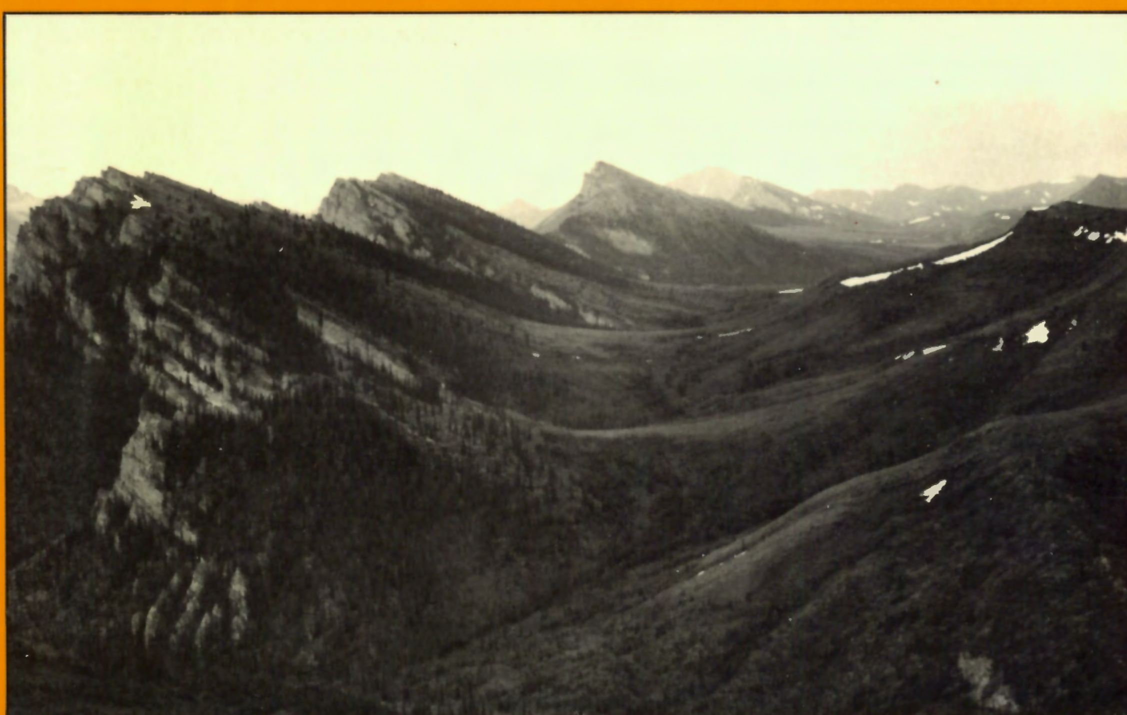
Geological Survey of Canada
Commission géologique du Canada

PAPER 86-14

THE MONSTER FORMATION: A COASTAL FAN SYSTEM OF LATE CRETACEOUS AGE, YUKON TERRITORY



B.D. Ricketts

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1988

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Available in Canada through

authorized bookstore agents and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W
Calgary, Alberta T2L 2A7

100 West Pender Street
Vancouver, British Columbia V6B 1R8

A deposit copy of this publication is also available for reference
in public libraries across Canada

Cat. No. M44-86/14E
ISBN 0-660-13075-0

Price subject to change without notice

Cover

Panorama of the Monster and Takhandit formations, north limb of the Monster Synclinorium (ISPG 1861-6).

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Original manuscript submitted: 83-04-14
Approved for publication: 85-09-25

References were up-to-date when this manuscript was submitted, but as a result of production delays recent publications are not included.

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THE MONSTER FORMATION: A COASTAL FAN SYSTEM OF LATE CRETACEOUS AGE, YUKON TERRITORY

Abstract

The Monster Formation consists of four informal members, collectively interpreted as of coastal fan origin. At the base of the formation, the Shale member disconformably overlies the Triassic Shublik Formation and represents a relatively deep water, offshore environment over which shoreface and foreshore sands of the Sandstone member prograded. Above this, the Sandstone-shale member and the uppermost or Conglomerate member represent the exposed portion of the fan. Gravelly, braided streams characterised the proximal fan environment, and low-sinuosity, meandering or braided streams distributed sand and mud in the lower fan setting. The exposed part of the coastal fan was periodically subjected to incursions by the sea.

The Monster Formation is older than previously thought, and is herein recognised as Cenomanian.

Following the initial submersion of the pre-Monster unconformity during Cenomanian time, fan progradation took place toward the northeast along the Monster Embayment. This embayment probably was connected at its eastern limit to the Eagle Plain Basin. The southern shoreline of the embayment was probably connected to the northern margin of the Bonnet Plume Basin. The stratigraphic successions in the Monster Embayment and Bonnet Plume Basin identify the southern limits of the sea during early Late Cretaceous time.

Keywords: *Monster Formation, coastal fan, Cenomanian, paleogeography.*

Résumé

La formation de Monster est constituée de quatre membres, qui, regroupés, semblent faire partie d'un cône alluvial côtier. Un membre à schiste argileux (Shale member), nouvellement désigné, situé à la base de la formation, correspond à un milieu pélagique, d'eau relativement profonde, sur lequel les sables de la zone infratidale et ceux de l'avant-plage du membre gréseux (Sandstone member) ont progressé. Les deux membres restants, celui à grès et schiste argileux (Sandstone-shale member) et le plus haut, celui à conglomérat (Conglomerate member), correspondent à la portion exposée du cône alluvial. Des dépôts graveleux et des cours d'eau anastomosés correspondent au milieu proximal du cône, et des cours d'eau peu sinueux, anastomosés ou à méandres, ont distribué les sables dans la partie inférieure du cône. La portion exposée du cône littoral a périodiquement subi des incursions marines.

La formation de Monster est plus ancienne qu'on ne jugeait auparavant, on la place maintenant dans le Cénomanien.

Le cône alluvial a progressé vers le nord-est le long d'une baie appelée baie (ou rentrant) de Monster, qui probablement était reliée sur sa limite est au bassin de la plaine d'Eagle. La rive sud de la baie est reliée à la limite nord du bassin de Bonnet Plume. Ces successions stratigraphiques de la baie de Monster et du bassin de Bonnet Plume permettent de définir les limites de l'extension de la transgression marine au début du Crétacé supérieur.

Mots clés: *Formation de Monster, cône alluvial côtier, âge cénomanien, paléogéographie.*

INTRODUCTION

Regional setting

Continental and marine strata of early and middle Late Cretaceous age are found throughout northern Yukon (north of the Tintina Trench), and record deposition during the dying stages of the Columbia Orogeny, or the earliest stage of Laramide deformation (Late Cretaceous to early and mid-Tertiary?). The Monster Formation is such a sequence and consists of alternating conglomerate, sandstone and shale. Earlier considered to be latest Cretaceous and possibly early Tertiary in age, the Monster Formation is now known to have been deposited during early Late Cretaceous time. New information that substantiates this age determination is presented herein.

The Monster Formation is exposed in two principal areas near the western margin of the Taiga-Nahoni Fold Belt: the east-trending Monster Synclinorium, which contains the type section; and a northeast trending recumbent syncline in the footwall of the Yukon Thrust (north Tatonduk River). To the north, east and west are unmetamorphosed Mesozoic and Paleozoic strata, which were folded and uplifted during the Laramide Orogeny to form the northern Ogilvie Mountains, and to the south are both metamorphosed and unmetamorphosed rocks of Precambrian and early Paleozoic age (Selwyn Fold Belt).

Previous studies

Strata exposed along the Monster River (Dawson map area) were first mapped by Green and Roddick (1962) and a section some 1200 m (4000 ft), and possibly as much as 2400 m (6000 ft) thick, was examined (Table 1). A Late Cretaceous or Tertiary age was indicated, based on scattered plant remains. The name Monster Formation was formally designated by Mountjoy (1967), who erected a type section on the northern limb of the Monster Synclinorium (Lat. 65°03'N, Long. 140°14'W; Air photograph A13231-161). At this locality, the thickness determined for the Monster was 966 m. Mountjoy (*op. cit.*) presumed that the approximately 200 m thick covered interval, between the lowest Monster sandstone and the Permian Takhandit Formation, was equivalent to the Triassic Shublik Formation that Green and Roddick (1962) had mapped on the southern limb of the syncline. However, Green and Roddick (1962) and Green (1972) showed that the Triassic strata wedge out toward the western nose of the syncline, and the Monster Formation was, therefore, considered to overlie the Takhandit disconformably. Later, Norris (1982) mapped the same covered interval above the Takhandit as possible Biederman Argillite (of Early Cretaceous age), with the qualification that some Upper Triassic rocks may be present. However, exposure of these contacts is poor because of the recessive nature of the lithologies. A similar situation exists in the north Tatonduk area where Biederman Argillite is mapped between the Monster and Takhandit.

In the present study, exposures of siltstone and shale of Monster age were found in this 'covered' interval at two localities: one in the north Tatonduk area, and the other north of Monster River. The Monster Formation is extended, therefore, to include the covered interval above the Takhandit (Table 1).

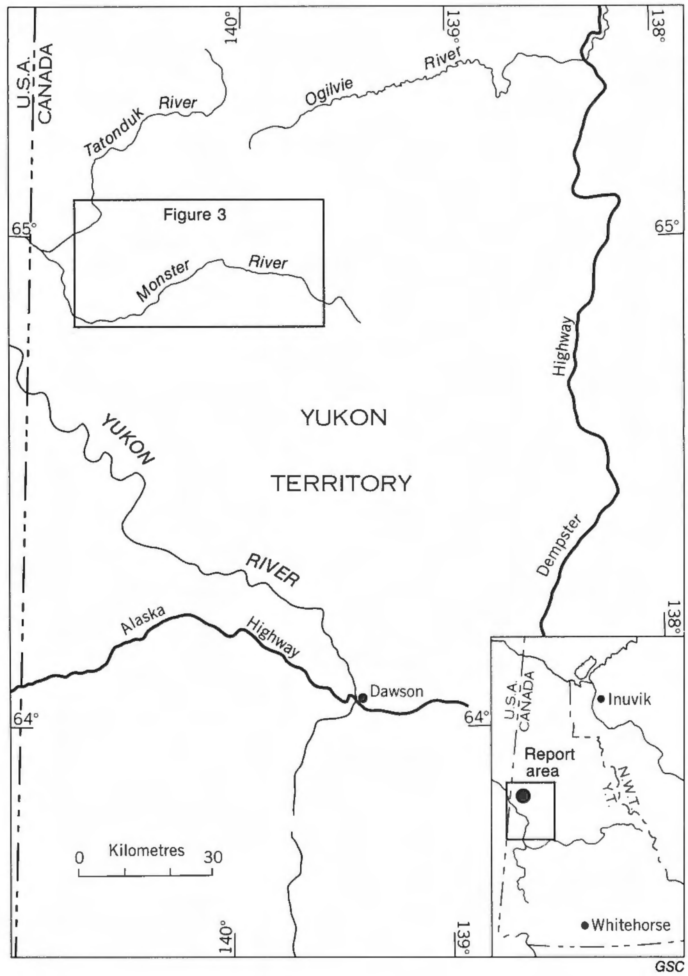


Figure 1. *Location map of the report area.*

Previous attempts to determine the age of the Monster Formation have been inconclusive. Late Cretaceous and possibly early Tertiary ages were suggested by Mountjoy (1967) and Green (1972), based on poorly preserved palynomorphs and fossil leaves. The Monster was considered to be the youngest sedimentary succession involved in Laramide deformation in the Ogilvie Mountains.

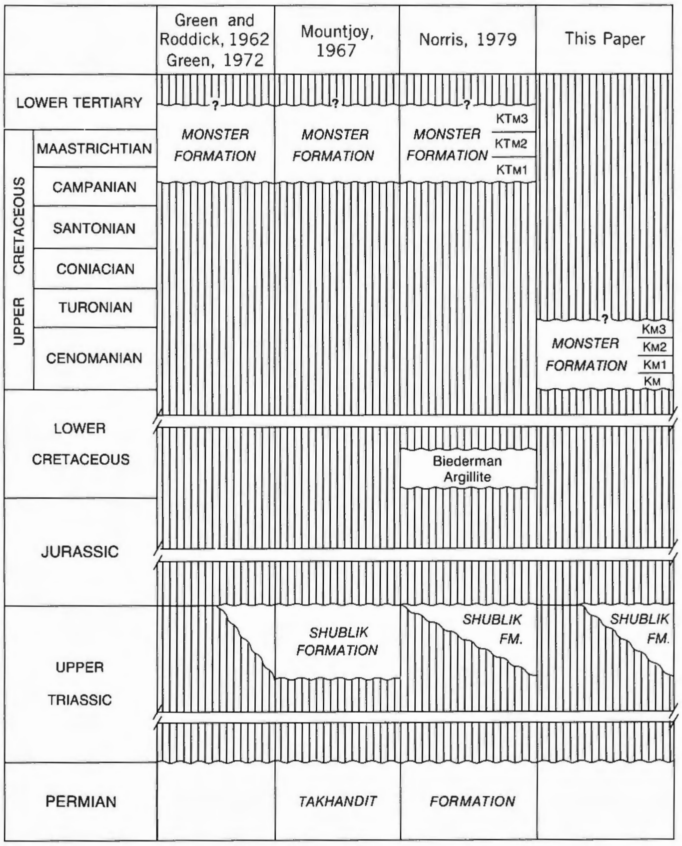
Because of the reconnaissance nature of earlier investigations, sedimentological interpretations of the Monster Formation were sketchy. Generally, it has been inferred that the sequence is predominantly fluvial in origin, with possible marine influence in the lower units (Mountjoy, 1967; Norris, 1982). The aims of the present investigation are threefold:

1. To obtain a better estimate of the age of the Monster Formation
2. To interpret the sedimentology
3. To compare the formation's paleogeographic relationships with the Bonnet Plume and Eagle Plain sequences.

Exposures of the Monster Formation are generally restricted to coarse grained lithologies, typically bluff-forming sandstones and conglomerates. In the Monster River area,

TABLE 1

Summary of stratigraphic nomenclature



thick conglomerates also form prominent buttes. At only a few localities is the exposure of fine grained lithologies of sufficient quality to permit detailed examination. Furthermore, profuse lichen growth on the exposed sandstones obscures sedimentary structures and prevents the measurement of all but a few crossbed azimuths.

A new fossil-locality was found in the Triassic Shublik Formation, and this is described briefly in the following section. Fieldwork was carried out in 1982 using fly camps and helicopter support.

STRATIGRAPHY

The Monster Formation was subdivided by Norris (1982) into three members: a basal Sandstone member (Norris' Map unit KTM1); a middle, alternating Sandstone-shale member (KTM2); and an upper Conglomerate member (KTM3) – in this paper these units are designated KM1, KM2, and KM3 respectively. The subdivision is herein extended to include a new basal member, the Shale member (Map unit KM), which is represented by grey shale, siltstone, and minor, thin beds of sandstone, that outcrop below the Sandstone member. Two representative, relatively complete stratigraphic sections of the Monster Formation are described in Appendix 1; one section from the Monster River, and the other from north Tatonduk River.

The basal unconformity

Basal strata of the Monster Formation that are in disconformable contact with the Shublik Formation, were located in outcrop on the north bank of a tributary of the Tatonduk River (Lat. 65°01'N, Long. 140°21'W). To date, this is the only known exposure of the Monster/Shublik contact. The exposed sequence here is approximately 50 m thick (Fig. 2) and is cut by a normal fault, downthrown to the west. Shublik strata are readily identified as black, fissile shales that are highly calcareous and contain an abundant but poorly preserved macrofauna. The fauna has been identified by E.T. Tozer (pers. comm., 1982) and includes *Halobia* sp. and indeterminate ribbed ammonoids and evolute smooth ammonoids, indicating a probable Late Triassic age. The black shale is interbedded with fine grained sandstone at the base of the sequence. At this locality, the Shublik displays coarsening- and thickening-upward trends in which the sandy lithologies become coarser grained (pebbly) and thicker bedded higher in the sequence. The uppermost unit is a chert-pebble conglomerate.

The chert-pebble conglomerate is abruptly succeeded by thinly bedded siltstone, light grey shale and fine grained sandstone. These lithologies are noncalcareous, and contain a considerable amount of fine carbonaceous material and plant fragments up to 10 cm long. Sandstone beds range from 2 to 25 cm thick. Some beds exhibit normal grading, whereas others have abrupt tops and bases. Current ripples and climbing ripples abound.

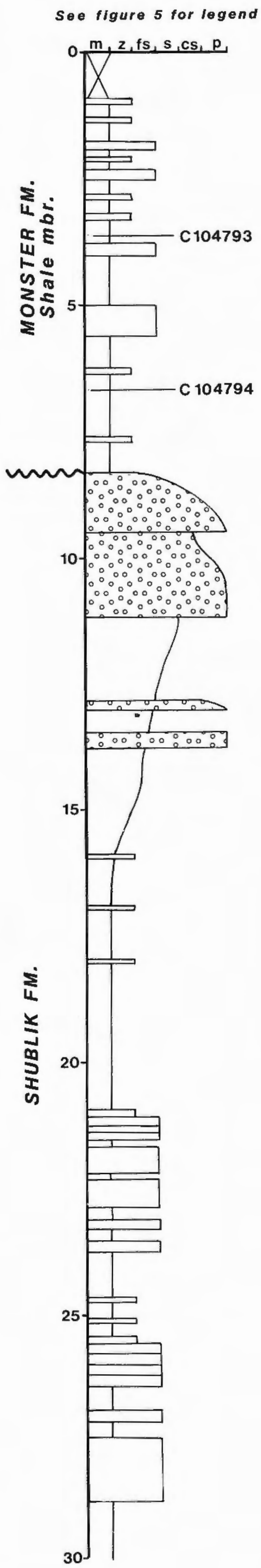


Figure 2. *Schematic representation of the section containing the Monster/Shublik contact. The location is shown on Figure 3. The two samples indicated were examined for microflora by A.R. Sweet and D.J. McIntyre. Thickness in metres.*

Shale member (KM) (new informal member)

The Shale member consists of very thinly but regularly bedded, dark grey siltstone and shale, with a few fine grained, turbiditic sandstone beds 5 to 20 cm thick (designated KM in Fig. 3). Two outcrops of this member have been located: the first in a river cutting in the north Tatonduk River area, at Latitude 65°12'N and Longitude 140°40'W. Here, some 40 m of siltstone and shale are exposed, approximately 60 to 80 m stratigraphically below the Sandstone member and, therefore, the minimum thickness of the Shale member is 100 to 120 m. The base of the member is not exposed. The second locality, already described above, contains the Monster/Shublik contact.

In Figure 3, the known exposure of the Shublik Formation (Ts) is extended to the northwest limb of the Monster Synclinorium. On this limb, the recessive interval beneath the Sandstone member is mapped as undifferentiated Shale member and Shublik Formation (Figs. 3, 4).

Sandstone member (KM1)

This is the lowest coarse grained unit in the Monster Formation, and is a distinctive, bluff-forming, slab-weathering litharenite. It is the most continuous unit found in the formation and can be traced around most of the Monster Synclinorium and the syncline in the north Tatonduk area. Its contact with the subjacent Shale member is gradational over a few metres, and the transition between these two members displays coarsening- and thickening-upward trends. Contact with the overlying Sandstone-shale member (KM2) is relatively abrupt but conformable. The member varies in thickness between 35 m and 50 m and consists of three to five interbedded shale and sandstone intervals, each of which constitutes a coarsening-upward sequence. In the north Tatonduk area the upper 5 m are conglomeratic.

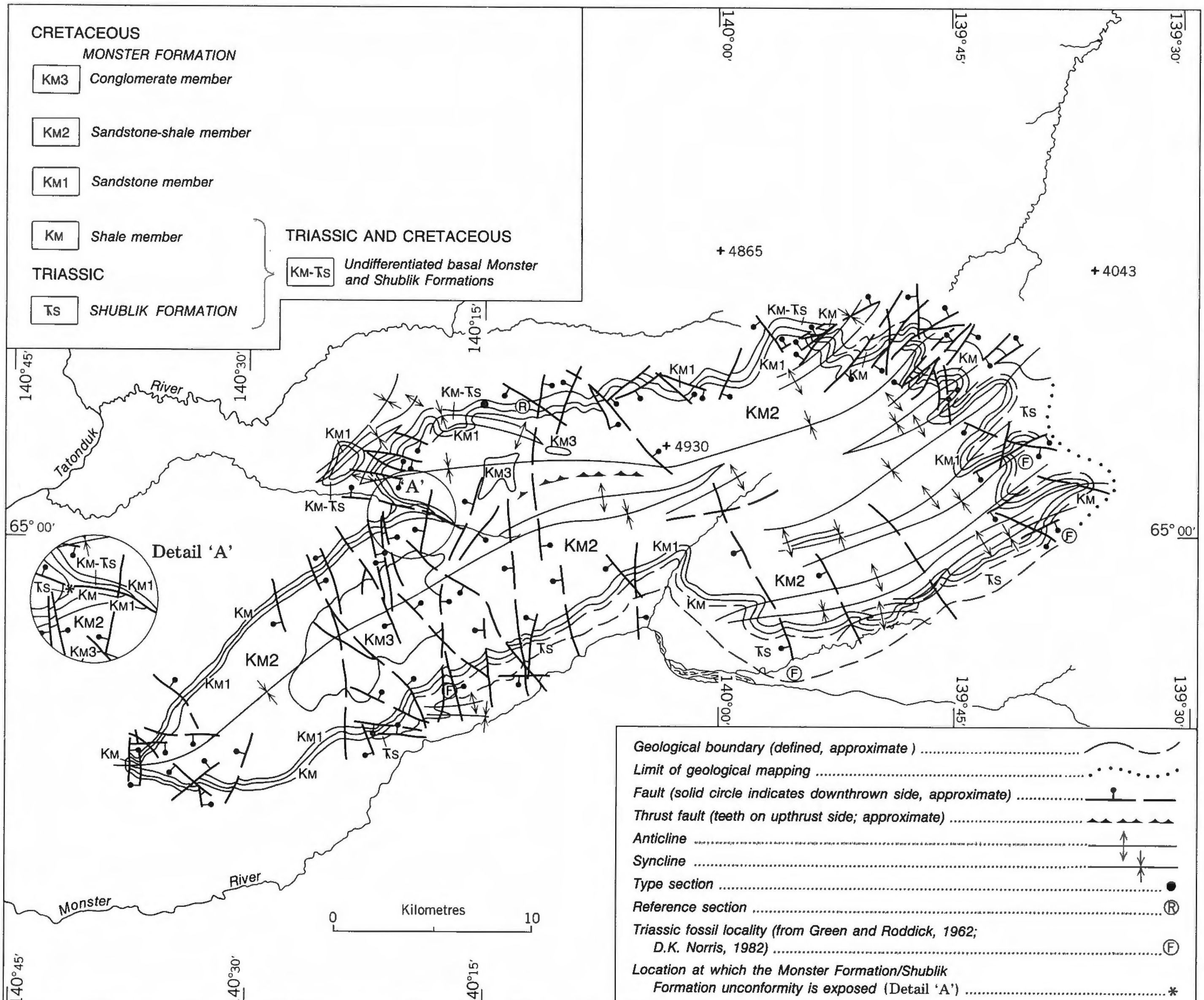


Figure 3. *Geological map of the Monster Synclinorium.*

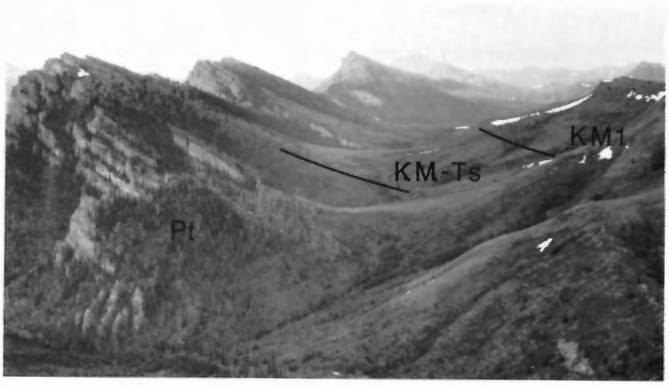


Figure 4. *Panorama of the Sandstone member (KM1), Shale member (KM) and Takhandit Formation (Pt). The KM-Ts interval includes possible Shublik Formation (Triassic). The view is almost due east along the northern limb of the Monster Synclinorium (ISPG 1861-6).*

Sandstone-shale member (KM2)

The Sandstone-shale member forms the bulk of the Monster Formation and consists of resistant bluff-forming litharenites 3 to 8 m thick, separated stratigraphically by recessive intervals up to 40 m thick. The few outcrops of these recessive intervals reveal mostly shale, siltstone and thin bedded, fine grained sandstone. The topographic expression of these recessive intervals is commonly seen as well defined breaks in slope that correspond to alternating sandstone and shale lithologies.

In the Monster Synclinorium, conglomerates make up a relatively minor part of the Sandstone-shale member. However, at north Tatonduk River, conglomerate beds up to 20 m thick comprise a significant portion of the sequence at an equivalent stratigraphic level, and lithologically are identical to, and in fact may be the equivalent of, conglomerates in the uppermost member of the Monster Formation (KM3). If this correlation is correct, the Sandstone-shale member pinches out between Monster River and north Tatonduk River, and is replaced by strata of Map unit KM3.

Conglomerate member (KM3)

The Conglomerate member is the highest stratigraphic unit in the vicinity of Monster River. The member consists of resistant bluff- and butte-forming conglomerates up to 35 m thick, and intervening recessive units of siltstone and shale, similar to recessive intervals in the Sandstone-shale member. The thick conglomerates in the Monster River area are in abrupt, but conformable, contact with the subjacent Sandstone-shale member. Nowhere is the stratigraphic top of the Conglomerate member exposed; in the Monster Synclinorium the top of the formation is erosional, and around north Tatonduk River it is tectonic.

Reference section

The type section of the Monster Formation erected by Mountjoy (1967) was reexamined and found to be structurally thickened by an anticline - syncline pair on the northwest limb of the synclinorium. The thickness of the repeated strata is difficult to determine because of poor exposure. Consequently, a reference section is proposed, located one kilometre due east of the type section (Lat. 65°03'N; Long. 140°13'W). Here, repeated beds can be traced through the folds and a more accurate measurement of stratigraphic thickness can be obtained. This section is 1053 m thick, including a 200 m covered interval above the Takhandit. Some of the covered interval may include 50 m or more of Shublik strata (details of this section are provided in Appendix 1).

STRUCTURE

In the Monster River area, strata of Permian, Triassic and Late Cretaceous age have been folded into a broad, open synclinorium, characterized by two principal west to southwest trending synclinal axes (Fig. 3). Numerous minor folds occur in the Mesozoic strata in the eastern and northern sectors of the synclinorium. The more competent Takhandit limestones, although highly faulted, generally are not involved in these minor structures and numerous detachment surfaces must occur, therefore, at the contact with the Shublik and/or Monster formations.

A similar structural style is found at north Tatonduk River, where a south-plunging, recumbent, open syncline in the Monster Formation has been overthrust by Precambrian Tindir Group rocks. The sequence is cut by abundant normal faults and a few, low-angle, reverse, or minor thrust faults.

PALYNOLOGY

Twenty-nine samples were submitted for microfloral analysis, five from the Shale member, and the remainder from the Sandstone-shale and Conglomerate members. A.R. Sweet (specialist in spores and pollen) and D.J. McIntyre (specialist in dinoflagellates) have, in personal communications (1982), provided the following information concerning the samples:

A characteristic feature of all samples is the low number of palynomorphs. In a few samples, this is a result of a relatively high degree of carbonization. However, the paucity of spores and pollen also is evident in samples showing good preservation and, therefore, it seems more likely that the low recovery is a reflection of the original number of palynomorphs present at the time of deposition.

All of the samples examined for spores and pollen were found to contain a sparse, but diverse assemblage of dinoflagellates. They are moderately well preserved, exhibit a relatively narrow age range, and are considered by D.J. McIntyre to be indigenous. Fusinite and woody tissue are common in all samples. The assemblage indicates some marine influence in all members of the Monster Formation.

Age

The spore and pollen assemblage has a distinctly mid-Cretaceous character, given by the combined presence of *Aequitriradites*, *Appendicisporites*, *Cicatricosisporites*, *Foraminisporis*, *Gleicheniidites*, *Microreticulatisporites*, possibly *Distaltriangulisporites*, and tricolpate angiosperm pollen. An age within the range of Middle Albian to possibly Santonian is suggested.

A more specific age of Cenomanian is indicated by the dinoflagellate assemblage. The following detailed description of the species has been provided by McIntyre (pers. comm., 1982): "*Chlamydophorella trabeculosa* (Gocht) Davey, which is present in many samples, is not known with certainty above the Cenomanian. *Luxadinium propatulum* Brideaux and McIntyre and *Chichaouadinium vestitum* (Brideaux) Bujak and Davies have known ranges of late Middle Albian to Cenomanian, while *Ascodinium scabrosum* Cookson and Hughes ranges from Late Albian to Cenomanian. *Eurydinium glomeratum* (Davey) Stover and Evitt and *Isabelidinium magnum* (Davey) Stover and Evitt are at present known only from the Cenomanian. The following species have their oldest occurrences in the Cenomanian and also occur higher in the Late Cretaceous: *Amphidiadema* sp. cf. *A. denticulata* Cookson and Eisenack (present in many of the samples), *Heterosphaeridium difficile* (Manum and Cookson) Ioannides, *Batioladinium* sp., *Laciniadinium arcticum* (Manum and Cookson) Lentin and Williams, *Spongodinium delitiense* (Ehrenberg) Deflandre, and *Trithyrodinium suspectum* (Manum and Cookson) Davey".

TABLE 2

Sedimentary facies

FACIES		DESCRIPTION
A	Massive conglomerates	Clast supported, tabular bedded, 10-100 cm thick. Vague parallel stratification or unstratified. Crude imbrication of pebbles.
B	Crossbedded conglomerate	Large planar-tabular crossbeds up to 3 m thick. Individual foresets graded and dip 12-20°. Toesets tangential or abutting.
C	Crossbedded conglomerate	Large trough crossbeds, up to 3.5 m thick.
D	Crossbedded sandstone	Planar crossbed sets average 5-60 cm thick, up to 150 cm thick. Fine to coarse grained toesets tangential or abutting.
E	Crossbedded sandstone	Trough crossbed sets average 5-60 cm thick. Fine to coarse grained.
F	Rippled sandstone	Asymmetric current ripples, 1-2 cm amplitude. Includes climbing ripples. Usually fine grained.
G	Pebbly sandstone	Trough-shaped scour-and-fill structures, commonly having a basal layer of pebbles.
H	Laminated sandstone	Horizontal - subhorizontal laminated, medium-fine grained. Parting lineations. Contains a few, small, trough crossbeds.
I	Laminated sandstone	Subhorizontal laminations and low-angle planar crossbeds; set contacts 5-8°. Parting lineations, a few groove and skip casts. Fine to medium grained.
J	Hummocky cross-stratified sandstone	Low-amplitude mounds 5-10 cm, spacing 1-3 m. Fine to medium grained.
K	Siltstone-shale	Thin, interbedded, laminated siltstone and dark grey shale, locally rippled. Rare root-bearing beds.
L	Shale	Thin bedded, grey siltstone and shale, finely comminuted plant debris, slightly bioturbated. Contains rare, fine grained sandstone beds, 2-20 cm thick (turbidites).

SEDIMENTARY FACIES

Sedimentary facies herein are defined by lithological homogeneity and sedimentary structures, and in the Monster Formation twelve such facies are recognized (denoted by A, B, C etc., in Table 2). Although the coarse grained facies are similar to those defined by Miall (1977, 1978) and Rust (1978), I have avoided using their facies codes (e.g. Gp, Sp, etc.). The facies and codes commonly are associated with braided stream deposits and, although these authors may not have intended this to be the case, their use might bias the interpretation of deposits as braided, especially when evidence is equivocal.

Conglomerates consist predominantly of chert pebbles of various types (80-90%), subordinate vein quartz (10-15%), and reworked quartz arenite and arkose (5%). At Monster River, pebble size averages 2 to 3 cm and clasts attain a maximum of 12 cm, whereas in the north Tatonduk area the average length increases to 3 to 4 cm with a maximum of 25 cm. Facies types A and B are the most common. Individual planar crossbed sets (Facies B) commonly can be traced 30 to 40 m laterally. One set, which attains a thickness of 3.5 m, was traced 80 m into an area of cover. Very few trough crossbedded conglomerate units (Facies C) were encountered; most show downcutting relationships, truncating Facies A and B, or some of the sandstone facies.

Of the seven sandstone facies identified, those containing planar, trough and ripple cross-stratified bed forms are most common (Facies D, E, and F respectively). Trough and planar sets may occur singly or in groups, and many are festooned. Facies F contains ripple trains or complex, multiple ripple sets. Facies D through H occur in the Sandstone-shale and Conglomerate members. The two laminated sandstone facies, H and I, are similar, except that Facies H usually contains a few trough crossbeds. The slabby weathering characteristic of Facies I also is distinctive. Facies I and J are found only in the Sandstone member. The hummocky cross-stratified facies (J) is similar to that described by Hamblin and Walker (1979).

Mudrock facies, K and L, are distinguished by the presence of rare root structures and dark grey colour in the former, and bioturbation in the latter.

FACIES ASSOCIATIONS

Very few sedimentary facies, especially the types described here, are diagnostic of specific depositional environments. For example, the crossbedded sandstone facies, D to I inclusive, can be found in a wide variety of marine and nonmarine settings. However, the number of options for interpretation of these facies can be narrowed considerably if: a) spatial associations of different facies are examined within specific lithological units, and b) stratigraphic associations, or vertical sequences, are examined. Both the facies and stratigraphic associations are interpreted by comparing them with associations that can be observed directly in modern environments, or with hypothetical vertical profiles (or models). Facies associations recognized in the Monster Formation are summarized in Table 3.

Conglomerate-sandstone association

A typical bluff-forming conglomerate-sandstone sequence is illustrated in Figure 5, Section a. The sandstone component accounts for 20 to 50 per cent of the thickness in these sequences. Most of these sequences display crude fining-upward and thinning trends, where the thickest cross-stratified sets (Facies B, C) occur in the lower part, and the proportion of sandstone increases upward. Within this general trend, a smaller scale cyclicity exists, manifested as 1 to 5 m thick intervals of stratified conglomerate capped by crossbedded sandstones and, locally, shale veneers (Fig. 6). The sandstones consist of Facies D, E, F, and H (Fig. 7), and form tabular or lenticular beds, the latter occurring where the sands were eroded during deposition of the overlying conglomerates. A typical conglomerate-sandstone cycle consists of:

1. A sharp top, commonly erosional
2. Remnants of a shale veneer
3. Rippled sandstone (Facies F)
4. Trough and planar crossbedded sandstone (Facies D, E)
5. Planar crossbedded and massive-bedded conglomerate (Facies A, B).

Some repetition may occur in the sandstone facies. There is no preferred facies order in the conglomerates, although the planar crossbedded facies (B) predominates (Fig. 8). Individual crossbed sets can be traced laterally for several tens of metres, whereupon they grade into massive conglomerate (Facies A) or sandstone facies. In some cases, superposed beds are truncated by large trough crossbedded conglomerate sets up to 3.5 m thick (illustrated in a field sketch, Figs. 9 and 5a). Reactivation surfaces are common in the large conglomerate bed-forms, as evidenced by thin sandstone drapes over cross-strata. Plant fragments up to one metre long also are common at the base of each cycle.

The internal organization of sandstone components is similar to the fining-upward sandstone association (see below), with the exception that pebbly sandstones, and pebble lags at the base of trough crossbeds are ubiquitous in the conglomerate sequences.

TABLE 3

Principal facies associations

Associations	Facies
Conglomerate-sandstone	A, B, C, D, E, F, G, H
Sandstone:	
Fining-upward	D, E, F, G, H
Coarsening-upward	I, J, K
Fine grained:	
Fining-upward	E, F, K
Shale	L

Fining-upward sandstone association

In the area around Monster River, sandstone sequences in the Sandstone-shale member become thicker toward the top of the formation. Also, the fining-upward and thinning-upward trends are more pronounced than those of the conglomerate-sandstone association. Thicker sequences (up to 18 m) also possess numerous smaller scale cycles (Figs. 5b, 10), in which a fairly regular vertical progression of facies is observed as follows:

1. Sharp top
2. Thin shale bed, may be eroded
3. Rippled sandstone
4. Planar crossbedded sandstone
5. Trough crossbedded sandstone
6. Subhorizontally laminated sandstone
7. Scour-and-fill, pebble lags.

The thicker, small-scale cycles (up to 7 m) tend to show a more complete sequence of facies, with subhorizontally laminated sandstones at the base, overlain by trough or planar crossbedded sandstones (Fig. 11). Thinner cycles that lack the lower laminated portion contain abundant trough and planar crossbeds. Contacts between successive cycles are demarcated by pebble lags and comminuted plant debris (at the base of the upper cycle), and thin shaly beds and lenses at the top of the subjacent cycle. Individual cycles can be traced laterally for a few tens of metres. Lateral facies changes include: amalgamation of successive thinner cycles to form composite units 1 to 2 m thick; and truncation of earlier-formed cycles by successive units, in which the truncation surfaces dip less than 10° and are delineated by pebble lags and shale veneers.

Coarsening-upward sandstone association

This coarsening-upward sandstone association is restricted to the Sandstone member, and the lowermost part of the Sandstone-shale member, and consists of three facies types: laminated sandstone (Facies I), hummocky cross-stratified sandstone (Facies J), and laminated siltstone-shale (Facies K). Ripple marks and small-scale crossbeds are rare.

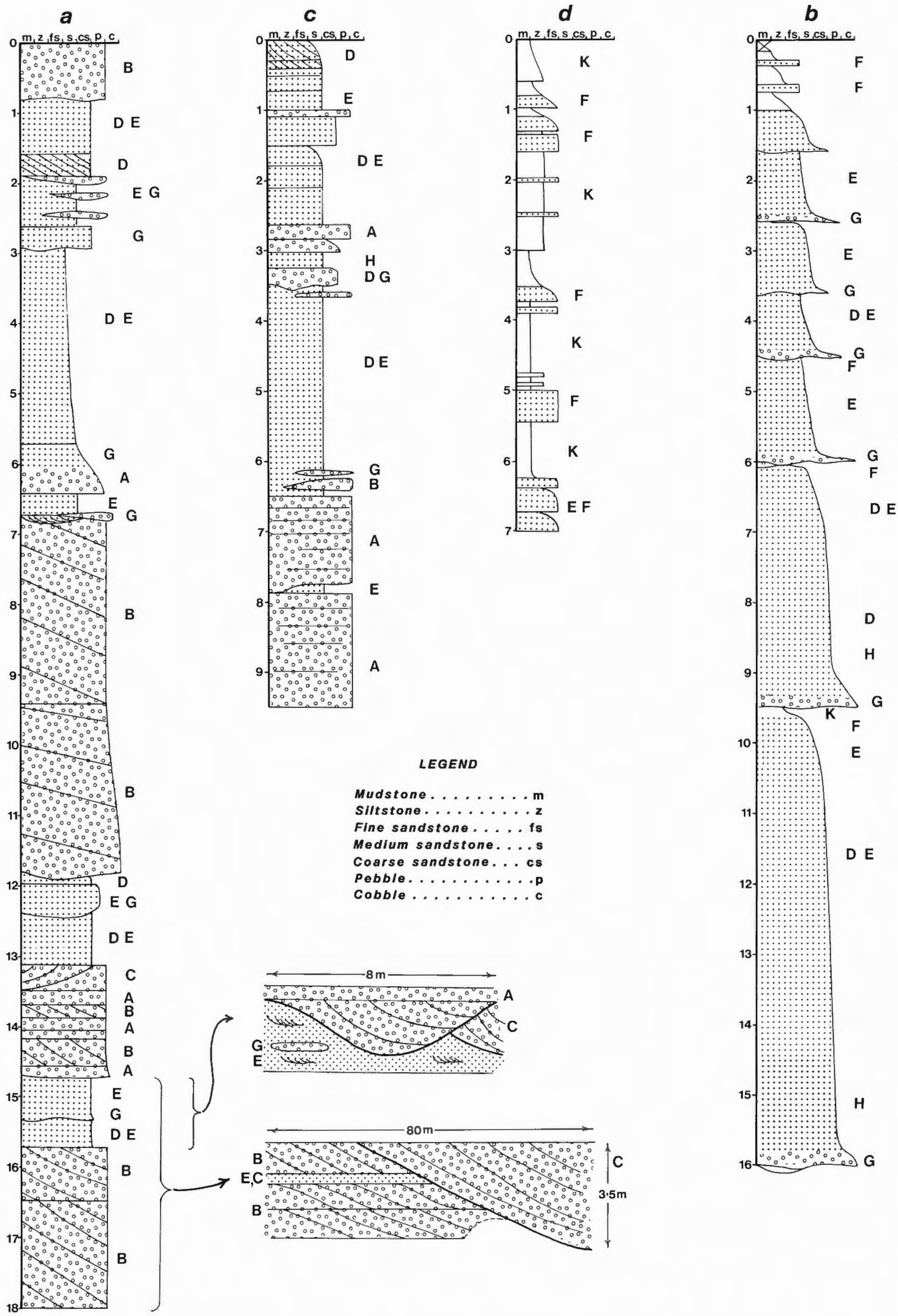


*Figure 5. Detailed measured sections (in metres) illustrating the vertical distribution of the conglomerate (a), sandstone (b, c) and shale (d) facies. Sections **a** and **c** are from the north Tatonduk area, **b** and **d** from the reference section north of Monster River. The insets in Section **a** illustrate some lateral facies changes. Photographs of Sections **a, b** and **d** are shown in Figures 9, 10 and 15 respectively. Facies symbols are from Table 2.*

Figure 6. The conglomerate-sandstone association from the Conglomerate member at the reference section. There are three sandstone units here, each truncated by successive crossbedded conglomerates. The facies correspond to those in Table 2. Scale is 150 cm long (ISPG 1861-92).

Intraformational pebble lags occur locally and the pebbles commonly form nucleii for ironstone concretions. Finely comminuted plant material is sparse. Bioturbation was not observed.

Two representative sections of the Sandstone member are shown in Figure 12. In the Monster River area, contact between the Sandstone member and superjacent Sandstone-shale member is sharp and mappable. However, in several sections, thin sandstone beds (1-2 m thick) composed of Facies I and J, and separated by thick siltstone and shale intervals, occur up to 60 m above this contact. In this interval, sandstones more typical of the fining-upward association alternate with the hummocky cross-strata-bearing sandstones, and the transition between these two associations appears to be gradational (Fig. 12). In the north Tatonduk River area, facies changes at the top of the basal Sandstone member differ considerably from their counterparts to the southeast. Here, the upper 20 m consists of sandstone facies D, E and H, which in turn are overlain by planar crossbedded conglomerates (Facies B) and thin, cross-bedded sandstones. The hummocky cross-stratified facies does not occur in this conglomerate interval. Interbedded (recessive) sandstone and shale overlie this member.

Figure 7. Planar crossbedded facies (above) and laminated sandstone facies (below) in the Conglomerate member. Same locality as Figure 6. Hammer is 33 cm long (ISPG 1861-89).

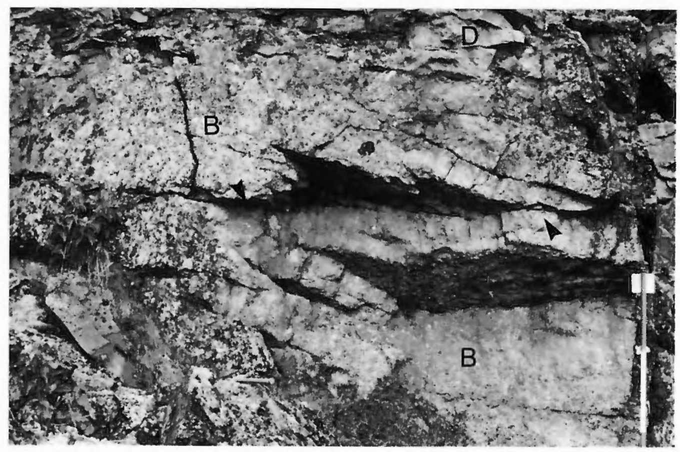


Figure 8. Two, large, superimposed planar crossbeds (B) in the Conglomerate member, north Tatonduk area, overlain by planar crossbedded sandstone (D). The set contact is indicated by arrows. Divisions on the scale are 50 cm long (ISPG 1861-153).

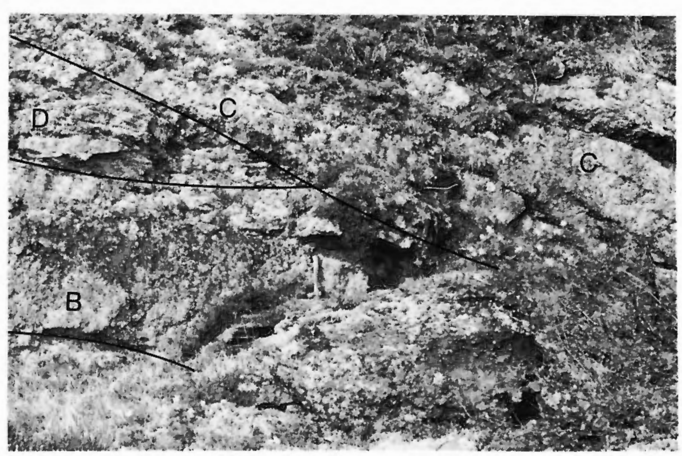


*Figure 9. Example of a thick (3.5 m) trough crossbed (C) in the Conglomerate member, truncating a large planar crossbed set (B) – contacts indicated. The planar crossbed can be traced 80 m laterally to the example pictured in Figure 8. The lateral facies changes also are depicted in the lower inset of Figure 5, Section **a**. Hammer is 33 cm long (ISPG 1861-166).*

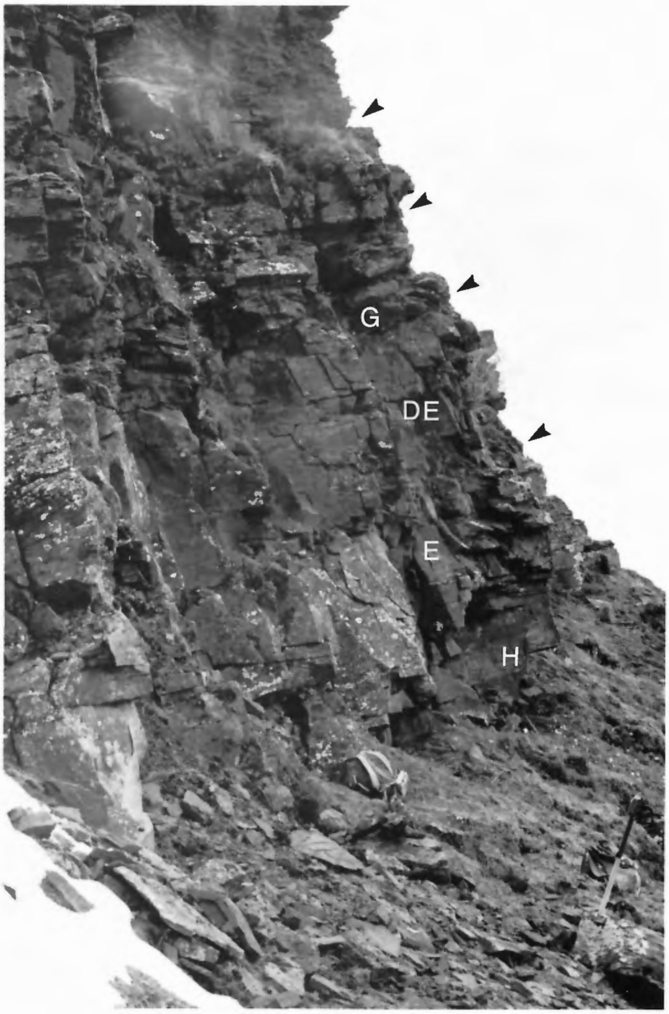


Figure 10. Stacked sandstone cycles (arrows) in the Sandstone-shale member, located at the reference section. See also Figure 5, Section b. Scale divisions are 50 cm long (bottom right) (ISPG 1861-69).

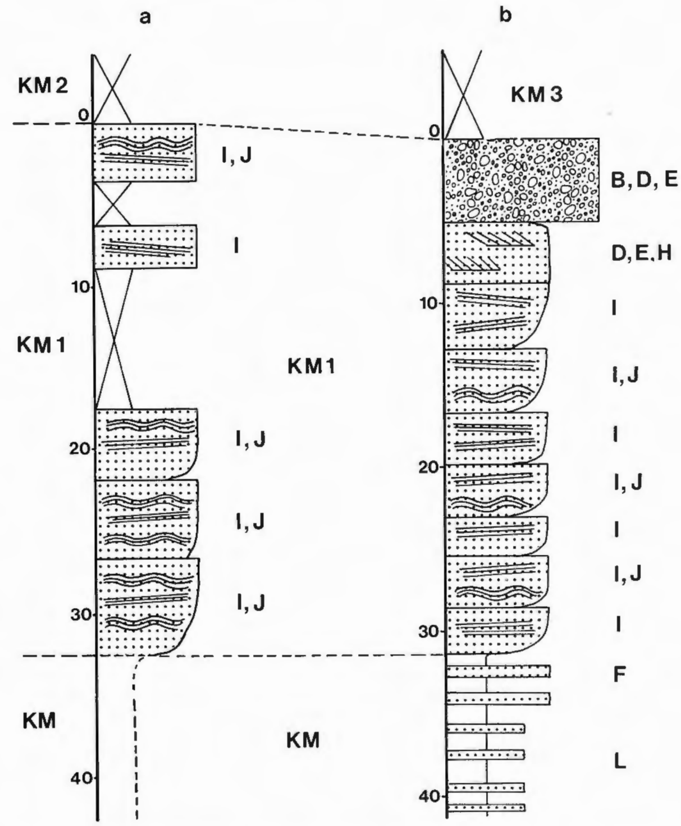


Figure 12. Schematic illustration of representative sections of the Sandstone member: (a) is from the reference section, Monster River area; (b) from the north Tatonduk area. Note the stacked, coarsening-upward sandstone units containing hummocky cross-strata. Depths in metres.

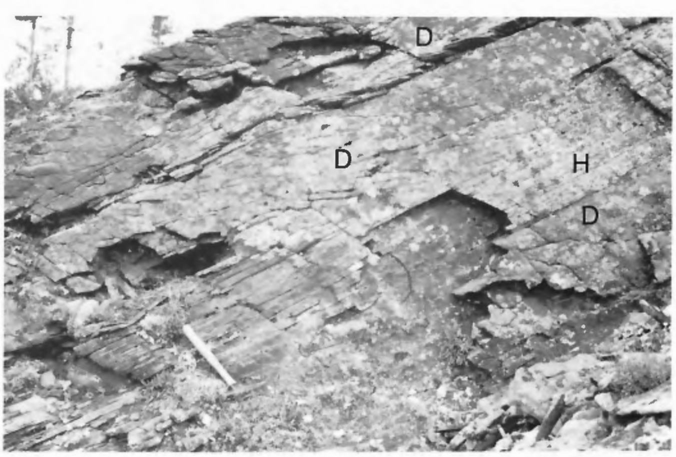


Figure 11. A profile through planar crossbeds (D) and parallel laminated sandstone (H) of the Sandstone-shale member. Hammer is 33 cm long (ISPG 1861-7).

Figure 13. A thickening- and coarsening-upward sandstone sequence from the north Tatonduk area, showing the transition from basal siltstone to hummocky crossbeds (J) and laminated sandstone (I). The top of the underlying sequence is marked by an arrow. Exposure is about 2.2 m high (ISPG 1861-179).

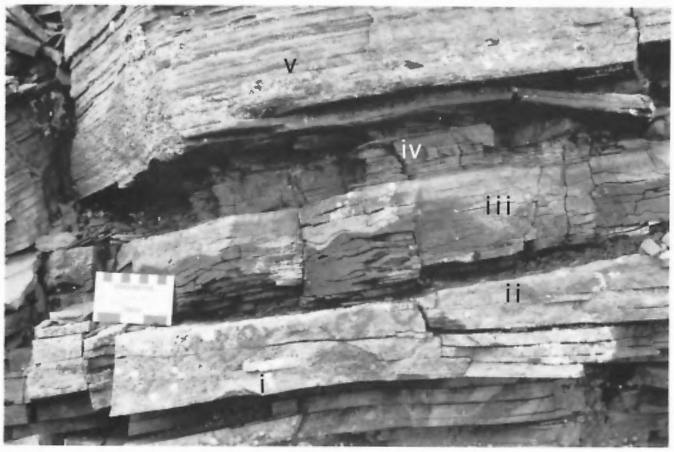


Figure 14. An example of hummocky crossbedding. A complete vertical sequence here contains: at the base, convex-upward laminae (i), grading into subhorizontal laminated sandstone (ii), ripple bedded sandstone (iii), and laminated siltstone as a recessive layer (iv). The succeeding hummocky bed (v) has partly eroded the siltstone unit (ISPG 1861-63).

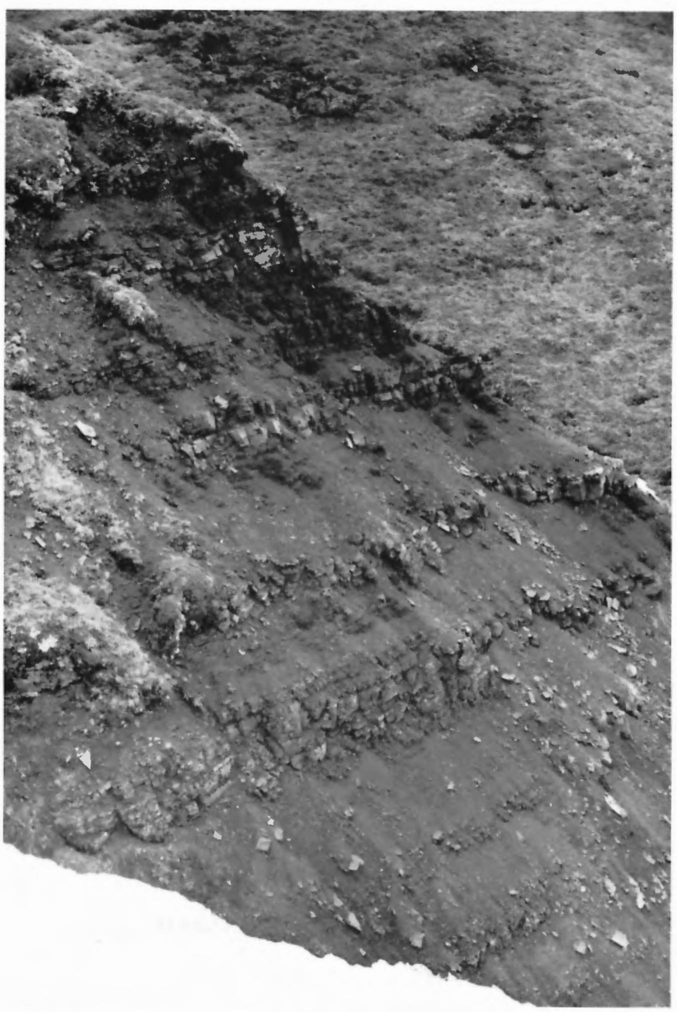


Figure 15. One of the few exposures of the fine-grained facies association, near the reference section. Individual sandstone beds (resistant units) fine upward into dark grey shale. Outcrop is approximately 10 m thick. See also Figure 5, Section d (ISPG 1861-52).

Smaller scale cyclicity is well developed in both areas, where individual cycles show the following vertical facies transitions:

1. Rippled, fine grained sandstone (Facies F) at top
2. Laminated and low-angle planar crossbedded sandstone (Facies I)
3. Thin bedded, hummocky cross-stratified sandstone (Facies J)
4. Thin shale-siltstone interbeds (Facies K) at base.

Contact with siltstone and shale of the overlying cycle is abrupt and flat. A typical example is shown in Figure 13. In any cycle some repetition may occur between Facies I and J. At least five cycles were observed in each section.

Hummocky cross-stratification

A distinctive feature found only in the coarsening-upward sandstone association is the hummocky cross-stratified sandstone facies. Only exposures normal to bedding were available for examination, but many of the attributes of these structures are similar to examples documented in the literature (e.g. Hamblin and Walker, 1979; Dott and Bourgeois, 1982). Laminated, fine to medium grained sandstones are arranged in sets up to 40 cm thick, and form convex-upward domes of 5 to 10 cm amplitude (Fig. 14). Dome spacing ranges from 1 to 1.5 m. Laminae tend to thicken laterally from dome crests, diverging toward the intervening troughs. In vertical sections, shallow dipping, hummocky laminae grade upward into subhorizontally laminated sandstone in which there are low-angle truncations. This sequence of structures is similar to the ideal stratigraphic sequence of hummocky beds described by Dott and Bourgeois (*op. cit.*), although the uppermost bioturbated interval is missing.

Fining-upward, fine-grained association

Exposure of strata composing this association generally is poor, but a few good sections outcrop at the head of a small valley between the type and reference sections. The section illustrated in Figures 5d and 15 is thought to be representative of most recessed intervals between bluff-forming sandstones and conglomerates, in the Sandstone-shale and Conglomerate members. Characteristically, the association consists of alternating dark grey shale and siltstone (Facies K), and fine grained sandstone (Facies E, F). The fining-upward trends referred to here include an overall decrease and concomitant thinning of the sandstone bed component. The sandstones occur in single beds or in groups of up to 10 beds, and individually also display a fining-upward character (Fig. 16).

Shale association

This association corresponds to the Shale member; the exposure located near north Tatonduk River consists solely of Facies L (Fig. 17). Although exposure is discontinuous here, contact with the overlying Sandstone member is considered to be gradational. The few thin, fine grained sandstones encountered have abrupt bases but grade upward into shale.

Lateral facies changes

The present thickness of the Monster Formation decreases from about 1300 m in the north Tatonduk area, to between 900 and 1100 m at Monster River. Significant lateral changes, concomitant with this eastward thinning trend, occur in the various conglomerate and sandstone facies. Conglomerates constitute a proportionally greater part of the sequence at north Tatonduk River, about 12 to 14 per cent, compared with 6 to 7 per cent at Monster River. In the west, conglomerates normally included in the Map unit KM3 interval are distributed throughout the formation above the Sandstone member, whereas at Monster River they are present only in the upper 200 m of the formation (Fig. 18). Clast size in the conglomerates also decreases toward the east; maximum cobble size in the west is 25 cm, decreasing to 12 cm in eastern exposures. A similar grain size decrease, but in a south-north direction, also is seen in the north Tatonduk area.

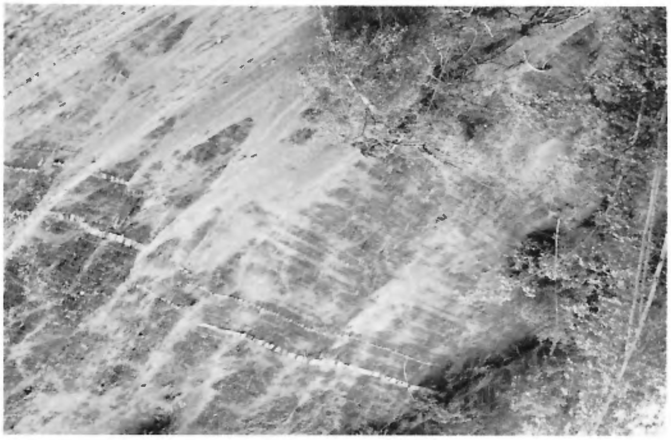


***Figure 17.** Outcrop of the Shale member, north Tatonduk area. Note the thin, resistant sandstone beds. Cliff is about 30 m high (ISPG 1861-183).*

***Figure 16.** Thinly bedded sandstone-siltstone shale of Facies K. Individual beds fine upward. Root structures are indicated by arrows (ISPG 1861-53).*

***Figure 18.** Panoramic view of butte-forming conglomerates composing the Conglomerate member. Intervening recessive lithologies consist principally of siltstone and shale, and some sandstone. The thickness of the KM3 member is 195 m. Individual conglomerate units range in thickness from 9 to 18 m. Note that the second conglomerate unit from the base of KM3 pinches out and is replaced by recessive, finer grained rocks (ISPG 1861-79).*

GENERAL STRATIGRAPHIC RELATIONSHIPS

The Monster Formation displays an overall coarsening-upward and bed-thickening stratigraphic trend within which there is subordinate cyclicity involving grain size and bed thickness changes (summarized in Fig. 19).

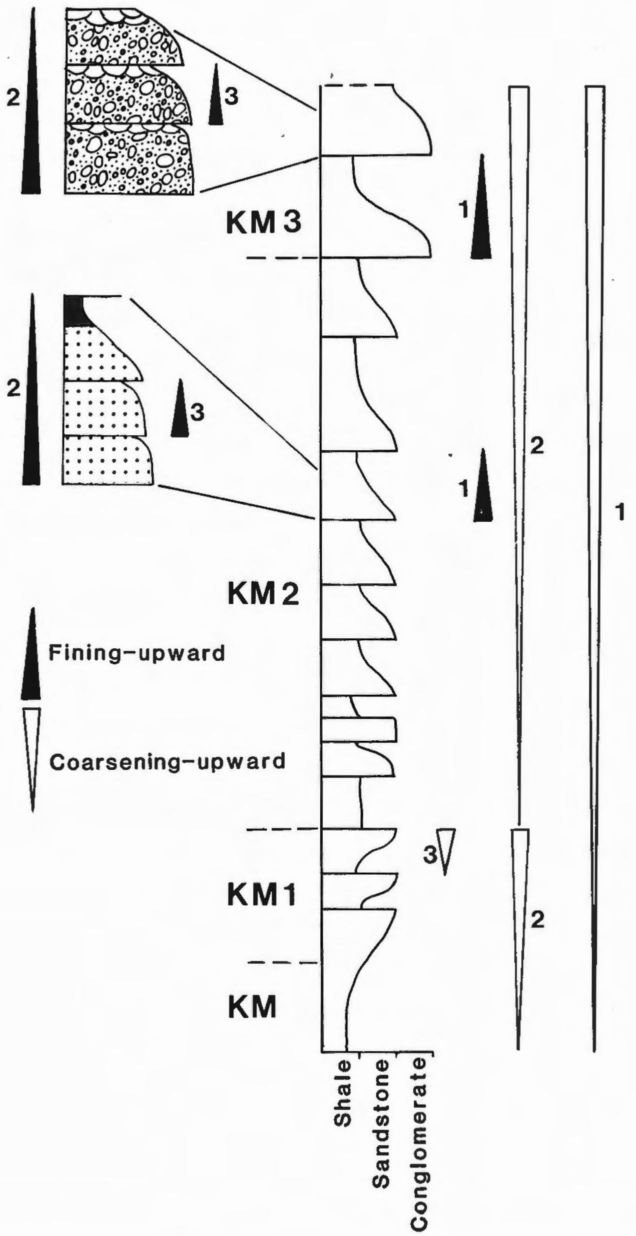


Figure 19. Schematic representation of fining-upward and coarsening-upward cyclicity in the Monster Formation. Numbers 1, 2, 3 refer to first, second and third order cycles. Second and third order fining-upward cycles are shown as insets in the KM3 and KM2 members.

Fining- and thinning-upward cycles

A threefold hierarchy of fining-upward cycles is observed in the Sandstone-shale and Conglomerate members. First-order cycles range from 10 to 100 m thick and include couplets of the conglomerate association or the fining-upward sandstone association, with the fining-upward fine grained association. Each first-order cycle consists of numerous second-order, fining-upward cycles up to 18 m thick, consisting of basal sandstone beds that grade into thinly bedded sandstone and shale. Some of the second-order cycles can be subdivided further into third-order cycles, on the scale of single beds; for example, individual sandstone beds within the fining-upward associations.

Coarsening- and thickening-upward cycles

The complete Monster Formation is classified as a first-order coarsening-upward cycle (see Figure 19). This is best developed in the Monster River area where conglomerate facies occur at the top of the formation. At north Tatonduk River, however, this coarsening trend is less pronounced because conglomerates are more evenly distributed throughout the sequence. The Monster also can be divided into two second-order, coarsening-upward cycles; the lowest cycle includes the Shale and Sandstone members, the upper cycle comprises the Sandstone-shale and Conglomerate members. The lower of these second-order cycles can be further subdivided into thinner (third-order) units of the coarsening-upward association. Individual first-order, fining-upward cycles in the Sandstone-shale and Conglomerate members become increasingly thicker toward the top of the sequence; this trend coincides with the upper second-order, coarsening-upward cycle shown in Figure 19.

INTERPRETATION OF FACIES ASSOCIATIONS

The conglomerate-sandstone association represents deposition by high-energy, bed-load transport. In terms of their scale and internal organization, the most appropriate modern analogues for the association of large-scale planar crossbedded and massive bedded conglomerates are transverse and longitudinal fluvial bars respectively; for example, those described by Williams and Rust (1969) in Donjek River, and by Hein and Walker (1977) from Kicking Horse River. These bar forms are typical of gravelly braided rivers, although similar types also have been observed in some meandering river channels and gravelly point bars (Bluck, 1971; Jackson, 1976). Thin, crossbedded sandstone layers, draping reactivation surfaces of planar crossbeds or capping third-order cycles, indicate waning flood conditions (decreasing stream competence). Shale veneers indicate deposition from suspension, probably in local ponded areas on bar tops, during the stage of falling water level.

Fining-upward sandstone associations are characterized by abundant trough and planar crossbeds, suggesting relatively confined, or channelized flow. As noted previously, many of the third-order fining-upward cycles contain a sequence of facies indicative of waning currents: initial scouring at the base and subsequent subhorizontal laminated sandstone (with parting lineation) suggest deposition under upper flow regime conditions; subsequent formation of transverse bedforms (planar, trough and ripple crossbeds) took place under a lower flow regime that became less competent during the waning stages of flooding. Vertical stacking of up to eight of these sequences gave rise to the second-order fining-upward cycles shown in Figure 19.

The fining-upward, fine-grained association is found immediately overlying both the sandstone and conglomerate associations and is considered to be a continuation of these associations. In this case, third-order sandstone-shale cycles indicate the transition from low energy bed-load transport (manifested as current ripples) to suspension dominated conditions. Sequences such as this are commonly found in areas subjected to frequent flooding, for example in overbank settings. Climbing ripples, formed by deposition from suspension plus traction, are common in floodwaters that have a high suspension load. Vegetation cover appears to have been particularly sparse.

A completely different sequence of sedimentary structures is seen in the coarsening-upward sandstone association. Large-scale, dune-type bedforms are rare and, instead, low-angle planar crossbeds and distinctive, hummocky, cross-stratified beds occur. Deposition within a nearshore setting is indicated. In particular, hummocky cross-strata have been interpreted by several authors as forming in water depths below fairweather wave-base but within the reach of storm generated waves. However, there is some dispute over the mechanism of hummocky bed formation. Hamblin and Walker (1979) observed an intimate association between beds containing evidence of density flow origin, and hummocky cross-stratified beds, and suggested that storm-wave oscillation reworked the earlier formed turbidites (i.e., during the same storm event). An alternative mechanism, suggested by Dott and Bourgeois (1982), combines vertical settling of suspended sediment with oscillation of storm waves impinging on a substrate. In the Monster Formation examples, rare turbidites occur in the underlying Shale member, but are not spatially associated with the hummocky cross-strata. Parting lineation is common in the laminated sandstones, and indicates plane bed, upper flow regime conditions. It is possible to invoke high energy, wave-generated currents for the hummocky cross-stratification in the Monster Formation, but it is unlikely that density currents were also involved. The transition to small-scale current ripples at the top of individual hummocky sequences represents a return to fairweather conditions.

The shale association at the base of the Monster Formation represents suspension-dominated sedimentation; there are few indicators of bed-load transport. The rare, thin, graded sandstones represent isolated turbidity-current deposits.

GENERAL INTERPRETATION

Before embarking on a general paleoenvironmental interpretation of the Monster Formation, the following constraints are reviewed:

1. The Monster Formation comprises a thick, clastic sequence that exhibits thinning and fining trends toward the east
2. There is pronounced cyclicity, particularly in the Sandstone-shale and Conglomerate members
3. A sparse but indigenous marine dinoflagellate flora occurs throughout the formation. These fossils are found in the thick, fine grained facies as well as in thin shale beds interbedded with the sandstones and conglomerates. Dinoflagellates also were found in intraformational mud clasts in a conglomerate near the type section of the Monster. The sparse assemblage does not necessarily indicate deposition directly in a marine environment, but suggests at least close proximity to shoreline, within reach of local reworking processes such as storm-generated floods
4. Neither coal beds nor paleosoils occur in the formation, indicating little in the way of vegetation cover.

It is useful to examine the Monster Formation in terms of its two second-order, coarsening-upward cycles. In the lower cycle, the Sandstone member represents a sandy foreshore and shoreface, which prograded over deeper water offshore deposits. Except for a few turbidite deposits, the offshore environment was virtually starved of coarse, clastic debris. The shoreline appears to have been subjected to numerous storms as evidenced by the presence of hummocky cross-strata.

The upper of these second-order cycles is characterized by numerous fining-upward sequences of sandstone and conglomerate. These sequences have a distinct fluvial aspect in which the basal sandstones or conglomerates represent channel deposition, and the fine grained portion accumulated in a floodplain environment. However, a problem arises in trying to specify the fluvial regime: Do the deposits represent meandering or braided river types? Superficially, the fining-upward cycles are similar to the classical model of meandering streams (e.g. Allen, 1970), although such trends have also been recognized in braided deposits (Miall, 1978; Cant, 1978). In the Monster Formation the thickness ratio of fine (muddy) to coarse lithologies is usually greater than unity, consistent with many other ancient analogues of meandering streams, but, as Jackson (1978, Tables 3-5) points out, this is problematical when compared to modern analogues whose ratios commonly are less than one. In the case of the Monster Formation, some of the fine grained deposits may be a product of marine flooding by storm-generated waves, resulting in an "exaggerated" fine component in these cycles.

The variety of sedimentary structures observed in the Monster Formation is common to both meandering and braided streams. Nowhere are epsilon crossbeds found; their absence does not, however, provide an argument against a meandering regime. Other bed forms, such as bars and dunes, are ubiquitous in braided systems, but also are relatively common in sandy meandering types. However, the vertical sequence of structures described in the fining-upward sandstone association also has been recorded by Cant and Walker (1976) from the Battery Point Formation, a Devonian, sandy, braided river deposit. The fine component of the fining-upward cycles is typical of overbank type deposits. Here, thin sandstone beds that also fine upward (third-order cycles in Fig. 19) are analogous to crevasse splay deposits. The rare occurrence of roots and complete absence of coal beds suggests there was little vegetation cover that might have stabilized the overbank environment.

Based on the criteria above, recognition of specific channel types in the fining-upward associations is equivocal. Nevertheless, channels characterized by bed-load transport of sand were predominant and low sinuosity patterns are envisaged here. Such patterns may correspond to the low sinuosity, meandering, braided or transitional channel types described by Schumm (1977; 1981, Fig. 6).

The conglomerate-sandstone association is characterized by large bedforms similar to transverse and longitudinal bars. Laterally extensive, planar, crossbedded conglomerate sets represent single large transverse or linguoid bars. The more complex associations of conglomerate facies that display cross-cutting relationships and numerous sandstone interbeds, are more indicative of bars that were dissected during the falling stage of flood events. These bedforms are typical of low sinuosity, braided stream channels. However, similar structures also can develop in low-sinuosity meandering streams, as alternate bars dissected by chutes (McGowen and Garner, 1970), or as coarse grained point bars (Bluck, 1971). Nevertheless, a braided analogue is favoured for the conglomerate association because of the relatively coarse clast size, the high proportion of conglomerate beds, and the ubiquity of large, conglomerate bed forms.

A coastal fan hypothesis

The stratigraphic relationships of the various facies, together with the close spatial relationship between marine and fluvial deposits, invite comparison with a coastal fan complex (also called fan deltas; Ricketts, 1986). In this setting, the conglomerate-sandstone association in the north Tatonduk area represents relatively steep slope, braided channel deposits in the higher proximal fan. Down-fan equivalents of these streams had lower slopes and a sandy bed-load, and probably formed as low-sinuosity meandering or braided streams; these are observed in the fining-upward sandstone associations at Monster River. Furthermore, the distal fan was frequently subjected to flooding by marine waters as a result of storm surges. The marine parts of the fan are represented by the Sandstone member, consisting of nearshore sand deposits, and the Shale member, consisting of deeper water offshore deposits.

Modern analogues

Coastal alluvial fans occur in a wide variety of tectonic settings and in recent years several have been described in some detail. One of the first comprehensive studies of coastal fan processes was undertaken on Gum Hollow Fan along the south Texas coast (McGowen, 1971). This fan is only half a kilometre wide, but offers a good opportunity to examine various phases of accretion (progradation), channel switching, and the interplay between marine and nonmarine processes. Other fans that have been investigated include the Yallahs Fan of Jamaica (Wescott and Ethridge, 1980) and several along the south coast of Alaska (Hayes and Michel, 1982). In these examples, a distinction can be made between fans that develop along wave-dominated coasts, namely arcuate-cuspate fans, and lobate fans, which tend to be restricted to sheltered bays. Stream patterns in both types usually are braided, although on the lobate fans illustrated by Hayes and Michel (1982, Fig. 4) channel thalwegs are moderately sinuous. Sedimentological criteria in the Sandstone member of the Monster Formation indicate that a comparison with the wave-dominated type of coastal fan is the most reasonable.

The analogy is less convincing, however, if the size (area, width) of these modern examples is compared to the Monster deposits. The exposed parts of most modern coastal fans tend to be limited to a few tens or hundreds of square kilometres in areal extent. For example, the Yallahs Fan is about 10 square kilometres. Two coalesced fans along the North Yukon coast are fed by the Firth and Malcolm rivers, and their combined area is about 300 square kilometres (Hughes, 1971). One of the largest modern coastal fans is found in New Zealand. This is the Waitaki Fan, which has an area of 670 square kilometres. In comparison, the approximate paleogeographic area likely to have been covered by the Monster Formation sediments during Cenomanian time was 2000 to 2500 square kilometres, based on present outcrop distribution. Despite the differences in these numerical values, the coastal fan analogue is considered realistic because: a) most of the modern fans have formed only in the few thousand years following the last glaciation (given the time span represented by the Monster, and an adequate supply of sediment, the modern fans could easily grow to a comparable size); and b) the Monster Formation may represent a number of coalescing fans.

Controls on cyclicity

Within the framework of this interpretation, the various cycles depicted in Figure 19 are viewed as follows (Ricketts, 1986):

A. Coarsening-upward cycles

1. First-order – overall progradation of the alluvial fan over marine equivalents
2. Second-order – progradation of sandy nearshore deposits, and progradation of the exposed part of the fan
3. Third-order – foreshore and shoreface progradation in the Sandstone member.

B. Fining-upward cycles

1. First-order – avulsion of major channels on the fan
2. Second-order – stacking of channels in thick sandstone and conglomerate units
3. Third-order – individual, or temporally related depositional events within channels and floodplain.

Beerbower (1964) recognized that two fundamental kinds of process affect the development of cyclic sequences, namely processes acting within the sedimentary system (autocyclic), and those acting outside this system (allocyclic). Autocyclic sequences are generated by sedimentary processes such as channel migration or point bar accretion. In these sequences, the controlling mechanism comes entirely from the sedimentary prism and is of relatively local importance. For example, on an alluvial fan, channel switching results when aggradation on one part of the fan produces a decrease in slope, whereupon the channel will migrate to an adjacent, formerly inactive part of the fan having steeper slope. An allocyclic sequence on the other hand is generated by regional, or basin-wide change, such as subsidence or sediment discharge, and may be related to tectonic events or changes in climate.

In the Monster Formation, the first- and second-order coarsening-upward cycles, because of their thickness and basin-wide extent, are allocyclic. Given the age of the formation, sediment supply and fan growth can be related to uplift and erosion following the last phase of the Columbian Orogeny and possibly the earliest phase of Laramide uplift. The third-order coarsening-upward cycles, plus the first-order fining-upward cycles, are probably a combination of autocyclic and allocyclic controls, although cycles up to 100 m thick are more likely to be allocyclic, for example, due to changes in basin subsidence (or conversely uplift in the hinterland), or compaction. Both second- and third-order fining-upward cycles can be explained in terms of facies shifts, or as single depositional events, and almost certainly are autocyclic.

In order to explain the close relationship between alluvial fan and marine influences, a general rise in relative sea level is proposed. Sediment produced by erosion of an uplifted hinterland was distributed over the fan by a system of braided and low sinuosity streams. During periods of stream flooding, deposition at the seaward margin of the fan was greater than the relative rise in sea level, resulting in progradation and vertical accretion. Channel switching to parts of the fan having greater slope, and/or periods of low sediment influx, gave rise to inactive fan lobes where the rate of deposition was less than relative sea level rise, and brief incursions of the sea upon the distal fan plain were now possible. Many of these incursions were probably enhanced by storm flooding.

PETROLOGY AND PROVENANCE

Thin sections of Monster Formation sandstones and conglomerates were examined to identify clast types and source rock types. A dozen of these samples were point counted in the hope of delineating any stratigraphic or facies trends in composition. Up to 250 points were counted in each sample. Modal compositions of the sandstones are summarized in Table 4, and graphically portrayed on a quartz-feldspar-lithic fragment diagram in Figure 20, where all samples clearly fall in the litharenite, or chert arenite compositional range (classification scheme after Folk, 1968).

The chert arenites are clast supported, and are moderately sorted with grains that are angular to subangular. Thus, on a textural basis the sandstones are submature, whereas compositionally they are mature.

Lithic grains of various kinds are by far the most abundant clast type and consist of chert, reworked sedimentary, and minor volcanic fragments. Quartz is next in abundance, whereas feldspar is a minor component. Heavy minerals are rare. Brief descriptions of these components are given below.

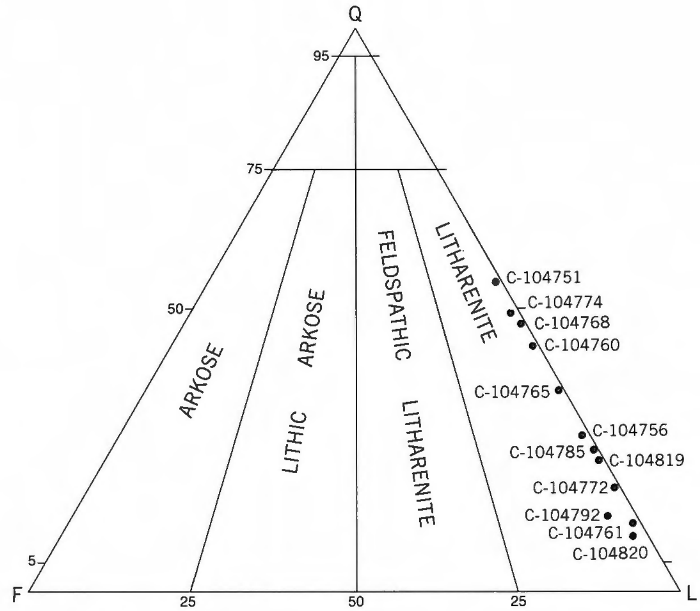


***Figure 20.** Ternary plot of principal framework components in Monster sandstones: Q = quartz; F = feldspar; L = total lithic grains. The values plotted have been recalculated to 100% from Table 4.*

TABLE 4

Modal compositions of Monster Formation sandstones as number per cent

Field Identification No. (RAK)	GSC Locality No.	Q	Arg. ch.	Clean ch.	ff ch.	Mst/Slt Lithic	VRF	Op. Lithic	Fsp	HM	Matrix	Grain Size
1-3	C-104754	49	40	-	-	-	-	-	-	-	11	V.F.
3-3	C-104756	24	12	7.5	0.5	31.5	4	7	1	-	12.5	Med.
7-3	C-104760	38	19	9	-	16	0.5	5	0.5	3	9.5	Med.
15-3	C-104761	11.5	31	3	1	32	3.5	8.5	1.5	-	8	Cs.
19-3	C-104765	32.5	25.5	4	1.5	16.5	-	9	0.5	-	10.5	F.
22-3	C-104768	44.5	28	3.5	0.5	11	-	5	-	-	7.5	F.
26-3	C-104772	17.5	38.5	9.5	3	14.5	-	10	-	-	7	Cs.
28-3	C-104774	45.5	24.5	1	-	14.5	-	6.5	0.5	0.5	7.5	F.
1-10	C-104785	23	37	7	-	14	0.5	10	-	0.5	8.5	Med.
1-12	C-104792	12	26.5	9.5	-	27.5	1	11	4	-	8.5	Cs.
2-14	C-104820	9	48	20	3	10	-	-	2	-	8	V.Cs.
1-14	C-104819	22.5	38.5	8	-	17	2	6	-	-	6	Cs.

Abbreviations: Q = total quartz
Arg. ch. = argillaceous chert
Clean ch. = clean, argillaceous-free chert
ff. ch. = fossiliferous chert
Mst/Slt = mudstone/siltstone lithic grains
VRF = volcanic rock fragments
Op. Lithic = opaque lithic grains
Fsp = feldspar
HM = heavy minerals

Note: Grain size grades are those of Wentworth.

Chert

Chert is the most important lithic type and ranges in composition from clean to highly argillaceous. Very little recrystallization is evident and the few grains that do exhibit this property probably are inherited. Some fibrous varieties may represent reworked fracture or void-filling chalcedony. The argillaceous varieties of chert commonly are fossiliferous and contain tintinnids (replaced by chert) and radiolarians; the wall structure in some radiolarians is visible. Sponge spicules and rare mollusc or brachiopod fragments also occur. Other rare fossil types that have been replaced by chert include crinoid plates, and finely reticulate patterns that may represent relic bryozoans or stromatoporoids.

Quartz

Polycrystalline varieties of quartz predominate, where grains consist of equant to subequant aggregates of quartz, each having undulose extinction. Rare grains have a stretched metamorphic pattern with small muscovite crystals aligned along subcrystal contacts. Some of the larger clasts (greater than 1-2 mm) show a distinct mylonitic texture. Fine, monocrystalline quartz grains also occur and probably were derived by mechanical disaggregation of polycrystalline clasts. A few coarse, rounded, monocrystalline quartz grains with abraded overgrowths are present, and may be a product of multicycle reworking.

Sedimentary lithic grains

This category includes reworked grains of mudstone and siltstone. Some difficulty was experienced in distinguishing between this grain type and highly argillaceous chert grains. However, the sedimentary lithic grains usually have a high proportion of very fine grained mica, and also have been subjected to a greater degree of compaction than the chert varieties.

Subordinate clast types

The feldspar content of these rocks ranges from 0 to 4 per cent and includes broken plagioclase crystals and some aggregates of plagioclase. One or two myrmekitic varieties were observed. All feldspar grains have been altered to differing degrees.

Volcanic rock fragments constitute a minor component of the sandstones and conglomerates (0-4%). Grains identified in this category contain small feldspar laths in a fine groundmass.

Heavy minerals are rare and only a few grains of pyrite and oxidized ferromagnesian minerals were found.

Composition of the conglomerates

In most cases, chert pebbles make up 80 to 90 per cent of the conglomerate framework in the Monster Formation (Table 5). Black, brown, and green varieties correspond to the argillaceous chert types in most sandstones (Table 4), and a few contain visible fossils. The sandstone pebbles also are variable in composition, ranging from quartz arenite to arkose, although the latter are not common. No pebbles of obvious volcanic origin were observed.

TABLE 5

Pebble counts for two conglomerates from Monster River (number per cent)

In each case, approximately 100 pebbles, ranging in size (longest axis) from 1 to 6 cm, were counted. Only pebbles in single depositional units were counted.

Variety	No. 1	No. 2
Black chert	41	34
Brown and grey chert	41	40
Green chert	4	3
White chert	10	9
Sandstone	4	14

Compositional trends

The first eight samples listed in Table 4 were collected from the reference section of the Monster Formation, and from these it is clear that there are no stratigraphic trends in composition. There is, however, a marked difference in the quartz content of samples having different grain sizes. The finest grained sandstones (in the Sandstone member) have approximately a 1:1 ratio of quartz and lithic fragments, with up to 50 per cent quartz. In comparison, the coarsest lithologies have as little as 10 per cent quartz. The antipathetic relationship between increasing grain size and the proportion of detrital quartz is probably a result of source rock control; in other words, the rocks that supplied the quartz were relatively fine grained.

Source rocks

The compositional nature of the formation indicates a largely sedimentary source for the Monster Formation sediments. Sedimentary chert, in particular, is most common in cherty carbonate sequences and, in this region, such lithologies are common in upper and lower Paleozoic units. In fact, the Monster Formation directly overlies cherty limestones of the Tatonduk Formation. The reworked sedimentary detritus, including the arenite pebbles, was also derived from clastic units associated with Paleozoic carbonates. At present, all of the likely source rocks are situated north of the Tintina Fault, and north and west of the Monster River area.

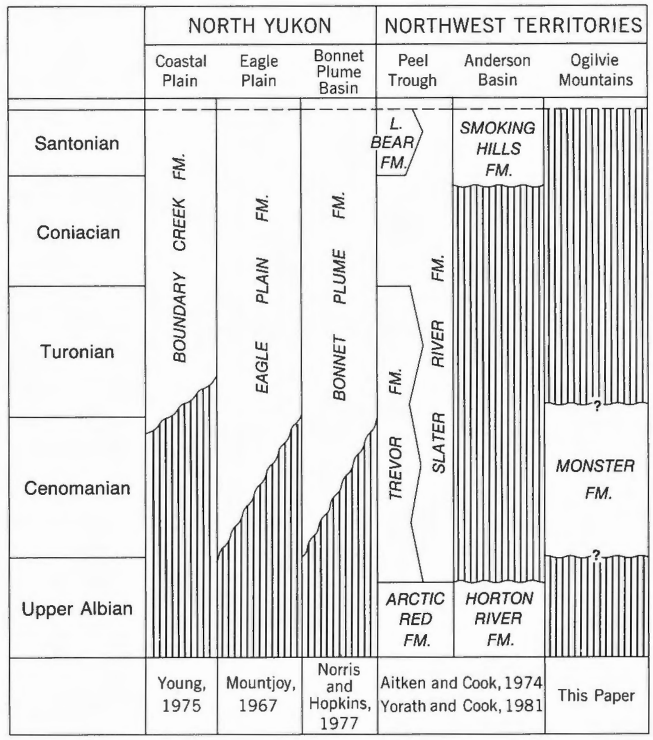
An additional terrane that might have supplied detritus during Monster time includes Precambrian rocks in the Mount Harper area (Dawson map sheet, Green and Roddick, 1972), which contain a variety of platform-type carbonate and volcanic rocks. However, this area is considered as a source terrane of only minor importance, because the basic volcanic rocks that form a significant part of the Precambrian sequence are rarely observed in the clastic component of the Monster sandstones, and they are not observed in the conglomerates. Other highly distinctive lithologies in the Precambrian terrane, such as hematitic jasper, also are not recognized in the Monster deposits. This Precambrian terrane must have had relatively low relief during the Cenomanian.

A similar argument can be applied to the Precambrian Tindir Group, which at present is exposed west of Tatonduk River, in the hanging wall of the Yukon Fault. Thrusting along this fault postdated the Monster Formation and, hence, the Tindir may not have been exposed during that period of deposition.

Strata south of Tintina Fault include relatively high grade metamorphic rocks and a variety of intrusions, none of which appears to have provided detritus during early Late Cretaceous time. Reconstruction of the 450 km, right-lateral, strike-slip displacement along the Tintina Fault (Tempelman-Kluit, 1979), places the Monster and surrounding Paleozoic strata north of a highly metamorphosed terrane (eastern Alaska) that includes felsic and basic intrusive rocks of Jurassic age and older. This terrane also appears to have been isolated from the Monster depocenter. There is no evidence that mid-Cretaceous movement along the Tintina Fault had any significant effect on sediment supply to the Monster Formation.

TABLE 6

Correlation chart for the Monster Formation



CENOMANIAN PALEOGEOGRAPHY

The Monster Formation overlies the Triassic Shublik Formation unconformably, although where the Shublik wedges out in the northwest segment of the Monster Synclinorium, the Monster may directly overlie Takhandit limestone. Approximately 100 million years is represented by the hiatus. Marine strata in the Shale member indicate an initial drowning event at some time during the Cenomanian. Comparison to other North American Upper Cretaceous sequences indicates a general rise in sea level from Albian to late Cenomanian time, with transgression peaking in the early Turonian (Hancock and Kauffman, 1979). In the southern Alberta Foothills, for example, the maximum effects of the transgression were not established until late Cenomanian - Turonian time (Stott, 1984). However, the Dunvegan delta, which appears to be correlative with the Monster coastal fan, was preceded by an early Cenomanian transgression. Farther north, in the Canadian Arctic, the late Cenomanian - Turonian phase of transgression is represented by the Boundary Creek Formation. In summary, the drowning event affecting the Monster Formation can be considered as part of the early Late Cretaceous transgression throughout North America and Europe, but a more accurate age assignment within the Cenomanian is not possible at present.

Based on microfloral analyses, the Cenomanian Monster Formation is correlated with the lower parts of the Eagle Plain and Bonnet Plume formations, south and west of the Richardson Anticlinorium (Table 6). Detailed palynological analyses of the Bonnet Plume Formation by A.R. Sweet (pers. comm., 1985) demonstrate a maximum lower age limit of Cenomanian, rather than Middle to Late Albian as reported by Norris and Hopkins (1977), and indicates that no major unconformity exists in the Upper Cretaceous part of the formation. East of the Richardsons, within the Peel Trough, correlative strata include the Trevor Formation and Slater River Formation, while along the northern coastal area the Monster Formation appears to be equivalent to the earliest phase of Boundary Creek Formation deposition. Correlations with east-central Alaska, north of the Tintina Fault, are less certain. The Kathul Greywacke forms part of the Kandik Basin in eastern Alaska and western Yukon, and is probably of Albian age (Brabb and Churkin, 1969; Norris, 1982) and is, therefore, older than the Monster Formation. Nonmarine deposits of Late Cretaceous and Tertiary age occur along the Tintina Fault in eastern Alaska (Brabb and Churkin, 1969; Foster, 1976), but like similar deposits in Yukon (Hughes and Long, 1980) are probably younger than the Monster Formation.

The Cenomanian paleogeography of northern Yukon and western Northwest Territories is presented in Figure 21. Various paleogeographic elements in this region have been discussed by several authors: Young et al. (1976) and Dixon (1982, the region north of Latitude 67°N); Norris and Hopkins (1977, the Bonnet Plume Basin); and Yorath and Cook (1981, the Peel Trough-Eskimo Lakes Arch area). An additional paleogeographic element is introduced in this paper. The Monster Embayment was a northeast-trending basin into which the Monster coastal fan prograded. Sediment transport was toward the northeast, and the submerged, distal part of the coastal fan may have reached as far as the Eagle Plain Basin. The southern shoreline of the embayment is projected eastwards to the northern limit of the Bonnet Plume Basin (a largely nonmarine basin whose margins are delineated by the Richardson Fault array – Norris and Hopkins, 1977; Long, 1978), and thence to the southern margin of Peel Trough. It is not clear whether there was a direct connection of the sea between the Eagle Plain Basin and Peel Trough; Laramide uplift associated with the Richardson Fault array may have isolated these two major areas of deposition.

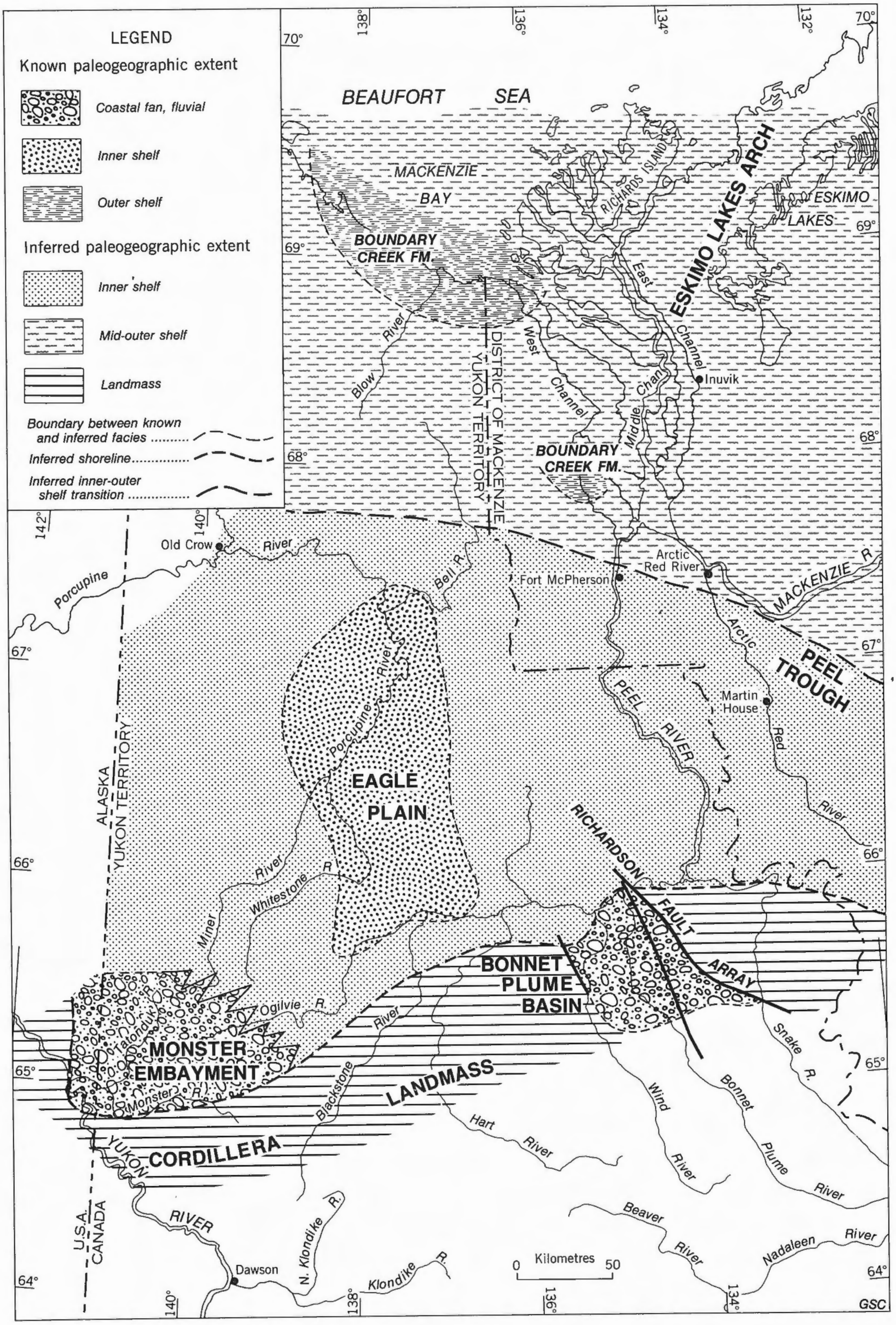


Figure 21. *The inferred paleogeography for northern Yukon and western Northwest Territories during Cenomanian time. The inferred limits of inner shelf to mid- and outer-shelf settings are from Dixon (1986).*

SUMMARY

The Monster Formation is interpreted as a coastal fan complex, based on facies analysis and the stratigraphic relationship of its four constituent members. A basal Shale member represents a relatively deep water, offshore environment, over which shoreface and foreshore sands of the Sandstone member prograded. The Sandstone-shale and Conglomerate members make up the remainder of the formation and represent the subaerial portion of the fan. The Conglomerate member thickens westward, completely replacing the Sandstone-shale member in north Tatonduk River sections, and represents gravel deposition on more proximal parts of the fan complex. In the Sandstone-shale and Conglomerate units, fining-upward conglomerate facies indicate deposition in a proximal fan setting where coarse, gravelly sediment was distributed by braided streams. Fining-upward sandstone cycles formed in the down-fan setting, where sand and mud were deposited in low sinuosity meandering and braided rivers.

Distinct cyclical trends characterize the Monster succession and both autocyclic and allocyclic sequences are recognized. Autocyclic sequences are attributed to local changes in the patterns of sedimentation, for example crevasse splays, or channel switching. Allocyclic sequences, on the other hand, are related to processes that have a basin-wide influence, and in the case of the Monster, include a general rise in relative sea level and possible fluctuations in sediment supply during the dying stages of the Columbian Orogeny or, possibly, the earliest stage of Laramide deformation.

Previous age determinations for the Monster Formation indicated that deposition occurred during the latest Cretaceous and possibly even early Tertiary. Examination of palynomorphs and dinoflagellates in the course of this study has demonstrated that deposition of the Monster Formation in fact took place much earlier, and a Cenomanian age can now be reported.

The principal source of sediment for the Monster Formation was the Paleozoic chert-bearing carbonates north of Tintina Fault, and north and west of the Monster-Tatonduk River area. Fan progradation was toward the northeast along the Monster Embayment, and may have reached as far as the Eagle Plain Basin. East of the Embayment and along depositional strike is the Bonnet Plume Formation, the lower part of which is correlative with the Monster Formation. The Bonnet Plume Formation is principally of nonmarine origin, although it is surmised that deposition near the northern limit of the Bonnet Plume Basin may have taken place in a paralic environment. Hence, the Monster, Bonnet Plume and Trevor formations provide limits for the southern extent of the sea during early Late Cretaceous time.

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APPENDIX

Stratigraphic sections

SECTION 1 (RAK 3). Details of the reference section for the Monster Formation, located on the north limb of the Monster Synclinorium, one kilometre due east of the type section. All four informal members are present, and the section is described from the base up.

Location:	Latitude 65°03'N; Longitude 140°13'W	Topographic maps:	NTS 116 G and 116 F (East Half)
	UTM grid references — 536213 (top of section)	Aerial photograph:	A13231-161
	— 537217 (base of section)	Total thickness:	1053 m

Unit	Description	Unit Thickness (metres)	Cumulative Thickness Above Base (metres)
	MONSTER FORMATION		
	Shale member (200 m)		
Note:	The base of the Monster Formation is not exposed.		
49	Covered interval. Includes the recessive Shale member, and possibly some Shublik Formation strata.	200	200
	Sandstone member (74.5 m)		
48	Covered interval. Slab-weathering sandstone talus	42.5	242.5
47	**Sandstone.** Principal bluff-forming unit in the Sandstone member. Unit consists of three slightly coarsening-upward sequences, each capped by very fine grained sandstone or shale veneers. Fine grained; subhorizontal and low-angle planar crossbeds. Prominent hummocky crossbedding, 5-8 cm amplitude, and hummock spacing of 1.5-2 m. Individual hummocky sets overlain by subhorizontally laminated sandstone, in turn overlain by current ripples. Local, intraformational, mudchip pebble lags and ironstone concretions. Rare bioturbation. Scattered, fine, carbonaceous material	15	257.5
	Lithological sample: C-104754		
46	Covered interval. Slab-weathering sandstone talus	7	264.5
45	**Sandstone.** Predominantly subhorizontally laminated; fine grained; some low-angle planar crossbeds; hummocky cross-stratification, amplitude 2-5 cm, and hummock spacing of 1 m	3	267.5
44	Covered interval. Distinctive slab-weathering sandstone talus	3	270.5
43	**Sandstone.** The uppermost unit of three bluff-forming sandstones. Predominantly subhorizontally laminated; with low-angle planar truncations; fine grained; some fine, carbonaceous debris.	4	274.5
	Sandstone-shale member (583.5 m)		
42	Covered interval. At least six sandstone-shale sequences indicated by breaks in slope. Frost-heaved shale at base of slope	48	322.5
41	**Sandstone.** Three beds up to 1.8 m thick, separated by covered intervals. Fine grained; mostly horizontally laminated with a few low-angle truncations; local small trough crossbeds; current ripples abound in uppermost bed	7.5	330
40	Covered interval	15.5	345.5
39	**Sandstone.** Two beds separated by 1.8 m covered interval. Fine grained; trough and planar crossbeds	4.5	350
38	Covered interval	19.5	369.5

Unit	Description	Unit Thickness (metres)	Cumulative Thickness Above Base (metres)
37	**Sandstone.** Three beds separated by **siltstone-shale.** Fine grained; abundant current ripples, amplitude 1-1.5 cm, wavelength 10-15 cm	2.5	372
36	Covered interval	70	442
35	**Sandstone.** Abundant trough and ripple crossbeds; fine, comminuted plant debris; rare leaf impressions; maximum grain size is coarse sand	4	446
	Macrofloral sample: C-104755 Lithological sample: C-104756		
34	Covered interval	13.5	459.5
33	**Sandstone.** Horizontally laminated sandstone in lowest metre of unit; planar and trough crossbeds; medium grained; thin grit lenses and scattered plant fragments; parting lineation; some ball-and-pillow structures. This unit can be traced through the small fold pair on the north limb of the Monster Synclinorium	7.5	467
32	Mostly covered. 1.5 m of silty shale exposed at base of unit	13.5	480.5
	Palynological sample: C-104757		
31	**Sandstone.** Appears massive, with only a few trough crossbeds; fine grained. Ironstone concretions have grown around nucleii of intraformational mudchips	6	486.5
30	Covered interval	43.5	530
29	**Sandstone.** Fine to medium grained; trough, planar and ripple crossbeds; local pebble lags in scours; scattered plant fragments	17	547
28	Covered interval. Some grey shale, siltstone and thin, very fine grained sandstone beds	42	589
27	**Sandstone.** Three fining-upward sequences capped by shale lenses. Planar and trough crossbeds; granule lags; mostly medium grained	5.5	594.5
	Palynological samples: C-104759; C-104758		
26	Covered interval. Several thin cycles indicated by breaks in slope	9	603.5
25	**Sandstone.** Fine to medium grained; trough crossbedding; a few thin pebble lags	6	609.5
24	Covered interval. Three breaks in slope indicating sandstone-shale sequences	56.5	666
23	**Sandstone.** Three fining-upward sequences, capped by shale veneers. Pebble lags at the base of each sequence. Mostly trough crossbeds, horizontal laminated sandstone in lower part of sequences. Fine to medium grained	12	678
22	Covered interval. 1.2 m thick, medium grained sandstone at 688 m	19.5	697.5
21	**Sandstone.** Fining-upward, capped by thin siltstone. Abundant planar and trough crossbeds, parting lineation. Fine grained	7.5	705
	Lithological sample: C-104760		
20	Covered interval. Four breaks in slope indicate thin, fining-upward, sandstone-shale sequences	73.5	778.5
19	**Sandstone.** Poorly exposed. Two or three fining-upward sequences	2	780.5
18	Covered interval. Recessive **shale** and **siltstone**	18	798.5
17	**Sandstone.** Three fining-upward sequences capped by thin shale. Abundant trough and planar crossbeds, pebble lags at base. Medium to coarse grained	6.5	805
	Lithological sample: C-104761		

Unit	Description	Unit Thickness (metres)	Cumulative Thickness Above Base (metres)
16	Covered interval. A few siltstones and shales exposed	8.5	813.5
15	**Sandstone.** Up to ten thin sandstone beds, each fining-upward into siltstone and shale. Abundant current ripples and small-scale, trough crossbeds. Rare root structures. Fine grained	4.5	818
	Palynological sample: C-104762		
14	**Shale.** Grey; laminated; with a few thin beds of fine grained sandstone and siltstone; slightly carbonaceous. Fines upward from subjacent unit 15	12	830
	Palynological sample: C-104763 at 828 m		
13	Covered interval. Recessive lithologies, some shale and siltstone exposed. A 1 m thick, fine grained sandstone at base of unit, contains trough crossbeds, and a few pebbles	28	858
	Palynological sample: C-104764 at 857 m.		
	Conglomerate member (195 m)		
12	**Pebble conglomerate.** Three fining-upward sequences capped with crossbedded, medium grained sandstone and shale veneers. Planar and some trough crossbeds in the conglomerates. Average pebble size is 2-3 cm, with a maximum of 5 cm, sub-rounded to well rounded. Small-scale trough and planar crossbeds in upper 1 m of sandstone. Abundant small plant fragments. Sharp base	12	870
	Lithological samples: C-104766, C-104765		
11	**Shale.** Laminated, with thin siltstone interbeds	2	872
	Palynological sample: C-104767		
10	**Pebble conglomerate.** At least three fining-upward sequences, each capped by thin, crossbedded, medium grained sandstone. Pebbles average 3 cm, with a maximum of 6 cm, moderately rounded. Mostly massive bedded, with some planar crossbedded conglomerates up to 90 cm thick. Sharp base	15	887
	Lithological samples: C-104769, C-104768		
9	Covered interval	8	895
8	**Pebbly sandstone.** Abundant trough and planar crossbeds. Pebbles occur as lags in scour troughs, as discrete lenses, or are scattered along planar crossbed foresets. Crossbed sets up to 60 cm thick. Scattered plant debris. Generally medium grained	18	913
7	**Shale.** Dark grey, laminated, with a few starved sandstone ripples	3	916
6	**Conglomerate.** Pebbles 1-1.5 cm. Vague crossbedding. Abundant plant fragments in thin, fine grained sandstone at top of unit	1	917
5	Mostly covered. Two thin **sandstone** beds exposed at 939.5 m and 933.5 m. Basal 1.5 m of dark grey **shale** exposed	22.5	939.5
	Palynological sample: C-104770		
4	Covered interval. Approximately ten, thin, fining-upward sequences indicated by breaks in slope	52.5	992
3	**Pebbly sandstone.** Poorly exposed	1	993
2	Covered interval. Thin unit of **shale** partly exposed	31	1024
	Palynological sample: C-104771		

Unit	Description	Unit Thickness (metres)	Cumulative Thickness Above Base (metres)
1	**Pebble conglomerate.** Top of prominent butte. Unit consists of ten fining-upward conglomerate-sandstone sequences. Massive bedded and large-scale planar crossbeds prominent in the conglomerates, with a few, large, trough crossbeds. Fine to medium grained sandstones contain abundant trough, planar and ripple crossbeds. Pebbles 2-3 cm, maximum size 12 cm. Intraformational mudstone clasts up to 10 cm in some cycles. Plant fragments up to 1 m are common at the base of most cycles. Base is sharp and slightly erosional	29	1053
	Lithological samples: C-104774, C-104772 Palynological sample: C-104773.		

SECTION 2 (RAK 14). Representative measured section of the Monster Formation, north Tatonduk River area. Only the Sandstone and Conglomerate members are exposed; the Shale member is covered. The top units strike 223° and dip 25° west.

Location: Latitude 65°08'N; Longitude 140°47'W
UTM grid references — 507225 (top of section)
— 511223 (base of section)

Topographic maps: NTS 116 G and 116 F (East Half)
Aerial photograph: A13137-25
Total thickness: 1280 m

Unit	Description	Unit Thickness (metres)	Cumulative Thickness Above Base (metres)
	MONSTER FORMATION **Shale member** (90.5 m)		
51	Covered interval (from top of the Takhandit Formation).	90.5	90.5
	Sandstone member (45 m)		
50	**Sandstone.** Discontinuous exposure. Bluff-forming. Slab-weathering talus. Fine grained	33	123.5
49	Covered interval	3	126.5
48	**Sandstone.** Discontinuous exposure. Crossbedding is vague. Medium grained	9	135.5
	Lithological sample: C-104821		
	Conglomerate member (1144.5 m)		
47	Covered interval	108	243.5
46	**Sandstone.** Discontinuous exposure. Upper few metres consist of **siltstone.** Lower part of unit contains abundant trough crossbedding. Fine grained	13	256.5
45	**Sandstone.** Coarse grained, locally pebbly; trough and planar crossbeds	3	259.5
44	Covered interval	31	290.5
43	**Sandstone.** Coarse grained, pebbly; tabular bedded, trough and planar crossbeds common; pebbles up to 1.5 cm, averaging 0.6-1 cm long	6	296.5
	Lithological sample: C-104820		

Unit	Description	Unit Thickness (metres)	Cumulative Thickness Above Base (metres)
42	Covered interval. Discontinuous exposure of fine grained **sandstone** and **siltstone**. Thin bedded	123	419.5
41	**Sandstone.** Thin bedded; fine grained; with siltstone and minor shale interbeds; some fine, carbonaceous debris; small-scale trough and ripple crossbedding	6	425.5
40	Covered interval	9	434.5
39	**Conglomerate.** Pebble-sized clasts; tabular bedded	6.5	441
38	Covered interval. Discontinuous exposure of medium to fine grained **sandstone.** A 2 m thick sandstone bed is exposed at base of unit	17.5	458.5
37	**Conglomerate.** Pebble-sized clasts; tabular bedded with thin sandstone interbeds; vague parallel and planar crossbedding	15.5	474
36	Covered interval	3	477
35	**Conglomerate.** Four tabular units each capped by thin sandstone. Similar to Unit 25	12	489
34	Covered interval	3	492
33	**Conglomerate.** Pebble-sized clasts; vague, tabular stratification with thin sandstone interbeds	8	500
32	**Sandstone.** Medium to fine grained; abundant trough and planar crossbedding	8	508
31	**Conglomerate.** Pebble-sized clasts; tabular bedded	2	510
30	Covered interval	35	545
29	**Conglomerate.** Tabular, pebble conglomerate beds separated by thin sandstone beds and lenses. Vague horizontal stratification in the conglomerates	7	552
28	Covered interval	12	564
27	**Conglomerate.** Tabular bedded, as in Unit 25. Cobbles up to 25 cm, well rounded. Unit consists of three, crudely fining-upward sequences, but lacking sandstone	6	570
26	Covered interval	12	582
25	**Conglomerate.** Tabular bedded, but with fewer thin sandstone lenses than Unit 25, and only 1-2 m in lateral extent. Cobbles up to 20 cm long, generally well rounded	16.5	598.5
24	Covered interval	2	600.5
23	**Conglomerate.** Tabular bedded with thin, fine grained **sandstone** interbeds. Fining-upward conglomerate-sandstone sequences, better defined than in Unit 21. Thin sandstone lenses separate successive crossbed sets; some appear as drapes on reactivation surfaces. Cobbles up to 25 cm long, average 3-4 cm. Some plant fragments	18.5	619
22	Covered interval	18	637
21	**Conglomerate.** Tabular bedded with thin, fine grained **sandstone** interbeds and lenses. Some fining-upward trends in the conglomerates. Cobbles up to 15 cm, subangular to well rounded. Only vague imbrication	9	646
20	Covered interval	79.5	725.5
19	**Conglomerate.** Basal 5 m is tabular conglomerate; upper 4 m pebbly, coarse grained **sandstone** with thin pebble lenses and trough crossbeds	9	734.5

Unit	Description	Unit Thickness (metres)	Cumulative Thickness Above Base (metres)
18	Covered interval	29.5	764
17	**Sandstone.** Poor exposure	1	765
16	Covered interval	12	777
15	**Conglomerate.** Tabular bedded; pebbles up to 8 cm, averaging 2 cm; some trough crossbeds in fine grained sandstone lenses	3.5	780.5
14	Covered interval	55	835.5
13	**Sandstone.** Coarse grained and pebbly; trough crossbeds; pebble lenses	2.5	838
12	Covered interval	67.5	905.5
11	**Sandstone.** Pebbly; many fining-upward **conglomerate-sandstone** sequences, each capped by fine grained sandstone and some shale veneers; abundant planar and trough crossbedding; common plant fragments. This unit forms a prominent bluff	20	925.5
10	Covered interval	6	931.5
9	**Sandstone.** Coarse grained and pebbly. Five fining-upward **conglomerate-sandstone** sequences 1-3 m thick, each capped by medium to fine grained sandstone. Pebbles up to 6 m long, averaging 2 cm. Planar crossbeds in conglomerates up to 60 cm thick; small-scale, planar, trough and ripple crossbeds in sandstones. Wood fragments up to 1 m in length	11	942.5
8	Covered interval	120	1062.5
7	**Sandstone.** Coarse grained and pebbly; trough crossbeds and subhorizontal laminae	3	1065.5
6	Covered interval	93	1158.5
5	**Sandstone.** Coarse grained; trough crossbedded	2	1160.5
4	Covered interval	60.5	1221
3	**Sandstone.** Coarse grained and pebbly. Three fining-upward sequences, each capped by fine grained sandstone. Mostly trough and ripple crossbeds. Parallel laminae at the base of each sequence	10.5	1231.5
2	Covered interval	46	1277.5
1	**Sandstone.** Located at the axis of recumbent syncline. Coarse grained, locally pebbly; some trough crossbedding.	2.5	1280