

PHOSPHORITES, IRONSTONES, AND SECONDARY PHOSPHATES IN MID-CRETACEOUS FLYSCH OF THE BLOW TROUGH, NORTHERN YUKON

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ABSTRACT

The Blow River Formation was deposited in the Blow Trough, a north-trending, middle Cretaceous downwarp near the junction of the Western Canada Seaway and the Brooks and Sverdrup Basins. At Rapid Creek, the Blow River Formation comprises a 380 m cyclic succession of thick, silty, siderite-phosphate pellet packstone and intraformational boulder-pebble conglomerate lenses interbedded with grey, laminated siltstone and sideritic siltstone. These rocks rest conformably on grey shale with thin ferruginous siltstone beds, and are overlain conformably by grey siltstone with chert pebbles and siderite concretions. To the west, the formation thickens dramatically, as the ironstone-bearing member interfingers with and overlies dark grey shales and thin sandstones. To the east, it thins, passing into 160 m of interbedded shale and sideritic shale at Boundary Creek. Facies changes indicate a clastic source to the west. Early Albian ammonites and charcoal fragments are locally common. The widespread iron and phosphorous-rich hemipelagic sequence is an important regional marker, and is best known for the variety of secondary phosphate minerals (MINFILE 117A 027) found as nodules or along fractures related to Eocene folding.

The Blow River formation contains about 7×10^8 tonnes of P_2O_5 . This major deposit (MINFILE 117A 027) falls between the peak global episodes of phosphogenesis in the Callovian and Campanian, and, like them, corresponds to the late stage of a global anoxia. Unlike most phosphorites, this is a high latitude deposit.

RÉSUMÉ

La formation de Blow River a été déposée dans la dépression de Blow, un fléchissement du Crétacé moyen d'orientation nord près de la jonction du passage marin de l'Ouest canadien et des bassins de Brooks et de Sverdrup. Au ruisseau Rapid, la formation de Blow River se compose d'une succession cyclique de packstone à granules de sidérite et phosphate, épais et silteux avec lentilles intraformationnelles de conglomérat de blocs et de galets, interstratifiées de siltstone feuilleté et de siltstone sidéritique gris d'une épaisseur de 380 m. Ces roches reposent en concordance sur le shale gris avec minces couches de siltstone ferrugineux et sont recouvertes en concordance par un siltstone gris à galets de chert et à concrétions de sidérite. À l'ouest, la formation s'épaissit de manière saisissante alors que le membre renfermant les roches sédimentaires ferrugineuses forme des interdigitations avec des shales gris foncé et des grès minces qu'il recouvre également. À l'est, elle s'amincit pour passer à 160 m de shale et de shale sidéritique interstratifiés au ruisseau Boundary. Le changement de faciès indique la présence d'une source de matériaux clastiques à l'ouest. Par endroits les ammonites et les fragments de charbon de bois de l'Albien précoce sont communs. La séquence hémipélagique riche en fer et en phosphore répandue constitue un important repère régional et est des mieux connues pour la grande variété de ses minéraux phosphatés secondaires présents sous forme de nodules ou le long de fractures associées au plissement de l'Éocène.

La formation de Blow River renferme environ 7×10^8 tonnes de P_2O_5 . Ce dépôt majeur se situe entre les épisodes de pointe globaux de phosphogénèse au Callovien et au Campanien, et comme ceux-ci, il correspond au dernier stade d'anoxie globale. À l'opposé de la plupart des dépôts de phosphorites, celui-ci constitue un dépôt de hautes latitudes.

INTRODUCTION

The rocks described in this report are part of a thick flyschoid sedimentary package deposited in the northern Yukon in middle Cretaceous time. The ironstone-phosphorite bearing unit is informally called the Blow River formation. It is preserved in a north-trending lowland area which lies between the Richardson and Barn Mountains and links the Old Crow Basin with the Mackenzie Bay area of the Beaufort Shelf. This area was the site of a major, north-trending tectonic depression developed during the Columbian Orogeny, known as the Blow Trough (Young et al., 1976) or Rapid Depression (Norris and Yorath, 1981). The regional geology has been described by Young (1972; 1977), Young and others (1976), and Norris and Yorath (1981). The secondary minerals in the Blow River Formation (MINFILE 117A 027) (Robertson, 1982) have attracted considerable attention from mineralogists and collectors. Locally common invertebrate fossils, including the pelecypod *Inoceramus ex gr. l. anglicus-cadottensis* and the ammonite *Sonneratia* sp., indicate that the Blow River formation is early Albian or younger (J.A. Jeletzky in Young, 1977).

The Blow River formation is unusual in many respects. (1) Phosphorites and ironstones are not commonly closely associated with each other. (2) Most phosphorites are believed to accumulate in tectonically stable settings in low latitudes, but this deposit accumulated in a tectonically active depression at high latitudes. (3) Although the secondary minerals are clearly related to their host rocks, the conditions under which they formed are not clear. In an attempt to resolve these problems, H.G. Ansell of the Geological Survey of Canada, and the writer, visited well-known exposures of the Blow River formation in July, 1988. The two exposures are located on Cross Cut Creek, a tributary of Rapid Creek (Fig. 1), and on the Big Fish River.

GEOLOGICAL SETTING OF THE BLOW RIVER FORMATION

Tectonics

Blow Trough (Young et al., 1976) is a structurally controlled mid-Cretaceous depression that developed near the junction of the Western Canada Intracratonic Seaway and the southern margin of the Amerasian Basin. It lies between Cache Creek High and the Romanzoff Uplift-Keele-Old Crow Landmass, the easternmost elements of the Brooks Range fold and thrust belt. It links the southwest-trending Keele-Kandik Trough and the southeast-trending Peel Trough with the Beaufort Shelf.

Blow Trough (Rapid Depression) developed in response to late Mesozoic dextral movement on the Kaltag-Porcupine Fault System (Norris and Yorath, 1981), in turn accommodating dextral transcurrent movement on the Tintina-Kaltag Fault system, and resulting ultimately from an increased spreading rate at the mid-ocean ridge separating the Pacific and Farallon

plates. This movement also resulted in north-directed thrusting and uplift of the Brooks Range. This tectonic activity in the northern Cordillera was accompanied by the deposition of clastic sediments in the foredeep of Colville Basin to the north and Blow Trough to the east.

Structure

The chief structural feature of northern Porcupine Plateau is the Rapid Fault Array, a family of steeply dipping, anastomosing northwest to northeast-trending faults which fan northward from the two major faults of northern Yukon, the dextral Kaltag-Porcupine Fault and the Yukon thrust fault (Norris, 1974 in Young, 1977; Norris and Yorath, 1981). Recent mapping by Lane (1988) indicates that the faults are predominantly west-directed thrust faults, rather than normal faults as interpreted by earlier workers. These faults cut Paleocene strata (Reindeer Formation) and hence were active in early Tertiary time (Norris and Yorath, 1981, Lane, 1988). Mid-Cretaceous facies changes between adjacent fault blocks of the Rapid Fault Array, and consistency of stratigraphy within each block (Young, 1977) indicate that many of the faults of the Rapid Fault Array are re-activated Cretaceous structures. Within the blocks of the Rapid Fault Array, strata as young as the early Paleocene upper Moose Channel formation are folded about north-trending axes. (Folding affects rocks as young as Norris' (1981) map unit Tmc3, but not Tak. The younger unit Tak is faulted, but not folded.)

Hence, the latest deformation event recorded in the Rapid Depression is east-west compression which occurred during Paleocene to Eocene time (Lane, 1988). The northerly orientation of the early Tertiary structures is most likely controlled by early Cretaceous extensional(?) features which also controlled Cretaceous sedimentation patterns in Blow Trough. Offset of the Shaktolik Formation and granitic intrusions of the Koyukuk Basin of Alaska suggests up to 130 km of dextral displacement on the Kaltag-Porcupine Fault system during the Late Cretaceous or Early Tertiary. In the Rapid Depression, this movement was accommodated by the east-west folding and thrusting outlined above.

Stratigraphy

During the Jurassic and Early Cretaceous (to early Neocomian), widespread epicontinental mudrocks of the Kingak and Husky formations and sandstones and siltstones of the Bug Creek Group and Porcupine River Formations were shed north and west across the area. These rocks are up to 1600m thick in the Richardson Mountains-Mackenzie delta area (Young et al, 1976). They lie disconformably on older strata.

The Jurassic-Early Cretaceous rocks are overlain conformably to disconformably (Norris, 1983) by transgressive, late Neocomian marine mudstones of the Martin Creek Formation and Unit Kmc (Norris, 1981; equivalent to the "upper shale-siltstone division" which Young et al (1976) interpreted to be Barremian). Lithofacies distributions (Young

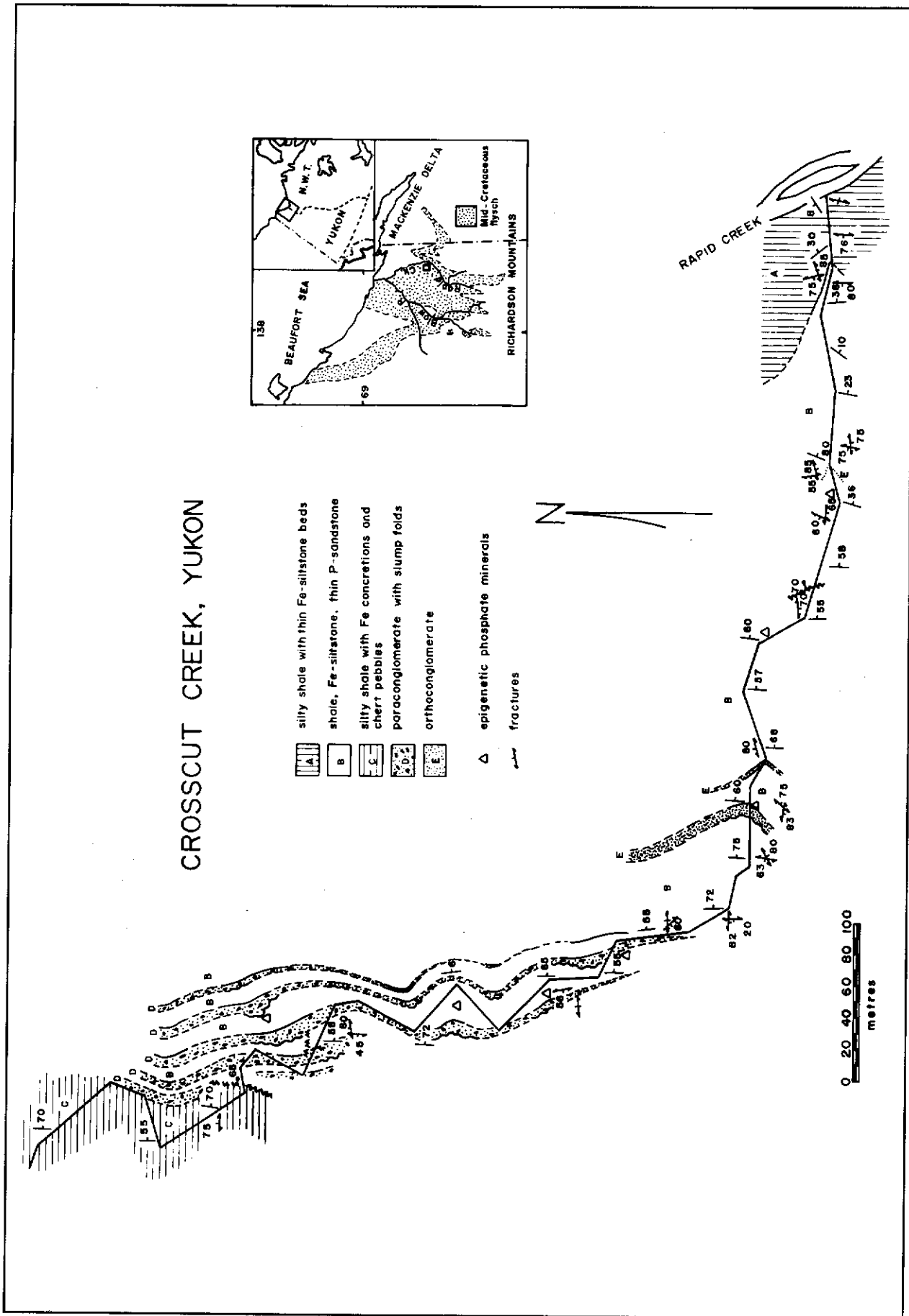


Figure 1. Map of Crosscut Creek, a tributary of Rapid Creek, where phosphate minerals were first found in 1962. Of thirty-two phosphate minerals recognized in these rocks, Rapid Creek is the type locality for seven.

et al, 1976) indicate that these clastics were also shed northwesterly. By this time, Blow Trough was an actively subsiding feature.

Regressive, coarse-grained marine clastics of the Aptian Mt Goodenough Formation ("lower shale" and "upper sandstone" divisions of Young, 1977) conformably to disconformably overlies unit Kmc and Martin Creek Formation rocks (Norris, 1983). Lithofacies distributions (Young et al, 1976) and limited sediment dispersal data (Young, 1973) suggest that these sediments were mostly shed westward from the North American craton. In the upper part of this interval, an increase in lithic fragments and a shift in sediment dispersal from an easterly to a westerly source marks a transition from epicontinental to flyschoid sedimentation (Young, 1973; Norris and Yorath, 1981).

The Mt Goodenough Formation is overlain unconformably (Norris and Yorath, 1981, Fig. 7) to conformably (Norris, 1983) by a sequence of flyschoid Albian mudstones, sandstones and conglomerates, here called the Rapid Creek Group. These rocks are described below.

The Rapid Creek Group is disconformably overlain (Norris, 1983) by transgressive Cenomanian mudstones of the Boundary Creek Formation.

The Boundary Creek Formation is disconformably overlain by a wedge of Maestrichtian, molassoid sandstones and siltstones, the Moose Channel Formation (Norris, 1983). This unit thickens northward, and marks a major, non-marine progradation (Norris and Yorath, 1981).

The Moose Channel Formation is conformably overlain by non-marine, coal-bearing Paleocene mudstones of the Reindeer Formation (Young et al, 1976; Norris, 1983).

Rapid Creek Group

The name Rapid Creek Group is here proposed for the thick sequence of flyschoid clastics between the mudrocks of the Mt Goodenough Formation (Upper sandstone and upper siltstone division of Jeletzky, 1971; Young 1972, 1974 and others) and the Boundary Creek Formation in northern Richardson Mountains. These strata have been variously called the upper Aptian to lower Albian flysch (Jeletzky, 1971), the Aptian-Albian flysch sequence (Young, 1972), the Albian flyschoid phase (Young, 1973; Norris and Yorath, 1981), or the Aptian-Albian flysch division (Young et al, 1976). Robertson (1980, 1982) proposed the name Rapid Creek Formation for this succession, but Young (1977) and Norris (1981, 1983) have shown that at least three units of formation rank can be recognized within it.

The Rapid Creek Group includes three map units, Ksr, Krr and Kbr distinguished by Norris (1981). The unit of chief interest here is unit Kbr, informally called the Blow River Formation. The other two are described briefly.

The Rapid Creek Group is correlative to the south with the Sans Sault Formation and Fort St John Group in the northern part of the Interior Seaway (Mannville and Blairmore equivalents). To the northwest it correlates with the Fortress Mountain, Torok, Oumalik and Topagarak Formations of

Colville Basin, north of the Brooks Range Uplift. It also correlates to the northeast with the Christopher Formation of the Sverdrup Basin. All of these middle Cretaceous strata were deposited during a period of global transgression (e.g. Haq et al. 1987).

Unit Ksr

Norris' (1981) map unit Ksr, informally called Skull Ridge Formation, corresponds lithologically to subunit A of Young's (1977) map unit K4b. It is best exposed at Skull Ridge, where polymictic orthoconglomerates overlain by sandstones form impressive cliffs. Clast compositions suggest a source to the southwest (Lane, 1988). According to Young (1977), this unit is about 550m thick. The Skull Ridge Formation is restricted to the west side of Blow Trough. It rests conformably on extensive grey-black shale with quartz sandstone and ironstone, chert pebble orthoconglomerate, and diamictite of the Mount Goodenough Formation (Unit K4a of Young, 1977).

Unit Krr

Norris' (1981) map unit Krr, informally called Rat River Formation, corresponds lithologically to subunit B of Young's (1977) Unit K4b. It comprises mainly grey sandstones and siltstones, the fine-grained distal facies equivalents of the Skull Ridge Formation on the east side of Blow Trough. Like the latter, the Rat River Formation conformably overlies shales of the Mount Goodenough Formation.

Blow River Formation

Norris' (1981) map unit Krb, informally called Blow River Formation, corresponds lithologically to Young's (1977) Units K4c and K4d. It comprises interbedded siderite ironstone and shale with sandstone and conglomerate. Found throughout Blow Trough, it overlies and interfingers westward with the Skull Ridge and Rat River Formations. It is overlain disconformably by grey shales of the Boundary Creek Formation. The easternmost exposures of the Blow River Formation, in the Big Fish River area, are relatively thin and comprise pelagic clay shale and siderite ironstone. Exposures of the Blow River Formation on Cross Cut Creek, the best known of several phosphate mineral locations in this unit, are described below.

CROSS CUT CREEK

Stratigraphy

On Cross Cut Creek the Blow River Formation is represented by 358m of interbedded dark grey silty shale, sideritic siltstone and phosphorite granule sandstone (Robertson, 1982). Beds of intraformational para- and orthoconglomerate are common in the lower part of the

ironstone- and phosphorite-bearing interval. Both sandstones and conglomerates are lenticular (Fig. 1). These rocks overlie a thick unit of pale grey silty shale with siderite concretions and scattered black chert pebbles, interpreted to be the Mt Goodenough Formation. They are overlain by light grey silty shale with thin, rusty weathering, sideritic siltstone beds. Robertson (1980) interpreted these to belong to the Boundary Creek Formation. Alternately, they may be a shaly upper member of the Blow River Formation, as suggested by Norris (1981).

A detailed section through the lower part of the succession on Cross Cut Creek (Fig. 2) shows that deposition of massive and laminated siltstones interbedded with massive, planar and ripple-laminated sandstones was interrupted episodically by scouring and deposition of silty pebble-boulder paraconglomerates. Internally deformed, laminated, intraformational siltstone blocks in the conglomerate are up to 6m across. These conglomerates also contain rounded grey chert pebbles, possibly derived from the underlying Mt Goodenough Formation. Some of the paraconglomerates pinch out laterally over a few hundred metres and infill channels up to 14 m deep in the rhythmically deposited clastic sequence. Ripple lamination in sandstone beds suggests local northwesterly sediment transport, but slump folds overturned towards the east indicate an easterly paleoslope.

Well preserved fossils are rare in the Blow River Formation. Ammonite impressions *Sonneratia* were observed locally, and fragments of charcoal were found in the lower part of the unit.

Structure

The style of deformation observed on Rapid Creek is consistent with that described farther west in Blow Trough by Lane (1988). In the vicinity of its tributary, Cross Cut Creek, Rapid Creek flows northward along the hinge of a north plunging syncline. Bedding at Cross Cut Creek is gently folded about north-trending axes. A minor, east-dipping reverse fault is exposed about 250m upstream on Cross Cut Creek. A comparable fault is exposed immediately upstream from the phosphate showings. Small-scale synthetic and antithetic duplex thrusts are common. Two sets of steeply dipping fractures are developed. North-trending fractures which lie subparallel to regional fold axes are generally not mineralized. East-trending fractures which lie normal to local fold axes commonly contain secondary phosphate minerals (Fig. 3).

Secondary Mineralization

The Blow River Formation is best known for the secondary minerals, chiefly phosphates, found as veins and breccia fillings in the Rapid Creek area (MINFILE 117A 027)(Fig. 1), and as nodules further east at Big Fish River (Robertson, 1982). Thirty-two phosphate minerals have been identified, and of these, about half a dozen are unique to the Blow River Formation. The best known is lazulite, Yukon's

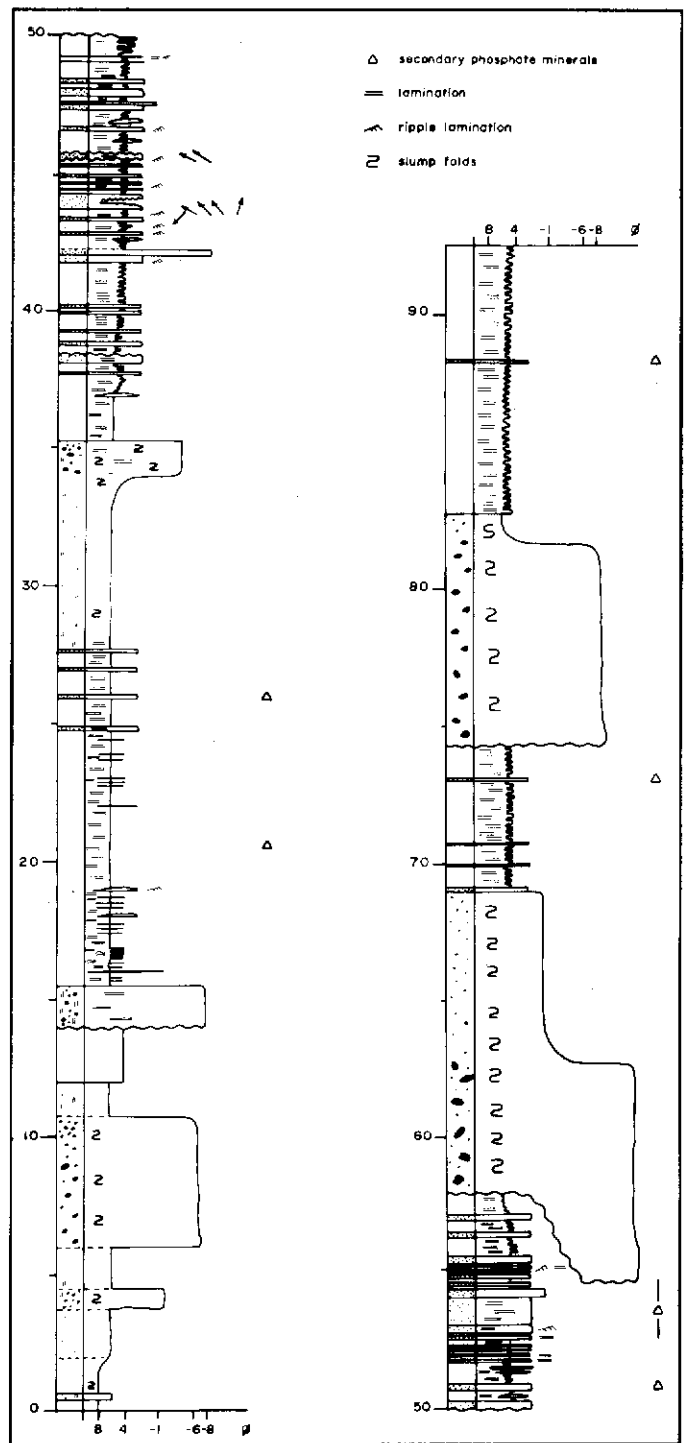


Figure 2. Graphic log of a section through the lower (western) part of the Crosscut Creek exposure of the Blow River formation. Thin to medium-bedded dark grey shale, phosphatic sandstone and siderite ironstone alternate with paraconglomerates containing slump folds and reworked intraformational fragments. The shales, sandstones and ironstones are interpreted as starved basin deposits; the paraconglomerates are inferred to be base-of-slope slump deposits.

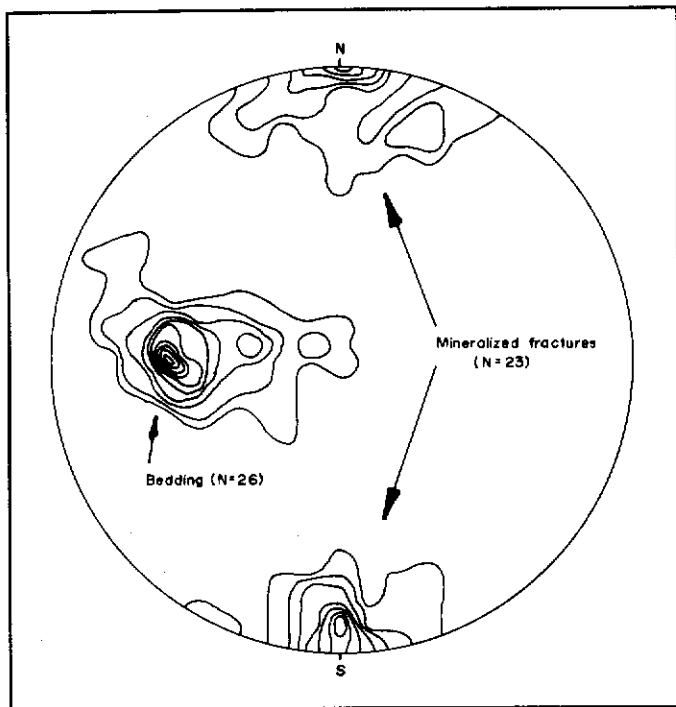


Figure 3. Contoured lower hemisphere stereonet plots of poles to bedding, and fractures containing phosphate minerals at the Crosscut Creek location. Contour interval is 1%. The plot indicates that the mineralized fractures are perpendicular to the poles to bedding, and were probably formed during Early Tertiary regional folding.

official gemstone.

Most of the work on the Blow River Formation has focused on the secondary phosphate minerals (Campbell, 1962; Coleman and Robertson, 1981; Mandarino and Sturman, 1976; Mandarino, Sturman and Corlett, 1971; 1978; Robertson, 1980; 1982; Sturman and Mandarino, 1976; Sturman, Mandarino and Corlett, 1977; Sturman, Mandarino, Mrose and Dunn, 1981; Sturman, Peacor and Dunn, 1981). Of these authors, only Robertson (1980; 1981; 1982) paid much attention to the host rocks and the controls on the secondary mineralization.

DISCUSSION

Depositional Setting of the Cross Cut Creek Member

Robertson (1980; 1982) inferred the Blow River Formation to be a shallow marine deposit, based on what he interpreted as coarsening-upward cycles at Cross Cut Creek. However, only the basal contacts of the conglomeratic beds are scoured, and the cycles fine rather than coarsen upward (Figures 1 and 2). There is no other evidence for a shallow water setting. The predominance of mudrock, scarcity of current structures, fossils, or trace fossils, all suggest that the

Blow River Formation is a deep water deposit, as Young (1973; 1977), Young and others (1976) have argued.

The Blow River beds on Cross Cut Creek can be interpreted according to Mutti and Ricci Lucchi's (1972; 1975) turbidite facies classification as Facies D (base-cut-out Bouma sandstones), Facies F (chaotic slump deposits), and Facies G (pelagic muds). This assemblage is probably a slope facies association (Mutti and Ricci Lucchi, 1972; 1975) deposited on or near the base of an east-facing submarine slope. The existence of such submarine bathymetric relief is consistent with active subsidence of Blow Trough during the middle Cretaceous.

Robertson (1980; 1982) interpreted the clastic sediments to have been derived from the east. Although local ripple lamination lends some support to this interpretation, regional easterly thinning of the Rapid Creek clastics, east-verging slump folds at Cross Cut Creek and elsewhere, (Young, 1977), sparse regional paleocurrent data (Young, 1973), and facies changes, especially the eastward-increasing proportion of chemical sediment, all indicate a source to the west or southwest.

Deposition of the Phosphorite Beds

It is widely believed phosphorites result from upwelling of nutrient-rich waters along basin margins in middle to low latitudes, an interpretation first developed by Kazakov (1937 in Gulbrandsen, 1969). Although most known phosphorites were deposited in low latitudes (Cook and McElhinny, 1979), there is no compelling reason why upwelling should be restricted by latitude. Investigations of global paleocirculation patterns (Curtis and Parrish, 1982) show that in the mid-Cretaceous, as at present, a high pressure cell was centred over the North Pole and the prevailing winds were easterly, parallel to the coastline. Under such conditions, surface waters will flow offshore, due to Ekman transport. Hence, the Blow River Trough, a re-entrant on the southern margin of the Arctic Basin, was a potential upwelling area in the mid-Cretaceous (Fig. 4).

The phosphorite beds at Cross Cut Creek are allochthonous phosphate granule sands. The phosphate granules most likely formed diagenetically in a shelf environment further west in Blow Trough and were mechanically concentrated and carried down slope by turbidity currents.

Phosphorite preservation should be favoured by anoxic conditions since in well-oxygenated waters, phosphate-rich organic matter is swiftly decomposed and the phosphorus is rapidly recycled. Although it has been argued that anoxic conditions are not necessary for phosphogenesis (Arthur and Jenkyns, 1981) there is a striking temporal correspondence between phosphogenesis and anoxic events (Fig. 5). Arthur and Jenkyns' argument was based on the fact that no major phosphorite deposit was known to correspond with the global Aptian-Albian anoxic event. The Blow River phosphorite was deposited during this interval, however, and it is a substantial

accumulation, containing roughly 7 billion tonnes of P_2O_5 according to data of Young (1977).

The relationship between anoxia and phosphogenesis may be a "chicken and egg" problem. Anoxic conditions would inhibit decomposers and recycling of phosphorus in the marine system, thus favouring preservation of phosphatic organic-rich sediments. Upwelling of phosphorus would result in dramatically increased biological productivity near the surface (e.g. present-day offshore Peru). A well known effect of increased organic productivity is increased biological oxygen demand in the water column, and expansion of the oxygen minimum zone. This might lead to the onset of an oceanic anoxic event. Reduced phosphorus upwelling due to the burial and removal of phosphate sediment from the system, active circulation under anoxic conditions, or perhaps a change in ocean circulation patterns (e.g. El Nino), could have resulted in a decrease in biological productivity, decreased biological oxygen demand, contraction of the oxygen minimum, and the end of an oceanic anoxic event.

Deposition of the Ironstone

As the Rapid Creek Group thins eastward, the proportion of ironstone increases, reaching a maximum in the Big Fish River area (Young et al, 1976). Such an accumulation of chemical sediment is typical of clastic-starved basins. Precipitation of primary siderite requires low Eh, high P_{CO_2} and low S (Berner, 1971). While anoxic conditions would result in reducing, CO_2 -enriched waters, the concentration of dissolved iron in sea water is typically very low, and organic-rich sediments should generate quantities of H_2S . With sufficient dissolved iron, pyrite precipitation is favoured. However, siderite precipitation is common under diagenetic conditions. Abundant pyritic nodules in shale in the Big Fish River area indicate that diagenetic conditions there favoured pyrite, as opposed to siderite. Hence it is unlikely that the siderite ironstone beds formed diagenetically in that part of the basin. Like the phosphorite beds, siderite must have formed diagenetically elsewhere in the basin, and was reworked into the beds in which it is now found. The high P_{CO_2} and low Eh conditions of anoxia should have favoured such siderite precipitation.

Phosphorites and sideritic ironstones rarely occur together, because the conditions under which siderite and phosphate minerals form are incompatible. In the presence of dissolved calcium, a major constituent of phosphate minerals, calcite rather than siderite should precipitate (Berner, 1971). Both minerals could precipitate sequentially, however. Resedimentation of authigenic siderite and phosphate grains, formed under different diagenetic conditions in the same part of the basin, probably accounts for the association between siderite ironstone and phosphorite beds in the Blow River Formation.

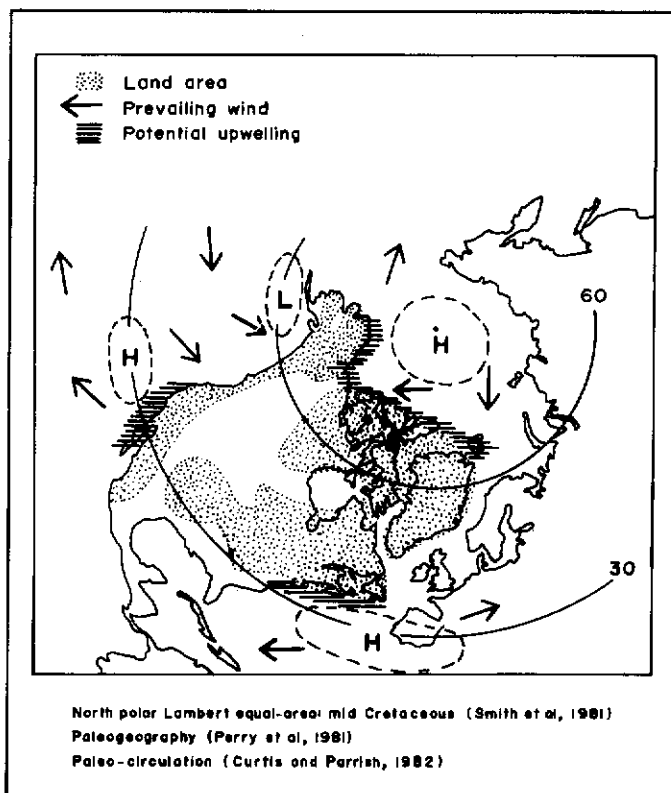


Figure 4. Unlike the Blow River Formation, most known phosphorites were deposited in low latitudes, probably in response to upwelling of nutrient-rich waters and increased biotic productivity. This figure shows there is no reason why phosphorite deposition should be restricted to low latitudes, as the rim of the Arctic Basin was a potential area of upwelling during the mid-Cretaceous.

Emplacement of the Secondary Minerals

The epigenetic phosphates and associated minerals are clearly related to their unusual host rocks. Robertson (1982) identified four phosphate mineral assemblages, each associated with a particular host rock type. Veins are most common in the more competent phosphorite beds. Poles to mineralized fractures are perpendicular to the domain of poles to gently folded bedding, indicating that the fractures are extensional cross-fractures related to regional folding (Fig. 3) which, as pointed out above, affects rocks as young as Eocene (Lane, 1988). This Early Tertiary compression probably also mobilized the relatively low temperature fluids which precipitated the secondary minerals (Robertson, 1982).

CONCLUSIONS

- (a) The Blow River ironstones and phosphorites are distal, deep water deposits, not shallow water deposits.

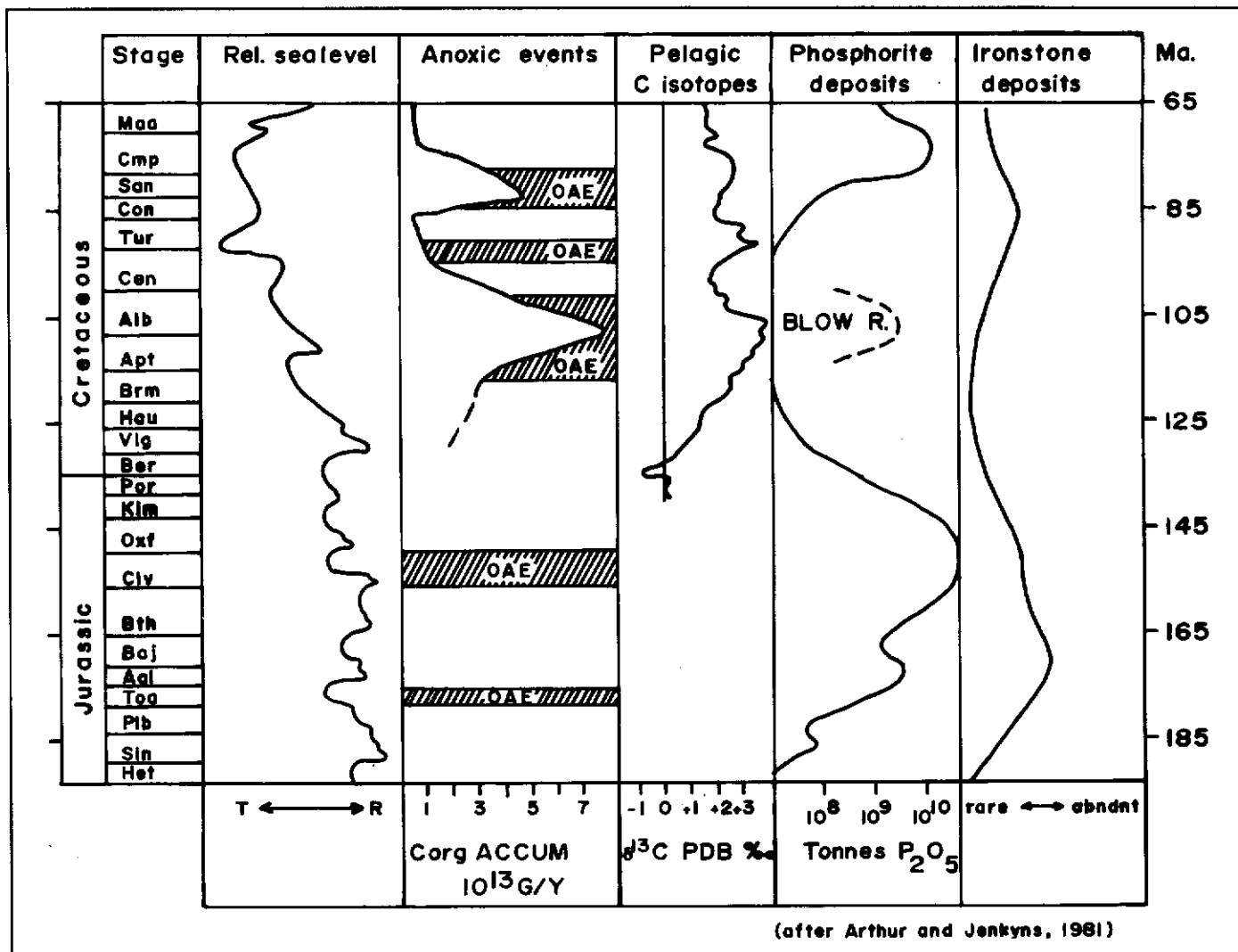


Figure 5. Strongly reducing conditions such as the Oceanic Anoxic Events (OAE's) which occurred repeatedly throughout the Mesozoic, favour accumulation and preservation of organo-sedimentary deposits including phosphorites. Major phosphorite deposits including the Blow River Formation appear to be associated with such anoxic events. There is no clear association with sea level changes.

- (b) Penecontemporaneous reworking of deep water sediments suggests continued tectonism in Blow Trough during the early Albian.
- (c) Anoxic conditions, as well as upwelling, favoured deposition of the phosphorites in Blow Trough.
- (d) The precipitation of phosphate minerals at Cross Cut Creek was controlled by the composition and competence of the host rocks and by early Cenozoic folding.

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