GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 73-31

# SEDIMENTARY HISTORY AND TECTONIC EVOLUTION OF THE SUSTUT AND SIFTON BASINS, NORTH-CENTRAL BRITISH COLUMBIA

Map 14-1973 Sustut Basin, north-central British Columbia
Pocket Figures, 1, 4, 5, 6, 7, 12, 13.

Gerhard H. Eisbacher



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CANADA

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Gerhard H. Eisbacher

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## ABSTRACT

The Sustu and Sifton basins of Late Cretaceous - early Tertiary age contain continental sedimentary rocks that were deposited during the uplift of the Columbian and Pacific orogens.

The present valley system of northern British Columbia seems to have been inherited largely from southeasterly-trending Eocene valleys although vigorous Pliocene to Recent stream capture has caused much of the drainage to be deflected towards the Pacific Ocean.

Within Sustut Basin the Sustut Group has been divided into two formations: the Tango Creek Formation (containing Cenomanian - Paleocene fossil leaves and palynomorphs) and the Brothers Peak Formation (containing Paleocene fossil leaves and radiometrically dated Eocene ash-fall tuffs). Thickness of the Sustut Group ranges from about 300 metres (1, 000 feet) to 2300 metres (7, 000 feet). Paleocurrents maximum clast-size trends, and clast composition suggest an easterly to northerly provenance for the Tango Creek Formation most of which was laid down by meandering rivers. The Brothers Peak Formation had a westerly to northerly provenance and was deposited in an alluvial fan environment which supplied debris to a southeasterly-flowing river system. The ash-fall tuffs of the Brothers Peak Formation are probably the airborne products of explosive volcanism in the Sloko volcanic province of northwestern British Columbia. Tectonic deformation in the western part of Sustut Basin proceeded during deposition of the Sustut Group and is reflected by changing paleocurrent patterns and tectonic overprinting along different structural trends.

Sifton Basin is in and near the northern Rocky Mountain Trench and is occupied by the Sifton Formation containing Late Cretaceous - Paleogene fossil leaves and palynomorphs. Paleocurrents and composition suggest local provenance and southerly-flowing rivers. Late-orogenic deformation disrupted the basin fill along northwesterly-trending fault zones.

Sustut and Sifton basins contain part of the Cordilleran 'molasse facies' and were separated from each other by a metamorphic culmination within the Omineca Crystalline Belt.

The Sustut Basin has potential for epigenetic uranium and fossil placer-gold occurrences.

## RÉSUMÉ

Les bassins Sustut et Sifton du Crétacé supérieur- début de l'ère tertiaire renferment des roches sédimentaires continentales qui ont été déposées lors du soulèvement des orogènes colombienne et pacifique.

Le système actuel de vallées du nord de la Colombie-Britannique semble en grande partie l'héritage de vallées éocènes à orientation sud-est, bien que la capture énergique de cours d'eau entre le Pliocène et le Récent a eu pour effet de détourner en grande partie le drainage vers le Pacifique.

A l'intérieur du bassin Sustut, le groupe de Sustut a été divisé en deux formations: la formation de Tango Creek (renfermant des feuilles et des palynomorphes cénomanéens-paléocènes fossiles) et la formation de Brothers Peak (renfermant des feuilles paléocènes fossiles et des tufs, dus aux retombées de cendres éocènes, datés par radiométrie). La largeur du groupe de Sustut varie entre 300 mètres (1, 000 pieds) environ et 2, 300 mètres (7, 000 pieds). Les courants de Lamb, l'orientation de roches clastiques de dimension maximum et leur composition

laissent supposer que la formation de Tango Creek, qui a été en majeure partie déposée par des rivières au cours sinueux, a une provenance orientée de l'est au nord. La formation de Brothers Peak avait une provenance orientée d'ouest au nord et s'est déposée dans un milieu favorable à la formation de cônes de déjection qui était la source de débris d'un réseau fluvial coulant en direction du sud-est. Les tufs dus aux retombées de cendres de la formation de Brothers Peak sont probablement les produits transportés dans les airs de phénomènes explosifs volcaniques qui se sont produits dans la province volcanique de Sloko de la Colombie-Britannique du Nord-Ouest. La déformation tectonique de la partie occidentale du bassin Sustut s'est poursuivie au cours de la formation du dépôt du groupe de Sustut et se traduit par les formes changeantes des courants de Lamb et les surimpressions tectoniques le long des diverses directions structurales.

Le bassin Sifton est situé dans la tranchée nord des Montagnes Rocheuses et à proximité de celle-ci et est occupé par la formation de Sifton renfermant des feuilles et des palynomorphes fossiles du Crétacé supérieur-Paléogène. Les courants de Lamb et la composition font supposer une provenance locale et des cours d'eau s'écoulant en direction du sud. Une déformation orogénique récente a disloqué les eaux du bassin le long des zones de failles orientées en direction du nord-ouest.

Les bassins Sustut et Sifton contiennent une partie du "faciès molasse" de la Cordillère et ont été séparés l'un de l'autre par une culmination métamorphique à l'intérieur de la zone cristalline d'Ominéca.

Le bassin Sustut est potentiellement riche en uranium épigénétique et a des venues d'or alluvionnaire fossile.

# SEDIMENTARY HISTORY AND TECTONIC EVOLUTION OF THE SUSTUT AND SIFTON BASINS, NORTH-CENTRAL BRITISH COLUMBIA

## INTRODUCTION

During the final stages of deformation in the north-central Canadian Cordillera, extensive nonmarine clastic sedimentary rocks were deposited in two northwesterly-trending basins flanking the metamorphic core zone of the Columbian Orogen (Fig. 1). The names Sustut Basin and Sifton Basin were proposed for these features by Souther and Armstrong (1966). These authors give an excellent overview of the tectonic evolution of the north-central Cordillera of British Columbia, in which they attempt to relate the transition, from the predominantly marine Bowser Assemblage (Upper Jurassic - Lower Cretaceous) to the overlying nonmarine Sustut - Sifton Assemblage (Upper Cretaceous - Paleogene), to tectonic events within the sedimentary basins. It was one purpose of this study to document these events by stratigraphic-structural mapping, and by analysis of paleocurrents, provenance, and sedimentology of the Sustut and Sifton basins. The outcrop area occupied by Sustut - Sifton Assemblage is about 10,000 $km^2$ (4,000 square miles).

The Geological Survey of Canada is presently completing reconnaissance mapping on the scale 1:250,000 in map-areas including Sustut Group and this study has been carried out to ascertain stratigraphic correlations and tectonic style of the nonmarine late-orogenic clastics of the Sustut Group across several map-sheet boundaries (Fig. 1).

Field work was carried out during the seasons of 1969, 1970, 1971 and 1972. A total of ten months was spent in the field.


## Acknowledgments

The author acknowledges the outstanding assistance of Mr. John Pomeroy during the summer of 1969. Logistic support at various stages of the project was given by members of the Geological Survey of Canada's Operation Finlay during the field seasons of 1970 and 1971. H. Gabrielse, J.O. Wheeler and J.G. Souther of the Geological Survey of Canada discussed many aspects of this project in the office and in the field and contributed to my understanding of Cordilleran geology.


## HISTORY OF GEOLOGICAL EXPLORATION

The remarkable nature of the land underlain by the sedimentary formations of the Sustut Group was first recorded by Samuel Black during his arduous exploration of the north branch of the Peace River. Emerging from the rainswept and treacherous canyons of the river that became later known as "Finlay" and moving over the calm waters of Thutade Lake, Black noted that:

> "... the higher mountains confining it make their appearance on both sides covered with snow and particularly at this place for the harmony of their strata rising like stairs and form a number of scoops or hollows near their tops like pressed cushions or resting places for the Naiades (suppose) to enjoy the cold aspect of the


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lake and snow clad mountains ..." (from Black's Journal, June 23, 1824. ed. E.E. Rich, The Hudson's Bay Record Society, London, 1955).

Samuel Black was looking at late glacial cirques that are common in flat-lying Sustut Group and which do resemble deep amphitheaters or "pressed cushions" (Fig. 2).

McConnell (1896) was the first geologist to explore the Finlay River although he did not reach its headwaters. He recognized extensive outcrops of "Laramide" sandstones and conglomerates on Takla Lake, in the Rocky Mountain Trench, and near Black Canyon which is now submerged beneath Lake Williston. His magnificent map shows the remarkable linearity of the northern Rocky Mountain Trench and the distribution of Laramide clastics between Deserters Canyon and Prairie Hill.

Around the turn of the century, British Columbia Government land surveyors crossed the northeastern Skeena and Omineca mountains and the discovery of placer gold on McConnell Creek and coal in the Groundhog Range led to local geological investigations.

Later explorations by Dolmage (1928, p. 29), and Hedley and Holland (1941, p. 42, 43) extended the range of probable Upper Cretaceous - Lower Tertiary rocks in the northern Rocky Mountain Trench to the Kechika River. Hedley and Holland (1941) proposed the name Sifton Formation for these rocks (after Sifton Pass in the Toodoggone map-area), and fossil leaves collected by them were determined by W.A. Bell as Upper Cretaceous - Paleocene.

Lord (1948, p. 34-41) and Armstrong (1949, p. 65, 74) first recognized the extensive Upper Cretaceous - Lower Tertiary continental clastic basin between Takla Lake and Cold Fish Lake. Lord (1948) mapped these sandstones and conglomerates in McConnell Creek map-area and named them Sustut Group after Sustut River. He collected fossil leaves which were determined by W.A. Bell as Cenomanian - Paleocene in age, described the tuff beds from the upper division, and proposed an easterly provenance for a major conglomerate horizon near Bear Lake.

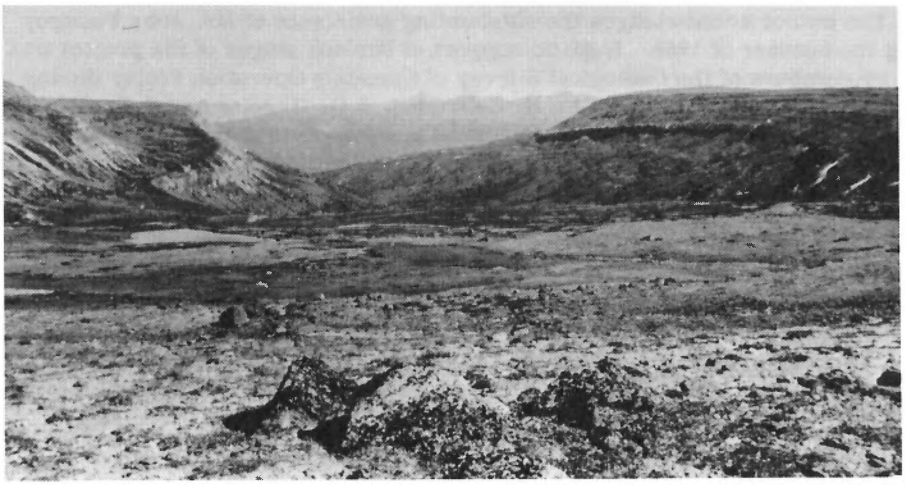

Figure 2. Late-glacial erosional cirques in Eocene Brothers Peak Formation near Edozadelly Mountain (Toodoggone map-area, looking north). GSC Photo 202477.

The northerly extension of the Sustut Group into Toodoggone and Spatsizi map-areas was confirmed by mapping during Operation Stikine (Geological Survey of Canada, 1957), but the northeastern part of the Sustut Basin was not examined.

Small isolated outcrop areas of probable Sustut strata have been described by Lang (1942), Roots (1954, p. 190-192), Sutherland Brown (1960, p. 36-38, and 1967, p. 459-460), Muller (1961), Gabrielse (1962a, b, 1963, p. 94-96), Rutter and Taylor (1968), Muller and Tipper (1969), Gabrielse et al. (1962), Souther (1972, p. 15-17). Some of these outliers have been dated by their plant remains by Bell (1965), Rouse (1967), and Rouse et al. (1970) but much work has yet to be done on the biochronology of Sustut Group rocks.

The tectonic framework of the Sustut Group has been discussed by Gabrielse and Wheeler (1961), Souther and Armstrong (1966) and Gabrielse (1967).

Results of the present investigation have been reported by Eisbacher (1970, 1971a, b, c, 1972a, b, 1973a, b, and Read and Eisbacher, in press).

## PHYSIOGRAPHY AND DRAINAGE EVOLUTION

Sustut Basin underlies the northeastern Skeena Mountains and much of Spatsizi Plateau (Holland, 1964). Peak elevations rarely exceed 2, 500 metres (7, 500 feet), and local relief is generally less than 700 metres (2, 000 feet).

Sifton Basin occupies part of the northern Rocky Mountain Trench, which in this area is a structurally controlled depression between the Omineca Mountains to the west and the Rocky Mountains to the east (Eisbacher, 1972b).

Drainage in the area can be understood only within a regional framework that includes the principal rivers draining to the Pacific Ocean (Fig. 3). As outlined later in this report the last depositional phase of the Sustut Group can be dated as Eocene and drainage was then controlled by tectonic structures with a predominant northwest-southeast trend. Many of the major valleys are probably inherited from this drainage system which was mainly directed to the southeast. Oligocene and Miocene paleodrainage is unknown due to lack of a depositional record. It can be assumed, however, that during Oligocene and Miocene time much of the area had undergone pedimentation and peneplanation because a profound erosion surface, overlain by Pliocene lavas, truncates the tectonic structures of the Skeena Mountains (Souther, 1970). This post-Eocene and pre-Pliocene land surface is now found locally at an elevation of about 2, 000 metres (6, 000 feet).

The present drainage, as shown in Figure 3, can therefore be understood in terms of two evolutionary stages. The first stage (Eocene - Miocene) was characterized by a structurally controlled logitudinal drainage with rivers flowing to the southeast and, to a lesser extent, to the north. This drainage pattern can still be recognized in the Bulkley (Bu in Fig. 3), Babine (Ba), Driftwood (D) drainage and the upper Stikine (St2), Tanzilla (Ta), upper Iskut (Is1) drainage. The longitudinal river system probably reduced much of the tectonic relief that had been created during the Late Cretaceous - Paleogene deformation.

The second stage (Pliocene - Recent) began with renewed uplift of the region in Pliocene time and was accompanied by extrusion of basaltic lava flows onto the elevated land surface.

The sedimentary record of the Pacific continental shelf is compatible with this two-stage evolution of drainage in north-central British Columbia: widespread transgression on the shelf characterizes the Oligocene - Miocene; crustal unrest can be shown for Middle Miocene, and a regressive phase was initiated during Late Pliocene (Shouldice, 1971).

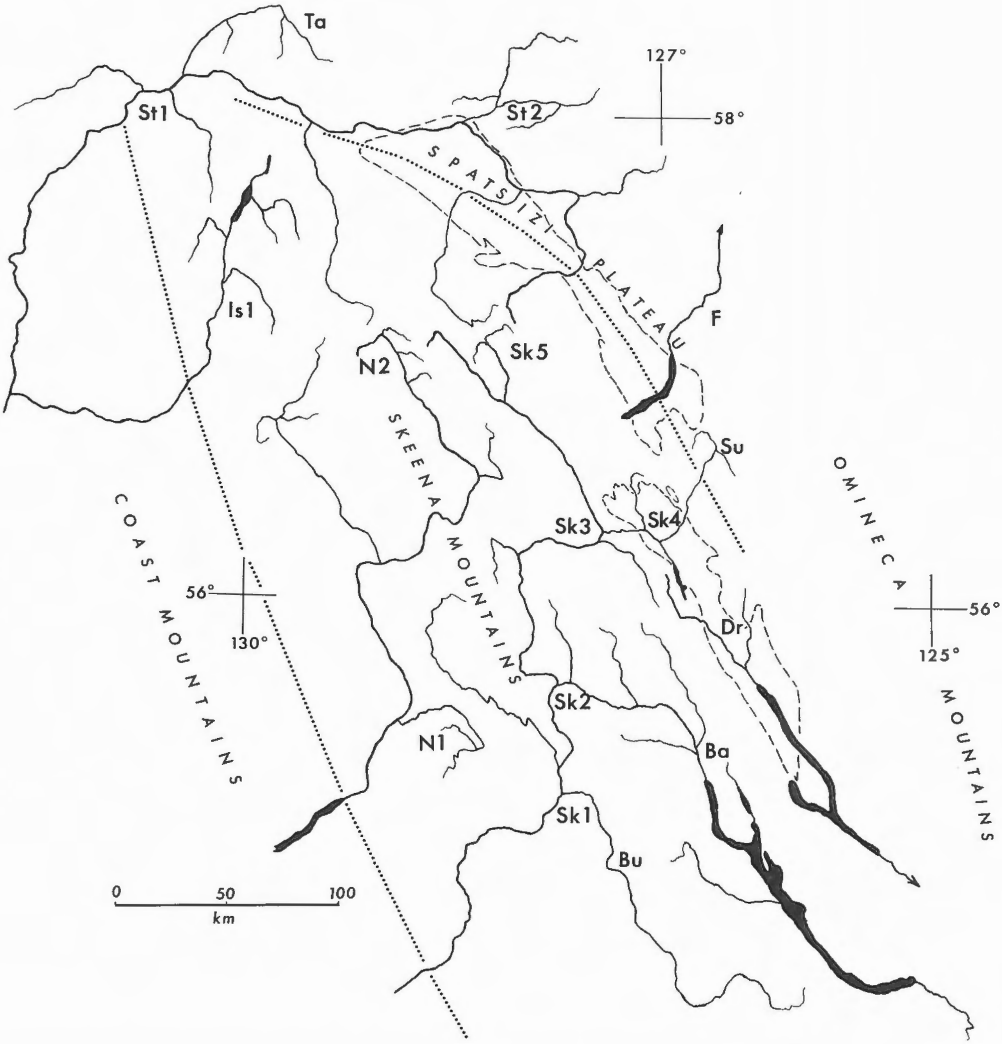


Figure 3. Present drainage of north-central British Columbia. Progressive stream capture of the Bulkley River (Bu at Sk1), Babine River (Ba at Sk2), Sustut and Driftwood drainage (Su and Dr at Sk3 and Sk4) by headward erosion of the Skeena River; stream capture of northerly-directed drainage (Ta= Tanzilla) by Stikine River (St, St2), Iskut River (Is), and Nass River (N2). Sustut Basin is outlined by a thin broken line.

Regional uplift during the Pliocene greatly increased the gradient of streams flowing to the Pacific Ocean and initiated vigorous headward erosion of westerly-flowing rivers transverse to the regional structural grain of the Skeena Mountains. The transverse rivers extended their headwaters to the east by capture of the longitudinal drainage which, at this stage, was probably only poorly incised into the underlying bedrock. Headward capture is particularly well illustrated by the Skeena River which progressively captured the Bulkley (Sk1), Babine (Sk2), Driftwood (Sk3, Sk4) drainage, and presently encroaches upon the easterly-directed drainage of the Finlay (F) and Ingenika rivers (Fig. 3). The interfluve between the main Pacific rivers (Skeena, Nass, Iskut and Stikine) is also characterized by mutual capture depending on the relative gradients of the rivers ( see Sk5, N1, N2, Is1).

Ice flow during Pleistocene time seems to have utilized the main valleys and drift barriers may in places have activated stream capture. The principal source of the ice was the area of the Coast Mountains, but during the waning stages of glaciation local ice caps formed in parts of the Skeena Mountains.

The vigorous downcutting of rivers draining to the Pacific combined with poor slope stability along the sides of most valleys (Eisbacher, 1971c) may create more serious problems for major engineering works in the Skeena Mountains than those generally encountered in the drainage basins east of the Spatsizi Plateau. This instability between river erosion and the relatively young uplift of the area calls for great care in the construction of all engineering works, not only from an economic point of view but also with regard to the unique scenic beauty of the northeastern Skeena Mountains and the Spatsizi Plateau.

## REGIONAL GEOLOGICAL SETTING

The Sustut Group was deposited on or contains clasts of rocks ranging in age from Proterozoic to Late Jurassic. It represents the late-orogenic clastic wedges that were deposited during Cretaceous uplift of the Columbian Orogen to the east and during deformation of the Late Cretaceous - Paleogene Pacific Orogen to the west (Wheeler and Gabrielse, 1972; Eisbacher, 1973b).

A brief discussion of the main rock-units adjacent to or underlying the Sustut Basin follows. The general distribution of rock-units and their function as source areas is shown in Figure 4 and will be discussed separately later in the report.

### Proterozic and Paleozoic Miogeoclinal Sedimentary Rocks

A large part of the Omineca Crystalline Belt and the adjacent Rocky Mountain Belt consists of feldspathic grits, phyllites, quartzites, slates and carbonates of Hadrynian and Paleozoic age. These sedimentary units are possibly more than 5,000 metres (15,000 feet) thick and were extensively folded, thrust faulted, and regionally metamorphosed during mid-Mesozoic time. They are in fault contact with Upper Paleozoic and Mesozoic eugeosynclinal rocks and are intruded by Mesozoic plutonic complexes.

#### Cache Creek Assemblage

The Cache Creek Assemblage of northern British Columbia is a eugeosynclinal succession containing chert, argillite, volcanic sandstones, limestone, meta-basalt and ultramafic rocks (Monger, 1973). The Cache Creek Assemblage has a known age range from Early Mississippian to Late Permian, and a thickness of 1,500-3,000 metres (5,000-10,000 feet). The Cache Creek rocks contain the oldest known record of eugeosynclinal deposition in north-central British Columbia.

Asitka Group

The Asitka Group occurs in the McConnell Creek area (Lord, 1948). It consists of acid to intermediate volcanic and volcaniclastic rocks and overlies the Cache Creek Assemblage unconformably (Monger, 1973). It has a thickness of a few thousand feet, but its age is unknown other than that it is bracketed by the underlying Cache Creek Assemblage and the unconformably overlying Sustut Group

Takla Group

The Takla Group comprises a very thick and laterally extensive succession of andesitic flows, fragmental volcanic rocks, redbeds, and minor limestone. This rock association has been described from many areas in north-central British Columbia and in a restricted sense is considered to be mainly of Late Triassic age (Armstrong, 1949; Tipper, 1963; Souther, 1967). Clastic sedimentary rocks of northwestern and north-central British Columbia so far have not been adequately named. They may in places exceed 600 metres (2,000 feet) in thickness (Souther, pers. comm., 1970).

Hazelton Group

The stratigraphic nomenclature of the Jurassic Hazelton Group is presently being revised by H. W. Tipper of the Geological Survey of Canada. The Hazelton Group incorporates a thick and varied assemblage of volcanic and volcaniclastic rocks. Because a separation into Takla and Hazelton volcanics has not been attempted for most of the area surrounding the Sustut Basin, the source areas made up of Upper Triassic - Middle Jurassic volcanics will be referred to informally as Takla - Hazelton Assemblage, including rocks of the Takla Group and unnamed units of the Hazelton Group.

Laberge Assemblage

The Laberge Assemblage is a Lower to Middle Jurassic synorogenic clastic wedge and represents the youngest unit known to be involved in penetrative deformation of the Columbian Core Zone. It consists of conglomerates and flyschoid sandstone sequences derived mainly from volcanic and granitoid terrane.

Bowser Assemblage

The Upper Jurassic - Lower Cretaceous Bowser Assemblage represents the fill of a large successor basin which developed southwest of the rising Columbian core zone (Souther and Armstrong, 1966; Eisbacher, 1973b). This non-volcanic unit has previously been mapped as Bowser Group (Duffell and Souther, 1964; Souther, 1972), and is characterized by clastic rocks rich in chert, volcaniclastics and locally granitoid fragments. It is mainly marine, and records the gradual withdrawal of the sea to the southwest, followed by extensive nonmarine deposition of the Sustut Assemblage (Eisbacher, 1973b). Along the southern margin of the basin the Bowser Assemblage is interbedded with volcanic units (Tipper, 1972).

### Omineca Intrusions

Granitic plutons of great dimensions have invaded Takla - Hazelton rocks and older stratigraphic units of the Omineca Crystalline Belt. By analogy with the Cassiar Intrusions to the northwest it seems probable that episodes of plutonic activity occurred throughout the time interval between Late Triassic and early Tertiary but that most of the Omineca Intrusions were emplaced in Early to Mid-Cretaceous time (Gabrielse, 1967; and Gabrielse, pers. comm., 1970).

## STRATIGRAPHY

Five terms are used presently in the regional geological literature to describe the late-orogenic continental clastics of north-central British Columbia. These are the terms Sustut Basin, Sustut Assemblage, Sustut Group, Sifton Basin and Sifton Formation.

### Sustut Basin

Sustut Basin contains the nonmarine clastic sequence which is preserved between Takla Lake in the southeast and Stikine River in the northwest and occupies a narrow belt between the Skeena and Omineca mountains (Fig. 4). Fossil leaves and palynomorphs indicate that the basin contains mainly Upper Cretaceous - Paleogene rocks, but it is possible that floras of Early Cretaceous age occur locally in nonmarine clastics within or in continuity with the Sustut Basin rocks.

### Sustut Assemblage

The Sustut Assemblage constitutes the predominantly Upper Cretaceous - Paleogene nonmarine clastic deposits of the north-central Canadian Cordillera. It generally overlies the coal-bearing Middle Jurassic to Lower Cretaceous Bowser Assemblage, and older rock-units of the Cordilleran eugeosyncline.

### Sustut Group

As defined by Lord (1948) near Sustut River, the Sustut Group constitutes the conspicuously bedded nonmarine strata of the Sustut Basin.

### Sifton Basin

Sifton Basin comprises the nonmarine clastic sequence which is preserved in or near the northern Rocky Mountain Trench. Fossil leaves and palynomorphs indicate that the basin contains Upper Cretaceous and Paleogene rocks.

### Sifton Formation

As defined by Hedley and Holland (1941) near Sifton Pass, Sifton Formation consists of continental conglomerate and sandstone of the Sifton Basin in and near the northern Rocky Mountain Trench.

## Sustut Group

The Sustut Group was first named by Lord (1948) from the area near Sustut River in McConnell Creek map-area and has been formally subdivided into two formations in the Toodoggone area by the author (Eisbacher, 1971b). These formations are mappable throughout the Sustut Basin and a further subdivision into members, suggested in this report, may prove useful for mapping on a more detailed scale than that of the present study.

### Tango Creek Formation

Lithostratigraphy The type section of the Tango Creek Formation has been described by Eisbacher (1971b) and is shown with other measured sections in Figure 5. The Tango Creek Formation generally rests unconformably on Bowser Assemblage and older igneous and sedimentary complexes along the margins of the basin. Complicated structural relationships within the unit, however, do not allow measurement of unbroken stratigraphic sections. Nonetheless, two informal members can be identified throughout most of the basin. These members grade vertically into each other and no sharp contact can be placed between them.

The lower unit, the Niven member is a sandstone-mudstone succession with sandstone being the most abundant. Sandstones are generally sub-quartzose (less than 75% quartz), feldspathic arenites. The Niven member commonly displays a polymictic 'basal conglomerate', which varies greatly in thickness from about 100 metres (300 feet) south of Niven River to complete absence. Higher in the section, 'red mudstone' and 'quartz-pebble conglomerate' beds were mapped as structural markers ( see Map 14-1973). The upper unit, the Tatlatui member, is a succession of dark grey mudstone and chert-pebble-bearing arenites, with mudstone being most abundant. Layers of dense, brownish weathering calcite concretions are relatively common within the dark grey mudstone intervals, and within the highest beds of the section thin seams of lignite can be found locally. Green and red mudstone predominates in the Niven member, dark grey mudstone is prevalent within the Tatlatui member. Volcanogenic rocks occur only near Mosque Mountain, where a buff-weathering clastic unit about 5 metres thick may represent a waterlain unit with a considerable ash-fall component.

Thickness of the Tango Creek Formation ranges from about 500 metres (1, 500 feet) along the east side of the basin to about 1, 400 metres (4, 200 feet) along the western part.

Age In the McConnell Creek area, Lord (1948) collected fossil leaves at nine localities within Sustut Basin. Six of his localities were clearly situated within the Tango Creek Formation. The collections were thought by W.A. Bell to be of Cenomanian - Turonian age ( in Lord, 1948, p. 39-40).

Armstrong (1949) made six collections of fossil leaves from Sustut rocks along and near Takla Lake. These rocks are probably correlative with Tango Creek Formation. The collections were studied by W.A. Bell who assigned them to the Upper Cretaceous, probably Cenomanian ( see Armstrong, 1949, p. 66-68).

During Operation Stikine (Geological Survey of Canada, 1957), L.H. Green made several collections of plant fossils within the Spatsizi map-area (GSC Plant loc. 4906, 4907, 4908, 4909). As far as the author could ascertain, all collections were made in the Tango Creek Formation. W.L. Fry identified the following flora:

*Asplenium puilasokense* Heer

*Ceroidiphyllum arcticum* (Heer) Brown

*Viburnum lakesii* Lesqu.

*Platanus* cf. *P. raynoldsi integrifolia* Lesqu.

cf. *Fraxinus* sp.

cf. *Sassafras* sp.

Fry assigns an early Tertiary and 'probably Paleocene' age to this flora.

In 1967 H. Gabrielse collected a plant assemblage from strata along the Stikine River (lat. 58°04') in the Dease Lake map-area (104 I). The collection was made about 16 metres (50 feet) above the base of the Sustut Group within the Tango Creek Formation. W.A. Bell determined the following florule:

*Pseudocycas unjiga* (Dawson) Bell

*Araliaephyllum parvidus* ? Hollick

*Dicotylophyllum* sp.

Bell considered the age to be Cenomanian.

During field investigations between 1969 and 1972 the author collected mudstone and siltstone samples from the Sustut Group for purposes of palynological work. Most samples unfortunately proved to be barren.

One sample from the Niven member of the Ross River Section (GSC Loc. No. C-13357) contained the following palynomorphs:

*Cicatricosisporites* sp.

*Pinus* sp.

*Retitricolpites* sp.

*Alnus* sp.

*Betula* sp.

*Triporites* sp.

This assemblage is considered by W.S. Hopkins to be Lower Tertiary. A systematically sampled section of mudstone-siltstone of the upper part of the Tango Creek Formation near Cold Fish Lake yielded, in stratigraphically ascending order, the following palynomorphs:

| | |
|---|---|
| GSC C-13362 | *Triletes* sp. |
| | *Cicatricosisporites* sp. |
| age: | ? Upper Cretaceous |
| GSC C-13363 | *Retitricolpites* sp. |
| age: | Upper Cretaceous - Lower Tertiary |
| GSC C-13364 | *Deltoidospora* sp. |
| | cf. *Picea* |
| age: | ? Upper Cretaceous |
| GSC C-13365 | *Cicatricosisporites* sp. |
| age: | Cretaceous - Lower Tertiary |

GSC C-13369 *Sphagnum* sp.
cf. *Baculatisporites* sp.
*Monosulcites* sp.
cf. *Compositae*
age: probably Tertiary

These determinations and age assignments by W. S. Hopkins indicate an Upper Cretaceous - Lower Tertiary assemblage.

In the uppermost units of the Tango Creek Formation near Cold Fish Lake, G. Rouse, University of British Columbia, found palynomorphs indicating a possible Paleocene age (G. Rouse, pers. comm., 1971).

In conclusion it can be said that the Tango Creek Formation was probably deposited during a time interval including Late Cretaceous and Paleocene.

## Brothers Peak Formation

Lithostratigraphy The type section of the Brothers Peak Formation has been described by Eisbacher (1971b) and is shown with other measured sections in Figure 6.

The Brothers Peak Formation generally rests conformably on mudstone and siltstone of the Tango Creek Formation, although locally angular unconformities may exist between the two formations along the northeastern margin of the basin ( see section on Structural Geology). The Brothers Peak Formation is characterized by numerous acidic ash-fall tuffs and thick conglomerate bodies. Its lower contact has been placed at the base of the conglomerate horizon below the stratigraphically lowest tuff horizon. This boundary can be mapped throughout the Sustut Basin.

Two informal members can be distinguished within the Brothers Peak Formation: the basal unit, the Laslui member, is characterized by coarse conglomerate interlayered with ash-fall tuffs. The upper unit, the Spatsizi member, is made up of pebbly sandstones interlayered with ash-fall tuffs and mudstone. The boundary between the two is arbitrarily placed where a marked decrease in conglomeratic beds and a change in paleocurrent directions is found. This boundary is indicated on Map 14-1973 by a thin broken line.

Sandstone of the Brothers Peak clastics are composed mainly of feldspar, quartz, volcanic rock fragments and chert. The conglomerates are rich in chert ( see section on Composition and Provenance).

Total thickness of the Brothers Peak Formation ranges between about 300 metres (1,000 feet) and 900 metres (2,700 feet). Measured thicknesses are directly related to amount of conglomerate in the section.

Age Lord (1948), while mapping in the McConnell Creek area, made three collections of fossil leaves in the tuffs of the 'upper division' of the Sustut Group, herein referred to as Brothers Peak Formation. W.A. Bell suggested a Paleocene - Early Eocene age for these collections ( see Lord, 1948, p. 40-41). The author collected samples of ash-fall tuffs which were submitted to the Geochronology Section of the Geological Survey of Canada for whole rock K-Ar age determination. One of the samples (GSC K-Ar 1798) represents the lowest exposed tuff horizon near the bend of Thutade Lake below Mount Jorgensen and yielded an age of 53±6 m.y. The second sample (GSC K-Ar 1797) was collected about 400 metres above the base of the Brothers Peak Formation (Chapea Lake section) and yielded an age of 49±5 m.y.

G. Rouse (pers. comm., 1971) collected an Eocene fossil leaf assemblage from tuff-bearing rocks north of Mount Forrest (about 6 kms east of Thutade Lake). He also submitted a specimen of tuff for whole-rock K-Ar dating to the Department of Geophysics, University of British Columbia, from which dates of 45 m.y. and 54 m.y. were obtained (Rouse, pers. comm., 1969).

In conclusion it can be said that the Brothers Peak Formation contains rocks of Eocene and possibly Paleocene age.

## Sifton Formation

Lithostratigraphy The Sifton Formation was named by Hedley and Holland (1941) after exposures near Sifton Pass, Northern Rocky Mountain Trench. Probable correlative rocks near Black Canyon, now submerged under Lake Williston, were referred to by McConnell (1896) as 'Laramide'. In the Rocky Mountain Trench exposure of Sifton rocks is poor and structure generally complicated. The best exposures of Sifton Formation are found a few kilometres west of Ware on the west-facing slopes of Mount Bennett and Cormier Range. Although no stratigraphic sections were measured there, scattered outcrop areas reveal a highly varied non-marine clastic assemblage of boulder conglomerates and breccias, conglomeratic sandstones, sandstones, siltstone and mudstone. Minor occurrences of lignitic coal have been reported by Hedley and Holland (1941).

No reliable figure of the thickness of the Sifton Formation has been obtained during the present study, but a continuous section near Mount Bennett exposes at least 100 metres (300 feet) of Sifton conglomerate, sandstone and mudstone.

Age A few plant remains collected by Hedley and Holland (1941) were assigned by W.A. Bell to the Upper Cretaceous or possibly Paleocene to Eocene ( see Hedley and Holland, 1941, p. 42).

While mapping in the Kechika area, H. Gabrielse (1962b) made three collections of fossil leaves. F.M. Hueber determined the following florules:

GSC loc. 5809
*Metasequoia occidentalis* (Newberry) Chaney
*Cercidiphyllum (Trochodendroides) arcticum* (Heer)
*Carpinus grandis* Unger
*Corylites fosteri* (Ward) Bell
*Populus* sp.
*Viburnum* sp.

GSC loc. 5810
*Metasequoia occidentalis* (Newberry) Chaney
*Cercidiphyllum (Trochodendroides) arcticum* (Heer)
*Alnus serrata* Newberry
*Corylus* sp.

GSC loc. 5811
*Metasequoia occidentalis* (Newberry) Chaney
*Cercidiphyllum (Trochodendroides) arcticum* (Heer)
*Alnus serrata* Newberry
*Corylites fosteri* (Ward) Bell
*Carpinus* sp.
*Platanus raynoldsii* Newberry
*Phamnites ovatus* (Penhallow) Bell

F.M. Hueber considered these assemblages to be of Paleocene age.

In 1960 H. Gabrielse collected fossil leaves from an isolated outlier of probable Sifton Formation near Turnagain River (Gabrielse, 1962b). This outlier is labelled as Turnagain Beds on Figure 1.

The following florule was determined by W.A. Bell

GSC loc. 5691 *Equisetum* sp.
*Metasequoia cuneata* (Newberry) Chaney pars.
*Alnus perantiqua* (Dawson) Bell
*Combretum cordifolia* (Lesquereux) Berry
*Ficus cockerelli* Knowlton
*Myrica* ? sp.

W.A. Bell considered this florule to be Upper Cretaceous and deposited within the time interval Santonian - Campanian.

In 1970 H. Gabrielse submitted four samples from the Sifton Formation at Deserters Canyon, Ware map-area, to W.S. Hopkins, Institute of Sedimentary and Petroleum Geology, Calgary, for palynological analysis. Two samples were found to contain palynomorphs and were determined by Hopkins.

| | |
|---|---|
| GSC loc. C-8680 | cf. *Taxodiaceae* |
| | cf. *Pinus* sp. |
| | *Spiny inaperturate* (? pollen grain) |
| | *Tricolpites* sp. |
| age: | *Upper Cretaceous* - Tertiary |
| | |
| GSC loc. C-8681 | cf. *Taxodiaceae* |
| | *Tricolpites* sp. |
| | *Triporites* sp. |
| | cf. *Pterocarya* sp. |
| | cf. *Alnus* sp. |
| age: | probably Tertiary |

During the present investigation by the author a sandstone sample rich in detrital muscovite was collected near Black Canyon from McConnell's 'Laramide' unit. From the muscovite concentrate a K-Ar age of 117±5 m.y. was determined (GSC K-Ar age 1930). This number represents the oldest possible age for the Black Canyon beds of the Sifton Formation.

Muscovite concentrates from granite boulders in Sifton conglomerates northwest of Ware yielded K-Ar ages of 94 and 104 m.y. (H. Gabrielse, pers. comm., 1973). These dates are maximum ages for the Sifton conglomerates in this area.

West of Ware several northerly-trending lamprophyre dykes intrude conglomerate of the Sifton Formation. Biotite concentrates from these lamprophyres yielded K-Ar ages of 48 and 37 m.y. (R.K. Wanless, pers. comm., 1973). These dates give minimum ages for the Sifton Formation in this area.

In conclusion it can be said that the Sifton Formation probably contains rocks of Late Cretaceous - Paleogene age.

## PALEOCURRENTS

Paleocurrents were determined by measuring (a) the orientation of forests in crossbedded sandstones and conglomerates, (b) the imbrication of clasts in conglomerates, and (c) the trend of ripple-drift crosslamination in fine-grained

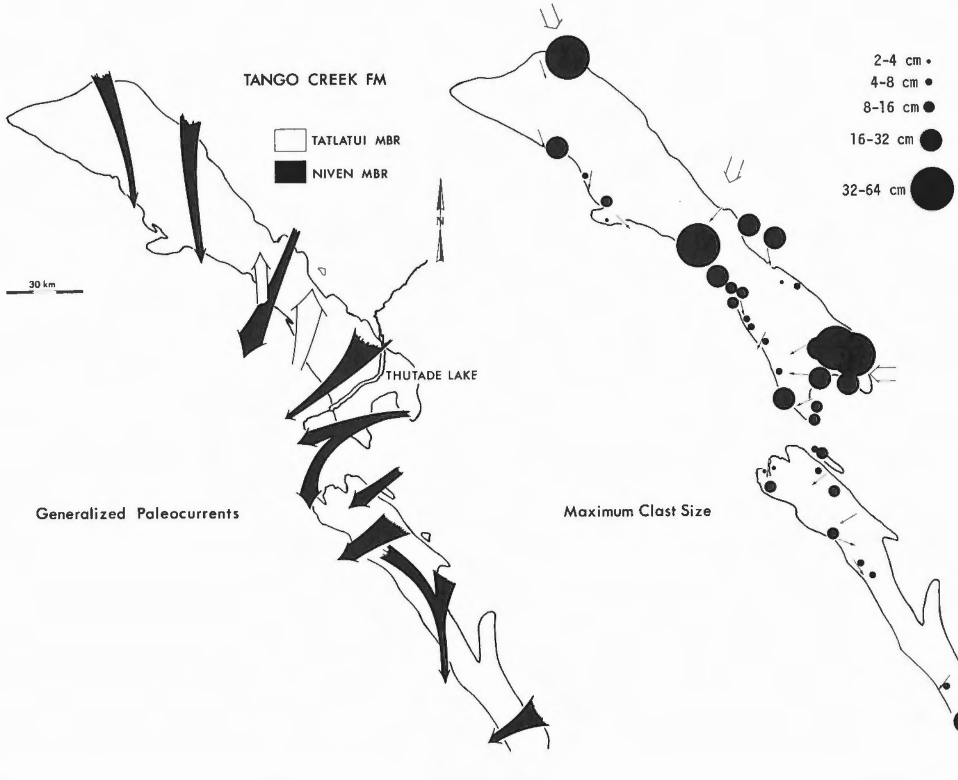


Figure 8. Generalized paleocurrents and maximum clast sizes of Tango Creek Formation.

sandstones, siltstones, and tuffs. About 2, 100 readings were taken in the field and corrected for tectonic tilt where necessary. Field work suggested at an early stage that major changes in the direction of the average paleocurrent vectors coincided with the principal lithostratigraphic boundaries within the Sustut Group (Eisbacher, 1971b). Further work concentrated on the definition of the different paleocurrent systems and the distinction between the upper (proximal) and lower (distal) portions of the alluvial plain. For this purpose maximum clast size was recorded in conglomeratic horizons by measuring the longest diameter of the largest clast found at any locality, and a record was kept of the stratigraphic position of the locality where the measurement was taken.

Paleocurrent rose-diagrams were compiled for appropriate stratigraphic intervals and outcrop areas, and a mean paleocurrent vector was obtained for each of the paleocurrent roses by the technique suggested by Curray (1956). The results of this compilation for the Tango Creek, Brothers Peak, and Sifton formations are shown in Figure 7.

In order to depict the regional paleoslope all paleocurrent vectors were plotted at their point of origin for the different paleocurrent rose-diagrams. The technique applied to derive the generalized paleocurrent pattern from the average paleocurrent vectors differs from that generally recommended (e.g. Potter and Pettijohn, 1963; Steidtmann, 1971). In the present study the vectorial means from individual paleocurrent roses were plotted on a separate map, and the space between the arrows was filled with lines enveloping the trend of the arrows at their point of origin. By

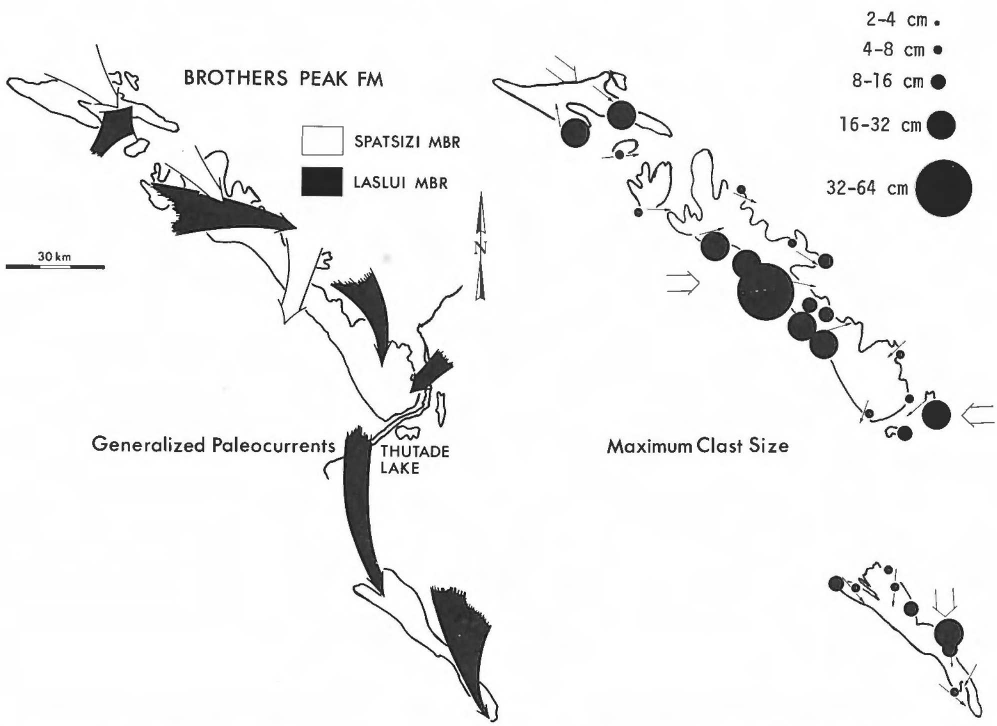


Figure 9. Generalized paleocurrents and maximum clast sizes of Brothers Peak Formation.

this procedure the trend of the calculated mean paleocurrents at any locality was preserved in the smoothed pattern. Thus convergence or divergence of interpolated "stream lines" probably indicate real elements of the paleoslope. The combination of the generalized paleocurrent pattern and the distribution of maximum clast sizes shown by Figures 8 and 9 permit certain conclusions as to the location of proximal and distal regions on the alluvial plain and give a rough idea of how the principal valleys ("talwegs") shifted in time.

Tango Creek Formation (Fig. 8)

Niven member In the northern part of the Sustut Basin the Niven member seems to have been deposited by two principal river systems: one entered the basin from the north, the other from the east. Near the present site of the Tatlatui Range, west of Thutade Lake these two systems merged and flowed to the southwest. In the southern part of the basin the principal rivers entered from the northeast and probably flowed to the southwest. On a regional scale the drainage pattern during deposition of the Niven member can therefore be considered centripetal to the southwest.

Tatlatui member Streams from the north seem to have been deflected by topography presumably related to tectonic uplift of the basin along its southwestern sector. The principal clastic input entered the northern part of the basin near Thutade Lake but seems to have been deflected to the northwest. The Tatlatui member signifies the transition from a centripetal to a longitudinal drainage system.

Brothers Peak Formation (Fig. 9)

Laslui member  The principal clastic input into the northern part of the basin occurred along a broadly arcuate apron along the western basin edge. Part of the drainage continued to flow to the north but most of the clastics were transported to the southeast. Near Thutade Lake this drainage was joined by another from the east, and together they flowed to the south and then to the southeast in the southern part of Sustut Basin. The drainage system of the Laslui member was therefore distinctly longitudinal.

Spatsizi member  The final phase of deposition of the Sustut Group is related to vigorous drainage entering the basin from the northwest, then swinging to the south and southwest, similar to the drainage of the Niven member. While still depositing sediment along the subsiding basin axis, this drainage probably was erosional towards the southwest.

Sifton Formation (Fig. 10)

Along the site of the northern Rocky Mountain Trench major drainage was directed to the south although vigorous local alluvial fans from the east may have

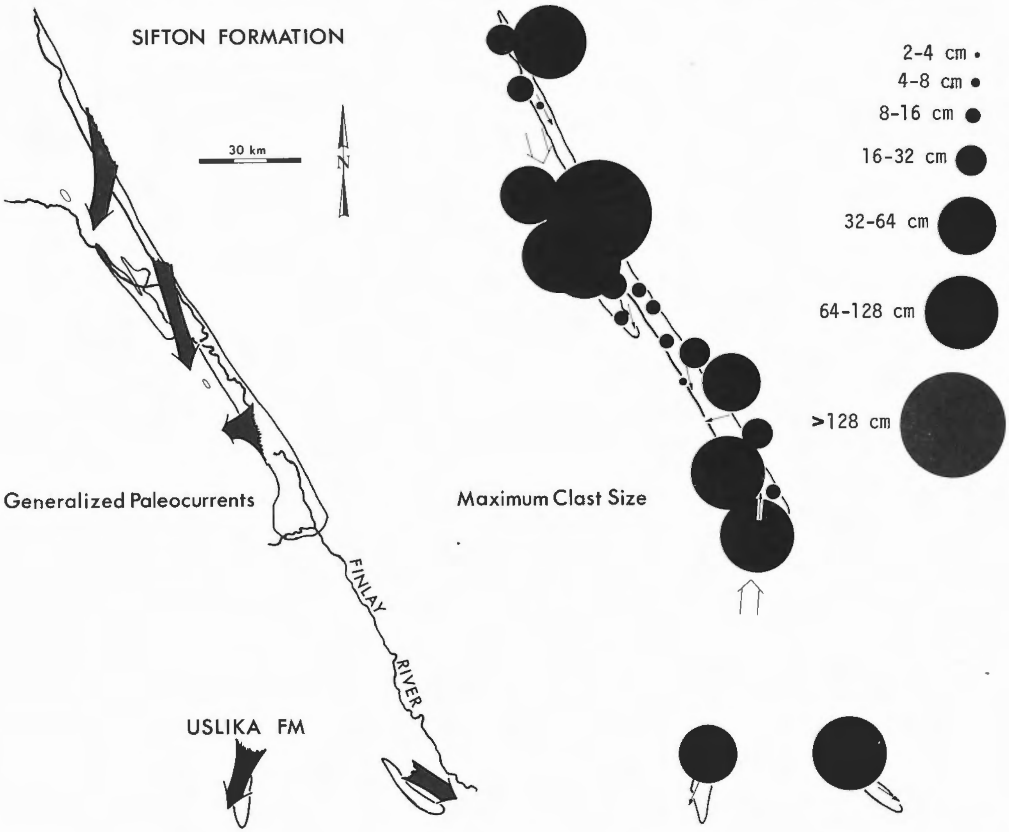


Figure 10. Generalized paleocurrents and maximum clast sizes of Sifton Formation.

caused a shift of the principal valley to the southwest. From the southerly directed paleocurrents it appears that Sifton Basin constituted a much broader alluvial plain than the present floor of the Rocky Mountain Trench. Drainage in the Sifton Basin was parallel with the regional structure and directed to the south, and probably included parts of Pelly Creek valley and the Black Canyon Beds of the lower Omineca River.

## PROVENANCE

Thin sections of sandstones from Sustut and Sifton basins show that most of the arenites are characterized by low compositional stability and textural immaturity (Eisbacher, 1971b). Sandstones and conglomerates therefore largely reflect the composition of rocks in the source area. From paleocurrent evidence presented in the previous chapter these source areas can be inferred for the individual units of the Sustut Group and Sifton Formation. In a general way the modal composition of the sandstones is compatible with rock-types presently exposed in the source area. No heavy mineral separations were carried out during this phase of the study but such an investigation might be of great value in refining the limits of source areas, their unroofing history, and the economic potential of the Sustut Group.

### Sandstones

Arenites of the lower Tango Creek Formation (Niven member) are characterized by contents of between 40% - 60% quartz, 10% - 30% feldspar, 5% - 20% mafic volcanic rock fragments, and a residual amount of phyllosilicates and chert. During deposition of the Tatlatui member an increase in chert (15% - 35%) and volcanic rock fragments (10% - 30%) and a dramatic decrease in quartz reflects the input of clastics from the rising folds of the Bowser Basin. The Brothers Peak Formation has generally about 10% quartz, 10% chert, 20% - 40% volcanic rock fragments, and 15% - 25% feldspar; some of the feldspar is clearly derived by reworking of interlayered ash-fall tuffs. The Sifton Formation varies greatly in modal composition but generally has about 10% - 50% quartz, 0% - 50% limestone, 0% - 40% feldspar, and 10% - 30% phyllosilicates.

Modal diagrams for the three formations are shown in Figure 11.

### Conglomerates

Clast composition counts have been carried out for conglomerates throughout the Sustut and Sifton basins and are shown in their regional distribution in Figure 12.

A generalized diagram was derived from the detailed compositional histograms and is shown in Figure 13. Because of the variation in the paleocurrent pattern during the deposition of the Sustut Group, the composition of conglomerates varies within the vertical succession of any particular region. As an example a schematized section near Cold Fish Lake in the northern part of Sustut Basin illustrates the way in which different paleocurrent systems and source terranes are reflected in the composition of conglomerates at various stratigraphic levels (Fig. 14). Near Cold Fish Lake the basal conglomerate beds consist of granitoids derived from Mesozoic plutons, andesite derived from Takla volcanics, and chert derived from Cache

Creek Assemblage or chert-pebble conglomerate of the Bowser Assemblage. A slight change in paleocurrents towards the southwest and the increase in quartzite fragments indicate that the Cambrian miogeoclinal quartz arenites formed part of a major new source area about 100 kilometres northeast of Sustut Basin. A complete reversal in paleocurrents to the north during Brothers Peak deposition is reflected by a great influx of chert clasts derived from Bowser chert-pebble conglomerate. The final establishment of longitudinal drainage to the southeast continued the earlier phase of downcutting into Mesozoic plutons, Takla volcanics and probably also initiated reworking of chert-bearing lower Sustut conglomerates.

## SEDIMENTOLOGIC INTERPRETATION

### General Considerations

Fluviatile deposits are the result of sedimentation by aggrading rivers and their floods. The vertical profile of any fluviatile succession can be interpreted in terms of specific river environments if analogs for the vertical and horizontal sequence of sedimentary structures and textures can be derived from recent stream

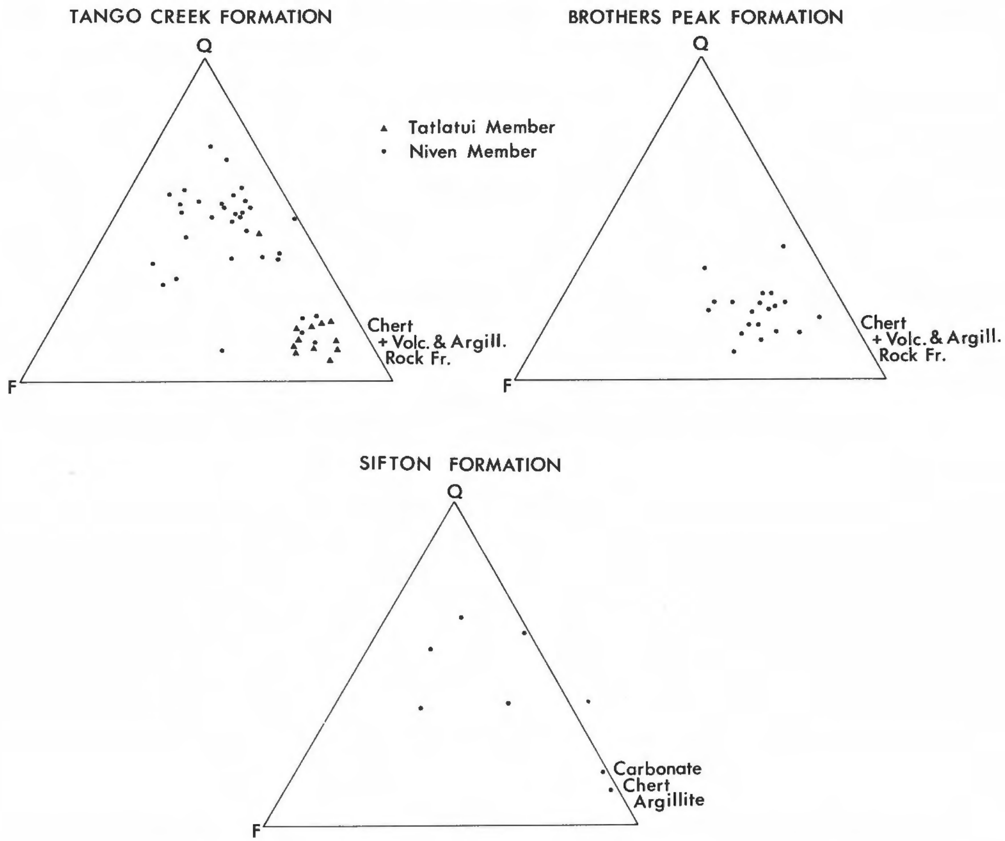


Figure 11. Modal composition of sandstones of Tango Creek Formation, Brothers Peak Formation, and Sifton Formation.

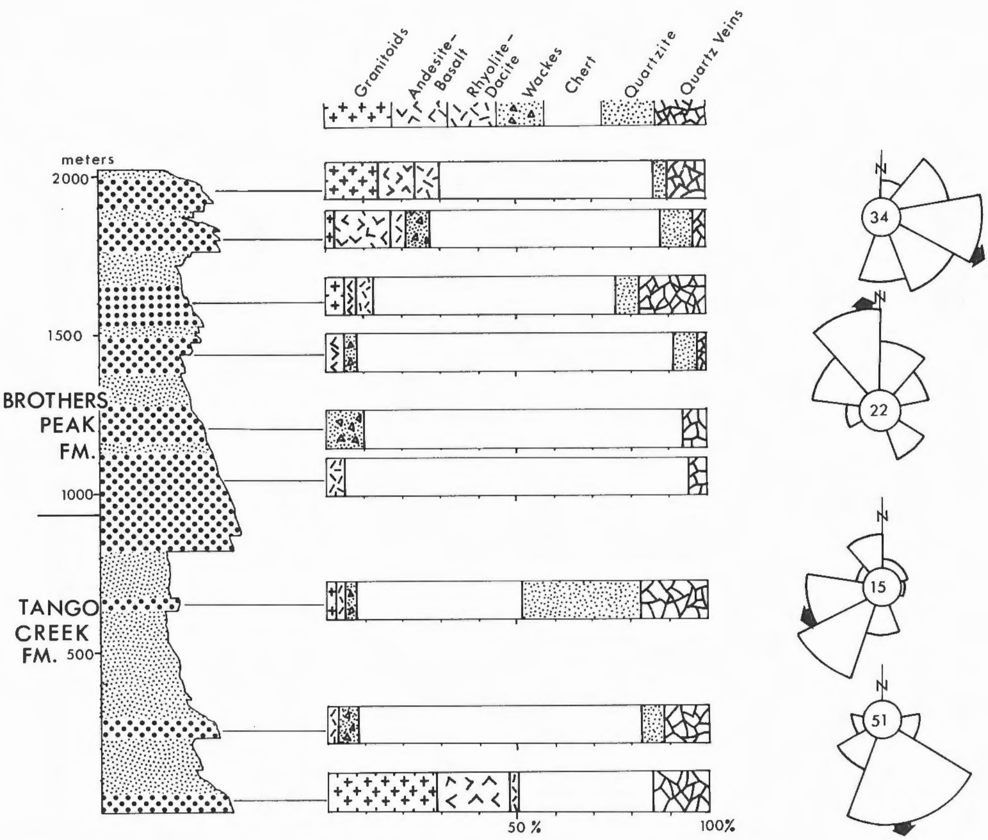


Figure 14. Change in the composition of conglomerate clasts with changing paleocurrents in the Sustut Group.

processes. A short review of recent studies of river deposits should aid in the understanding of the stratigraphic units of the Sustut Basin.

Leopold and Wolman (1957) have recognized the fundamental significance of three different types of alluvial channels: braided, straight, and meandering. Similarly, Schumm (1963) has classified river channels into low-sinuosity and high-sinuosity stream beds. An areally more restricted aggradational setting characterized by a conical geometry and high surface gradient is found on alluvial fans (Blissenbach, 1954).

Processes in recent alluvial environments are generally expressed in terms of measurable quantities such as width and depth of the channel, discharge of water, quantity of transported bedload and suspended load, sediment size, sorting, river gradient, sinuosity, degree of braiding, and bank stability.

Three relationships seem to be particularly significant in the stability of channel processes:

(1) Degree of braiding $\sim$ D, S (Leopold and Wolman, 1957)

(2) $\dfrac{\text{Bedload}}{\text{Suspended Load}} \sim \dfrac{w,\ I,\ S}{d,\ P}$ (Schumm, 1968)

(3) Water Discharge $\sim \dfrac{w,\ d,\ I}{S}$ (Schumm, 1968)

Bedload = Sediment that moves by sliding, rolling, or saltation on or very near the bed.

D = Discharge

S = Slope (or gradient)

w, d = Width and depth of channel

I = Wavelength of meander

P = Sinuosity (river length/valley length)

Expressions (1), (2), (3) and observations in recent river channels suggest that a few parameters are particularly critical in the adjustment of rivers to external influences.

The principal effect of high discharge is a widening of the river bed and the establishment of a low-sinuosity channel. The principal effect of a high gradient seems to be a tendency towards an anastomosing (braided) channel pattern with sediment transport taking place mainly in the form of bedload. Grain size influences the channel form indirectly: if much of the sediment is carried as suspended load, sinuous channels will predominate; if, on the other hand, sediment is transported predominantly as bedload, straight, wide or braided channels will develop. Bank stability, which is a function of vegetation and clay content, tends to inhibit braiding and enhances meandering.

Channel forms therefore adjust in response to external factors, such as discharge, gradient, vegetation, and sediment load. Examples for dramatic river adjustment are known. To quote from Schumm (1963, p. 1097): "For example, a depletion of vegetational cover on hill slopes has caused an influx of coarse sediment into the channels of some New Zealand rivers. The result is a change from a narrow meandering channel, to a wide straight one." Or from Schumm (1968, p. 1581): "... a reduction in both peak discharge and annual discharge has caused a major reduction in the width of the North and South Platte Rivers, the Arkansas River, and the Red River. In addition, each of these channels has become more sinuous, suggesting that the quantity of bedload moved through the channels has been reduced."

Work on recent alluvial deposits suggests that sedimentary structures, combined with changes in grain size and texture, provide some clues as to the recognition of alluvial fans, braided streams, and meandering streams in ancient deposits, and hence of their environment of deposition.

## Alluvial Fan (Fig. 15)

Alluvial fans form principally in mountainous areas where narrowly confined, high-gradient mountain streams enter broad alluvial valleys. Deposition of coarse sediment results from a decrease in depth and velocity of flow as the stream widens and loses its carrying power. The area covered by alluvial fans increases with the size of the source area (Bull, 1963; Hooke, 1968).

Two principal types of deposits occur on alluvial fans: debris flow deposits, and water flow deposits. Deposits of intermediate type are also common (Hooke, 1967).

In most alluvial fans, an upper fan portion (fanhead), can be distinguished from a lower fan segment. The fanhead is subject to entrenchment, and debris flows are generally confined to narrow channels. On the lower fan segment, debris flows spread out and sediment is deposited as debris lobes. Coalescence of alluvial fans results in compound fans or "bahada". The preservation of alluvial fans in the geological record depends on rapid subsidence of the alluvial valley which is commonly achieved by faulting along one or both sides of the valley. Vertical sections

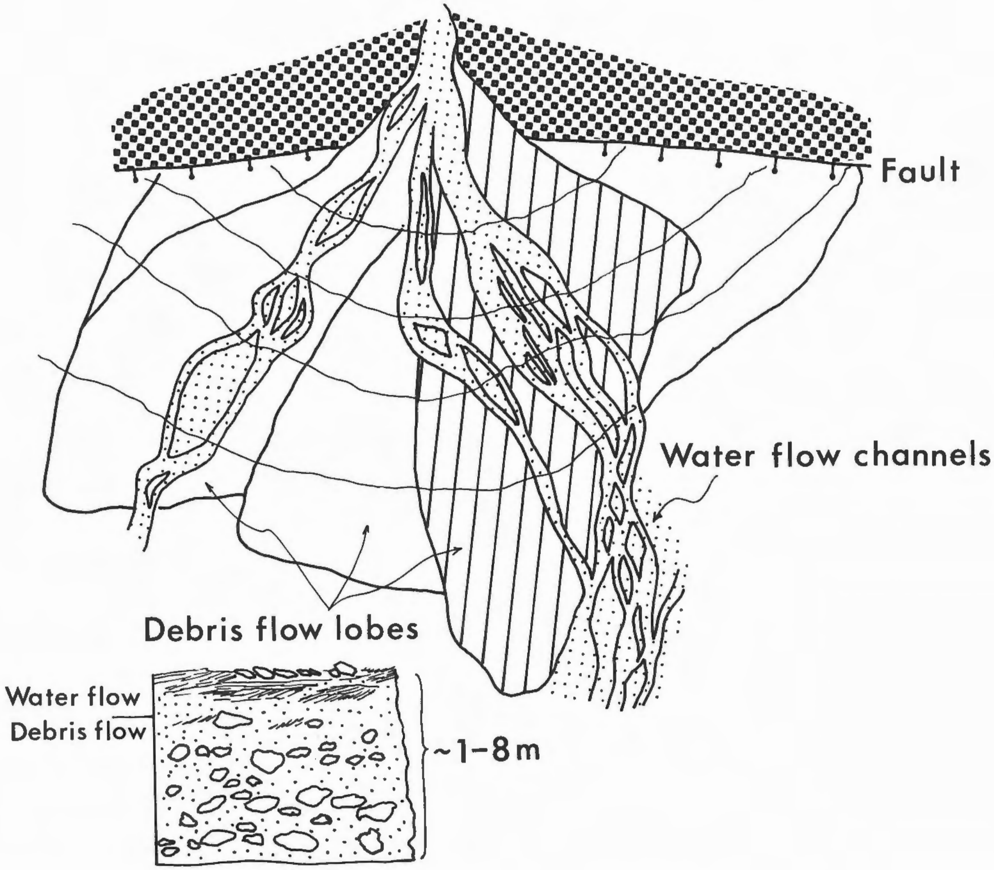


Figure 15. Alluvial fan depositional model.

through recent alluvial fans have been illustrated by Blissenbach (1954), Sharp and Nobles (1953), and later workers (Fahnestock, 1963; Bull, 1972). The outstanding feature of debris-flow lobes is a lack of internal stratification, poor sorting, a sharp basal contact, and a flat top (Hooke, 1967). Bulk thickness of the debris flows, their maximum clast size, and angularity of clasts within individual debris lobes decrease downstream (Blissenbach, 1954; Bull, 1963; Bluck, 1964), but despite this relationship in individual debris lobes, textural parameters in composite alluvial fans do not bear out simple down-fan gradients (Bluck, 1967; Miall, 1970). Sharp and Nobles (1963) report occasional boulders of up to 45 cm at a distance of 18 km from the source of a recent debris flow in California. At this distance, the median grain size had decreased to as little as 0.6 mm.

The waterlain portion of the alluvial fan merges with the channel system of the valley stream, and is commonly made up of braided channels that rework much of the debris flow deposits.

Braided Stream (Fig. 16)

Leopold et al. (1964), Ore (1964) and Smith (1970), have shown that braiding of river channels can arise from either gradual emergence of longitudinal gravel bars or the dissection of transverse bars made up predominantly of coarse sand. Longitudinal bars dominate the upper reaches of a braided river course, whereas dissected transverse bars seem to occur in the lower reaches (Smith, 1970; Williams and Rust, 1969).

Longitudinal bars are made up of coarse-pebble deposits which display a crude horizontal stratification. Pebble concentrations occur commonly in transverse ribs (McDonald and Banerjee, 1971) with alignment of the longest clast axes perpendicular to the stream flow direction and imbrication of clasts into the upstream direction.

Transverse bars are characterized by well-developed planar cross-stratification that forms whenever bedload encounters a depression in the stream bed. Individual planar foresets originate by avalanching of sand on the downstream slip faces of migrating bars (Smith, 1971). Dissection of the bar occurs when discharge over the bar surface decreases.

Leopold et al. (1964) emphasized that the establishment of a braided reach is accomplished by rapid lateral shifting of the channel and rapid erosion of the river banks. Fine-grained overbank deposits are quickly eroded and swept away. The vertical succession of braided stream deposits therefore consists of intensely channeled gravels and sands, but only minor siltstone and mudstone intervals.

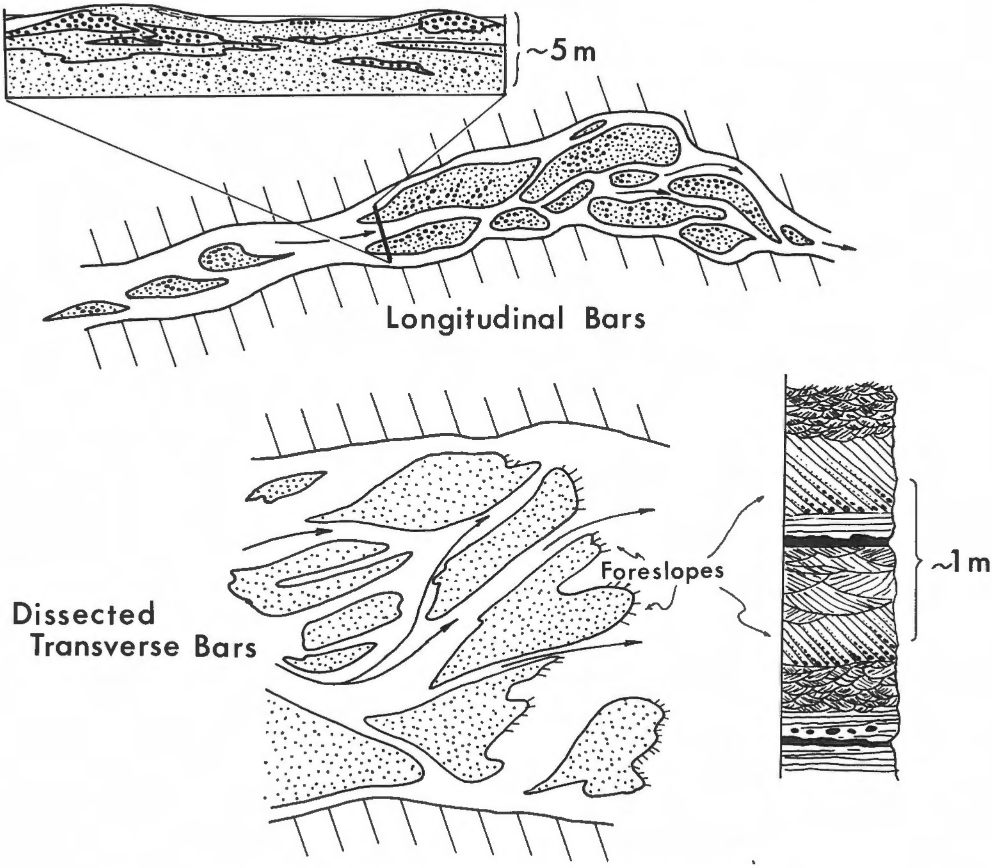


Figure 16. Braided stream depositional model.

Meandering Stream (Fig. 17)

Allen (1965, 1970), Visher (1965), and others have demonstrated that vertical sections of fluviatile deposits commonly consist of numerous "fining-upward" cycles, recording the lateral accretion of meandering rivers and dislocation of channels during flood stage. These cycles range in thickness from a few to several tens of metres and record the establishment of channel deposition on the inside of a meander bend (coarse-grained member), and gradual replacement of channel and point bar deposition by less vigorous overbank deposition (fine-grained member). The basal scoured surface is commonly overlain by a thin (less than 10 cm) conglomerate facies, followed by a cross- or horizontally-stratified sandstone facies, a cross-laminated sandstone facies, and finally a fine-grained siltstone-mudstone member. Predominance of the flatbedded sandstone facies suggests a low-sinuosity river (Allen, 1970). Predominance of the crossbedded sandstone facies, on the other hand, probably indicates point bar deposition on well-developed meander bends (Beutner *et al.*, 1967).

Meandering rivers with extreme flood stages are characterized by more irregular successions. Such rivers tend to develop two levels of crossbedded point bars for the respective water levels - a lower point bar for the low water stage, and a higher bar for the flood stage (Harms *et al.*, 1963; McGowen and Garner, 1970).

Fine-grained overbank flood deposits have been described by McKee *et al.* (1969). These deposits seem to be predominantly flatbedded with occasional intervals of crossbedding and convolute lamination. Flood deposits of ephemeral streams from central Australia were described by Williams (1971). They are made up of sediment lobes with abundant planar and trough cross stratification, most of which seems to have formed during the waning stages of the flood.

## Tango Creek Formation

### Niven member

The bulk of the Niven member is made up of relatively monotonous sandstone-siltstone-mudstone "fining-upward" sequences and interbedded conglomerates deposited on a southeasterly-dipping paleoslope.

The conglomerate channels, which overlie the basal unconformity, vary in composition, roundness, and geometry from locality to locality. Conglomeratic units higher in the section tend to be much more uniform. The basal conglomerates in places are tens of metres thick, but generally pinch out rapidly along strike and commonly are absent altogether. In the latter case, the base of the formation is defined by sandstone channels or grit lenses deposited onto underlying bedrock pediment. The distinctly pedimented bedrock on the east side of the basin suggests that vigorous dissection of the upland area had taken place before and during deposition of the Niven member. Furthermore, no chaotic fault-scarp alluvial-fan deposits seem to lie at the base of the Niven member. During deposition of the basal Niven member, topography east of the Sustut Basin must have exceeded 150 metres close to the basin edge, and a relief of about 50 metres is suggested from within the basin. The first figure can be estimated from conically shaped mountains that presently overlook the exhumed pediment near Metsantan Lake (Fig. 18), the second value is obtained from the thickness of basal conglomerate wedging out laterally into sandstones. A thorough study of the topographic surface underneath the basal Sustut along the northern and eastern edge of the basin has not been undertaken

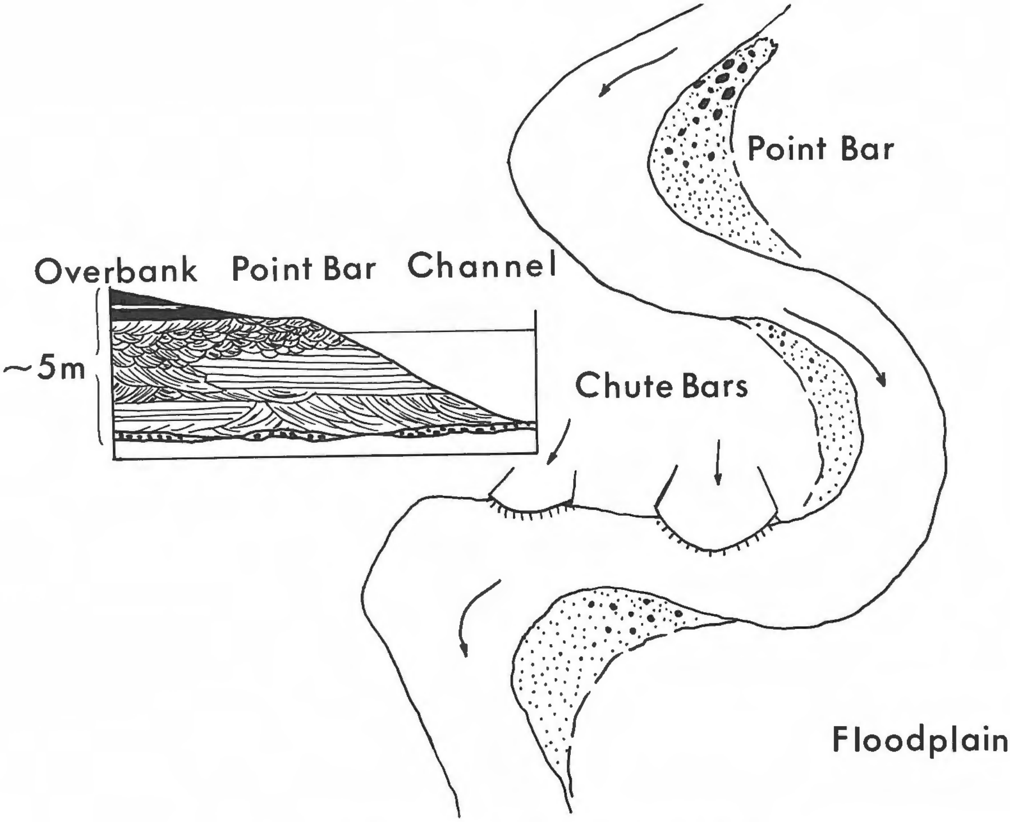


Figure 17. Meandering stream depositional model.

Figure 18. Exhumed pediment underneath Sustut Group, east of Lawyer's Pass (Toodoggone map-area, looking north). GSC Photo 202477-A.

Figure 19

Large scale crossbedding in basal conglomerates of Niven member, north of Niven River (McConnell Creek map-area). GSC Photo 202477-B.

Figure 20. Sandstone-mudstone sequences in Niven member, west of Dawson River (Spatsizi map-area, looking southwest). GSC Photo 202477-C.

during this study, but could possibly be of economic interest ( see Economic Potential).

Clasts in the basal conglomerates reflect the lithology of the pediment along the northeast and north side of the basin and are generally subrounded to rounded, suggesting a transport distance of at least a few miles. Basal conglomerates are intensely channeled, and commonly interstratified with crossbedded sandstones (Fig. 19). Sedimentation on the erosional bedrock pediment therefore probably began in stream channels made up of longitudinal gravel bars, which rapidly buried pre-existing topographic irregularities by the lateral migration of a high-gradient braided river bed. The upward decrease in maximum clast size of the basal conglomerates ( see Section Niven River) suggests progressive backcutting and flattening of the initial river gradient. Only in the apical regions of the Sustut Basin where the main rivers entered the aggradational alluvial plain have gravel bars prograded frequently during deposition of the Niven member ( see Section Forrest Mountain).

Initial filling of the valley floors was followed closely by meandering streams with a distinct separation of the depositional environment into channel and overbank areas. The cyclic repetition of channel sandstones grading into overbank siltstones and mudstones constitutes the dominant lithological characteristic of the Niven member (Fig. 20). Individual fining-upward sequences have an average thickness of 5 to 15 metres. The only interruption within the cyclic sandstone-mudstone succession is brought about by a few highly mature and laterally persistent conglomerate units made up almost entirely of quartzite, vein-quartz and chert clasts. Spatially, these mature conglomerates are closely associated with red mudstone layers, and their lateral persistence indicates that they are deposits of longitudinal bars of a generally braided stream system. Near Cold Fish Lake, this type of conglomerate contains silicified trees with diameters up to 70 cm, suggesting considerable stream power. The quartz arenite clasts (commonly pink) suggest that the rivers had a source area of Lower Paleozoic quartzose clastics, presently exposed 50-60 kms to the northeast, and that the braided streams prograded sporadically over the meandering alluvial valleys possibly due to tectonic uplift of the source area. The present dip of the basal pediment is about 10 degrees to the southwest and some of this tilting could have been accomplished during Niven deposition. The quartzite and vein-quartz pebble conglomerates strongly resemble "mature sheet gravels" as described by Stokes (1950), Potter (1955), Meckel (1967) and others. The close association of red mudstones and mature sheet gravel deposits suggests that a more elevated braided alluvial plain permitted in situ weathering of detrital mafic rock fragments (Walker, 1967; Wellman, 1970).

In contrast to the northern portion of Sustut Basin, sections through the Niven member near Bear Lake ( see Section Bear Lake) show a distinct lack of mudstone, and display thick composite sandstone bodies (Fig. 21). The sandstones are channeled and cross-stratified, and suggest that braided transverse sandbars occupied this reach of the alluvial system during most of Tango Creek deposition.

## Tatlatui 'Mudstone' member

The Tatlatui member consists of dark grey mudstones, calcareous siltstones, concretionary horizons, carbonate-cemented pebbly sandstone, and a few lignite seams (Fig. 22).

Paleocurrents and sandstone composition in the central part of the basin suggest that during Tatlatui deposition the Bowser Basin rocks had become a significant source terrane and that drainage in parts of the basin was almost diametrically reversed from the depositional trend of the Niven member. During this reversal of

Figure 21

Massive sandstones of Tango Creek Formation east of Bear Lake; note large sandwaves in the centre of photograph (McConnell Creek map-area). GSC Photo 202477-D.

the drainage, the surface of Sustut Basin must have constituted an alluvial plain with a very low gradient. As most of the Bowser Assemblage is pelitic, rivers draining the Bowser terrane must have been extremely rich in suspended load.

The low river gradient inferred from tectonic relationships and the inferred high proportion of suspended load of the rivers probably caused alluvial deposition in well entrenched meandering rivers. This interpretation of the Tatlatui member is supported by distinct channel characteristics (fining-upward) of the pebbly, and commonly concretionary, sandstones. The high proportion of mudstone-siltstone signifies the existence of elevated channel banks and extensive overbank areas occupied by ephemeral freshwater lakes (Allen and Friend, 1968). The overbank nature of the mudstone-siltstone of the Tatlatui member is also supported by numerous layers of early diagenetic calcite-silica concretions contained within them. The organic content of the mudstone and siltstone is low, and samples collected for palynological study were mostly barren. In the highest part of the Tatlatui member a few seams of lignite can probably be interpreted in terms of stagnating clastic input, establishment of stable river channels with natural levees, and the development of floodbasin swamps (Jacob, 1972).

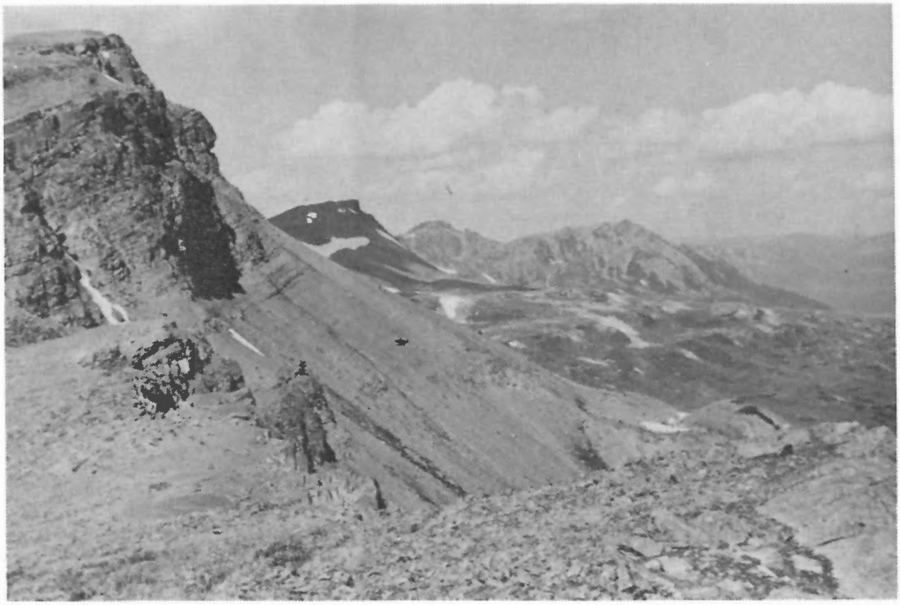

Figure 22. Massive Tatlatui sandstone channels interbedded with mudstones and siltstones south of Thutade Lake (McConnell Creek map-area, looking north). GSC Photo 202477-E.

## Brothers Peak Formation

### Laslui 'Conglomerate' member

The Laslui member consists of an association of thick conglomerate units, ash-fall tuffs, and tuffaceous siltstones. Directional sedimentary structures and regional clast size distribution of conglomerates suggest a paleocurrent trend compatible with a longitudinal alluvial basin fed by high-gradient tributary streams (Fig. 9).

The conglomerates are commonly massive and poorly sorted (Fig. 23), but differentiation into beds displaying parallel and planar cross-stratification is common farther down the paleocurrent gradient. Two partial sections from the basal Laslui member illustrate debris-flow deposits with crude parallel layering and low-angle cross-stratification, channel deposits of cross-stratified pebbly sandstones, and imbricated conglomerate layers (Fig. 24). The origin of the crude layering in massive conglomerate beds is probably due to slight shearing parallel to bedding, rather than layer-by-layer deposition. Such internal shearing of unconsolidated coarse debris-flow deposits has been invoked for crude layering of sub-sea mass flow deposits (Hendry, 1972). Lenses of imbricated pebble layers and cross-stratified pebbly sandstones indicate reworking by flowing water. The length of individual planar foresets in cross-stratified intervals is generally between 25 and 250 cm, suggesting water depths of about one metre. Most clasts of Laslui conglomerates are subangular to subrounded, in contrast to the generally subrounded to rounded clasts of Niven and Tatlatui conglomerates. Because a fair proportion of clasts represent reworked products of subrounded Bowser and Tango Creek conglomerates, this apparent decrease in roundness is probably due to breaking and pitting of clasts during deformation of Tango Creek and Bowser rocks which preceded or occurred concomitant with deposition of the Laslui member. The change

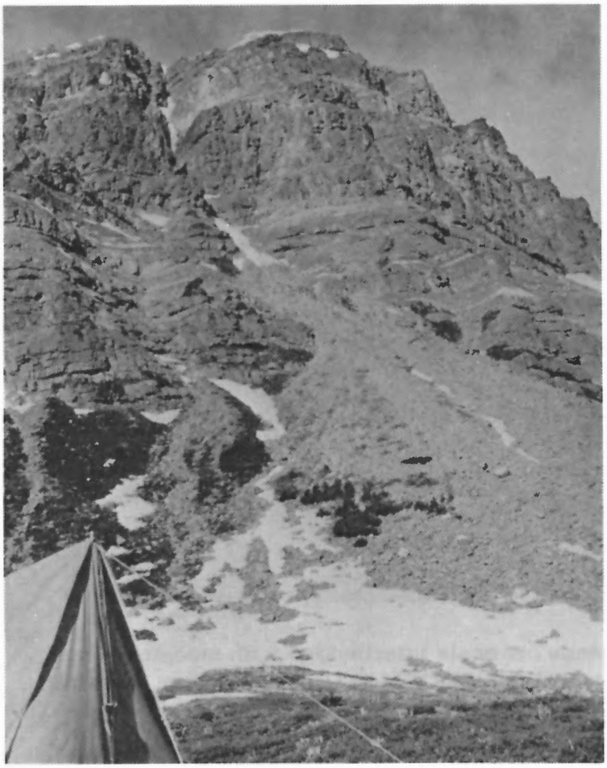

Figure 23.

Laslui conglomerate member of the Brothers Peak Formation north of Sustut River (McConnell Creek map-area). GSC Photo 202477-F.

in clast size within any section of the Laslui member is not one of simple fining-upward, but rather illustrates continued input of coarse clastics due to uplift and tectonic rejuvenation of the principal source area to the west.

The paradox of the stratigraphic succession of the Laslui member is the interlayering of thick conglomerate beds with laterally very extensive ash-fall tuffs (Fig. 25 and Fig. 26). The preservation of these tuff sheets within a vigorous erosional and depositional setting requires explanation. Several tuff units can be traced for more than 5 km along strike, although no detailed study of the physical continuity of individual beds has been carried out. Most of these tuffs are very fine grained and commonly show ripple-drift crosslamination and slump-folds indicating that large amounts of ash were temporarily suspended in water characterized by weak current activity, causing deposition in the form of climbing ripples (McKee, 1965) followed by slumping due to loose packing of the tuffs. The basal contact surface between conglomeratic units and tuffs or tuffaceous siltstones is generally irregular, and conglomerate beds display a variety of sole marks, examples of which are illustrated in Figure 27a and b. These sole marks have the shape of curving and tapering ridges which interact in a variety of ways, but their most conspicuous characteristic is their lack of symmetry: most of the ridges are overturned toward one side or the other. Friend (1965, p. 59, Pl. III) illustrated sole marks from the base of continental sandstones (Devonian Wood Bay Series, Spitzbergen) which are identical to the ones observed at the base of the conglomeratic beds of the Laslui member. Friend (ibid. p. 58), interpreted these "elongated welts, 2-10 cm across, up to 5 cm in relief" as having resulted from erosion of a muddy floor and subsequent filling of the erosional furrows by the coarsest fraction of the overlying bed. He also pointed out that these longitudinal ridges, grooves and flutes are much larger and more irregular than those generally found on the soles of marine turbidites. The highly irregular cross-section and asymmetry of the sole marks in the Wood Bay and Laslui examples, suggests that clastic infilling of the erosional mold was followed closely by compaction of mold and underlying loose mud under the weight of the newly formed clastic deposit. From the nature of these welts, flutes, and crescents, it must be inferred that deposition of the Laslui member occurred at least partly into subaqueous environments. It is proposed that the coarse debris flows of the Laslui member originated on alluvial fans and subsequently spread rapidly into shallow ponds and lakes of the main alluvial valley, which still had the sluggish depositional characteristics inferred for the Tatlatui member. Many of the conglomeratic horizons are therefore probably the result of episodic vertical accretion rather than slow lateral accretion from shifting gravel bars of perennially flowing rivers. Within ponds and shallow lakes, the ash-fall tuff possibly received some admixture of non-volcanic silt and clay components, but there they had a chance of being protected from erosion and reworking until they were covered by debris from nearby alluvial fans. The abundance of tuffs in any particular section should be inversely proportional to the amount of alluvial channel deposits within the section. In spite of extensive preservation of tuff sheets in favourable environmental "niches", much tuffaceous debris must also have been incorporated into conglomeratic sandstones by fluviatile reworking of both tuffs and debris flow deposits. Large scale planar or trough cross-stratification in these pebbly sandstones suggests clearly that reworking was achieved by erosion and bedload transport in alluvial channels. Processes responsible for the reworking of coarse "dump" deposits and volcanic ashes similar to the ones inferred for the Laslui member have been invoked by Wolf and Ellison (1971) from small-scale deltas in Pliocene lake deposits of Oregon.

### Spatsizi member

The Spatsizi member constitutes the uppermost 200-300 metres of the Brothers Peak Formation. It is characterized by a change of paleocurrent directions and the gradual replacement of tuffs as the principal fine-grained components by non-tuffaceous mudstones and thin seams of lignite ( see Brothers Peak Section).

Thick conglomerates in the northwestern part of the basin are probably deposits of alluvial fans and high-gradient braided streams (Fig. 28). Farther to the southeast a meandering alluvial plain is indicated by lensoid channels of concretionary sandstones which display "fining-upward" cycles and slumping of cross-beds. Thin layers of lignite within the mudstone-siltstone units indicate stagnation of the alluvial plain and entrenching of stable meandering river courses. Erosional downcutting and stream capture along the drainage divide northeast of Sustut Basin eventually terminated alluvial deposition.

## Provenance of Tuffs in the Brothers Peak Formation

From measured sections it appears that 10 to 30 per cent of the Brothers Peak Formation consists of ash-fall tuffs or highly tuffaceous mudstone. The composite thickness of tuff and tuffaceous mudstones ranges probably between 50 and 200 metres depending on the amount of fluviatile reworking. Individual ash-fall layers, however, are generally less than a metre thick. In terms of the frequency of ash falls

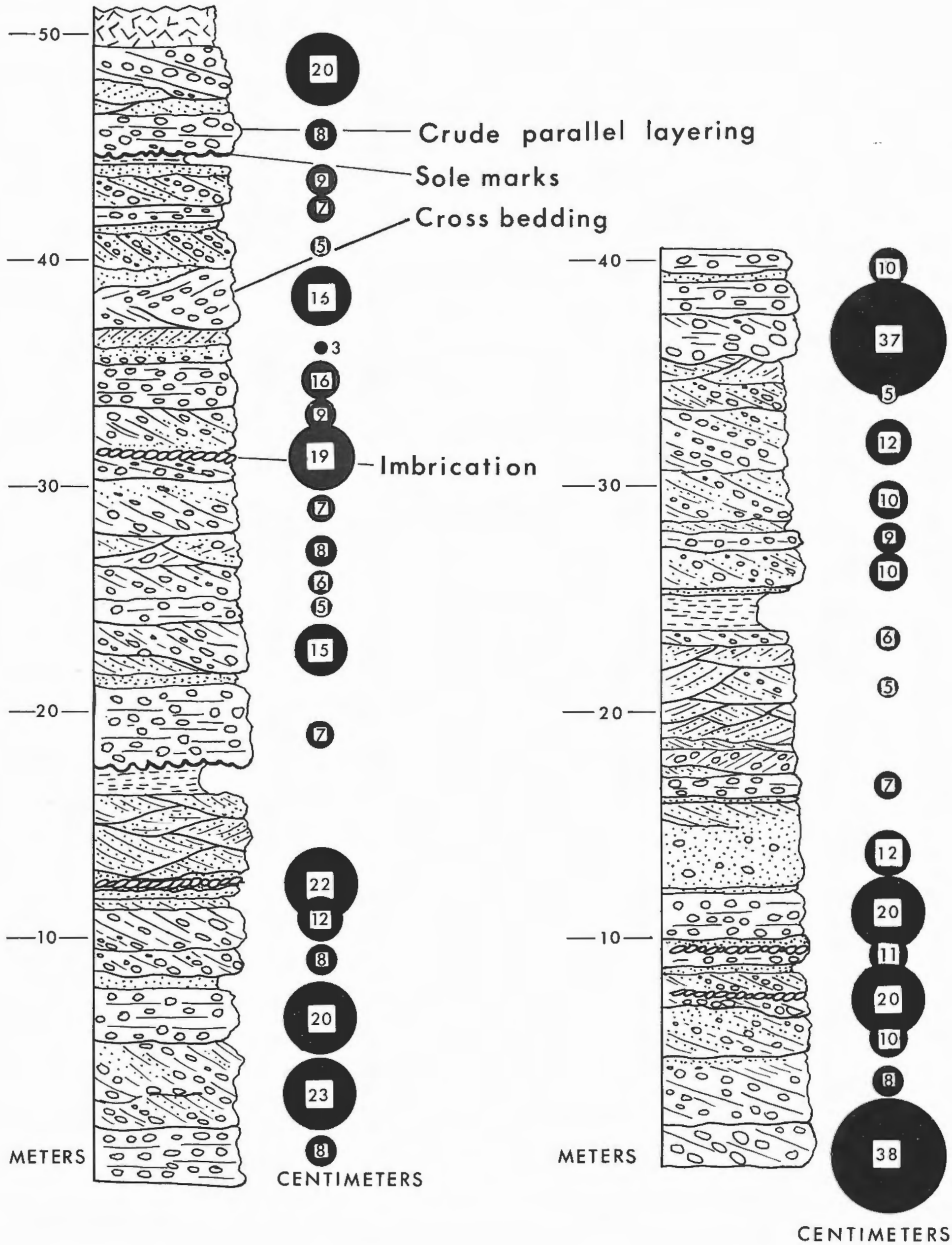


Figure 24. Partial sections through basal Laslui 'conglomerate' member south of Chapea Creek, showing variations in maximum clast sizes (in centimetres) and sedimentary structures.

Figure 25.

Composite ash-fall tuff in Brothers Peak Formation near Edozadelly Mountain (Toodoggone map-area). GSC Photo 202477-G.

this means that at least 50 to 100 explosions must have occurred to supply all the tuffaceous material of the Brothers Peak Formation. Paleocurrents in the lower Brothers Peak Formation indicate that this explosive volcanism was accompanied by tectonic uplift west of the Sustut Basin.

The tuffs do not contain primary fragments larger than fine sand, and there is no microscipic evidence of welding. The fine grain size rules out a local volcanic source for most of the ash-fall tuffs within the Brothers Peak Formation.

Extensive explosive acidic to intermediate volcanic products and related caldera-like structures have, however, been described along the east side of the Coast Crystalline Belt of northern British Columbia and the Yukon Territory. Recent radiometric age determinations of these volcanic centres ("Sloko Volcanics") yielded K-Ar ages between 49 and 51 m.y. (Lambert, 1972) and therefore seem to overlap the age bracket of the Brothers Peak tuffs (45 to 54 m.y.). Other volcanic fields of similar nature and age occur in central and southern British Columbia (Souther, 1967).

Eaton (1964) has analyzed the distribution of windborne volcanic ashes from recent volcanic explosions and found that the isopachs of individual ash falls are distinctly elongate or oval-shaped in the direction of present day high-level winds, i.e. more or less east-west and perpendicular to the present rotational axis of the earth. McBride et al. (1968) have used such a model of high-level winds to explain the large quantity of ash-fall tuffs in the Oligocene Gueydan Formation of South

Texas. Inferring easterly directed high-level winds and considering the nearest age-equivalent volcanic field, they concluded that the airborne tuffs (which according to their description seem to resemble those of the Brothers Peak Formation) had to originate at least 300 km west of the depositional basin.

These investigations suggest that given a reasonable model of paleo-wind directions, it may be possible to infer a source area for the tuffs of the Eocene Brothers Peak Formation. Recent studies by Frakes and Kemp (1972) of paleo-pole positions and climatic zonation during the Eocene suggest that west winds prevailed during Eocene time in northern British Columbia (Fig. 1 in Frakes and Kemp, 1972). On the basis of palynological studies Rouse et al. (1970) proposed that "during the middle Eocene large mountain ranges such as the present Coast and Cascade Mountains were either very low or non-existing" in the Canadian Cordillera. It is therefore proposed that powerful volcanic eruptions in the "Sloko" volcanic province supplied sufficient material to air currents in the high atmosphere, and that west winds, unimpeded by mountainous topography, carried large quantities of ash into the Sustut Basin, some 100 to 200 kms east of the volcanoes (Fig. 29).

## Sifton Formation

The Sifton Formation consists of a varied assemblage of clastics ranging from boulder conglomerates to thinly laminated siltstones. Structurally unbroken or well exposed sections of Sifton Formation were not found during field work. A comprehensive understanding of the depositional environment in Sifton Basin is therefore seriously impeded. However, the common occurrence of conglomerate indicates that a high gradient alluvial system, fed from the north and east side of the basin, had the most profound effect on the evolution of the Sifton Formation. Three types of conglomerate are present and are described below in their order of increasing abundance.

Figure 26

Ash-fall tuff overlying conglomerate bed west of Birdflat Creek (McConnell Creek map-area, looking south).
GSC Photo 202477-H

Figure 27a, b

Sole marks on alluvial fan conglomerate beds of Laslui member arrows indicate paleocurrent flow. GSC Photo Nos. 202477-I and 202477-J.

(a) Massive boulder breccias which rest unconformably on low-grade metamorphic bedrock. The matrix of these breccias consists of loose angular fragments which have the same composition as the principal clasts of the breccia (phyllite, limestone, quartzite). It commonly displays a reddish colour. In analogy to interpretations by other authors made elsewhere (e. g. Nilsen, 1969) these breccias are interpreted as scree or talus. Good examples are exposed near the lower entrance of Long Canyon on Finlay River.

(b) Massive or crudely stratified boulder conglomerates consisting of rounded boulders of granitoid igneous rocks, quartzite, and subordinate limestone. Some crude stratification can generally be recognized in the form of elongate lenses of sandstone, rich in feldspar and mica. These conglomerates contain boulders up to 250 cm in maximum diameter and probably represent mountain stream deposits. They are well exposed north of Prairie Mountain, 15 km northwest of Ware (Fig. 30).

(c) Matrix-rich boulder conglomerates and breccias with angular clasts of slaty argillite and limestone (up to 150 cm), and subrounded boulders of quartzite (up to 100 cm). Many of the clasts are suspended in a massive matrix of reddish brown calcareous sandstone. Some crude layering originates from changes in grain size and thin zones of imbricated pebbles. Local lenses of crossbedded sandstone interrupt the monotony of these deposits. These matrix-rich conglomerates were probably laid down as debris flows on alluvial fans related to fault scarps along the Rocky Mountain Trench. Examples can be seen in Deserters Canyon of the Finlay River and the nearby Bluff Hill (Fig. 31).

Sandstones of the Sifton Formation are generally crossbedded and of fluviatile origin. Laminated siltstones and mudstones intercalated with coarse-graded beds displaying extensive slump folds were probably deposited into lakes along the deepest part of the valley floor, west of the main fault scarps along the Rocky Mountain Trench. Thin seams of lignite interbedded with channel sandstones suggest temporary or local stagnation of alluvial sedimentation.

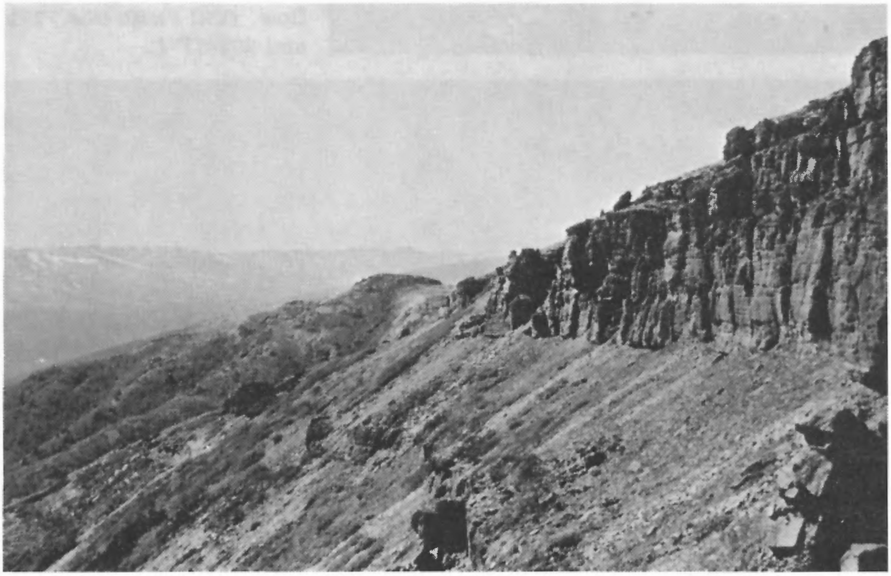

Figure 28. Pebbly sandstones of Spatsizi member north of Hyland Post (Spatsizi map-area, looking west). GSC Photo 202477-K.

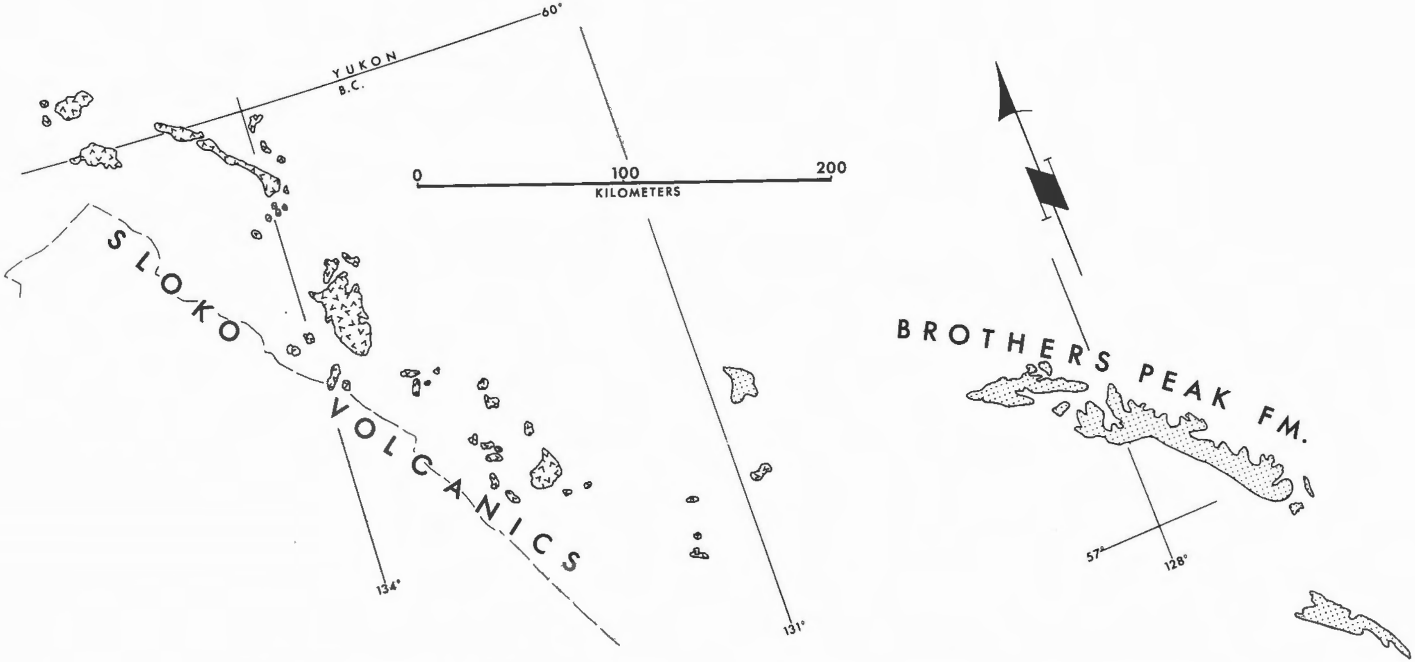


Figure 29. Probable source region of Brothers Peak tuffs in the Sloko volcanic province.

Figure 30

Massive granite-quartzite boulder conglomerate on Prairie Mountain (Ware map-area). Note boulder of granite (2.5 metres) near the top of photograph.
GSC Photo 202477-L.

Figure 31

Limestone-quartzite debris-flow conglomerate near Estella Lakes (Fort Grahame map-area). GSC Photo 202477-M.

# STRUCTURAL GEOLOGY

## Sustut Basin

### Tectonic framework

The sedimentary units of Sustut Basin were deposited during the late stages of the Columbian and Pacific orogenic movements (Wheeler and Gabrielse, 1972) and the structural style reflects the interaction between these two orogenic belts.

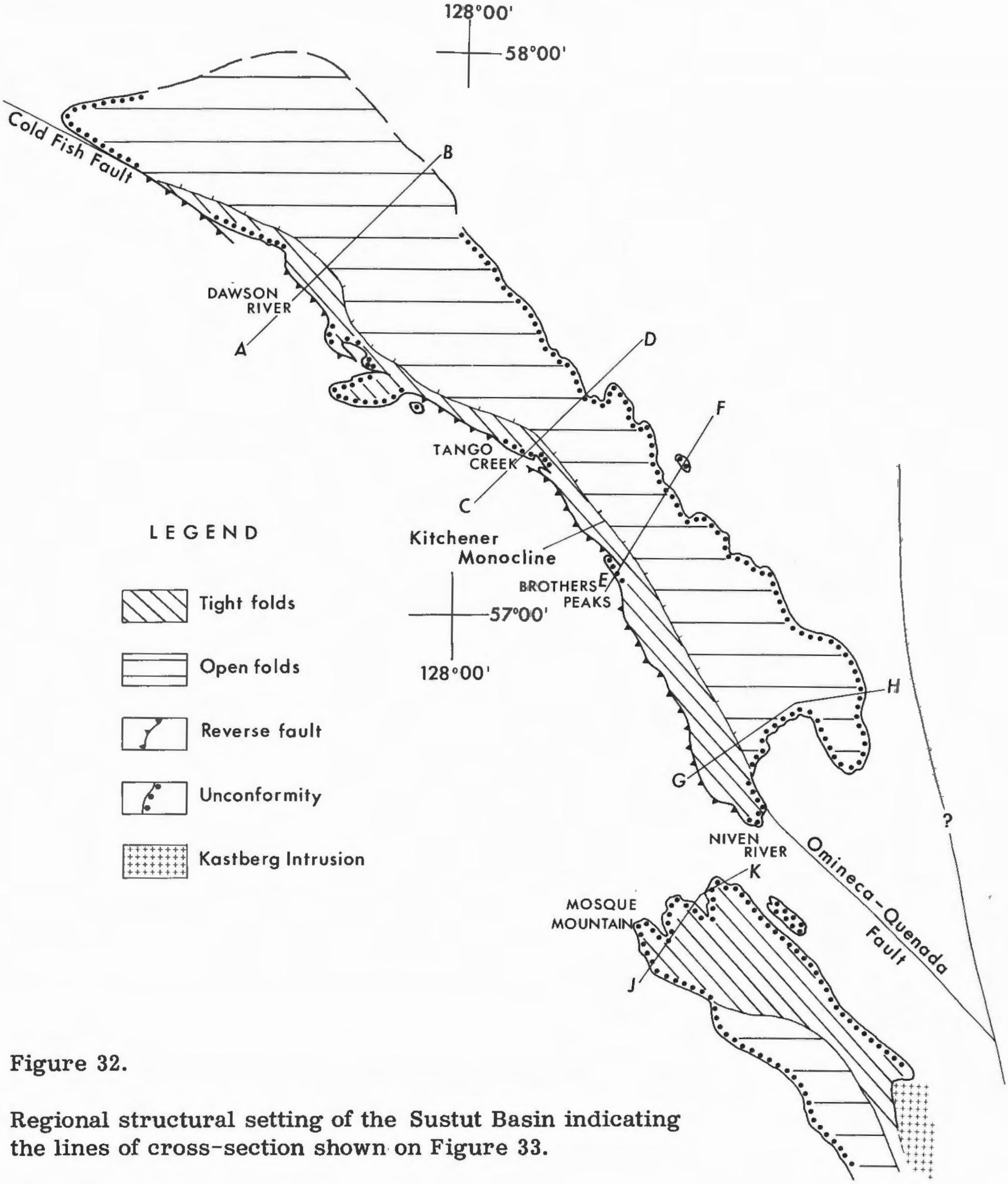


Figure 32.

Regional structural setting of the Sustut Basin indicating the lines of cross-section shown on Figure 33.

Two fundamentally different structural zones can be recognized in the Sustut Basin (Fig. 32): (a) the part of the basin which lies on the pedimented surface carved into Takla-Hazelton volcanics and granitoid plutons, and (b) parts of the basin underlain by predominantly pelitic Bowser Assemblage. The first is characterized by open folds and gentle dips in the Sustut Group; the second is characterized by many tight and commonly thrust faulted anticlines and synclines, similar to those in the adjacent Bowser Assemblage. In the northern part of the basin these two structural zones are separated by the Kitchener Monocline which constitutes the most prominent topographic feature of the area and can be traced from Cold Fish Lake in the north via Laslui Lake and the Brothers Peaks to Thutade Lake and probably continues as the reverse Quenada-Omineca Fault in Takla-Hazelton rocks to the south (Lord, 1948; Eisbacher, 1971a). The Quenada-Omineca Fault may represent a continuation of the Pinchi Fault (Armstrong, 1949) and was probably offset by a northerly-trending branch of the Takla Fault (Eisbacher and Tempelman-Kluit, 1972). The Takla Fault is indicated on Figure 32 by a question mark. To the northwest the extension of the Kitchener Monocline may be represented by the Cold Fish Fault (Eisbacher and Tempelman-Kluit, 1972), a reverse fault in Takla-Hazelton rocks.

Throughout most of the basin the Kitchener Monocline follows the base of the Brothers Peak Formation where differential weathering between the conglomerate of the Laslui member and the underlying Tatlatui member causes a pronounced topographic expression (Fig. 33). The dip of bedding along the monocline ranges from gentle to very steep, and locally the Brothers Peak Formation is slightly overturned to the northeast.

Because of erosional pedimentation of the Takla-Hazelton Assemblage and intrusive bodies within it, the basal unconformity underneath the Tango Creek Formation is profound. The basal surface is well exposed near Niven River and beneath the Sustut outlier east of Lawyer's Pass ( see Fig. 18).

Southwest of a line connecting the Cold Fish Fault, Kitchener Monocline, and Quenada-Omineca Fault most of the Sustut Group was deposited on Bowser Assemblage rocks and the unconformity between Sustut Group and underlying Bowser Assemblage is involved in regional deformation along the southwestern margin of the basin. This boundary is therefore partly an angular unconformity, and partly a reverse fault (Fig. 32).

Near the southern boundary of McConnell Creek map-area the eastern contact of the Sustut outcrop is formed by the Kastberg Granodiorite (Lord, 1948) which intrudes Tango Creek Formation and is probably of early Tertiary age.

Intense deformation of the Bowser Assemblage produced tight asymmetric folds overturned to the northeast and thrust faults dipping to the southwest. The style of folding and thrust faulting indicates relative tectonic transport of higher units to the northeast and therefore deformation related to the Pacific orogenic belt (Wheeler and Gabrielse, 1972). Gentle and open folds northeast of the Kitchener Monocline reflect the same sense of movement, but only in a very subdued fashion ( see Map 14-1973).

The evolution and superposition of structures in the intensely deformed belt of the Sustut Basin can best be discussed by the description of five areas from which some general conclusions will be drawn. These areas are indicated on Figure 32, but for details the accompanying geological map and cross-sections should be consulted.

Dawson River area (Cross-section AB Spatsizi map-area)

In this area Takla-Hazelton volcanics are exposed beneath Bowser Assemblage rocks, and both units are involved in the deformation of the Sustut Group. South of

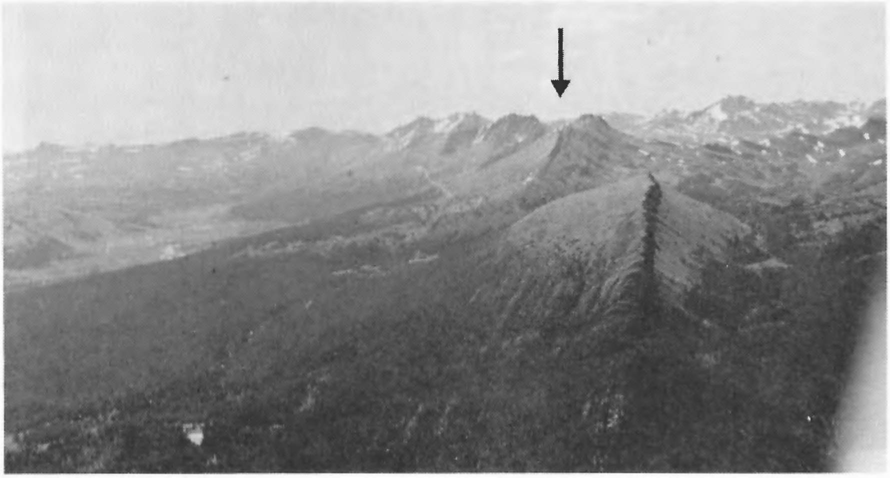

Figure 33. Kitchener monocline near Chapea Creek (Toodoggone map-area, looking southeast). GSC Photo 202477-N.

Figure 34. Folded Niven member near Dawson River (Spatsizi map-area, looking southeast). GSC Photo 202477-O.

Griffith Creek, shales of Bowser Assemblage rest unconformably on deformed Takla-Hazelton volcanic flows and pyroclastics, but it has not been determined how much of the tectonic deformation of the Takla-Hazelton Assemblage occurred before deposition of the Bowser Assemblage. From the basal Bowser shales Callovian (upper Mid-Jurassic) fossils were collected by E.F. Roots in 1957 and determined by H. Frebold. The earliest deformation of Takla-Hazelton rocks must therefore have

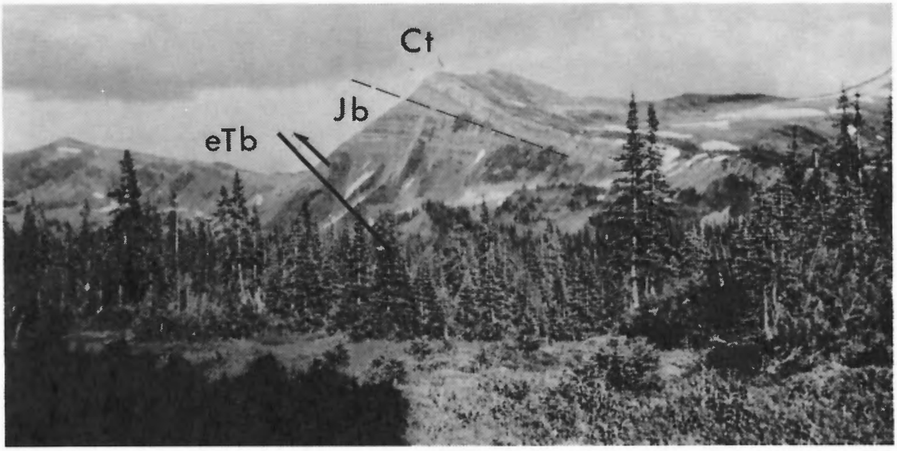


Figure 35. Angular unconformity between Tango Creek Formation (Sustut Group) and Bowser Assemblage near Mosque Mountain (McConnell Creek map-area, looking east). Ct = Tango Creek Formation, Jb = Bowser Assemblage, eTb = Brothers Peak Formation. GSC Photo 202477-P.

been pre-Callovian. The basal Bowser shales grade upwards into siltstone, sandstone and plant-debris-bearing conglomerates with intraformational unconformities of up to 20 degrees. These unconformities suggest syn-sedimentary downbending of the basin margin.

Although the surface of unconformity between Takla-Hazelton and Bowser Assemblages near Griffith Creek is only slightly sheared and cleavage-bedding intersections plunge concordantly with the folded unconformity at about 25 degrees to the southeast, only a few kilometres to the northwest the Takla-Hazelton Assemblage is emplaced over Bowser Assemblage along a southwesterly-dipping thrust fault.

The Bowser Assemblage in turn is emplaced over the Tango Creek Formation along a high-angle reverse fault. For about six kilometres across strike, Tango Creek rocks are thrown into a series of tight folds (Fig. 34). Near the mouth of Mink Creek these folds are overlain by a klippe of Bowser conglomerate which was obviously emplaced during movement along the high-angle boundary fault between Tango Creek Formation and Bowser Assemblage (Eisbacher, 1972a). Five kilometres to the northwest and about 10 kms to the southeast the basal Tango Creek overlies Bowser rocks with distinct angular unconformity.

From these relationships it can be clearly demonstrated that the Bowser Assemblage was deformed before the deposition of Tango Creek sediments. It has been shown in a previous section that paleocurrents during Tango Creek deposition flowed to the south. Therefore the overthrusting of Bowser Assemblage on Tango Creek Formation, the folding of Tango Creek Formation and the emplacement of the Bowser klippe along northwesterly-structural trends must have terminated deposition by southerly-flowing paleocurrents. Conglomerates of Brothers Peak Formation on Skady Mountain contain clasts derived from Bowser Assemblage and Tango Creek Formation, and display paleocurrents which flowed to the east. Thus reworking of Tango Creek Formation into Brothers Peak conglomerates suggest that the Eocene Brothers Peak Formation represents the clastic wedge related to deformation of all the underlying rock-units.

Subsequently, Eocene Brothers Peak Formation was tilted to the northeast (up to 40 degrees) and disrupted by extension faults perpendicular to the trend of folding. This extension can probably be interpreted as the result of renewed deformation of Bowser and Tango Creek rocks along a somewhat different (east-southeasterly) trend, brought about by buttressing along the Takla-Hazelton volcanics. The discordance of this new trend to the older one is well expressed near the headwaters of Ross River ( see Map 14-1973).

For the Dawson River area it can be concluded that deformation preceded, was contemporaneous with, and outlived deposition of the Sustut Group.

Tango Creek area (Cross-section CD Map 14-1973)

The Bowser Assemblage in this area is made up of conglomerate, interlayered with shale and siltstone. An angular unconformity and pre-existing structure in Bowser rocks underneath the unconformity between Bowser Assemblage and Tango Creek Formation can clearly be demonstrated: a sharp north-northwesterly-

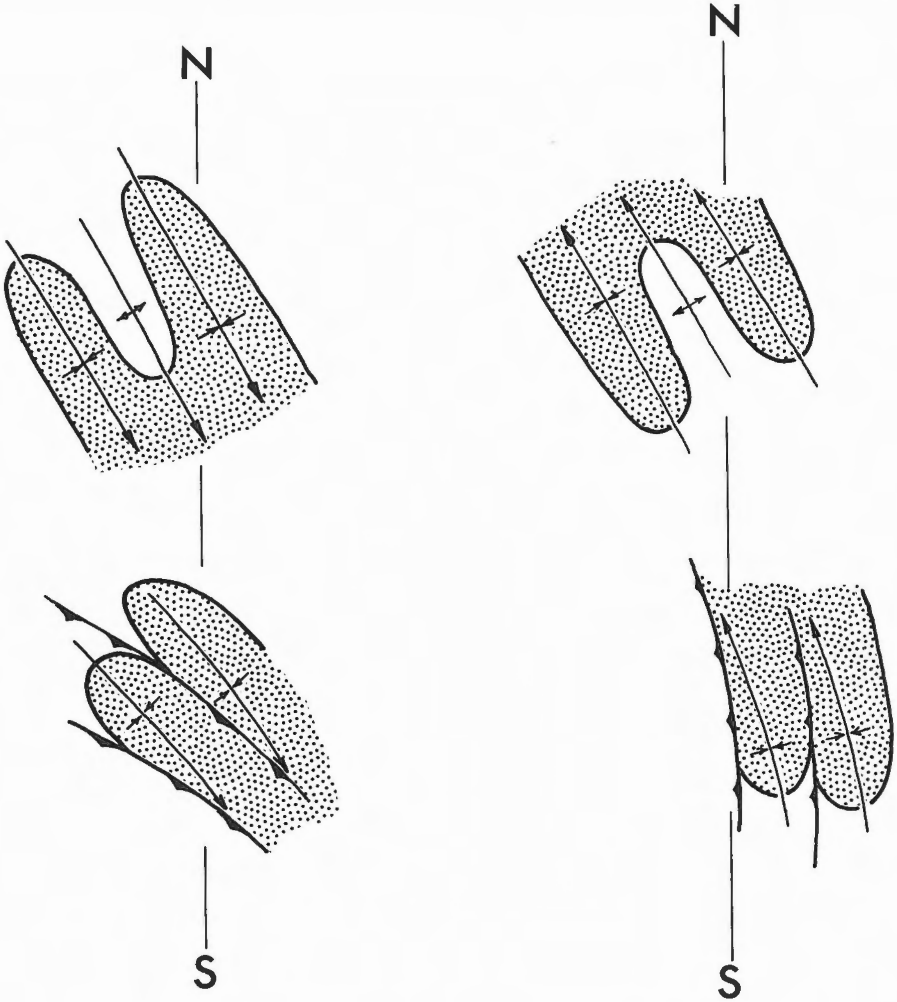


Figure 36. Influence of plunge on closure of folded structures.

trending anticlinal ridge of Bowser conglomerate, although later reactivated, was truncated by a southwesterly-flowing alluvial system and subsequently covered by the basal Tango Creek Formation. This ridge is not reflected in the structure of the quartz-pebble conglomerate marker, about 200 metres above the base of the formation. Only two kilometres southeast of the unconformity steeply plunging folds underlying the unconformity are overridden by Bowser rocks along a northwesterly-trending thrust fault, which deformed Tango Creek Formation into tight overturned folds and subsidiary thrust faults. Probably related to this later tectonic phase is the tilting of (up to 60 degrees) of Brothers Peak Formation.

Brothers Peak area (Cross-section EF Map 14-1973)

Bowser Assemblage, consisting of conglomerate, sandstone and shale in this area, is overlain unconformably by basal Tango Creek Formation. Several north-northwesterly-trending folds in Bowser rocks are truncated by the unconformity. Above the unconformity only one broad, southeasterly-plunging syncline is developed in the Tango Creek Formation. Within a short distance to the north, thrust faults with a west-northwesterly trend undercut the gently folded unconformity together with the underlying fold structures in the Bowser Assemblage. Along strike towards the southeast the same system of thrust faults first overturns and then overrides the unconformity. The Brothers Peak Formation along the Kitchener Monocline displays a dip of up to 40 degrees to the northeast. Paleocurrents in the Tango Creek Formation flowed southerly, in the Brothers Peak Formation easterly. This suggests that the younger tectonic phase may have been the cause for deposition and tilting of the Brothers Peak Formation.

Niven River area (Cross-section GH Map 14-1973)

In this area Tango Creek Formation rests unconformably on Takla-Hazelton Assemblage along the southeastern margin of the basin. The Takla-Hazelton complex plunges to the northwest underneath an intensely folded and thrust faulted belt of Tango Creek Formation and Bowser Assemblage. Along the western margin of the Tango Creek outcrop the north-northwesterly plunging folds are overlapped by the almost north-trending boundary thrust that brings Bowser rocks over Tango Creek Formation. This structural truncation of north-northwesterly folds is either the result of erosion or the effect of buttressing by Takla-Hazelton rocks to the southeast restricting the advance of later thrusting.

Paleocurrents in both Tango Creek and Brothers Peak formations flowed to the south-southwest suggesting that much of the structural pattern in the Sustut Group was imprinted after deposition of the Brothers Peak Formation.

Mosque Mountain area (Cross-section JK Map 14-1973)

The structure of this area is very complicated and is the result of at least two structural episodes with almost mutually perpendicular trends.

An angular unconformity between Tango Creek Formation and Bowser Assemblage of up to 25 degrees is well exposed about six kilometres northeast of Mosque Mountain (Fig. 35). Drainage during deposition of Tango Creek sediments was to the south-southeast. Early tectonic structures in the Tango Creek Formation have a north-northeasterly to north-northwesterly trend and folds are overturned to the east.

Paleocurrents in the Brothers Peak Formation flowed to the southeast and deposition of the Brothers Peak Formation was followed by folding and thrust faulting of both Tango Creek and Brothers Peak rocks along strong northwesterly trends. On the mountain six kilometres northeast of Mosque Mountain, Bowser Assemblage and unconformably overlying Tango Creek Formation are thrust northeastward over an asymmetric isoclinal fold of Brothers Peak Formation.

The effect of plunge of early folds on later deformation of Sustut strata

The complicated map pattern along the western margin of the Sustut Basin as illustrated by the five areas described above suggests that the plunge of early fold axes in the Bowser Assemblage and Tango Creek Formation had a profound effect on the development of the final structures in the Sustut Group. Due to the effect of unequal buttressing along plunging structures later folds and faults were generally deflected from the earlier ones as illustrated by Figure 36.

The principal effect of plunge on growing structures is steepening of the plunge, closing of anticlinal ridges into sharply piercing reverse faults, and subsequent overriding of plunging synclines by advancing anticlinal cores.

This lateral overriding of synclines along reverse faults is seen along southeasterly plunging structures in the Dawson River, Tango Creek, and Brothers Peak areas, and near northwesterly plunging structures in the Niven River area ( see Map 14-1973).

General conclusions

From the description of the five areas along the western margin of the Sustut Basin it can be inferred that fold structures existed in the underlying Bowser Assemblage before deposition of the Sustut Group. The changing paleocurrent system and the overlap of different structural trends further suggests that deformation and sedimentation related to uplift in the Pacific Orogen overlapped and outlived an earlier depositional phase related to uplift in the Columbian Orogen. No clear unconformities have yet been found within the Sustut Group, but they probably do exist. On Forrest Mountain, southeast of Thutade Lake, a striking angular relationship exists between the Tango Creek and Brothers Peak formations, and reworking of Tango Creek sandstones into Brothers Peak conglomerate suggests the possibility of an angular unconformity (Fig. 37). Shearing along the contact, however, makes it impossible to ascertain the original angle between the two formations.

From regional considerations it is clear that the most profound tectonic event regarding deformation and deposition of the upper units of the Sustut Group was probably related to Late Cretaceous and Early Tertiary uplift in the area of the Coast Crystalline Belt and the consequent growth of structures in the Bowser Assemblage along northwesterly trends.

## Sifton Basin

The structural geometry of the Sifton Formation is the result of two episodes of deformation which have been documented for the area near Ware in the northern Rocky Mountain Trench (Eisbacher, 1972b).

Initial uplift of the Columbian Orogen in Mid-Cretaceous time probably resulted in extension and normal faulting near the Rocky Mountain Trench and related lineaments; this phase of normal faulting was probably closely followed by deposition of intermontane clastics of the Sifton Basin. A later pulse of brittle deformation

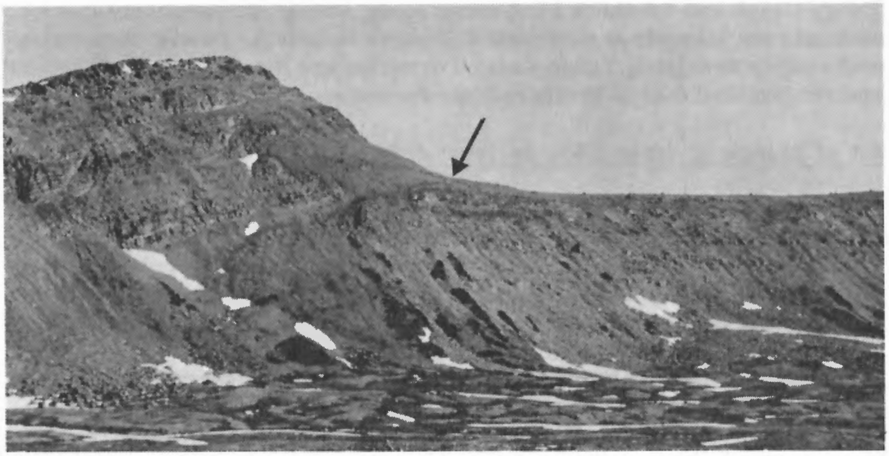

Figure 37. Angular discordance between Tango Creek and Brothers Peak Formations on Forrest Mountain (McConnell Creek map-area). For explanation see text. GSC Photo 202477-Q.

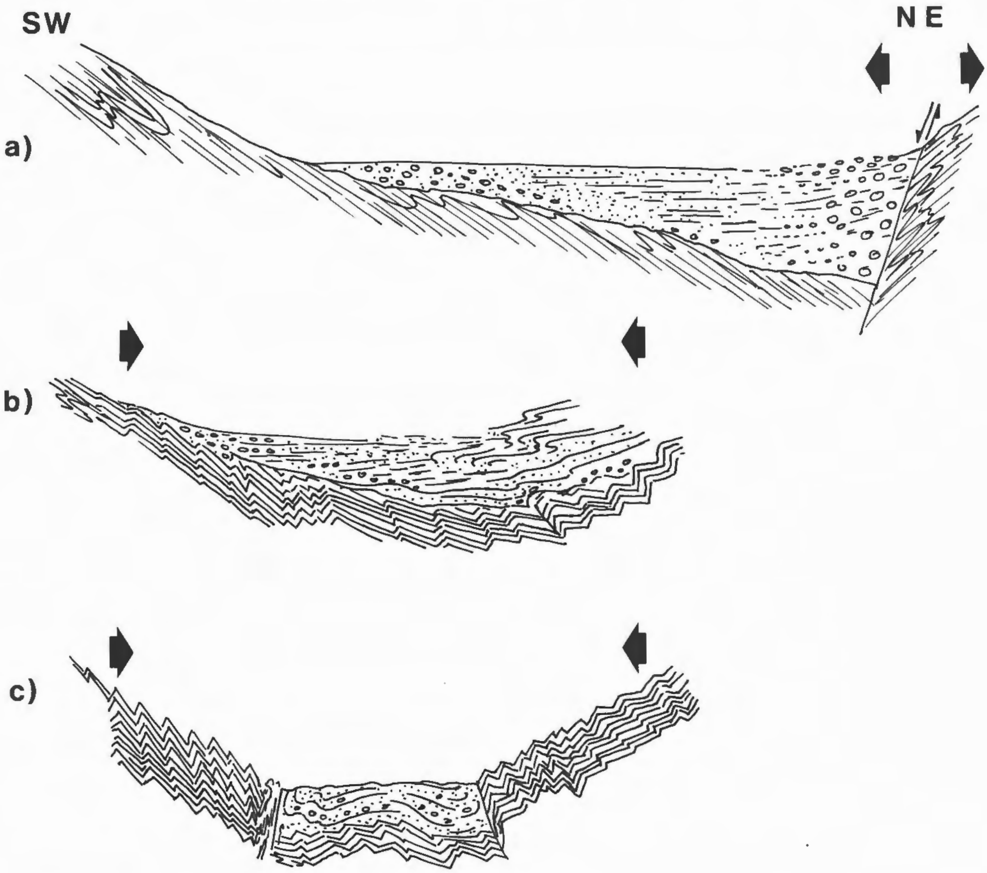


Figure 38. Schematic diagram for the structural evolution of the Sifton Basin.

initiated kink folding in the low-grade metamorphic rocks underneath the intermontane clastics and caused disruption of Sifton strata along a series of high-angle faults ( see Eisbacher, 1972b).

This evolution is illustrated schematically for a northeast-southwest section through part of the Sifton Basin west of Ware (Fig. 38).

## PROBABLE OUTLIERS OF SUSTUT ASSEMBLAGE IN NORTH-CENTRAL BRITISH COLUMBIA

In a number of places in north-central British Columbia small outcrop areas of probable Upper Cretaceous - Paleogene nonmarine sedimentary rocks have been reported in the literature and it is likely that more will be found and described during future investigations. The location of the major known outliers is shown on the Index Map of Figure 1. Some of these outliers were visited during the present study.

### Uslika Formation

Roots (1954) described a massive nonmarine conglomerate body of about 100 $km^2$ near Uslika Lake, and made the following general statement about it:

"The Uslika formation includes a single body of conglomerate exposed east and north of Uslika Lake, together with faulted, contiguous blocks south of Conglomerate Mountain and in the lower part of Vega Creek Valley. Beds of black argillite and chert-pebble conglomerate that outcrop on Vega Creek, just west of, and in apparent conformable relations with, the main mass of conglomerate, are also tentatively assigned to this formation." (Roots, ibid., p. 187).

Figure 39. Uslika Formation on Conglomerate Mountain (Fort Grahame map-area, looking northwest). GSC Photo 202477-R.

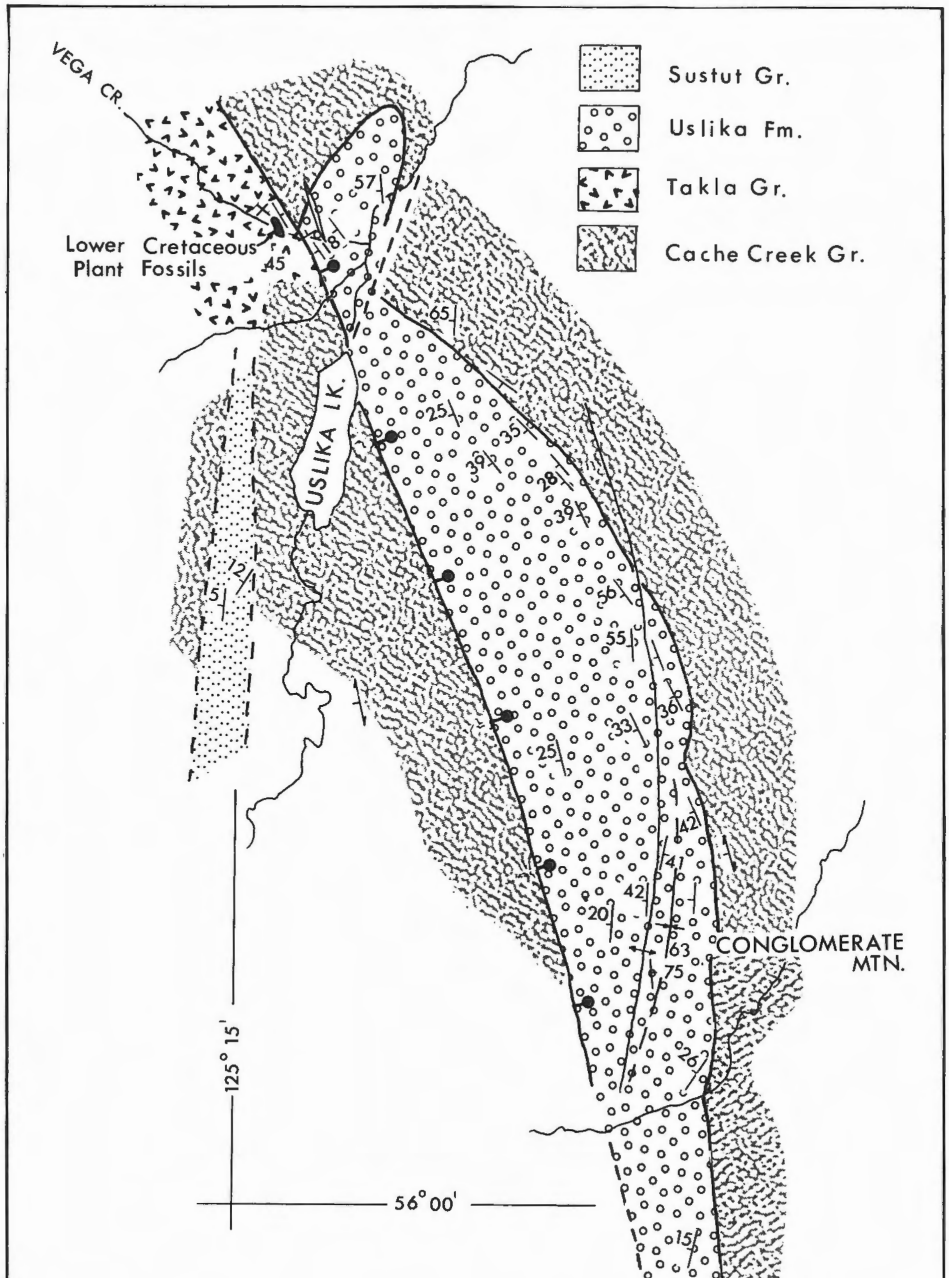


Figure 40. Sketch map of the area near Uslika Lake.

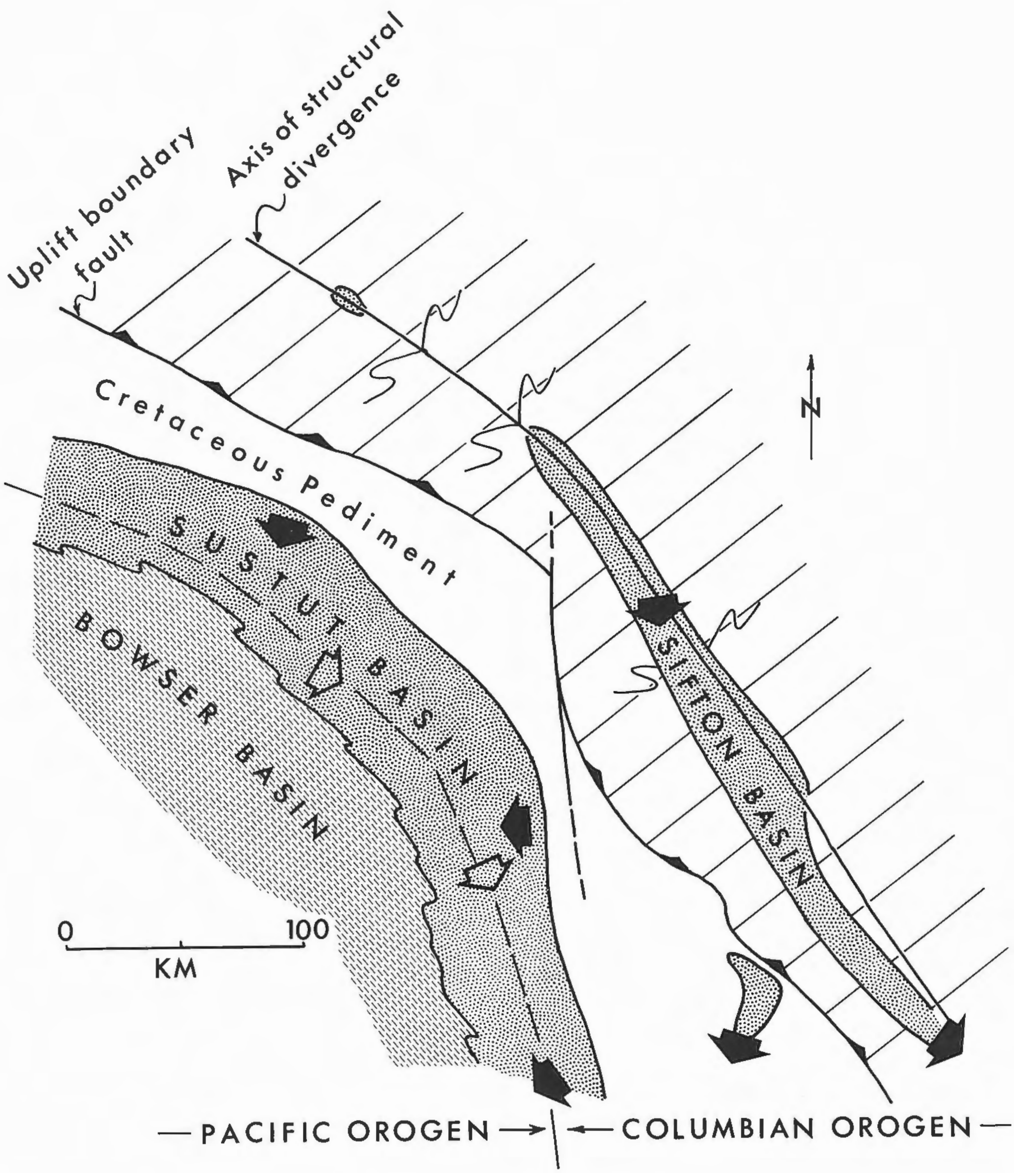


Figure 41. Tectonic setting of Sustut and Sifton basins and principal directions of sediment transport.

From the argillites on Vega Creek, Roots made a plant collection which was assigned a probable Aptian age by W.A. Bell ( see Roots, ibid., p. 190). By correlating the lithologically different Uslika conglomerate with the argillite and chert-pebble conglomerate of Vega Creek Roots suggested an Aptian age for the Uslika Formation. The author visited the Uslika Lake area and suggests on the basis of observed field relationships that this correlation may not be valid.

The Uslika Formation consists of a massive, dark reddish weathering conglomerate and intercalated lenses of sandstone. It is best exposed on Conglomerate Mountain (Fig. 39). Along most of its eastern contact the Uslika Conglomerate overlies unconformably Cache Creek Group (Fig. 40). The western boundary is probably a high-angle reverse fault. The Uslika Formation covers a dip slope southeast of Uslika Lake and forms essentially a homocline which is only interrupted by one tight anticline (Fig. 40).

Roots suggested (ibid., p. 189) that the Uslika Formation may represent a klippe which had moved eastward onto the older Cache Creek rocks. The development of a regolith at the unconformity underneath the conglomerate suggests that this hypothesis is not valid and that the Uslika Formation is entirely autochthonous with respect to the underlying Cache Creek Group. Roots (ibid., p. 188) reported a total stratigraphic thickness in excess of 4, 200 feet (1, 300 metres), which appears to be vastly in excess of actually exposed or inferred section. From an attempt to derive a reasonable thickness for the Uslika Formation in a creek bed north of Conglomerate Mountain the author proposes an upper thickness limit of about 400 metres (1, 200 feet).

The Uslika conglomerate is composed of clasts with a relative abundance of about 50% andesite, 10% - 20% granitoids, 10% - 15% quartzite, and about 25% chert and volcanic arenite. Source areas for andesite and granitoids are found only a few kilometres to the northwest, quartzite occurs a few kilometres to the north, and chert occurs in Cache Creek rocks immediately underneath the conglomerate. The mean paleocurrent vector derived from twenty crossbedded sandstone lenses points to the south-southwest. Maximum clast size encountered is about 30 cms. From these observations it is inferred that the Uslika conglomerate represents the deposit of a high-gradient south-southwesterly flowing river.

The black argillite and chert-pebble conglomerate on Vega Creek from which an Aptian flora was collected is neither in stratigraphic continuity nor along structural trend with the Uslika Formation. It is separated from the Uslika conglomerate by a ridge of andesitic Takla volcanics and a pronounced fault zone (Fig. 40). It therefore seems that the Aptian age may be applicable to the dark argillite and the chert-pebble conglomerate but not to the Uslika Formation which probably constitutes a separate and younger unit.

West of Uslika Lake Roots (ibid., p. 191) reported a narrow fault-bounded outcrop belt of nonmarine conglomerate, sandstone, and mudstone which yielded a flora assigned to the Upper Cretaceous - Lower Tertiary by W.A. Bell ( see Roots, ibid., p. 192), suggesting a possible correlation with the Sustut Group of the McConnell Creek area. With the exception of common mudstone, the rocks of this Upper Cretaceous - Lower Tertiary unit closely resemble those found in the Uslika Formation east of Uslika Lake. It is therefore tentatively proposed that the Uslika Formation may correlate with nonmarine Sustut Assemblage.

## Moricetown beds

Sutherland-Brown (1960) described an outcrop belt of nonmarine conglomerate, sandstone, mudstone and thin coal seams from the Bulkley Valley near Moricetown. Composition of conglomerates reflects volcanic and sedimentary source rocks that are part of the underlying Mesozoic formations. During the present investigation a section of tilted strata with measured minimum thickness of about 130 metres (400 feet) was found along Bulkley River at Moricetown. The mean paleocurrent vector derived from 28 readings on channel trends and crossbedding points to the south-southwest.

Sutherland-Brown made a small collection of fossil leaves which were assigned to Paleocene by W.L. Fry ( see Sutherland-Brown, 1960, p. 37).

## Smithers "Fossil beds"

A conspicuous outcrop of lacustrine tuffaceous siltstones on Driftwood Creek near Smithers, known locally as "Fossil beds", has yielded many well-preserved fossil leaves and insects. Rouse et al. (1970) have studied palynomorphs from these beds and they suggest an early Eocene age. The tuffaceous character of the siltstones suggests that these rocks may correlate with the Brothers Peak Formation of the Sustut Basin.

## Burns Lake beds

Discontinuous outcrops of nonmarine chert-quartz conglomerate, sandstone, and mudstone were found in two creeks northwest of Burns Lake. Crossbedding in pebbly sandstones indicates a mean paleocurrent vector to the south-southwest. H.W. Tipper (pers. comm., 1972) collected mudstone samples for palynological study which yielded palynomorphs of Late Cretaceous age.

## TECTONIC EVOLUTION OF THE SUSTUT AND SIFTON BASINS

Penetrative deformation in the Columbian core zone during Middle and Late Jurassic time and extensive emplacement of granitoid batholiths in the Early Cretaceous created the framework for major changes in the depositional history of the Cordilleran sedimentary basins. It has been shown elsewhere (Jeletzky, 1971; Eisbacher, 1973b) that during deposition of the Upper Jurassic - Lower Cretaceous Bowser Assemblage the sea gradually withdrew to the southwest and that late in Early Cretaceous time the marine foreland basins east of the Columbian Orogen had become permanently separated from the marine successor basins west of the Columbian core zone. Radiometric ages within the Omineca Crystalline Belt and the first highly micaceous clastics in marine sediments of Albian age within the Bowser Basin (Tipper, 1972; Richards and Dodds, 1973) suggest that metamorphic complexes and granitic massifs of the Omineca Crystalline Belt had become continental source areas about 120 m.y. ago. This change from marine to nonmarine conditions over large regions of the north-central Canadian Cordillera also caused widespread Early Cretaceous coal swamp deposition along prograding shorelines.

Slow uplift of the Omineca Crystalline Belt continued into Late Cretaceous time and was accompanied by erosion and pedimentation of the deformed and metamorphosed eugeosynclinal and miogeoclinal rocks.

Seen within this context the Sustut and Sifton basins constitute late-orogenic basins which, in their sedimentary record, reflect uplift of the north-central Canadian Cordillera. In other mountain belts of the world continental sedimentary sequences associated with the final uplift of folded and thrust faulted mountain ranges have generally been referred to as 'molasse' after the term used for the eugeosynclinal late-orogenic deposits of the Alps. The Sustut Basin represents the 'molasse facies' of both the Columbian Orogen (Tango Creek Formation) and the Pacific Orogen (Brothers Peak Formation). The Sifton Basin represents an 'intramontane molasse' within the Columbian Orogen with a drainage to the southeast and possibly connected with the Columbian foreland basins through the Peace River structural re-entrant (Fig. 41).

In terms of its geological position the Sustut Basin also constitutes a 'successor basin' (or 'epieugeosyncline') superimposed onto deformed and intruded eugeosynclinal rock assemblages. The nonmarine Sustut Basin unconformably overlies the older, predominantly marine, Bowser successor basin of Middle Jurassic to Early Cretaceous age.

The fundamental Uplift Boundary Fault between the metamorphic miogeoclinal sedimentary rocks and the predominantly volcanic units to the west probably follows closely the drainage divide between Sustut and Sifton basins. The Sifton Basin formed along a wide valley floor that followed the 'axis of structural divergence' of the Columbian Orogen, separating areas of earlier tectonic transport to the west from those with earlier tectonic transport to the east (Fig. 41). Sifton Basin was probably separated from Sustut Basin by a drainage divide that not only followed a major structural break, but also coincided with a metamorphic culmination ( see Fig. 4).

Late Cretaceous to Paleogene uplift of the Coast Crystalline Belt (Hutchison, 1970) and related northeasterly-directed folding and thrust faulting of Bowser Assemblage terminated Tango Creek sedimentation and initiated deposition of the Brothers Peak Formation and drainage within the Sustut Basin changed from centripetal to longitudinal.

Continued Paleogene folding and thrust faulting in the Sustut Basin and faulting along the northern Rocky Mountain Trench (and related lineaments) outlived clastic deposition in both areas.

## ECONOMIC POTENTIAL

The importance of fluviatile sandstones as host rocks for epigenetic uranium concentrations has been recognized in many parts of the world. The major regional and local controls for uranium mineralization have recently been ably summarized by Gabelman (1971). In the Sustut Basin the sandstone - mudstone ratio and structural complexity varies greatly and makes the assessment of relative uranium potential very difficult. The presence of extensive tuff sheets in the Brothers Peak Formation might indicate a potential source material for uranium. In terms of structure and the predominance of thick sandstone bodies, the area near Bear Lake could be of particular interest with regard to uranium exploration.

The occurrence of gold veins in the Omineca Mountains east of the Sustut Basin as reported by Lord (1948) and confirmed by recent exploration activity points to the possible existence of fossil placers of gold and silver within the conglomerates of the Tango Creek Formation derived from the gold-bearing rocks and transported by westward flowing rivers ( see Paleocurrents). Therefore the basal Tango Creek Formation along the northeastern basin edge seems to have a higher potential than the rest of the basin fill with regard to placer concentration.

Thin seams of lignite in the Tango Creek Formation do not appear to be of any economic significance at the present time.

The scenic beauty of the Spatsizi Plateau region with its lakes and rivers has been recognized by many individuals fortunate enough to visit this part of the Cordillera. The long-range economic benefit of this unique recreational resource that is created by open terrane, low-gradient streams teeming with fish, and tranquil lakes in the midst of rugged mountain country must definitely be considered in any future land-use scheme proposed for northern British Columbia.

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