amplitude of dropping in temperature from the Coniacian to early Campanian, coinciding with the climax of CORB deposition, is strongest in this whole process, with evidences being found in every ocean of the world (Jenkyns, et al., 1994; Clarke and Jenkyns, 1999). The reason for this general trend of global cooling in the Late Cretaceous has been ascribed predominantly to the reduction of warmhouse effects of CO_2, levels of which in the oceanic/atmospheric system had decreased dramatically as a result of weakening of oceanic volcanism including the ocean crust production and LIPs (large igneous province) at that time, and the large scale burial of organic carbon (Arthur et al., 1988; Larson, 1991b) during the Middle Cretaceous.

The global cooling during the Late Cretaceous would favor the increase of equator-pole temperature gradient, which drives the oceanic currents and formation deepwater in the high-latitude region, and therefore, the transportation of oxygen to the deep ocean. Poulsen et al. (2001) have pointed out that the cycle of the global ocean had stengthened considerably after OAE2 at the Cretaceous-Tertiary Boundary, due to the initiation of a deep connection between the North and South Atlantic ocean; and the deepwater of global ocean had been oxygenated completely with the southern pole as the source regions of deepwater, which is in accordance with the occurrence of CORB. Hay (1995) emphasized, however, the importance of low-latitude region for the deepwater. It is worthy of further consideration, if there are any relationships between the low-latitude distribution of CORBs and the in-situ deepwater. On the other hand, the atmospheric oxygen content in the Late Cretaceous was relatively high compared with other periods of the Phanerozoic (Berner et al., 2003); then with the combination of global cooling and the dramatic change in the ocean currents, the oxygen flux between the ocean and atmosphere were certain to increase, which is favorable to the occurrence of CORBs and their global distribution.

Acknowledgements

The research is jointly supported by the Key Project of the National Natural Science Foundation of China (No. 40332020), Prophase Special Research of Vital Projects in the Basic Research of the Ministry of Science and Technology of China (No. 2001CCA01800), International Geological Correlation Program (IGCP463/494). Thanks are also given to Professor Massimo Sarti of the University of Ancona, Italy, Professor Luba Jansa of the Atlantic Geological Survey of Canada, Professor Robert Scott of Tulsa University for providing part of the data and their helpful suggestions.

Manuscript recived Jan, 10, 2004
accepted March 18, 2004
edited by Xie Guanglian

References

Arthur, M.A., Dean, W.E., and Pratt, L.M., 1988. Geochemical and climatic effects of increased marine organic carbon burial at the Cenomanian/Turonian boundary. *Nature*, 335: 714–717.

Barrera, E., and Johnson, C.C., 1999. *Evolution of the Cretaceous Ocean-Climate System*. Geological Society of America Special Paper, 332: 1–445.

Berner, R.A., Beerling, D.J., Dudley, R., Robinson, J.M., and Wildman, R.A., 2003. Phanerozoic atmospheric oxygen. *Ann. Rev. Earth Planet. Sci.*, 31:105–34.

Bice, L.K., Bralower, J.T., Duncan, A.R., Huber, T.B., Leckie, M. R., and Sageman, S.B., 2002. *Cretaceous Climate-Ocean Dynamics: Future Directions for IODP. Workshop on Cretaceous Climate and Ocean Dynamics*, Nature Place, Florissant, Colorado, 14–17.

Bralower, T.J., Premoli Silva, I., and Malone, M.J., 2002. New evidence for abrupt climate change in the Cretaceous and Paleogene: An Ocean Drilling Program expedition to Shatsky Rise, northwest Pacific. *GSA Today*, 12(11): 1–10.

Clarke, L.J., and Jenkyns, H.C., 1999. New oxygen isotope evidence for long-term Cretaceous climatic change in the Southern Hemisphere. *Geology*, 27: 699–702.

Eren, M., and Kadir, S., 2001. Color genesis of Upper Cretaceous palegic red sediments within the Eastern Pontides, NE Turkey. *Yerbilimeri*, 24: 71–79.

Gorur, N., Tuysuz, O., Aykol, A., Sakinc, M., Yigitbas, E., and Akkok, R.,1993. Cretaceous red pelagic carbonates of northern Turkey: Their place in the opening history of the Black Sea.

Eclogae Geol. Helv., 86(3): 819–838.

Hay, W.W., 1995. Cretaceous paleoceanography. *Geologica Carpathica*, 46: 257–266.

Hu Xiumian, 2002. *Sedimentary Geology in the Southern Tibet and the Upper Cretaceous Marine Redbeds-the Oceanic Oxic Events.* Doctoral Dissertation, Chengdu University of Technology, Chengdu (in Chinese with English abstract).

Hu Xiumian, Wang Chengshan, Jansa, L., Sarti, M., and Scott, R., 2003. Prelimilary result of global correlations of the Upper Cretaceous oceanic red beds (CORB): distributions, compositions, age, and environments. *Cretaceous Research*, (submitted).

Jenkyns, H.C., Gale, A.S., and Corfield, R.M., 1994. Carbon and oxygen isotope stratigraphy of the English Chalk and Italian Scaglia and its paleoclimatic significance. *Geol. Mag.*, 131: 1–34.

Larson, R. L., 1991b. Latest pulse of the Earth: Evidence for a mid-Cretaceous superplume. *Geology*, 19: 547–550.

Li Xianghui, Wang Chengshan, Wan Xiaoqiao and Tao Ran, 1999. Verification of stratigraphical sequence and classification of Chuangde Section of Gyangzê, South Tibet. *J. Stratigr.*, 23(4): 303–309 (in Chinese with English abstract).

Norris, R.D., Kroon, D., and Klaus, A., 2001. Cretaceous-Paleogene climatic evolution of the western North Atlantic: results from ODP Leg 171B, Blake Nose. In: Kroon, D., Norris, R.D., and Klaus, A. (eds.), Proc. ODP, Sci. Results, 171B [Online]. Available from World Wide Web: http://www-odp.tamu.edu/publications/171B_SR/intro/intro.htm.

Poulsen, J.C., Barron, J.E., Arthur, A.M., and Peterson, H.W., 2001. Response of the mid-Cretaceous global oceanic circulation to tectonic and CO_2 forcings. *Paleoceanography*, 16 (1): 1–17.

Sarti, M., and Hu Xiumian, 2002. *Abstracts and Programs: Upper cretaceous oceanic redbeds: response to ocean/climate global chang.* 2002 Workshop of IGCP 463, Ancona, Italy, 1–115.

Shipboard Scientific Party, 2002. Leg 207 Preliminary Report. *ODP Prelim. Rpt.*, 107. http://www-odp.tamu.edu/publications/prelim/207_prel/ 207PREL.PDF.

Shipboard Scientific Party, 2003. Leg 208 Preliminary Report. *ODP Prelim. Rpt.*, 108 [Online]. http://www-odp.tamu.edu/publications/prelim/208_prel/ 208PREL.PDF.

Stoll, H.M., and Schrag, D.P., 2000. High-resolution stable isotope records from the Upper Cretaceous rocks of Italy and Spain: Glacial episodes in a greenhouse planet? *GSA Bulletin*, 112: 308–319.

Tuysuz, O., and Yikilmaz, B. (eds.), 2003. *Abstracts and Guide Book: Upper cretaceous oceanic redbeds: response to ocean / climate global change.* 2003 Workshop of IGCP 463, Bartin, Turkey, 1–118.

Wan Xiaoqiao, Lamolda, A.M., Li Guobiao and Si Jialiang, 2003. Foraminiferal stratigraphy of Cretaceous red beds in Southern Tibet. *Cretaceous Research* (submitted).

Wang Chengshan, Hu Xiumian, Jansa, L., Sarti, M., Scott, W. R., and Li Xianghui, 2003. Upper Cretaceous oceanic redbeds in southern Tibet: a major change from anoxic to oxic condition. *Cretaceous Research* (submitted).

Wang Chengshan, Hu Xiumian, Jansa, L.F., Wan Xiaoqiao and Tao Ran, 2001b. The Cenomanian-Turonian oceanic anoxic event in southern Tibet. *Cretaceous Research*, 22 (4): 514–526.

Wang Chengshan, Hu Xiumian, Li Xianghui and Jansa, L., 2000a. Late Cretaceous Oceanic Oxic Event in Tibetan Himalayas, In: *6th Internal Cretaceous Symposium*, Viena, Vienna, 143.

Wang Chengshan, Li Xianghui, Wan Xiaoqiao, Tao Ran, 2000b. The Cretaceous in Gyangze, southern Xizang (Tibet): Redefined. *Acta Geologica Sinica* (Chinese edition), 74(2): 97–107 (in Chinese with English abstract).