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Proterozoic-Cambrian Phosphorites

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A Brine-leaching Mechanism of Phosphorite Genesis

by *R.A. Henderson, C. Cuff* and *P.N. Southgate,* James Cook University of North Queensland, Townsville

Many geologists regard upwelling waters as fundamental to phosphate genesis but such a circumstance is difficult to sustain for the extensive Middle Cambrian phosphorites of the Georgina Basin, northeastern Australia. The Georgina Basin is a platform terrain of truly cratonic nature, underlain by Precambrian crystalline basement, which extends for several hundred km beyond the basin margin in every direction. It follows that outer shelf environments in which upwelling might be expected to apply, are foreign to the sedimentary context of the Georgina Basin. Indeed lithographical data for the phosphorite and its enclosing stratigraphy is consistent with their deposition in a shallow water, inner shelf situation.

Georgina phosphorites are typically underlain by an interval of what was black, organic-rich shale prior to weathering. This in turn passes down to a leached, collapsed horizon formerly occupied by an evaporite of uncertain original thickness, now represented entirely by chert pseudomorphs. The nature of "collapse-related" deformation structures suggest that evaporite dissolution was an early diagenetic event which took place before the accretion of a substantial overburden and lithification of the overlying shale.

It is proposed that the black shales represent a disseminated phosphate source and that brines derived from dissolution of the evaporite, leached phosphate during their upward migration towards the seafloor. The efficiency of brines as a phosphate leaching agent has been assessed by a computer-based modelling technique (WATEC) using all pertinent, currently available phosphate solubility data. Concentrated brines, largely through the agency of Mg-ion pairing, show a dramatic increase in phosphate solubility relative to normal seawater. Seawater concentrated to a tenth of its volume has its phosphate solubility potential increased by two orders of magnitude.

We believe that phosphate concentrated and transported in this way was precipitated near the sediment/seawater interface where the brines must have experienced dilution and eventual oversaturation in phosphate. Mechanisms involving calcium carbonate replacement, probably under kinetic control, appear to have been important in nucleating apatite precipitation. Petrographic data suggest that most clasts of pelletal phosphorite varieties are replacements of calcium carbonate precursors. We believe the final concentrating process to have been mechanical. Submarine reworking of the sediment column is thought to have occured, leaving clean well sorted pelletal phosphorite, typical of the Georgina deposits, essentially as a lag accumulate.

The genetic model argued here for the Georgina Basin phosphorites may be of general application. A black shale-dolomite-chert association characterises many other deposits. Evaporites are also associated with some, but for most they have probably been removed by dissolution, as is the case for the Georgina Basin sequence.

The Role of Cyclic Sedimentation in the Formation of Phosphorite Deposits

by *E.A. Eganov,* Institute of Geology & Geophysics USSR Academcy of Sciences, Novosibirsk.

High-grade bedded phosphorites are confined to those parts of carbonate sequences which contain layers of clayey, cherty and silty-sandy rocks. They are, in addition, frequently confined to particular portions of the sequence. Studies of the distribution of carbonate cherty shaly and clastic beds from various sedimentary phosphate deposits show that these beds occur in a particular cyclical order. Cyclical phosphate-bearing sections were established some time ago for the Permian Western Phosphate Field in the USA. More recently, similar cycles were established for phosphorite deposits in northern Mongolia (Upper Precambrian, Hubsugul Basin) by I. Semeykin and others, and subsequently by the present author in Lower Cambrian phosphate-bearing sections in Karatau (Kazakhstan, USSR). Comparison of sequences in major phosphorite deposits in the Lower Cambrian of China, and Mesozoic and Paleogene deposits of North Africa and Asia Minor, reveal essentially the same cyclical nature of sedimentary sequences.

The phosphatic cycles usually reflect the alteration of transgressive and regressive tendencies in the development of a basin. Initially shallow sedimentation takes place, followed upward by more deep-sea sediments. These may be followed by a shoaling sequence and sometimes ending with scouring of the upper beds. The shallowest parts of a cycle are composed of dolomites and clastic rocks; deeper parts consist of cherty rocks (bedded cherts, cherty carbonates, etc.) and phosphorites represent still deeper environments. The deepest strata in a cycle are represented by siliceous shales, shales and laminated black limestones. Bedded phosphorites occur near the outer shelf edge. They are found in those formations which result from marine transgression onto peneplained coasts. Phosphorites form not at the beginning of a transgression, but at a time when the sea depth in the shelf zone reaches a sufficient depth. Further deepening creates the environment for deposition of siliceous and non-siliceous shales, and ultimately terminates the phosphogenic process. However, the formation of phosphorites may resume during shoaling. The process of phosphorite formation reaches its peak during major deepening cycles.

In Figure 10, the distribution of relative depths through the sequence of the phosphate-bearing units of the Karatau basin is shown. It is evident that there is a major transgressive cycle, and it is this cycle that is phosphate-bearing. Phosphates are present in cycles I-IV, but the most phosphogenic cycle is cycle II. The sequence of Middle Cambrian deposits in the Georgina Basin (Table 4).

When a basin only deepens once there is only one unit of phosphate rock deposited, but where deepening alternates with shoaling of equal or greater amplitude, two phosphorite members are formed, separated by a deeper water unit. Sections of some deposits (for instance, in Syria) display reversed cycles, that is regressive-transgressive cycles where two horizons of phosphorite are separated by a shallow-water non-phosphatic member.

The main (phosphate-bearing) sequence of a transgressive phase consists of three stages of development:

1) deposition of relatively coarse detritus in a shoaling coastal zone, or on the coastal plain in alluvial-lacustrine and supratidal environments;
2) deposition of phosphate-bearing carbonates, mostly dolomite and some cherty and clayey sediments, on a submerging shelf;
3) deeper marine pelagic sedimentation on the outer shelf or continental slope where siliceous, clayey and silty sediments or dark limestones form.

The presence of such a transgressive sequence of beds, or of a reversed (regressive) sequence, is a good prospecting guide for high grade phosphorite.

Table 4 Similarity of the sequence of lithological units in the Karatau and Georgina Basins.

Karatau Basin		Georgina Basin	
Shabakty Suite	Bugul subsuite	Upper calcareous unit	
	Gillan subsuite	Lower shaly unit, Inca Formation	
	Brown dolomite	(Perhaps the lowest part of Inca Fm.)	
	Fe-Mn horizon of dolomite		
	Upper phosphorite	Upper phosphorite	Beetle Creek Formation
	Shaly member	Lower Siltstone	
	Lower phosphorite	Lower phosphorite	
	Chert horizon	"Chert Member"	Thorntonia Limestone
	Lower dolomite	"Dolomite Member"	
Kyrshabakty Suite (red beds)		Mount Birnie Beds) Riversdale formation) Mt Hendry Formation)	

LEGEND (FIG. 10)

1 – Phosphorites (a – minor occurrences, b – economical);
2 – surfaces of erosion (major – thick, minor – thin);
3 – coarse elastic sediments;
4 – coarse clastic sediments which formed due to currents near sea-floor;
5 – sandy sediments;
6 – silty-clayey sediments;
7 – siliceous-clayey sediments;
8 – black carbonates;
9 – bedded cherts;
10 – secondary silicification and chert nodules;
11 – red beds and variegated material;
12 – glauconite thick circles indicate glauconite abundant; dashed circles indicates glauconite scattered;
13 – carbonate oncolites;
14 – wavy stromatolitic structures;
15 – patchy stromatolitic structures;
16 – columnar stromatolitic structures;
17 – flat-planar-wavy stromatolitic structures
18 – siliceous spicules;
19 – calcareous spicules;
20 – zone of fine grained phosphorites (microphosphorite);
21 – zone of oolitic-pelletal phosphorite;
22 – zone of bioclastic phosphorite.

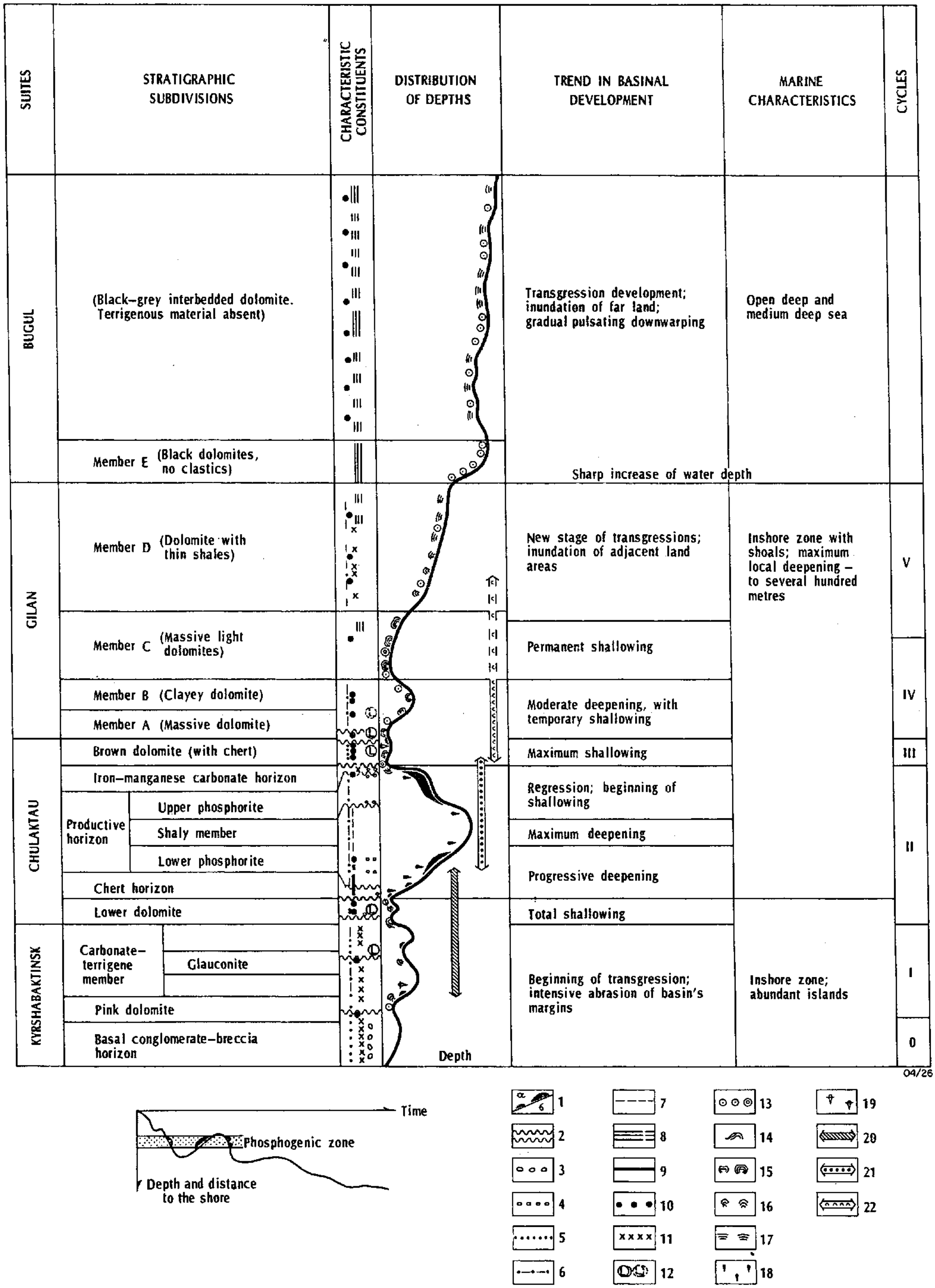

Fig.10 Rhythmic sedimentation in the Lower Cambrian Sequence of Karatau, Kazakhstan

Discussion

In response to a request by Notholt for corrections and additions to his preliminary tabulation of world deposits, newly discovered late Precambrian deposits in the Gurupi group in Para, Brazil, and the Precambrian Hirapur deposits in the Sagar district of India were mentioned. The exclusions of igneous deposits from this conference was questioned and justified by the initial aims of the IGCP project and the fact that igneous deposits contribute less than 20% of the world's phosphate production.

In response to the talk by Sheldon, the point was raised that many deposits seen on the present sea floor are not necessarily forming today and may, in fact, be as old as mid-Tertiary. The very high grade of the island deposits was questioned and explained as the result of complete replacement of clean limestone by phosphate-rich solutions derived from guano. Their age, as determined by uranium-series dating by H.H. Veeh, is greater than 800,000 yrs. The question of the earliest occurrence of upwelling organic-rich ocean water was raised but not resolved.

The analogies drawn by Cook and McElhinny between the temporal distribution and textural characteristics of phosphorite and iron formations were discussed. The high apatite content of banded iron formations associated with some base metal deposits in Australia was noted, as well as the enormous amount of P_2O_5 ($\sim10^{11}$ tonnes) contained at much lower concentration in, for instance, the Hamersley iron formations. The association of high P_2O_5 data from DSDP holes are in hand but their interpretation is not complete. The necessity of secondary mechanisms of sedimentary concentration of phosphatic materials produced by upwelling was of a correlation between petroleum occurrences and times of phosphorite formation. The inversion of sedimentary sequences proposed in the rifting model could be explained as forming in a converging rather than diverging situation.

The palaeogeographic reconstructions of Zeiger *et al.* discount the possibility of an expanding earth. The possibility of upwelling occurring on any shelf with water depth greater than 100 m was cited in answer to objections that upwelling would not explain the Georgina Basin deposits which were situated up to 500 km from the continental margin.

The problem of mass balances in the derivation of thick phosphorite over thin shales and the lack of evaporites associated with many deposits was raised in response to the hypothesis of Henderson *et al.* The required presence of organic-rich muds in this model suggests upwelling as at least a first stage process. The occurrence of unreplaced aragonitic shell material filled with phosphatic mud in some deposits does not support replacement of carbonate as a mechanism of phosphate precipitation but does not preclude mechanical mixing of previously precipitated phosphate. The problem of fluorine enrichment in phosphorites was discussed.

Eganov considered that the depth of formation of the phosphatic interval in Karatau is thought to be roughly 10 to 100m. Secondary effects are seen, but the major phosphate concentration is sedimentary. No evaporites are seen in the Karatau area, but red clastic sediments were deposited both below and above phosphorite horizons. Palaeontological information for the interpretation of depositional environments is very sparse. It was pointed out the lithologic similarity between Karatau and the Georgina Basin (despite the different ages), reflect similarities in tectonic control over gross sedimentation patterns.