accompanied by
7 figures (7a - 7g)

SEDIMENTOLOGY AND STRATIGRAPHY OF THE SOUTHERN SUSTUT BASIN, NORTH CENTRAL BRITISH COLUMBIA

By

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ABSTRACT

The Sustut Group within the study area is a nonmarine succession of fine to coarse grained clastics, deposited in an alluvial fan environment. Regionally, the Sustut Group is divisible into the Tango Creek and Brothers Peak Formations. In the study area, the two formations are entirely Late Cretaceous (Campanian to Maastrichtian) in age, based on palynological evidence.

In the southern Sustut Basin, only the uppermost 400 m of the Tatlatui Member of the Tango Creek Formation is exposed. Sediments of the Tatlatui Member are divided into fine and coarse grained lithofacies. The fine grained lithofacies is composed of interbedded mudstone, siltstone and fine grained sandstone, which is interpreted as an alluvial plain deposit. Pebble conglomerate interbedded with coarse to medium grained sandstone comprise the coarse grained lithofacies which is considered to be a braided river deposit.

The Brothers Peak Formation comprises 1 000 m of diverse clastics and tuffs, which are divisible into the lower and upper Laslui Member, and the overlying Spatsizi Member. The lower Laslui Member conformably overlies the Tatlatui Member of the Tango Creek Formation, and is characterized by several fining upwards sequences of cobble conglomerate to medium grained sandstone, attributed to deposition by high energy braided streams in the mid-fan region of an alluvial fan complex. Sediments of the upper Laslui Member are divided into a fine grained lithofacies consisting of mudstone, interbedded with lesser amounts of siltstone, fine grained

sandstone and tuff beds, and a coarse grained lithofacies composed of orthoconglomerate, paraconglomerate and coarse grained sandstone. The fine grained lithofacies comprises the majority of the sequence and is interpreted as an alluvial plain deposit. Coarse grained sediments of the upper Laslui Member were likely deposited during stages of high water discharge, by major distributaries, sheetfloods and debris flows. The Spatsizi Member is gradational from the upper Laslui Member and is composed of sandstone/mudstone sequences interpreted as sandy braided stream deposits of an alluvial plain.

Detrital components of the Tango Creek and Brothers Peak sandstones are mainly chert, quartz, plagioclase and volcanic rock fragments. Paleocurrent measurements and provenance considerations suggest source terranes were located to the east during Tango Creek deposition, and to the west during Brothers Peak deposition. In the southern Sustut Basin, the Tango Creek Formation documents uplift and erosion in the Omineca Belt and Paleozoic rock units, following accretion of the first composite terrane (terrane I) to the North American Margin. The Brothers Peak Formation is considered a result of local uplift and volcanic activity, accompanying the accretion of a second composite terrane (terrane II).

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INTRODUCTION

GENERAL STATEMENT

The Sustut Group is the youngest regionally correlatible sedimentary assemblage in the Intermontane Belt of north-central British Columbia. A thick nonmarine succession of alternating fine and coarse grained sediments accumulated in the Sustut Basin which records the final stages of deformation and deposition in the Canadian Cordillera. Lord (1948), defined the Sustut Group as "a thick assemblage of conspicuously bedded and banded continental strata of relatively simple structure." Eisbacher (1974), outlined the sedimentary history and tectonic evolution of the Sustut Basin, but believed the sequence to be Late Cretaceous (Cenomanian) to Tertiary (Eocene), however, palynological evidence from the study area indicates the succession is entirely Late Cretaceous (Campanian to Maastrichtian). The present study provides a more detailed and comprehensive analysis of the Sustut Group in the southern Sustut Basin with particular emphasis on the depositional history and evolution of the strata.

The principal objectives of this thesis are to:

1) describe the major clastic lithofacies of the Sustut Group and provide stratigraphic correlation;

2) determine the depositional environments of the major clastic lithofacies;

3) utilize the mineralogy and paleocurrent data to interpret the provenance;

4) resolve the age of the Sustut Group through the

identification and dating of palynomorphs;

5) document the coalification level of the Sustut Group; and

6) reconstruct the tectonic and depositional history of the southern Sustut Basin.

STUDY AREA

The Sustut Group occurs in two large outliers, referred to as the northern and southern Sustut Basin. Collectively, the two sub-basins trend northwest to southeast between the Skeena and Omineca Mountains, and cover roughly 6 000 square kilometers (Figure 1). This study deals with the southern Sustut Basin and more specifically the sediments that make up the Connelly Range, located east of Bear Lake on the McConnell Creek map sheet, 94 D (Figure 2).

Physiographically, the area is mountainous, with peak elevations ranging from 1 600 m to 2 500 m. Local relief is generally less than 2 000 m and the valleys are commonly deep and broadly U-shaped. Ridges of the Connelly Range are asymmetrical with the west side of the ridge being a dip-slope (30 degrees SW), whereas the east side is characterized by nearly vertical cliffs and steep talus slopes, accounting for the excellent exposure of the uppermost 1 000 m to 1 500 m (Plate 1). Lower in the section, exposure is limited by grassy slopes and dense tree cover.

Drainage of the study area is mainly by the Sustut River, which flows westward into the Skeena River that in turn empties into the Pacific Ocean. Eastward drainage is principally by the Finlay River that is locally fed by the Omineca River, which eventually drains into the MacKenzie River and the Arctic Ocean (Figure 1).

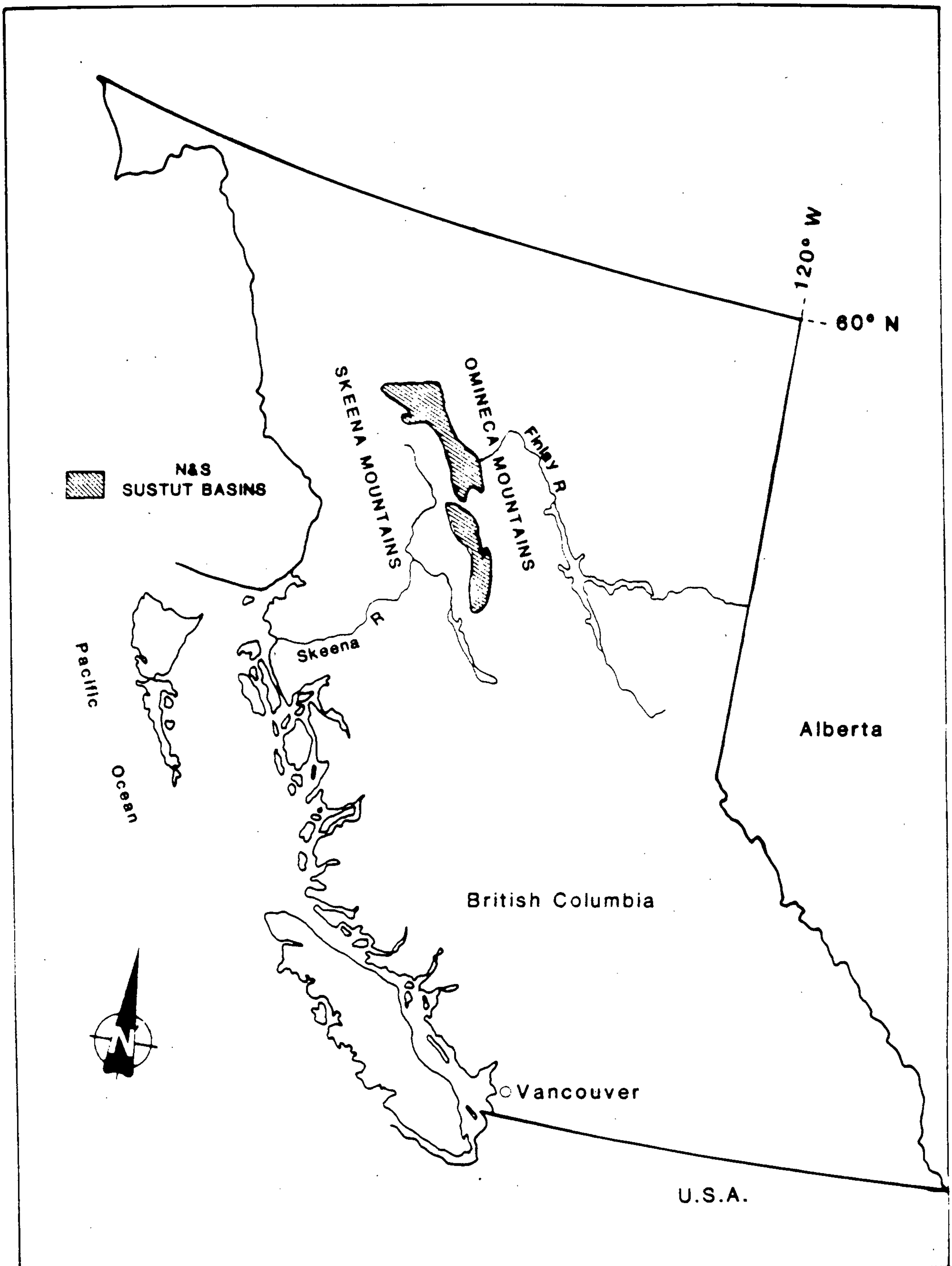


Figure 1. Location of the northern and southern Sustut Basins

Plate 1. East side of the Connelly Range showing the excellent exposure of the Sustut Group.

A. Looking to the southwest.

B. Looking to the northwest.

TECTONIC SETTING

The location of the Sustut Basin with respect to the tectonic belts of the Canadian Cordillera is shown on Figure 3. The Canadian Cordillera is a "collision orogen" involving the accretion of a collage of allochthonous terranes to the western margin of the North American continent. Accretion of terranes in Mesozoic time was accompanied by high grade metamorphism, granitic intrusions and uplift along deep crustal faults. Uplift led to the progradation of thick clastic wedges into the Bowser Basin in Middle to Late Jurassic, and the Sustut Basin in Late Cretaceous Time (Eisbacher, 1981).

Several terranes are thought to have amalgamated prior to accretion with the ancient North American continent and are referred to as composite terranes (Monger, 1984). Composite terranes I and II are shown on Figure 4. The accretion of terrane I in mid-Jurassic time and terrane II in mid-Cretaceous time is considered largely responsible for the present configuration of the Canadian Cordillera (Monger, 1984). Boundaries formed by these accretions coincide spatially with the belts of intense deformation, metamorphism, and granitic intrusion, the Omineca and the Coast Plutonic Belts (Figure 4).

During Middle to Late Jurassic time in the Bowser Basin, thick and extensive deposits of marine and non-marine clastics accumulated. Following a hiatus in the Upper Jurassic-early Lower Cretaceous (Tipper and Richards, 1976), marine and non-marine sediments of the Lower Cretaceous Skeena Group were

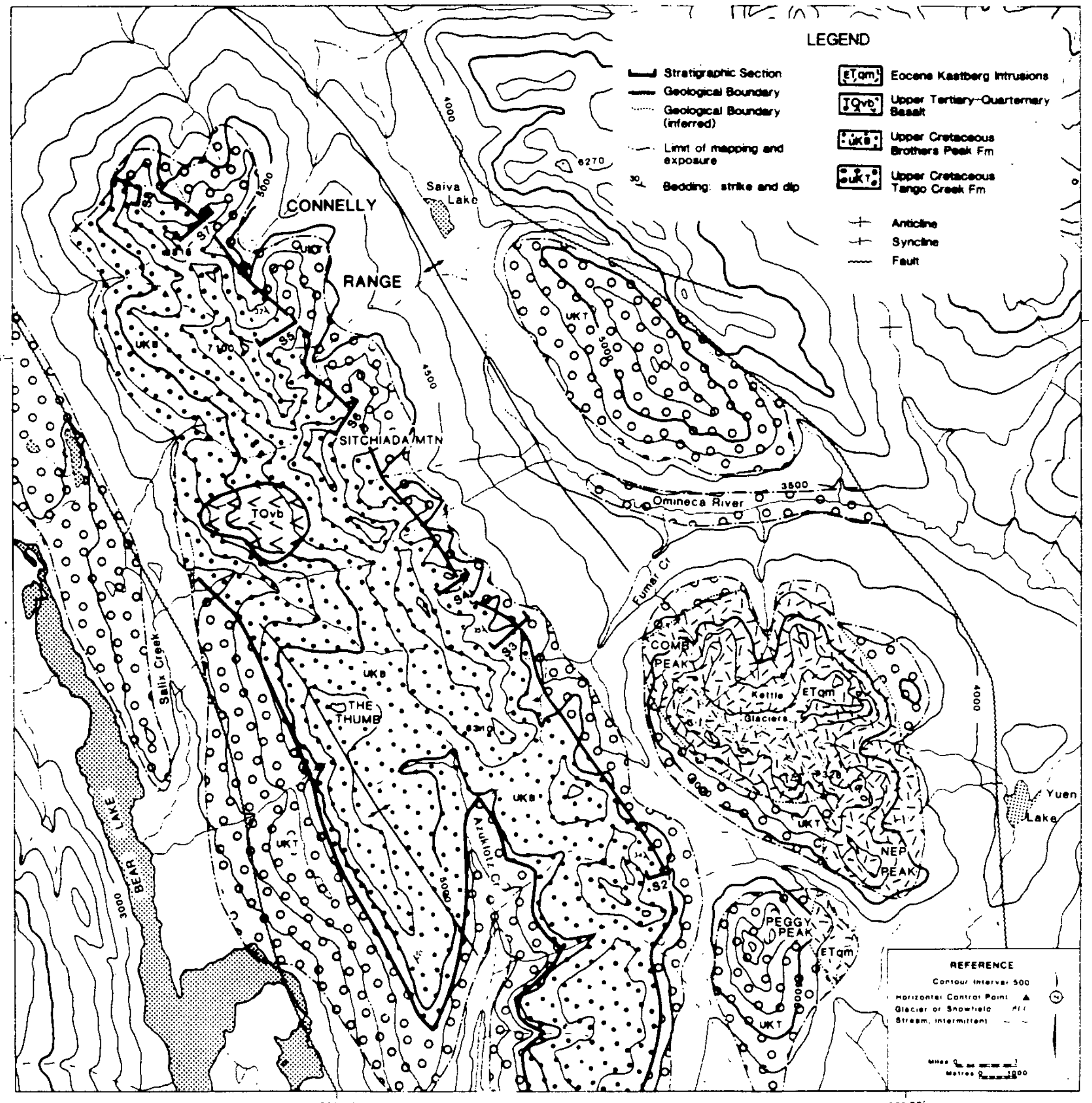


Figure 2. Geological map of the study area. (modified from Richards, 1976)

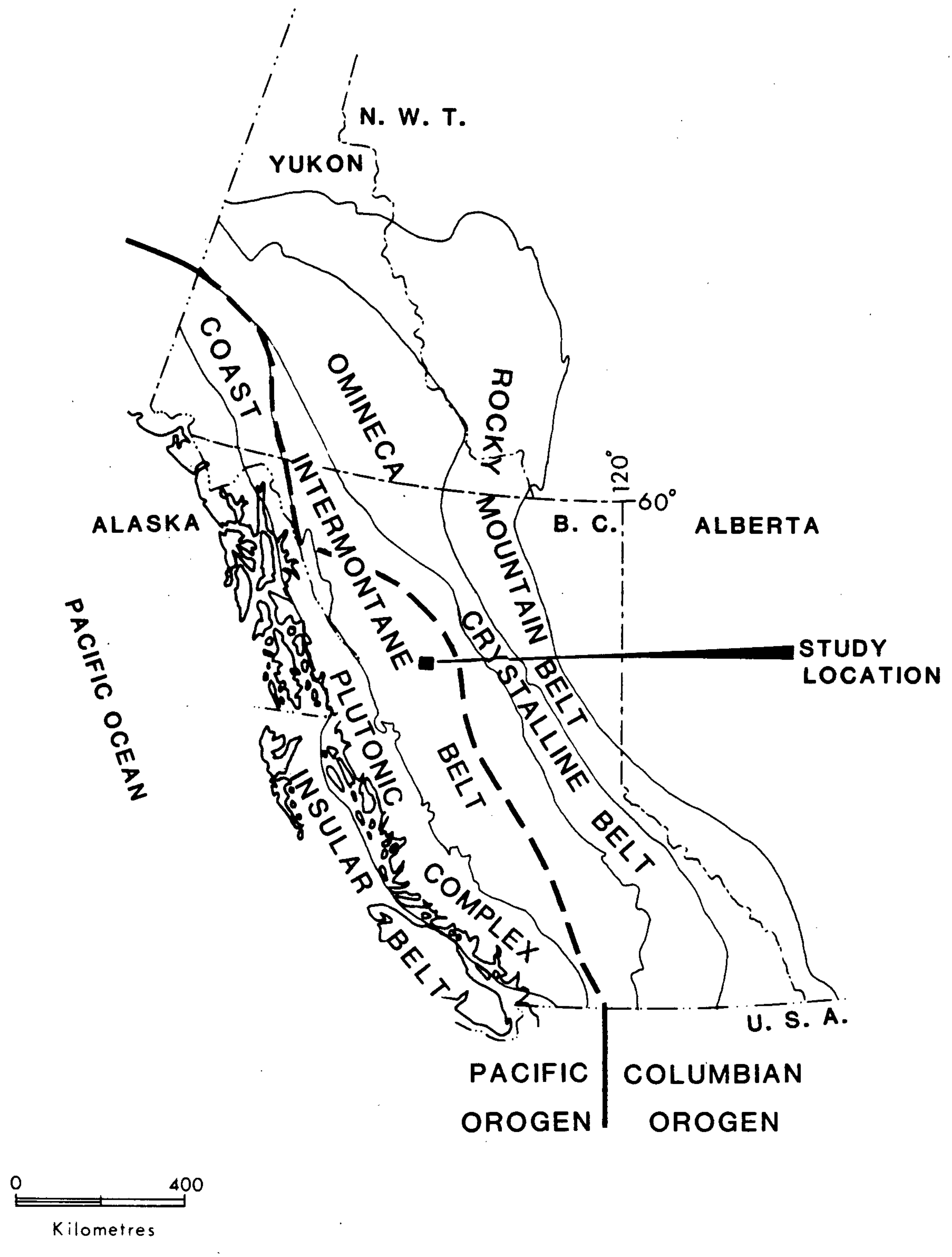


Figure 3. Major tectonic elements of the Canadian Cordillera. (modified from Wheeler and Gabrielse, 1972)

deposited. Skeena sediments contain an abundance of quartz and muscovite suggesting uplift of a high grade metamorphic complex, presumably the Omineca Belt (Tipper and Richards, 1976). By mid-Cretaceous time, the final accretion of composite terranes to the western edge of North America was complete (Monger, 1984). Sedimentation resumed in the Late Cretaceous, initially reflecting high angle faulting in the Omineca Belt (Eisbacher, 1981), and later in response to volcanic activity and uplift of the Coast Plutonic belt. Both the high angle faulting in the Omineca Belt and the accretion of terrane II, resulting in uplift and volcanic activity, are documented by the progradation of alluvial sediments into the Upper Cretaceous Sustut Basin.

STRUCTURAL SETTING

Within the study area, Sustut strata are folded into a broad northwest trending syncline-anticline pair. At the south end of the Connelly Range, Eocene Kastberg Intrusions truncate the Sustut Group (Figure 2). Minor, smaller scale folding and faulting occur at the north end of the Connelly Range. Further north, however (including the northern Sustut Basin), the strata are structurally more complex, deformed by closely spaced, northwest trending thrust faults and folds (Eisbacher, 1974).

Adjacent to the eastern margin of the Sustut Basin are several right-lateral strike slip faults. The most westerly is the Takla Fault, followed by the more eastern Vital Fault and the Pinchi-Finlay fault system.

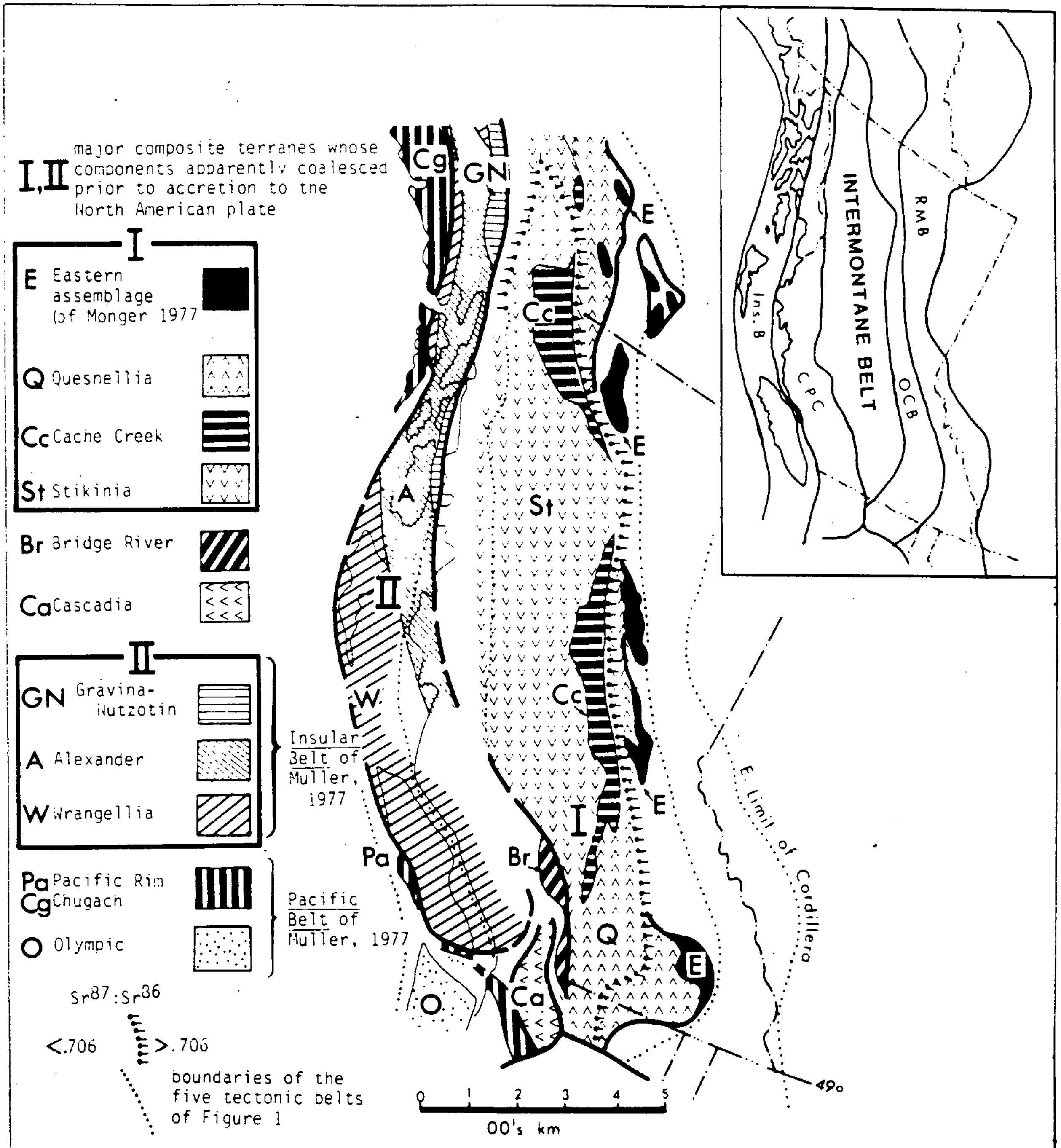


Figure 4. Allochthonous terranes of the Canadian Cordillera (modified from Price et al., 1981)

REGIONAL GEOLOGICAL SETTING

Figure 5 is a correlation chart of Triassic to Tertiary rock units surrounding the Sustut Basin. The main units adjacent to, or underlying, the Sustut Group range in age from Proterozoic to Early Cretaceous, representing various terranes and events in the Canadian Cordillera, and will be discussed below. Distribution of the various rock units is shown on Figure 6.

The Omineca Belt consists of a mid-Proterozoic to mid-Paleozoic miogeoclinal sequence, as well as Paleozoic and Mesozoic volcanic and pelitic rocks. In mid-Mesozoic to Tertiary time, these rocks were highly deformed and variably metamorphosed and intruded by Jurassic and Cretaceous plutons.

The Cache Creek Group which occupies a narrow belt to the east of the study area, consists of radiolarian chert, argillite, basalt, ultramafics, carbonate and locally blueschist, ranging in age from Mississippian to Upper Triassic (Monger, 1984). The Cache Creek Group is part of composite terrane I.

Patchy outcrop of the Asitka Group occurs to the east and northeast of the study area. The Asitka Group is composed of chert and tuffaceous limestone of Permian age, and andesitic to rhyolitic volcanic and volcaniclastic rocks of unknown, but possibly Permo-Triassic age (Monger and Davis, 1983). The Asitka Group overlies the Cache Creek Group unconformably, and locally is unconformably overlain by the Sustut Group (Monger, 1973).

Period	Epoch	Woodsworth et al., 1983 — TERRACE AREA	Eisbacher, 1974 — SOUTHERN BOWSER BASIN	This Study — SOUTHERN SUSTUT BASIN
TERTIARY			Sustut Group: Brothers Peak Formation	
CRETACEOUS	Upper	Brian Boru Formation	Sustut Group: Brothers Peak Formation; Tango Creek Formation	Sustut Group: Brothers Peak Formation; Tango Creek Formation
CRETACEOUS	Lower	Skeena Group	Skeena Group	
JURASSIC	Upper	Bowser Lake Group	Bowser Lake Group	Bowser Lake Group
JURASSIC	Middle	Hazelton Group	Hazelton Group	Hazelton Group
JURASSIC	Lower	Hazelton Group	Hazelton Group	Hazelton Group
TRIASSIC	Upper	Takla Group	Takla Group	Takla Group
TRIASSIC	Middle			

Figure 5. Correlation chart of Triassic to Tertiary rock units surrounding the Sustut Basin

The Takla Group comprises basaltic and andesitic volcanic rocks, (dominantly augite porphyries), pelitic rocks and minor limestones, that crop out to the northeast of the southern Sustut Basin. Tipper and Richards (1976) consider the Takla Group to be mainly Late Triassic.

The Hazelton Group is Early to Middle Jurassic in age and is a thick assemblage of varicolored basaltic to andesitic volcanic and volcaniclastic rocks, sedimentary rocks and minor carbonate rocks. The Hazelton Group crops out long narrow belts to the east and more extensive to the west surrounding southern outcrops of the Sustut Group. The Asitka, Takla and Hazelton Groups form part of the Stikine terrane of composite terrane I.

The Bowser Lake Group is composed of a thick marine to non-marine assemblage of chert rich clastic rocks which were deposited in the Bowser Basin in Middle to Late Jurassic time. The Bowser Lake Group crops out over an extensive area to the west of the study area.

The Skeena Group is composed of interbedded marine and non-marine sedimentary rocks with abundant detrital muscovite (Tipper and Richards, 1976). Woodsworth et al. (1983) consider the Skeena Group to be Early Cretaceous in age. Tipper and Richards (1976) and Eisbacher (1981), have speculated that the Sustut Group is the nonmarine equivalent of the upper portion of the Skeena Group. Outcrops of the Skeena Group occur to the south and west of the Sustut Group.

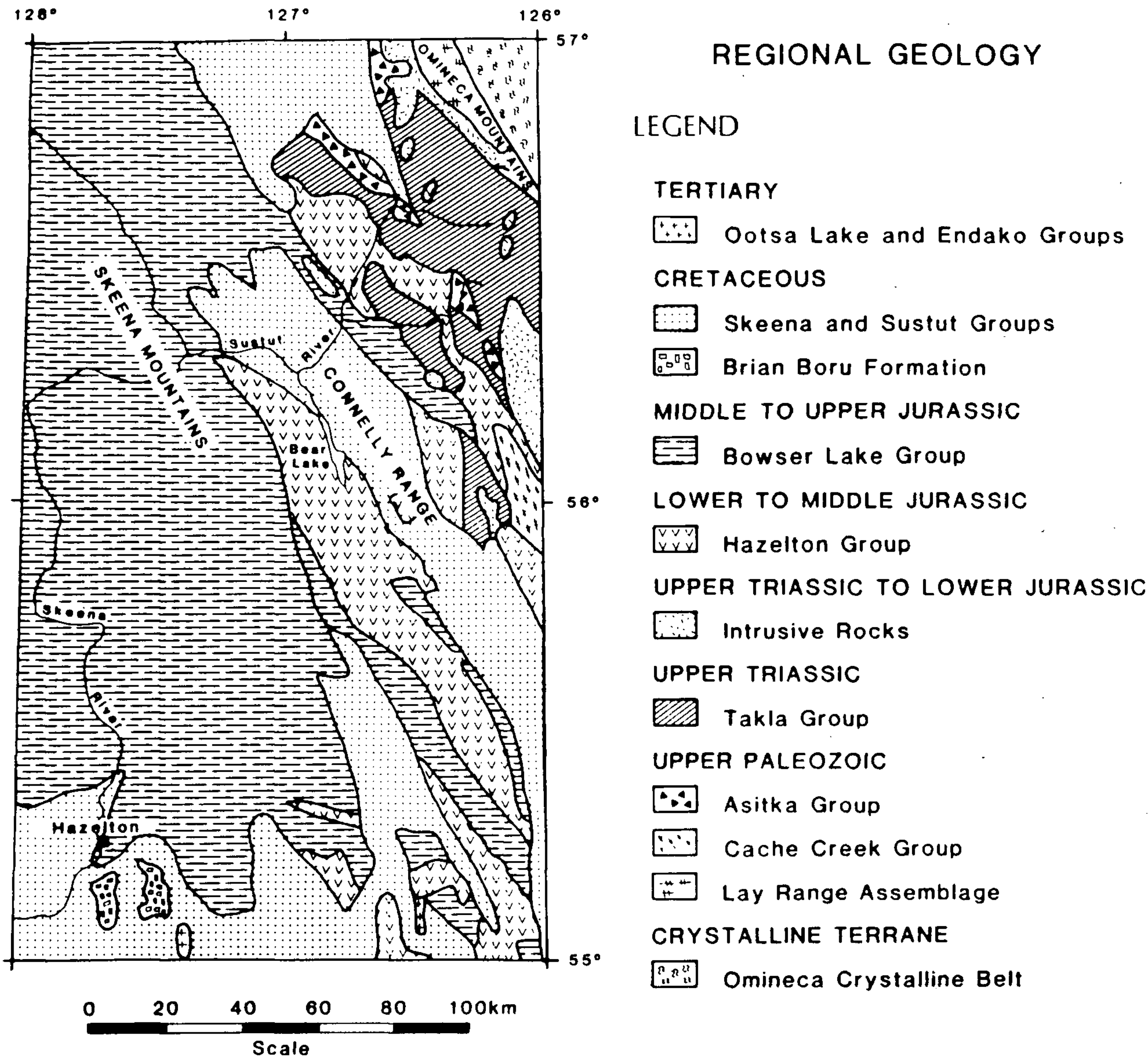


Figure 6. Regional Geology
(modified from Tipper and Richards, 1976)

Unconformably overlying the Skeena Group is the volcanic Brian Boru Formation composed of calc-alkaline basalt to rhyolite with a preponderance of plagioclase-hornblende porphyry. Cogenetic intrusive bodies have been dated as Late Cretaceous (70 - 84 Ma) (Woodsworth et al., 1983). The Brian Boru Formation crops out south and east of the city of Hazelton.

The Kastberg Intrusions locally occur in the study area and consist of grey to buff porphyritic rocks of granodiorite to quartz diorite composition. They intrude Sustut Group rocks at the south end of the Connelly Range and have yielded K/Ar age dates of 48 and 45 my (Richards, 1976). Andesitic and basaltic Tertiary or Quaternary flows, necks and numerous small dikes also intrude the Sustut strata in the Connelly Range.

METHODS AND DATA

Field Study

Field work was conducted during the summer of 1983. The initial base camp was situated immediately north of Bear Lake with subsequent fly-camps located on the east side of the Connelly Range. Transportation was by helicopter and light aircraft.

Seven stratigraphic sections were measured using a 1.5 m Jacob's staff equipped with a clinometer. The sections located along the east side of the Connelly Range, are shown in Figure 2. Over 200 samples were collected for further analysis in the laboratory.

Petrology

Grain size was estimated using the Wentworth (1922) scale, and bedding descriptions were based on thicknesses outlined by Ingram (1954). Roundness and sphericity, sorting and estimation of detrital grain percentages were determined by visual comparison with standard charts as prepared by Powers (1953), Folk (1968), and Terry and Chilangarian (1955), respectively. Sandstones were classified using Folk's (1968) triangular diagrams.

For heavy mineral analysis, 17 samples ranging from fine sandstone to granule conglomerate were crushed and sieved to very fine sand size (0.125 mm), and then separated by gravity using heavy liquids (Krumbein and Pettijohn, 1938). After separation, a magnet was used to separate out magnetite, which presumably removed most of the ilmenite.

A total of 27 thin sections were selected for modal analysis. These sections were stained for K^+ and Na^+ to aid in the identification of potassium feldspar and sodium-rich plagioclase, respectively, using the method outlined by Bailey and Stevens (1960). Approximately 300 grains were point counted per thin section. This number was arrived at by approximating the method outlined by Solomon (1963) which takes into account the average grain size, the grid spacing and the total area of the grid in an attempt to minimize the variance.

For determining coalification levels, samples of carbonaceous shale and coal fragments were crushed to -850 µm and formed into pellets, using a thermo-plastic that melts at less than 100° C, and polished with a final grit size of 0.05 µm. For each sample, maximum reflectance measurements were made by rotating the stage through 360° as the reflectance was recorded. A minimum of 50 maximum reflectance measurements were made and the mean and standard deviation determined for each of the 6 samples.

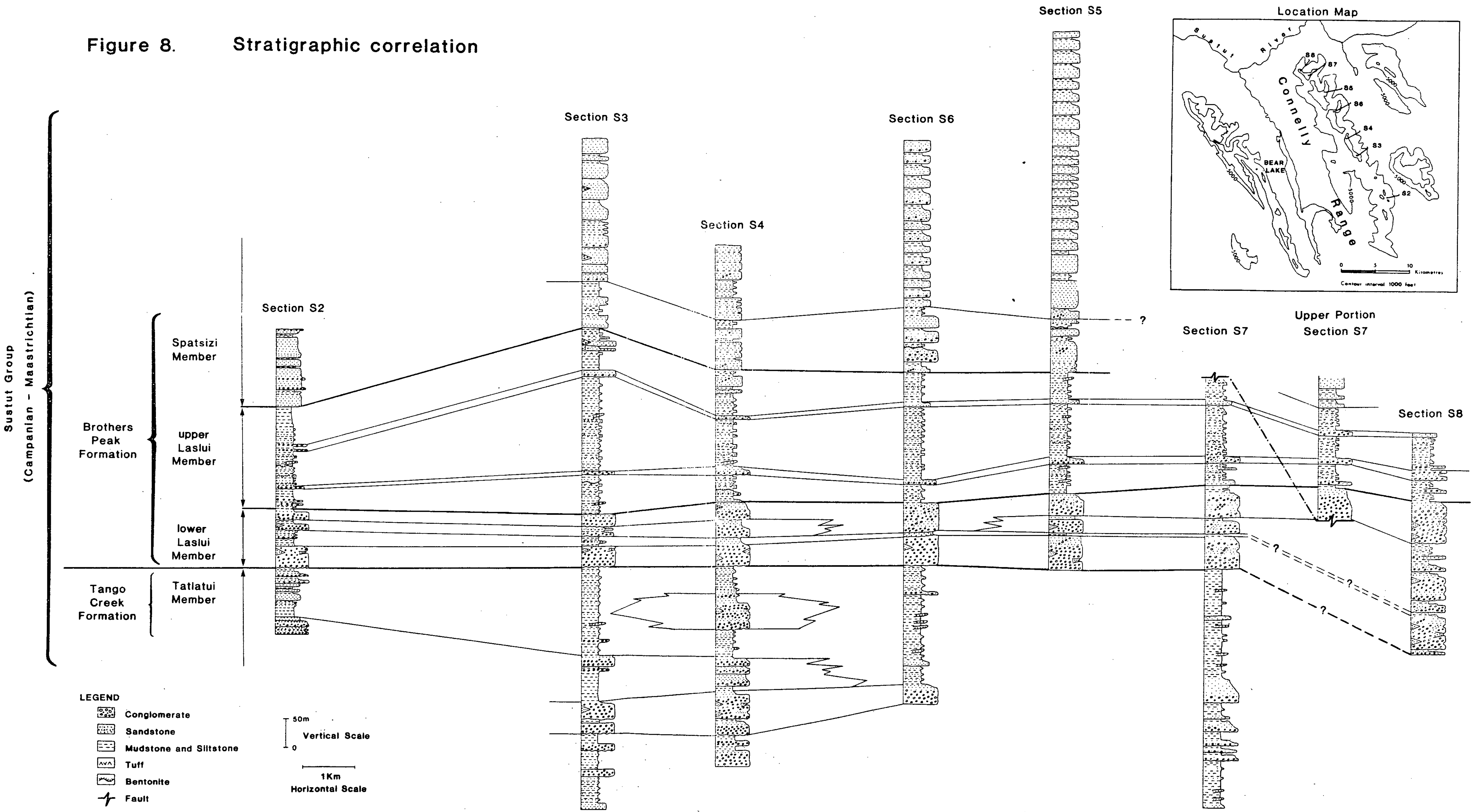
LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

The Sustut Group is an Upper Cretaceous assemblage of non-marine sedimentary and volcaniclastic units. Eisbacher (1971) recognized two formations that can be identified throughout the Sustut Basin; the Tango Creek and the Brothers Peak. Eisbacher (1971) considered the Tango Creek Formation to be Late Cretaceous (Cenomanian to Turonian) in age, based on the identification of fossil flora, and the Brothers Peak Formation to be mainly of Eocene age based on fossil plants and two age dates obtained from tuff samples. Palynological results from the present study, as discussed later, indicate however that the Tango Creek Formation and the Brothers Peak Formation in the study area, are both Late Cretaceous (Campanian to Maastrichtian) in age and that they are conformable. Thick and extensive pebble conglomerate beds of the Brothers Peak Formation are in erosional contact with the underlying recessive mudstone beds of the Tango Creek Formation. This contact can be traced throughout the Sustut Basin (Figure 2). The two formations can be subdivided into members which are discussed further below. Detailed lithologic logs and accompanying descriptions for each of the measured sections are in the pocket of the thesis (Figures 7a-7g). Figure 8, is a stratigraphic correlation of the measured sections.

TANGO CREEK FORMATION

In the Sustut Basin, the Tango Creek Formation varies in thickness from 400 m in the south to over 1 400 m in the

Figure 8. Stratigraphic correlation



north. Eisbacher (1974) defined two informal members that can be identified throughout most of the basin: the lower Niven Member and the upper Tatlatui Member. The contact between these members is gradational from predominantly red and green mudstone in the Niven Member to mainly grey mudstones of the Tatlatui Member. In the study area, only the uppermost 400 m of the Tatlatui Member is exposed (for a detailed description of the Niven Member, see Eisbacher, 1974).

TATLATUI MEMBER - LITHOFACIES DESCRIPTION

The Tatlatui Member consists of several laterally continuous conglomerate and medium to coarse grained sandstone units, separated by thick sequences of interbedded mudstone, siltstone and fine grained sandstone. Two lithofacies are recognized in the Tatlatui sequence: a coarse grained lithofacies and a fine grained lithofacies (Plate 2).

Coarse Grained Lithofacies

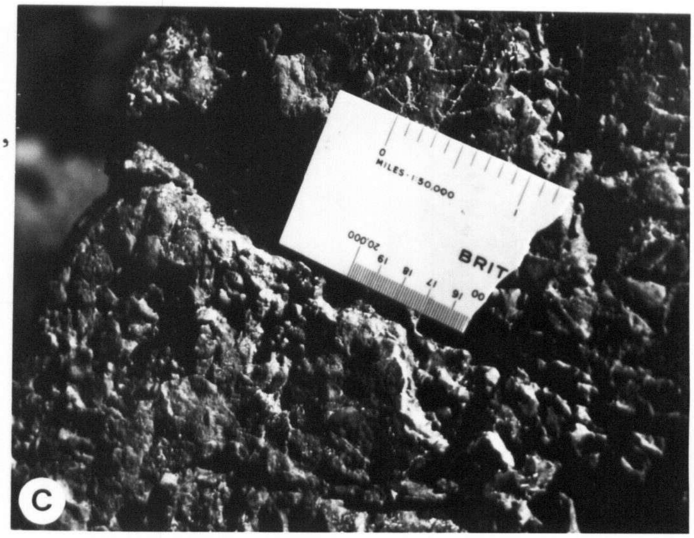
The coarse grained lithofacies is a minor component of the Tatlatui Member, except in section S4 where the lithofacies comprises over half of the measured section (Figure 8). The coarse grained lithofacies comprises internally discontinuous sequences ranging from 2 m to 20 m in thickness, composed of massive to thickly bedded pebble conglomerates interbedded with, and locally fining upwards into, coarse to medium grained,pebbly sandstone. Underlying mudstone or siltstone of the Tatlatui Member is in erosional contact with the coarse grained lithofacies.

Plate 2. Characteristics of the Tatlatui Member

2a. Outcrops showing thickly bedded conglomerate interbedded with fine grained sediments.

2b. Outcrops showing interbedded fine grained sediments.

2c. Close-up of a poorly sorted, pebble conglomerate.



Pebble conglomerates are poorly sorted with a modal clast size of 1.5 cm (Plate 2). Locally, in section S4 clasts up to 11 cm occur. Poor to moderately sorted matrix comprises 10 to 30% of the conglomerate and ranges from silt to coarse sand size. Sandstones are typically cross-stratified in tabular sets 40 to 50 cm thick. Trough cross bedding, massive to medium horizontal stratification and scour surfaces are present to a lesser extent.

Mudstone rip-up clasts, up to 10 cm in length, commonly occur at the base of the conglomerates and within some of the sandstones. Carbonaceous fragments, log impressions up to 3 m long, and calcareous sandstone nodules, 40 cm by 20 cm in diameter, occur locally throughout the lithofacies.

Fine Grained Lithofacies

The fine grained lithofacies comprises interbedded sequences up to 100 m thick. Mudstone is the main lithology, with lesser amounts of siltstone and fine to very fine grained sandstone. Individual lithologies range from 30 cm (fine grained sandstone) to 12 m (mudstone) in thickness and are laterally discontinuous. Resistant beds of sandstone and local siltstone occur within the overall recessive interbedded sequence.

The various units are massive to thinly bedded and highly fractured, although zones of carbonaceous flecks and mudstone rip-up clasts are common in some fine grained sandstone units.

TATLATUI MEMBER - INTERPRETED DEPOSITIONAL ENVIRONMENT

Fabric, texture and morphology of the Tatlatui sediments suggest deposition by fluvial processes. The fine grained lithofacies is interpreted as a floodplain deposit. The coarse grained lithofacies has many features indicative of channel deposits, such as erosive basal contacts and lateral discontinuity. Of the four principal river types: straight, braided, anastomosing and meandering, described by Miall (1977) and illustrated in Figure 9, the coarse grained lithofacies most closely resembles deposits of a braided river.

Braided rivers produce internally complex deposits as a result of the build-up and migration of longitudinal and transverse bars, and the rapid lateral migration of channels across the braidplain (Miall, 1977). The coarse grained lithofacies is conglomeratic at the base and fines upwards into horizontally and cross-stratified sandstone, with local erosional scours filled with cross-stratified sandstone. Analogous deposits are found in the braided Donjek River, Yukon (Rust, 1972), which is dominated by longitudinal bars. Similar to the coarse grained lithofacies of the Tatlatui Member, the longitudinal bars of the Donjek River are composed of a mixture of conglomerate and sandstone, and are commonly dissected by low-order channels, producing local pods of cross-stratified sandstone. Cross-stratified sandstone is also commonly attributed to accumulation in transverse bars, as documented by Smith (1970) in the Platte River, Nebraska.

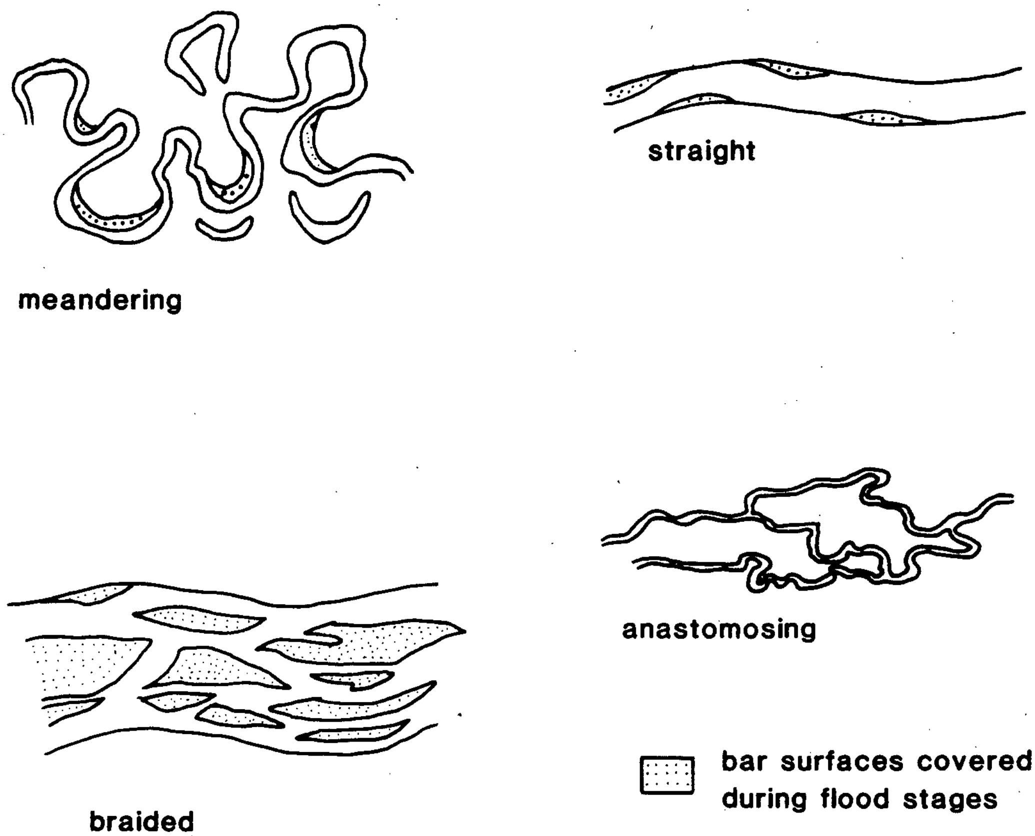


Figure 9 Principal braided river types (modified from Miall, 1977)

The abundance of cross-stratified sandstone within the coarse grained lithofacies suggests deposition occurred in both transverse and longitudinal bars.

Deposits with complex internal variation similar to the coarse grained lithofacies of the Tatlatui Member are also attributed to the erosion and dissection of braid bars during waning flood stages (Miall, 1977). These erosional processes make the original shape and size of the bar impossible to discern. Waning flood stages may also lead to the accumulation of a thin mud layer on bar tops, and if subaerially exposed, often leads to the formation of mudstone rip-up clasts, which are incorporated as a lag deposit in the next flood stage. Mudstone rip-up clasts are abundant within the Tatlatui strata, suggesting that variation in water discharge was frequent during deposition of the coarse grained lithofacies. Carbonized logs up to 3 m in length within the coarse grained lithofacies are also interpreted as a lag deposit, analogous to the Cannes de Rouche Formation, Gaspe, in which Rust (1978) recorded logs measuring 5 m in length.

Vertically and laterally, the fine grained lithofacies of the Tatlatui Member is extensive, with the exception of section S4, where the coarse grained lithofacies comprises over half of the measured section (Figure 7c). Organic black mudstone within the fine grained lithofacies suggests a humid climate capable of supporting vegetation; however, the absence of coal seams indicates that conditions were not conducive to the accumulation and/or preservation of peat. Discontinuous fine grained sandstone units, present within the fine grained lithofacies, suggest that minor distributary channels were periodically active during flood stages, analogous to distal alluvial fan deposits (Nilsen, 1982).

The association of organic black mudstone, siltstone and fine sandstone together with conglomerate and sandstone suggests that the Tatlatui sediments were deposited in an alluvial plain environment, periodically occupied by a braided river complex (Figure 10). But, because of the distribution of braided river deposits, and their lack of lateral continuity, it is interpreted that the migration of the braided river tract was somewhat confined. Inactive areas on the alluvial plain supported vegetation and generally accumulated mud, receiving silt and sand via small distributary channels and during flood stages.

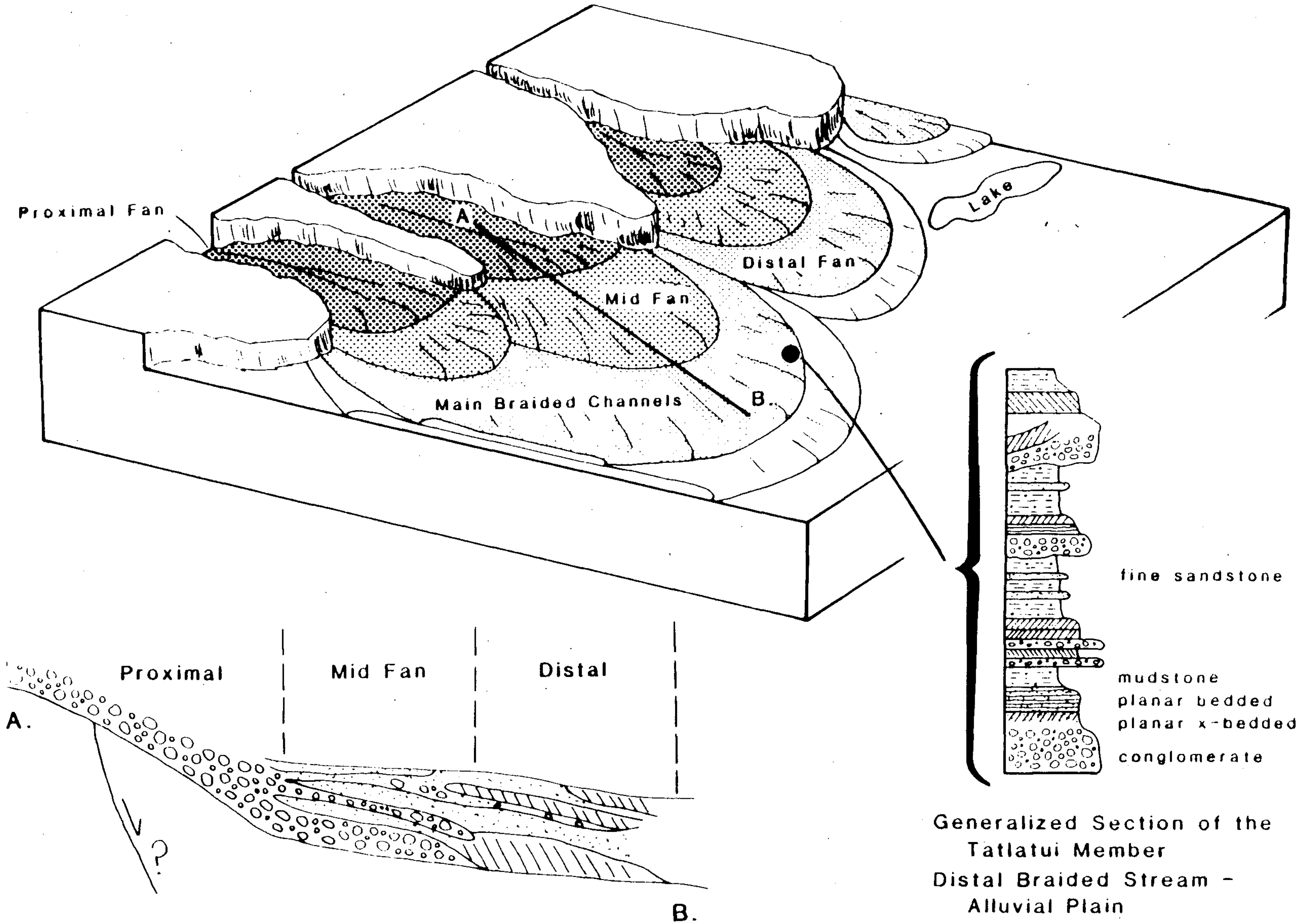


Figure 10. Interpreted depositional environment of the Tatlatui Member

BROTHERS PEAK FORMATION

In the Sustut Basin, the Brothers Peak Formation varies in thickness from 300 m to over 1000 m. Eisbacher (1974) distinguished two members within the Brothers Peak Formation: the Laslui Member, and the overlying Spatsizi Member. In the study area, the Laslui Member is subdivided into a lower sequence characterized by a predominance of thick conglomerates and an upper sequence of finer grained sediments interbedded with ash-fall tuffs. Numerous pebbly sandstone/black mudstone sequences characterize the Spatsizi Member. The contact between the Laslui and Spatsizi Members is placed at the base of the first sandstone/mudstone sequence, contrary to Eisbacher (1974), who placed the contact where a marked decrease in conglomeratic beds and a change in paleocurrent directions occurred.

LOWER LASLUI MEMBER - LITHOFACIES DESCRIPTION

Fining upwards successions of conglomerate, sandstone, siltstone, and mudstone typify the lower Laslui Member. Successions vary in thickness from 100 to 150 m. At the base of the sequence is a resistant conglomerate zone in erosional contact with mudstones of the Tatlatui Member. Sediments of the lower Laslui Member are divided into two lithofacies; a conglomeratic lithofacies, including both sandstone and conglomerate, and a fine grained lithofacies consisting predominantly of mudstone and siltstone.

Conglomeratic Lithofacies

The conglomeratic lithofacies which is the main component of the lower Laslui Member forms two and locally three laterally continuous, fining upwards sequences ranging in thickness from 30 to 60 m. The lithofacies is composed of pebble-cobble orthoconglomerate and medium grained sandstone. At the base of the lower Laslui Member is the thickest and coarsest conglomerate unit with imbricated clasts ranging up to boulder size (Plate 3a). Above the base the modal grain size of the conglomerate decreases markedly to 1 cm, with local clasts up to 25 cm. Internally each conglomerate sequence exhibits rapid lateral variation in texture (Plate 3b). In sections S2 and S3, 2 to 4 m thick conglomerate units are also found interbedded with sandstone and finer grained sediments.

Conglomerate is generally massive to thickly bedded, but locally horizontal or tabular cross-stratification occurs in

Plate 3. Characteristics of the lower Laslui Member.

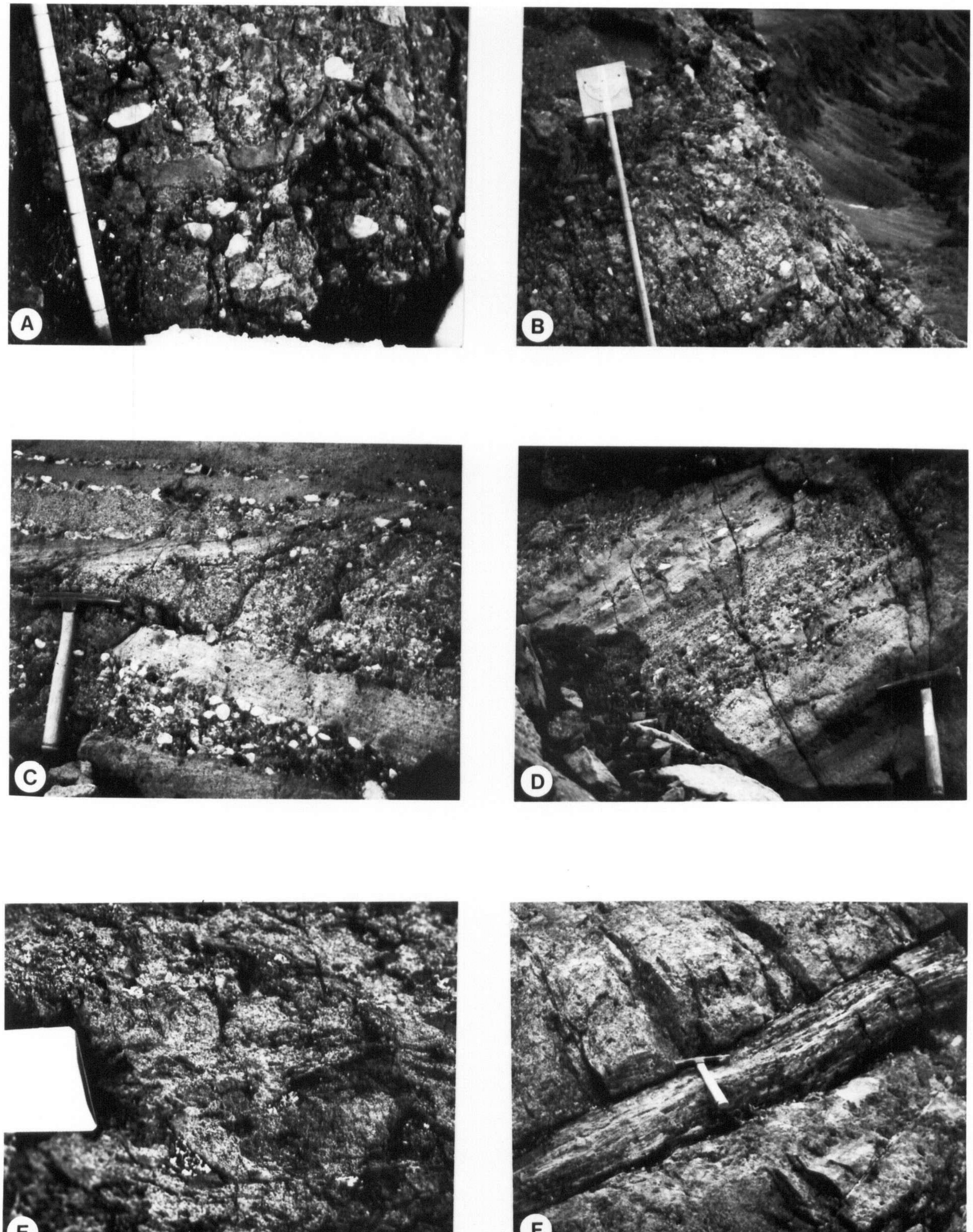
3a. Imbricated clasts at the base of the lower Laslui Member.

3b. Internally complex and rapid variation in texture, both vertically and laterally.

3c,d. Tabular cross-stratification.

3e. Mudstone rip-up clasts in sandstone.

3f. Log impression within a very coarse sandstone sequence.


A
B
C
D
E
F

30 cm sets (Plate 3c, 3d). The conglomerate is poor to moderately sorted and contains 10 to 30% matrix. Matrix ranges in size from fine to coarse sand and is moderately sorted. Sandstone is thickly bedded or tabular cross-stratified in 10 to 20 cm sets. Scour channels up to 5 m in thickness and 10 m in lateral extent also occur within the sandstone interval. Mudstone rip-up clasts, carbonaceous fragments and log impressions are common throughout the conglomeratic lithofacies (Plate 3e, 3f).

Fine Grained Lithofacies

The fine grained lithofacies is a minor component and consists of 2 to 5 m thick intervals of carbonaceous mudstone, siltstone and local fine grained sandstone. In sections S4 and S6 the fine grained lithofacies is absent. When present, the fine grained lithofacies is gradational from the conglomeratic lithofacies, capping the overall fining upwards sequences. The units are thinly bedded and highly fractured. Locally, fine grained sandstones contain carbonaceous flecks.

LOWER LASLUI MEMBER - INTERPRETED DEPOSITIONAL ENVIRONMENT

A complex association of conglomerates and pebbly sandstones, with lesser amounts of finer grained sediments characterizes the lower Laslui Member. Overall, the coarseness, thickness, and extent of the coarse grained deposits, plus the complex internal facies relationship are suggestive of deposition by a high energy braided river complex in a humid alluvial fan (mid-fan position), similar to the facies of the glacial outwash deposits in the San Joaquin Valley (Cherven, 1984).

At the base of the lower Laslui sequence are massive to parallel laminated, locally imbricated conglomerates interpreted as longitudinal bars, analogous to deposits of the modern braided Donjek River, Yukon (Rust, 1972), and braided outwash fan deposits in the northeastern Gulf of Alaska (Boothroyd and Ashley, 1975). The lower Laslui conglomerates are coarsest at the base, locally possessing a lag deposit which is thought to initiate the formation of longitudinal bars (Boothroyd and Ashley, 1975; Cant, 1982), and vertically grade into parallel laminated pebbly sandstones. Tabular cross-stratification is less common but may develop at the down current end of the bar. Rust (1972) described a similar sequence for longitudinal bar deposits in the Donjek River.

Pebbly cross-stratified sandstone that locally dominates the upper sections of the coarse grained lithofacies, probably represent transverse bar deposits as documented in the Platte River, Nebraska, by Smith (1970).

Capping the overall fining upwards sequences, is the fine grained lithofacies which represents floodplain deposition during decreased water flow levels, similar to Facies A and B on the Donjek River (Williams and Rust, 1969). With sustained low levels of discharge, clay, silt, and fine sand may accumulate over the channel surface, as a floodplain deposit. Otherwise, the fine sediments are removed during subsequent floods, which explains the paucity of mudstone and siltstone in the lower Laslui sediments. Erosion of thin mud layers is evident by the incorporation of mudstone rip-up clasts into channel lags at the base of longitudinal bar deposits, indicating rapid fluctuation of water discharge from stages of erosion to stages of deposition.

The overall decrease in clast size of successive fining upwards sequences indicate deposition by cyclical floods which decreased in overall water discharge throughout deposition of the lower Laslui Member. The complex overlapping and erosion of longitudinal and transverse bars results in rapid internal lateral variations in the texture of the coarse grained lithofacies. Analogous fining upwards sequences occur in modern stream gravels described by Smith (1974), and in ancient equivalents described by Steel and Thompson (1983). Because of the rapid lateral shifting of channels, braided rivers typically produce extensive sheets of coarse grained sediments with subordinate amounts of fines, analogous to the coarse grained lithofacies of the lower Laslui sequence.

Braided river deposits are a major component of alluvial fan complexes as documented by many authors, such as Bull (1972), Boothroyd and Nummedal (1978), Collinson (1981), and Rust (1984). The lower Laslui strata contain many of the characteristics of alluvial fan deposits as summarized by Nilsen (1982), such as: 1) complex changes in lateral and vertical facies; 2) paucity of organic matter; 3) limited suite of sedimentary structures, most commonly medium to large-scale cross-strata and planar stratification; 4) rapid down fan decreases in both average and maximum clast size; 5) typically poor sorting, containing a great range of grain sizes; and 6) deposition by high energy flows. The absence of gravity flows within the lower Laslui strata likely reflects continual sedimentation and sustained high water discharges during deposition, as gravity flows are usually prompted by abundant but sporatic water supply (Bull, 1972).

The lower Laslui Member is interpreted to have been deposited in proximal braided rivers in a mid-fan position on an alluvial fan complex (Figure 11). Both the lateral extent and association of facies within the lower Laslui Member has many similarities with fining upwards proximal braidplain deposits of the Malbaie Formation, Eastern Gaspé, Quebec, described by Rust (1984). In the mid-fan position, many channels are present and are free to migrate across the alluvial fan (McGowan and Groat, 1971). Thus, a mid-fan position accounts for the coarseness of the sediments and the lateral continuity of the deposit.

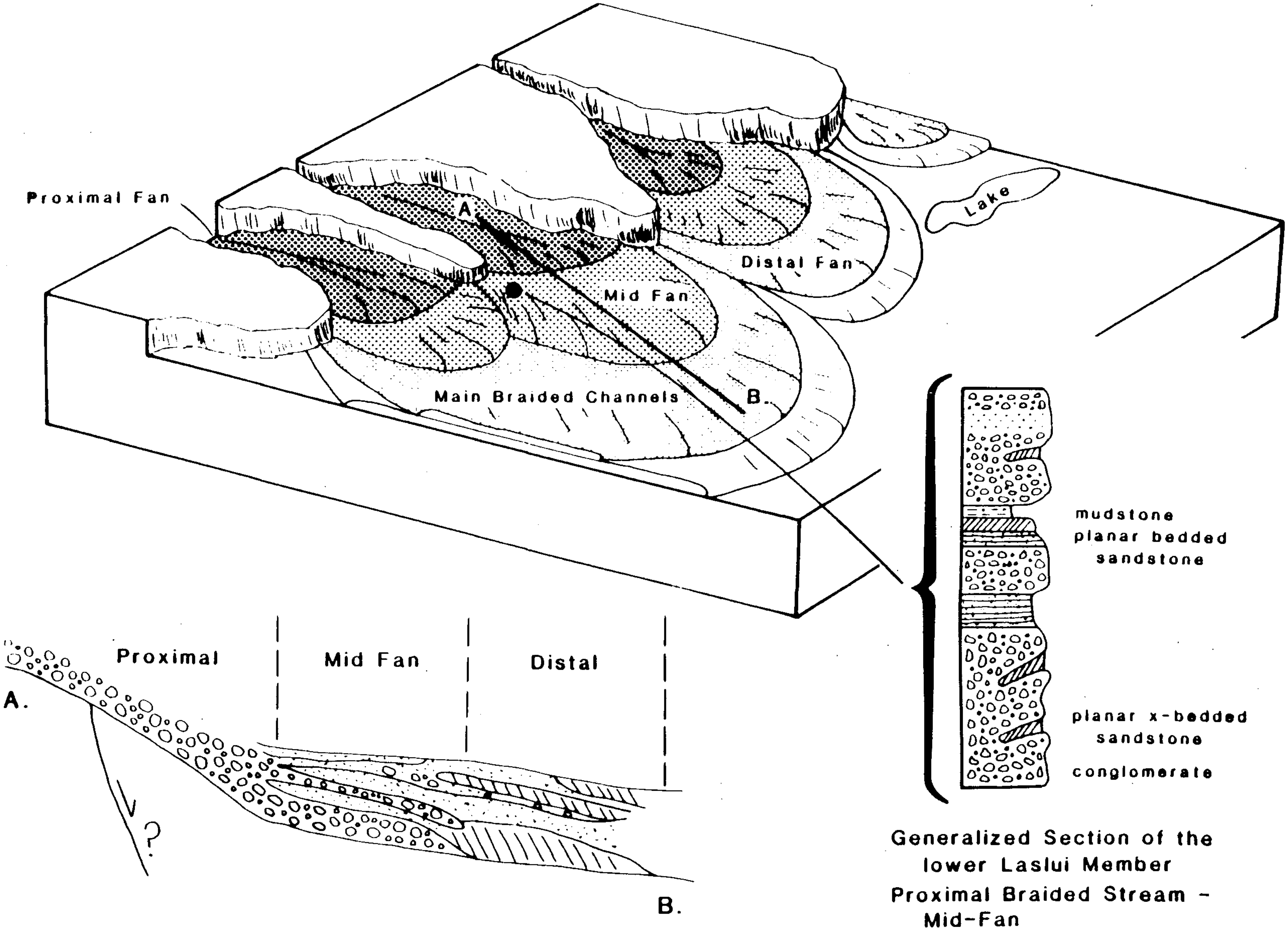


Figure 11. Interpreted depositional environment of the lower Laslui Member

UPPER LASLUI MEMBER - LITHOFACIES DESCRIPTION

Sediments of the upper Laslui Member abruptly overly the lower Laslui Member and comprise a distinctive assemblage of interbedded fine grained deposits interspersed with resistant conglomerate and sandstone units (Plate 4). Approximately 900 m thick, the upper Laslui Member can be divided into a coarse grained and an interbedded fine grained lithofacies.

Coarse Grained Lithofacies

Sandstones and conglomerates of the coarse grained lithofacies comprise roughly one third of the upper Laslui Member, and generally form widely spaced, resistant and laterally discontinuous units 2 m to 12 m thick. Orthoconglomerates, paraconglomerates and sandstones all occur within the coarse grained lithofacies. The orthoconglomerates are divided into sub-facies "A" and "B" as described below.

Orthoconglomerate "A" forms two laterally continuous, 10 to 12 m thick, massive to poorly stratified, granule to pebble conglomerate sequences that fine upwards into pebbly, fine to medium grained sandstone (Plate 5a). The bases of the sequences are in erosional contact with mudstones and locally expose longitudinal scours, similar to the gutter casts of Collinson and Thompson (1982; Plate 5b). Orthoconglomerate "A" is poorly sorted and contains 10 to 20% matrix. The matrix is moderately sorted and has a mean grain size of fine to medium sand. Sandstone associated with orthoconglomerate

Plate 4. Overview of the upper Laslui Member, illustrating the distinctive lenticular, white tuff beds.

"A", is commonly cross-stratified in tabular sets 10 to 15 cm thick. Horizontal stratification and trough cross-stratification are less abundant. Sandstone also occurs in erosional scours 50 cm thick and 2 to 3 m in lateral extent. Carbonaceous fragments, log impressions (Plate 5c) and mudstone rip-up clasts are abundant throughout the sequences.

In contrast to orthoconglomerate "A", Orthoconglomerate "B" forms several thinner units ranging from 10 to 25 cm in thickness. Locally these thin, massive conglomerates are laterally continuous for 50 m, but commonly persist for only a few meters, (Plate 5d). Orthoconglomerate "B" is poorly sorted and clasts range in size from 1 cm to 1 mm. Matrix comprises 10 to 30% of the rock, and ranges from silt to clay.

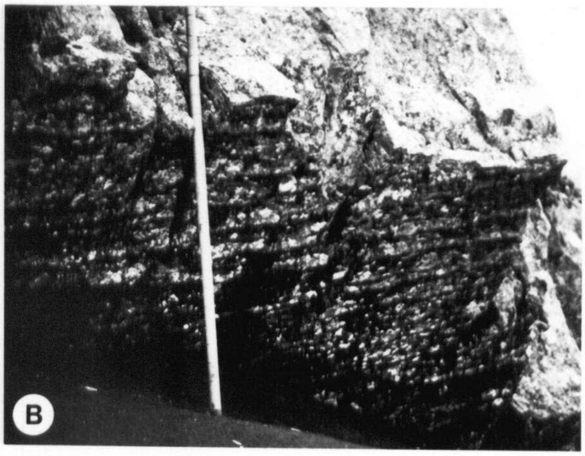
Paraconglomerates are approximately 2 m thick and form laterally discontinuous, finger-like lobes. Although a minor component, paraconglomerates occur in all the sections measured. These granule conglomerates have a resistance intermediate between adjacent sandstones and recessive fine grained sediments (Plate 6a). The paraconglomerates have sharp upper and lower contacts, are both normally and reversely graded (Plate 6b), and are poorly sorted containing up to 50% matrix. The matrix has a mean grain size of silt to clay.

Medium to coarse grained, laterally discontinuous sandstone units range in thickness from 15 cm to 5 m. The thinner units form part of the interbedded fine grained lithofacies. Sandstone fines upwards from an erosional basal

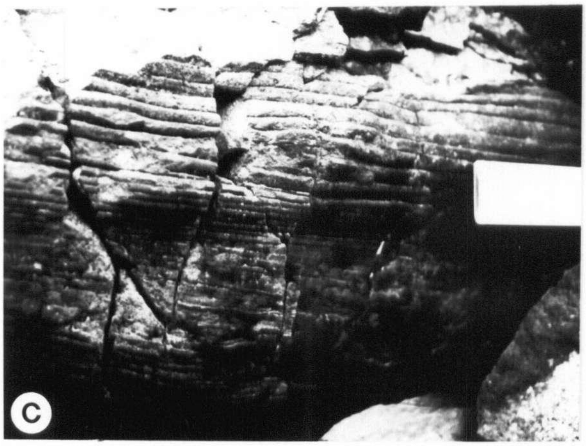
Plate 5. Characteristics of the upper Laslui Member orthoconglomerates.

5a. Orthoconglomerate 'A' caps a sequence of interbedded fine grained sediments, including tuffs.

5b. Longitudinal scours, or 'gutter casts' exposed on the base of orthoconglomerate 'A'.



5c. Log impressions within orthoconglomerate 'A'.



5d. Laterally discontinuous exposure of orthoconglomerate 'B', within a sequence of interbedded fine grained sediments.

contact with mudstone or siltstone and are horizontally stratified.

Interbedded Fine Grained Lithofacies

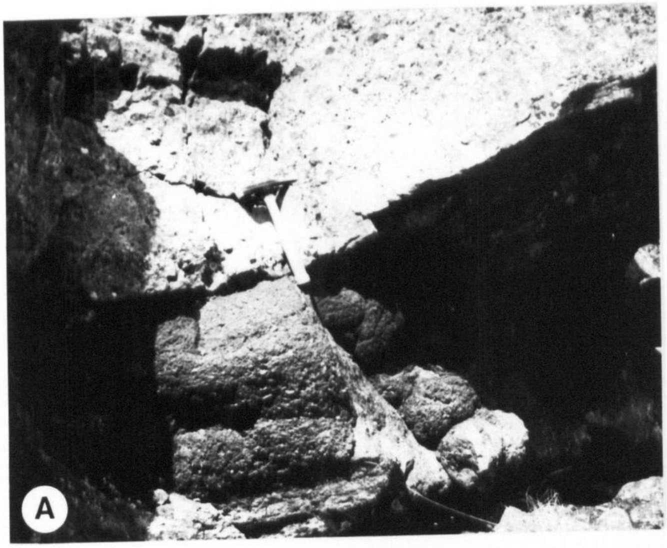
The interbedded fine grained lithofacies forms over half of the upper Laslui Member. Mudstone is the most abundant lithology with lesser amounts of siltstone, fine grained sandstone and tuff beds.

Green, highly fractured mudstone form recessive intervals of up to 20 m thick throughout the upper Laslui Member. In the lower half of the upper Laslui sequence, 1 to 2 m thick red mudstone units are commonly interbedded with green mudstones, but are absent higher in the section. Black, carbonaceous mudstone and siltstone are minor components of the interbedded fine grained lithofacies. Occurring as either 15 to 20 cm thick laterally discontinuous resistant units, or as 1 to 3 m thick recessive intervals.

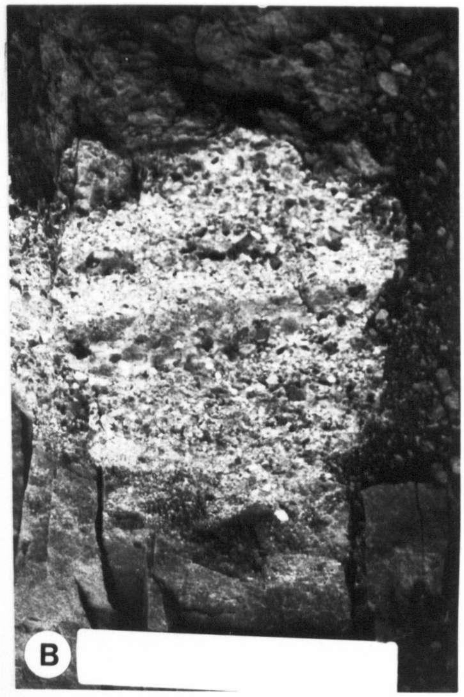
Fine grained sandstone occurs as 20 to 30 cm thick laterally discontinuous units within the fine grained lithofacies. Contacts are commonly sharp and locally channeled bases occur. Fine grained sandstone exhibits horizontal stratification in 1 cm sets.

Locally, tuff comprises about a quarter of the upper Laslui Member. The tuff units occur in lenticular beds up to 40 m in length and average 40 cm in thickness. Both upper and lower contacts are sharp even though surrounding units are commonly tuffaceous (Plate 6c). Tuffs are massive to thinly bedded with local occurrences of small scale cross-

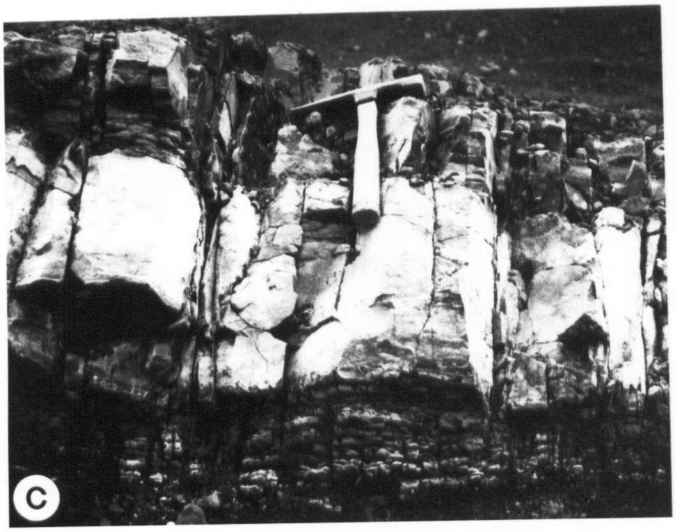
Plate 6. Characteristics of the upper Laslui Member paraconglomerate and tuff.



6a. Paraconglomerate, less resistant than above pebble orthoconglomerate. Note the overall darker color of the paraconglomerate bed.



6b. Paraconglomerate showing both normal and reverse grading.



6c. Tuff bed showing sharp lower and upper contacts.

stratification. Closely associated with tuff are thin, 5 to 10 cm bentonites.

UPPER LASLUI MEMBER - INTERPRETED DEPOSITIONAL ENVIRONMENTS

The upper Laslui Member is dominated by fine grained sediments, with the coarse grained facies forming discontinuous pods, except for two laterally continuous conglomerate sequences. The facies are interpreted as alluvial plain deposits.

Many of the facies present have characteristics suggestive of deposition in semi-arid conditions, however, the presence of palynomorphs from very hot and humid climate flora (Rouse, pers comm., 1985) indicates alternating wet and dry conditions existed, at least locally, during deposition of the upper Laslui sequence. The variety of colors of mudstone in the upper Laslui Member, also suggests fluctuations in the level of the water table. Red mudstone suggests oxidizing conditions, common in areas with a low water table, facilitating the weathering of ferromagnesium minerals (hornblende and biotite) to clay minerals such as hematite (Collinson, 1978). However, as the red mudstone units are subordinate to green mudstone units, oxidizing conditions must have been local or of short duration. Overall, green mudstone dominates the upper Laslui sequence and is indicative of either a more humid climate with a higher water table (Graham, 1975), or represents deposition in a locally deeper, wetter position on the floodplain. The presence of black, organic mudstone, although in minor amounts, suggests swampy or vegetated areas, also must have been locally present. Hence, conditions on the floodplain, with respect to the water table level, were highly variable during deposition.

In close association with the mudstone deposits are sheet - like deposits of horizontally stratified fine grained sandstone and siltstone, similar to modern day floodplain deposits. McKee et al. (1967), recorded a horizontally laminated sheet deposit between 1 and 4 m thick, in the Bijou Creek, Colorado and on further examination, concluded that sheet sedimentation on the floodplain occurred as a result of flooding on small and insignificant channels. In the upper Laslui Member, deposits of siltstone and fine sandstone up to 3 m thick may have a similar origin.

Well preserved, thick, cross-stratified, lenticular tuff beds that occur throughout the upper Laslui Member necessitates a subaqueous environment free of erosion, such as small lakes or ponds. Tuffaceous mudstone and siltstone is common directly above and below the tuff horizons, suggesting a close association in space and time between accumulation and deposition of thick ash deposits, and sediment carried by floods to the alluvial plain.

In association with lakes and floodplain deposits, Steel (1974) has documented finger-shaped distal lobes of stream channel sandstone and conglomerate, and mudflows that are enveloped vertically and laterally by finer grained sediments, in the New Red Sandstone, Scotland. Similarly in the upper Laslui strata, discontinuous lobes of orthoconglomerate "B", medium to coarse grained sandstone and paraconglomerate are present within a dominantly fine grained, floodplain succession. Orthoconglomerate"B", and the medium to coarse grained sandstone deposits are typically poorly sorted, thin, discontinuous units analogous to stream channel deposits characteristic of alluvial fan deposits described by Steel (1974).

The paraconglomerates are interpreted as gravity flows similar to the debris flows described by Wasson (1977) and Heward (1978). Debris flows are common on many alluvial fans of both humid (Heward, 1978) and semi-arid climates (Bull, 1972; and Allen, 1981) and have become a characteristic for the recognition of alluvial fan deposition. In the upper Laslui Member, both mudflow and grainflow deposits occur, grainflows being less abundant. Mudflow deposits are most abundant near the fan apex, and generally follow stream channels (Bull, 1972). However, Steel (1974), and Steel and Aasheim (1975), have documented distal mudflow deposits beyond the normal range of fan activity in association with floodplain and playa sediments, analogous to the upper Laslui strata. According to Bull (1972), mudflows are prompted by abundant but sporatic water supply, steep slopes, and further require a fine grained source for the matrix. In the upper Laslui Member, volcanic ash was the dominant source for the fine grained matrix as evidenced by the tuffaceous composition of the mudflows and grainflows. The gravity flows exhibit inverse and normal grading and have a wide compositional variety of very angular clasts, suggesting rapid deposition.

Debris flows with similar characteristics have been described from semi-arid settings (Bull, 1972; Larson and Steel, 1978) as opposed to the debris flows in humid areas that are composed of well-rounded clasts and which commonly lack stratification (Wasson, 1977; Iwaniw, 1984).

Two laterally extensive deposits of orthoconglomerate "A", in the upper Laslui sequence have many features of braided stream deposits such as complex internal variation in texture, and an overall fining upwards sequence from massive conglomerate to horizontal stratified and cross-stratified sandstone, similar to sheetflood deposits described by Muir and Rust (1982). Sheetflood sediments recognized on alluvial fans (Nilsen, 1982), are deposited by surges of sediment laden water spreading out from the main stream channel in the form of many shallow distributary channels and result in laterally extensive deposits analogous to orthoconglomerate "A" of the upper Laslui Member. Fining upwards deposits of orthoconglomerate "A" are less than 12 m thick, suggesting that: 1) the distributary channels were shallow, although extensive; and 2) the deposits represent single flood events.

Typically, the association of ponds, swamp and sheetflood deposits is characteristic of distal alluvial fans and alluvial plains in humid climates (Heward, 1978). However, debris flow deposits are usually more abundant on arid to semi-arid alluvial fans (Cherven, 1984). Thus, the upper Laslui Member has features typical of both wet and dry conditions, suggesting that the water table level must have fluctuated, at least locally, during deposition.

The wide variety of facies present in the upper Laslui Member is similar to facies associations from the mid-fan to distal fan or alluvial plain, described by Muir and Rust (1982) for the Snowblind Formation, N.W.T., and Zaitlin and Rust (1983) for the Bonaventure Formation, Gaspe and New Brunswick. Deposition on the distal alluvial fan-alluvial plain accounts for the interfingering of fine grained sediments with coarse grained sediments in the upper Laslui Member (Figure 12).

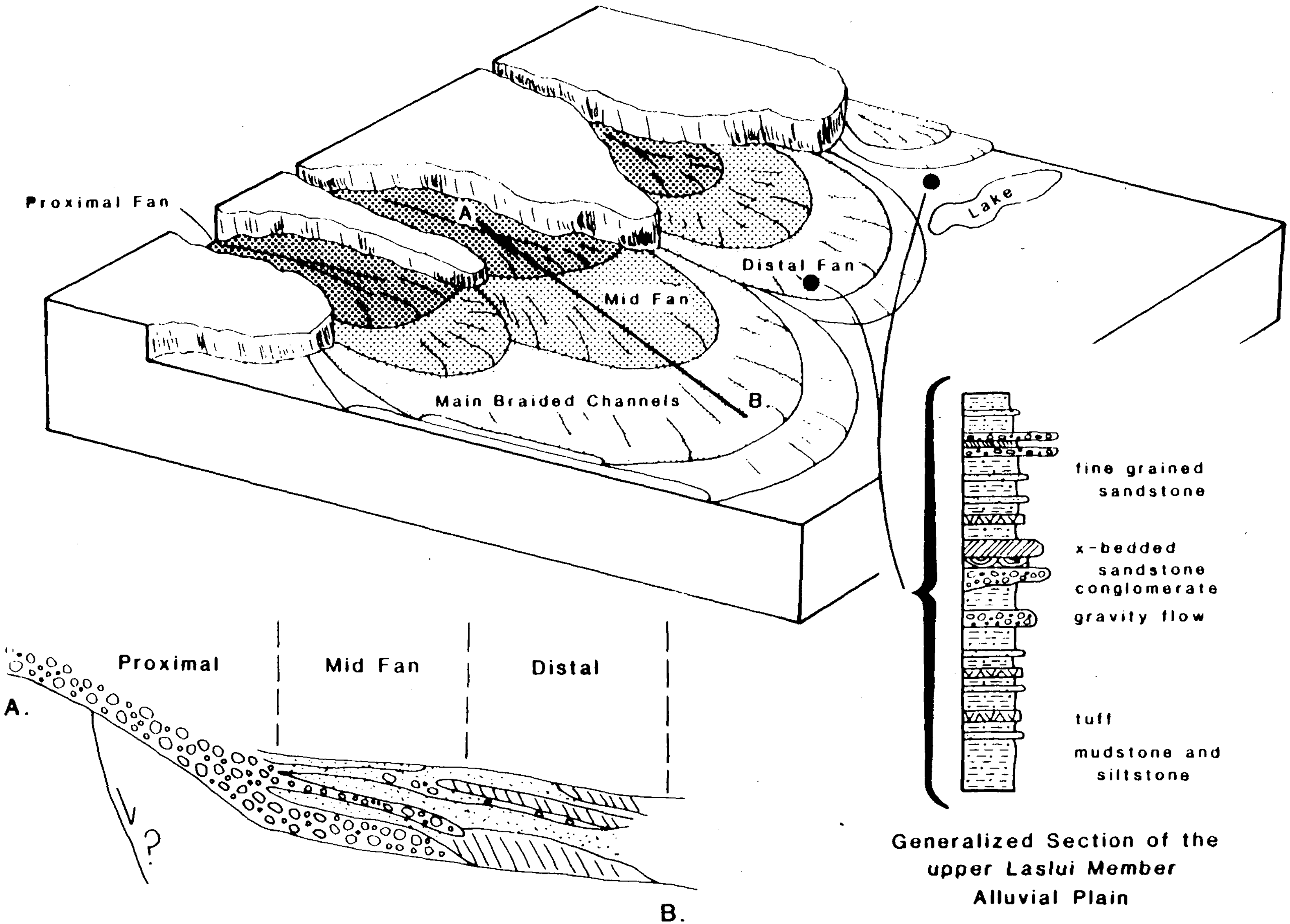


Figure 12. Interpreted depositional environment of the upper Laslui Member

SPATSIZI MEMBER - LITHOFACIES DESCRIPTION

Up to 600 m of the Spatsizi Member is exposed in the study area. In contrast to the rest of the Sustut Group, the Spatsizi Member is cyclic, composed of monotonous sandstone/mudstone packages; as many as 22 cycles occur at a single locality. The sandstone/mudstone sequence is laterally continuous, but correlation of individual sequences between sections was not possible.

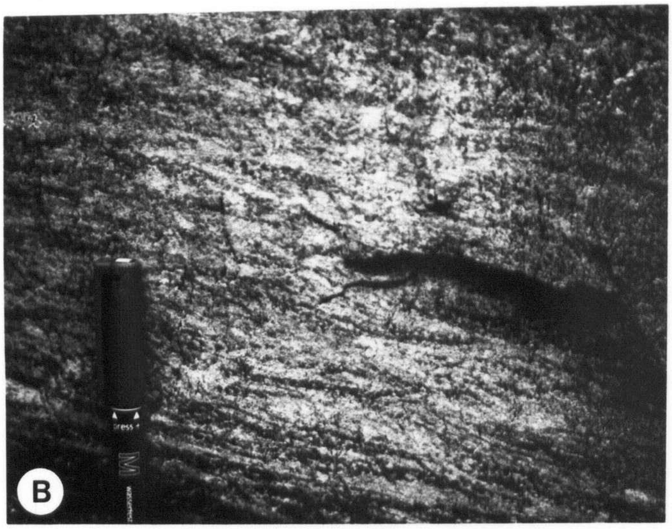
Medium grained, moderately well sorted, sandstone units ranging from 2 to 18 m in thickness dominate the Spatsizi Member. Sandstone units have channeled bases and commonly contain pebble lag deposits in the lower portions of the Member.

The majority of the sandstones exhibit medium scale horizontal stratification. Small scale (5 to 10 cm) tabular cross-stratification (Plate 7a), trough cross- stratification and ripple cross-stratification (Plate 7b) are less abundant. Convolute bedding is also present, but limited to the uppermost sandstones (Plate 7c). Locally, pebble zones, carbonaceous fragments and wisps, and calcareous nodules occur.

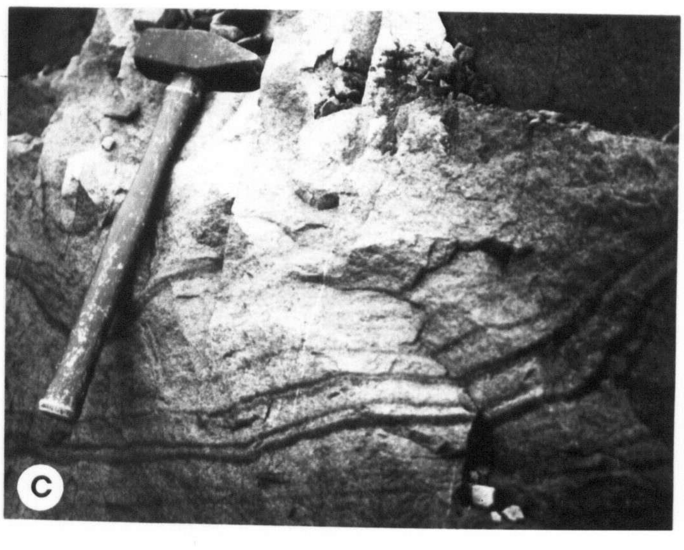
Recessive, black mudstone up to 30 m thick is commonly the only fine grained lithology except for local, thin fine grained sandstone units containing mudstone rip-up clasts and minor flaser bedding. A limited number of tuff horizons, up to 2 m thick, are locally present in the lower portion of the Spatsizi Member.

Plate 7. Characteristics of the Spatsizi Member sandstones.

7a. Small scale tabular cross-stratification.



7b. Ripple cross-stratification



7c. Faintly convoluted and contorted bedding.

SPATSIZI MEMBER - INTERPRETED DEPOSITIONAL ENVIRONMENT

Fining upwards sediments of the Spatsizi Member are cyclical, in contrast to sediments of the Tatlatui and Laslui Members. Well developed cyclicity results from topographic differentiation between channels and overbank areas in river systems (Rust, 1984). The fining upwards sequences of the Spatsizi Member have previously been interpreted as meandering river deposits (Eisbacher, 1974). However, both the braided Donjek river, Yukon (Rust, 1972) and the braided South Saskatchewan river (Cant, 1978) produce fining upwards cyclical deposits similar to the Spatsizi sequence.

There are no absolute criteria for distinguishing cyclical deposits of a distal braided river from meandering river deposits. Generally though, trough cross strata are more abundant than planar cross strata within a meandering river deposit, in contrast to the dominance of planar cross strata in the Spatsizi Member. In meandering river deposits, planar cross strata are limited to scroll bar deposition (Jackson, 1978), whereas in braided river deposits, planar cross-strata can develop at any level within the sequence (Cant, 1978), and hence are more abundant, similar to the occurrence of planar cross-strata in the Spatsizi sequence. Also, the subordinate amount of overbank mudstone deposits within the Spatsizi Member suggests that the river system was free to migrate across the alluvial plain, unrestricted by stabilized overbank areas. Unrestricted flow would favor a braided system over a meandering one (Schumm, 1981).

Deposits of the braided South Saskatchewan river described by Walker (1976) and summarized by Miall (1977) very closely resemble the repetitive sandstone/mudstone deposits of the Spatsizi Member. Both deposits fine upwards beginning with intraclasts on a channeled surface, interpreted as a channel lag. In the South Saskatchewan River, the channel lag is overlain by trough cross strata which are overlain by sets of planar cross-strata interpreted as deposits of sandy foreset bars (Walker, 1976). But overlying the basal channel lag in the Spatsizi sediments are sandstones dominated by planar cross-stratification, almost to the exclusion of trough cross-stratification. Both the South Saskatchewan and Spatsizi sequences end with rippled sandstone and mudstone of varying proportion. Trough cross-stratification within the South Saskatchewan river is not always well-defined (Cant, 1978), and thus poor preservation may explain the sparse occurrence of trough cross-stratification within the Spatsizi sediments.

Local occurrences of convolute bedding in the uppermost Spatsizi sediments are interpreted as the product of increased shear stress due to an increased current velocity as a result of a sudden rise in turbulence.

Sediments of the Spatsizi Member are most similar to the braided alluvial model S-II of Rust (1978), and the model by Miall (1978) based on the South Saskatchewan River. Both models consist of fining upward sandstone cycles, deposited by braided rivers transitional to meandering rivers that occupy an alluvial plain environment, (Figure 13).

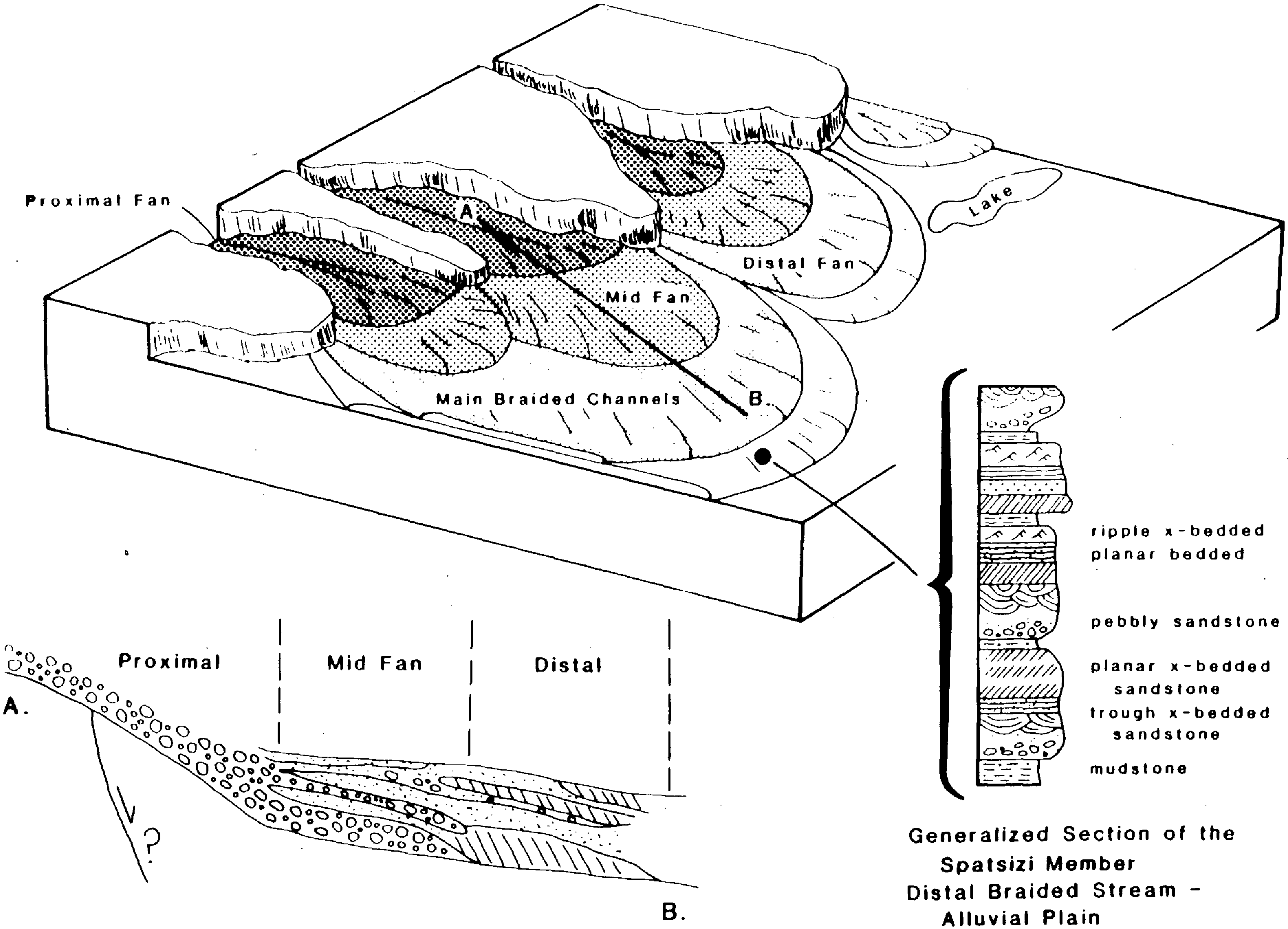


Figure 13 Interpreted depositional environment of the Spatsizi Member

PETROLOGY OF THE SUSTUT GROUP

PETROGRAPHY AND MINERALOGY

Volcaniclastic Sediments

Tuffs range in color from aqua to green to buff, and weather a characteristic chalky white color. Tuffs commonly grade into tuffaceous mudstone and siltstone beds. Both vitric and crystal tuffs were originally deposited in the Brothers Peak Formation. Subsequently, the vitric shards have been replaced by the zeolites, heulandite and laumontite as well as quartz, albite and clay minerals (see the section on diagenesis for further discussion). Other framework grains include plagioclase, quartz and minor biotite. Weathering of tuff beds has commonly produced bentonites, which vary in color from light green to dark yellow.

Volcanic dikes

Red-brown weathering, volcanic dikes occur locally throughout the study area and are generally vesicular, porphyritic andesites. The dikes are less than 1 m thick and are nearly vertical in orientation. Augite phenocrysts are typically the largest and most abundant, with subordinate phenocrysts of orthopyroxene, olivine, and plagioclase. Olivine phenocrysts are altered to a reddish brown idingsite. Roughly one quarter of the vesicles are partially filled with calcite giving a local amygdaloidal texture.

Conglomerates

Pebble orthoconglomerate is the main lithology in the coarse grained lithofacies of the Tatlatui Member. In the Brothers Peak Formation, cobble-pebble orthoconglomerate dominates the lower Laslui Member, whereas the coarse grained lithofacies of the upper Laslui Member consists of granule ortho- and paraconglomerates. In the Spatsizi Member pebbles occur locally in sandstones as a lag deposit but conglomerate is absent.

In the orthoconglomerates of the Tatlatui Member, clasts are rounded to subrounded and are dominantly composed of green, grey and black chert, with lesser amounts of volcanic, sedimentary and granitic rock fragments. The matrix is composed of subangular to subrounded chert; subangular volcanic and sedimentary rock fragments, quartz, plagioclase feldspar, micas and clay minerals.

Orthoconglomerates of the lower Laslui Member, are composed of subrounded, bladed to equant shaped clasts. The clasts consist of equal amounts of black and grey chert, quartz and volcanic rock fragments with lesser amounts of sedimentary and granitic rock fragments. Locally, zones of mudstone rip-up clasts occur. Matrix is composed of subangular to subrounded chert, quartz, volcanic and sedimentary rock fragments, plagioclase feldspar, micas and clay minerals.

The coarse grained lithofacies of the Upper Laslui Member consists of orthoconglomerate "A" and "B" as well as paraconglomerates. Orthoconglomerate "A" is composed of subrounded to angular clasts. Clasts are composed of green, grey and locally red chert, green volcanic rock fragments (including tuff) and grey sedimentary rock fragments, in approximately equal abundances. The matrix is composed of subangular to subrounded chert, quartz, volcanic and sedimentary rock fragments with lesser amounts of plagioclase feldspar, mica and clay minerals.

Orthoconglomerate B is composed of subangular to angular clasts of dominantly red and green chert and volcanic clasts (including tuff), with lesser amounts of grey chert, quartz, and granitic and sedimentary rock fragments. The matrix is mainly composed of clay. Orthoconglomerate "B" is commonly weathered.

The very angular to subangular clasts of the paraconglomerates are dominantly composed of red, maroon and green volcanic rock fragments, green, red, black chert, and sedimentary rock fragments, with subordinate quartz and granitic rock fragments. The tuffaceous matrix weathers to a dark brown and fresh colors are various shades of green.

Sandstone

A total of 75 sandstones were examined in thin section; 27 were selected for modal analysis. The results, along with heavy minerals, sorting and average clast size are shown in Tables 1-4. Using Folk's (1968) sandstone classification, 13 of the samples are litharenites, 7 are feldspathic litharenites, and 7 are lithic arkoses (Figure 14). The sandstones generally contain less than 5% original matrix, which according to Folk (1968), classifies them as submature.

Average grain size ranges from very fine sand to very coarse sand and locally include granule to pebble sized clasts. Quartz, chert, plagioclase feldspar and volcanic rock fragments are the main framework grains, with lesser amounts of sedimentary and metamorphic rock fragments, orthoclase, micas, chlorite, calcite and heavy minerals. The matrix is composed of smectite, celadonite, kaolinite, zeolites, quartz, albite and minor clinozoisite and sphene. In the upper Laslui Member the matrix is commonly highly tuffaceous. Cement is ubiquitous; and the type of cement present is controlled by post-depositional alteration.

The degree of rounding, sorting and sphericity is highly variable. Most samples are poorly to moderately sorted, with angular quartz, and subrounded chert, feldspar, and volcanic rock fragments. Generally, quartz has a low sphericity whereas chert, feldspar and volcanic rock fragments have moderate to moderately high sphericity.

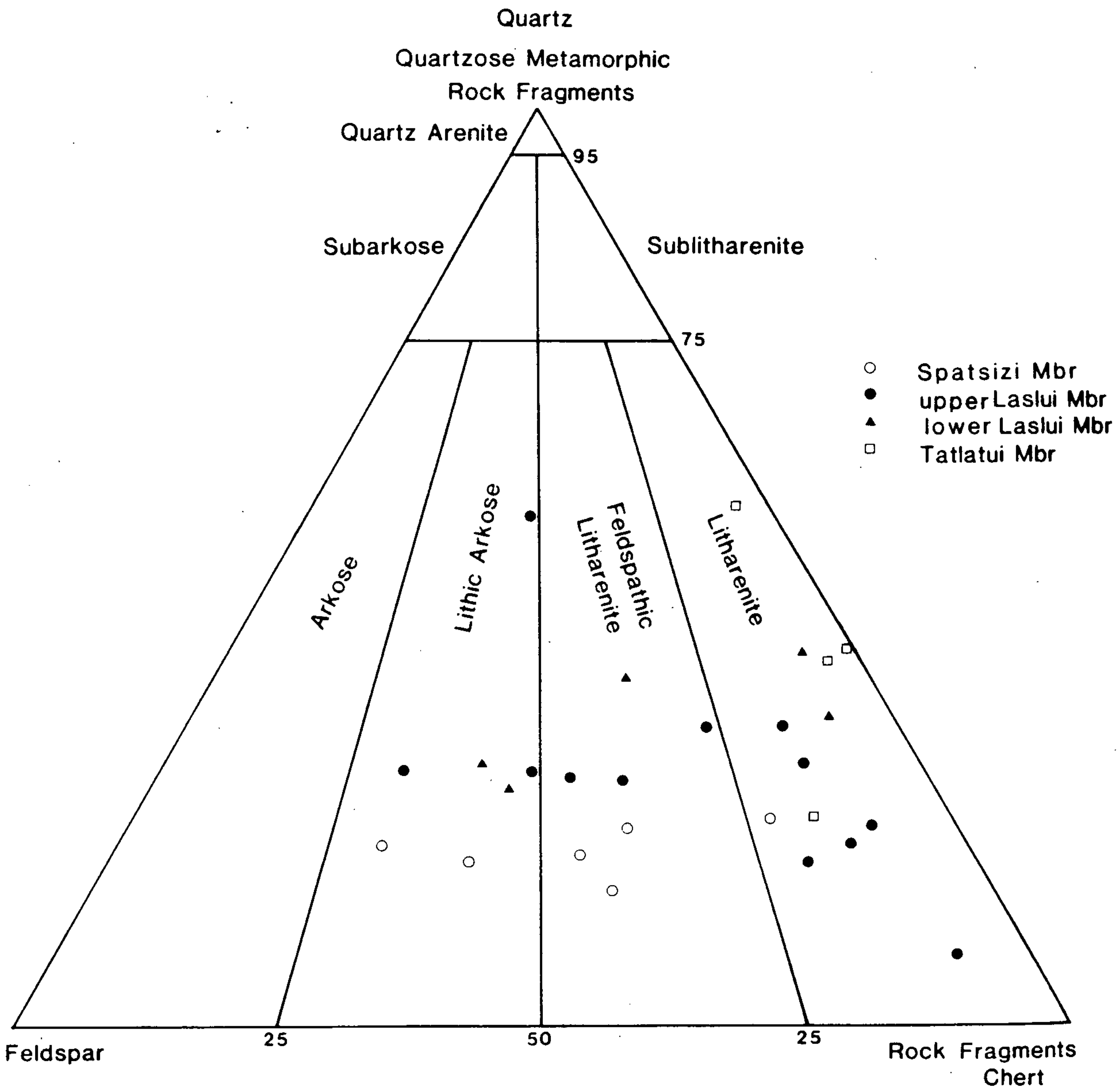


Figure 14. A triangular diagram illustrating the composition of the Sustut Group sandstones.

Tables 1-4

Location, grain size, modal analysis of detrital clasts, heavy minerals and cement types of representative samples from the Tango Creek and Brothers Peak Formations.

Key

Modal Analysis - Detrital Clasts

Q - Quartz
Ch - Chert
Ps - Plagioclase Feldspar
Ks - Potassium Feldspar
SR - Sedimentary Rock Fragments
VR - Volcanic Rock Fragments
MR - Metamorphic Rock Fragments
Mi - Mica
Og - Organics

Cement Types

Cl - Clay
Ca - Calcite
Qtz- Quartz
Ab - Albite
Hl - Heulandite
Lm - Laumontite

Grain Size

Cg - Conglomerate
VCs- Very Coarse Sand
Cs - Coarse Sand
Ms - Medium Sand
Fs - Fine Sand
VFs- Very Fine Sand

Heavy Minerals*

Ep - Epidote
Cl - Clinozoisite
Zi - Zircon
R - Rutile
T - Tourmaline
Gt - Garnet
Sp - Sphene
Ap - Apatite
CPy- Clino-pyroxene
H - Hornblende
OPy- Ortho-pyroxene
Sl - Spinel
Op - Opaques (Magnetite and Ilmenite)

tr - trace

* - heavy minerals separated for analysis

( )- estimated percentages for samples not point counted

Table 1

Tango Creek Formation

Sample No.	Metres Above Base	Grain Size	Modal Analysis - Detrital Clasts%									Heavy Minerals	Cement Type
			Q	Ch	Ps	Ks	SR	VR	MR	Mi	Og		
S2-26	0	Cg	(20)	(30)	(5)	(-)	(15)	(25)	(-)	(tr)	(tr)	--	Ca,Cl,Qtz
S2-28	25	Ms	32	16	6	5	10	21	tr	tr	tr	Ep	Cl, Ca,Qtz(10)
S2-29	30	Fs	(35)	(15)	(20)	(-)	(7)	(9)	(7)	(4)	(tr)	Ep,Zi,R,Gt,Ap,H, Sl,Op	Ca,Cl,Qtz
S2-31	65	Ms	25	35	5	-	4	tr	3	3	-	--	Ca,Cl (21)
S2-36	115	Fs	(no analysis)									Zi,R,T,Gt,H,Op	Cl,Ca
S3-80	375	Ms	47	20	3	tr	11	7	3	4	tr	Ep, Op	Cl (3)
S6-173	160	Ms	23	27	15	11	6	9	3	tr	-	Ep,Zi,R,T,Gt,Sp H,OPy,Sl,Op	Cl (3)

Table 2

lower Laslui Member

Sample No.	Metres Above Base	Grain Size	Modal Analysis - Detrital Clasts%									Heavy Minerals	Cement Types
			Q	Ch	Ps	Ks	SR	VR	MR	Mi	Og		
S2-41	180	Cs	25	29	5	tr	11	15	tr	-	-	Ep,Cl,Op	Qtz,Ca,Cl(14)
S2-42	195	Ms	18	9	29	4	4	14	3	tr	tr	Cl,Op	Qtz,Cl(14)
S3-83	475	VCs	29	12	4	tr	8	26	4	3	-	Ep, Op	Cl,Qtz(12),lm(?)
S3-84	490	Ms	26	17	30	9	2	8	4	-	tr	Ep,Op	Ca,Cl(3), Qtz
S4-128	450	Cs	35	14	20	3	8	16	2	tr	-	Ep,Zi,R,T,Gt,Sp * Cpy,H,Op	Cl(tr),Qtz
S5-156	10	Cs	(no analysis)									Ep,Zi,R,Gt,Sp, * Ap,Cpy,Op	
S5-159	100	Fs	24	11	25	7	21	4	5	2	-	Ep,Cl,Zi,R,Gt, * Sp,Ap,CPy,Op	Ca,Cl
S5-165	300	Ms	23	27	15	11	9	9	-	tr	-	Ep,Cl,Zi,R,T(?)* Gt,Sp,CPy,H,Sl,Op	Cl,Ca(3)

Table 3

upper Laslui Member

Sample No.	Metres Above Base	Grain Size	Modal Analysis - Detrital Clasts%									Heavy Minerals	Cement Type
			Q	Ch	Ps	Ks	SR	VR	MR	Mi	Og		
S2-50	260	Ms	(15)	(25)	(20)	(-)	(15)	(25)	(tr)	(tr)	(-)	Ep,Zi,R,Gt,Sp, * CPy,H,OP	Qtz,Cl,Ab
S2-54	320	Ms	15	42	6	-	7	7	2	-	-	Ep,Op	Cl,Cl(18),Hl
S2-60	355	Ms	40	7	16	tr	4	5	3	tr	-	Ep,Op	Cl,Ca(14),Qtz
S3-95	625	Vcs	16	22	9	tr	18	16	2	-	-	Ep,R,Op	Cl,(16),Lm(?)
S3-101	760	Vcs	31	19	18	-	6	23	tr	tr	-	Ep,Op	Cl,Qtz,Lm(?)
S4-151	630	Ms	31	44	9	tr	3	5	tr	2	tr	Ep,Cl,Zi,R,T, * Gt,Sp,CPy,H,Op	Cl,Ca(3)
S5-168	350	Ms	24	14	34	9	tr	5	tr	3	tr	Ep,Cl,Zi,R,T(?) * Gt,Sp,Ap,CPy,H,Op	Cl,Ca(10)
S7-207	625	Cs	27	15	9	2	6	38	-	tr	-	Ep,Zi,R,T(?),Gt, * Sp,CPy,H,OPy,Sl,Op	Cl(2),Qtz,Ab
S7-212	875	Cs	15	47	13	tr	3	19	-	tr	-	Ep,Cl,Zi,R,T(?), * Rt,Sp,CPy,H,OPy,Op	Cl,Ca(tr)
S8-221	330	Cs	25	19	26	6	10	15	-	tr	-	Ep,Zi,R,Gt, * Sp,CPy,H,Op	Cl,
S8-225	400	Cg	7	47	4	3	30	6	tr	-	-	Ep,Op	Cl(tr),Qtz,Ab

Table 4

Spatsizi Member

Sample No.	Metres Above Base	Grain Size	Modal Analysis - Detrital Clasts% Q	Ch	Ps	Ks	SR	VR	MR	Mi	Og	Heavy Minerals	Cement Type
S2-62	425	Ms	12	9	27	4	6	25	2	tr	-	Ep,Op	Cl,(10)
S2-63	430	Ms	20	13	23	6	4	25	tr	tr	-	Ep,Cl,Zi,R,T, * Gt,Sp,CPy,H,Op	Cl,Qtz(9),Ab
S2-65	500	Fs	18	14	25	26	tr	9	-	tr	-	Ep,Zi,R,T,Gt, * Sp,H,Sl,Op	Cl,Ca(8)
S3-110	1160	VFs	17	18	27	6	tr	20	-	4	5	Ep,Op	Cl,(4)
S5-169	410	Cs	24	27	15	2	10	17	2	tr	-	Ep,Op	Cl(tr),Hl
S7-214	963	Ms	17	6	34	13	2	26	-	tr	-	Ep,Cl,Zi,R,T(?), * Sp,CPy,H,OP	Cl(2),Qtz

Quartz comprises 2 to 60% of the framework grains, averaging 25%. The lowest percentage is from the upper Laslui Member gravity flows. Quartz is a major component in sandstones of the Tatlatui and lower Laslui Members. Monocrystalline quartz with straight to slightly undulose extinction is slightly more abundant than polycrystalline quartz. Needle-like microlite inclusions are common within monocrystalline quartz (Plate 8a). Quartz overgrowths (Plate 8b) are rare. Polycrystalline quartz grains are unimodal or bimodal with respect to internal crystal size, and show sutured or less commonly straight internal contacts (Plate 8c). Quartz grains are generally angular and have a low sphericity, except in the Spatsizi Member, where the grains are subrounded and have a moderate sphericity.

Chert comprises 1 to 50% of the framework grains averaging 30% The higher percentage is invariably from coarser grained samples. Chert occurs in a wide variety of colors including shades of grey, green, black and red and have a cryptocrystalline and/or microcrystalline texture. Some grains contain argillaceous material or chalcedony crystals and show circular remnant radiolarian(?) structures (Plate 9). External grain boundaries are indistinct if chert is also present as matrix. Chert grains are subrounded to rounded and have low to moderate sphericity.

Feldspar content ranges from 5 to 40% of the total framework grains. Plagioclase is the predominant feldspar comprising up to 75% of the total feldspar, with subordinate amounts of orthoclase. Plagioclase in volcanic rock fragments

Plate 8.

8a. Thin section photomicrograph of quartz with needle-like microlite inclusions.

8b. Thin section photomicrograph showing quartz overgrowths.

8c. Thin section photomicrograph of a bimodal polycrystalline quartz grain with sutured internal contacts. Nicols crossed.

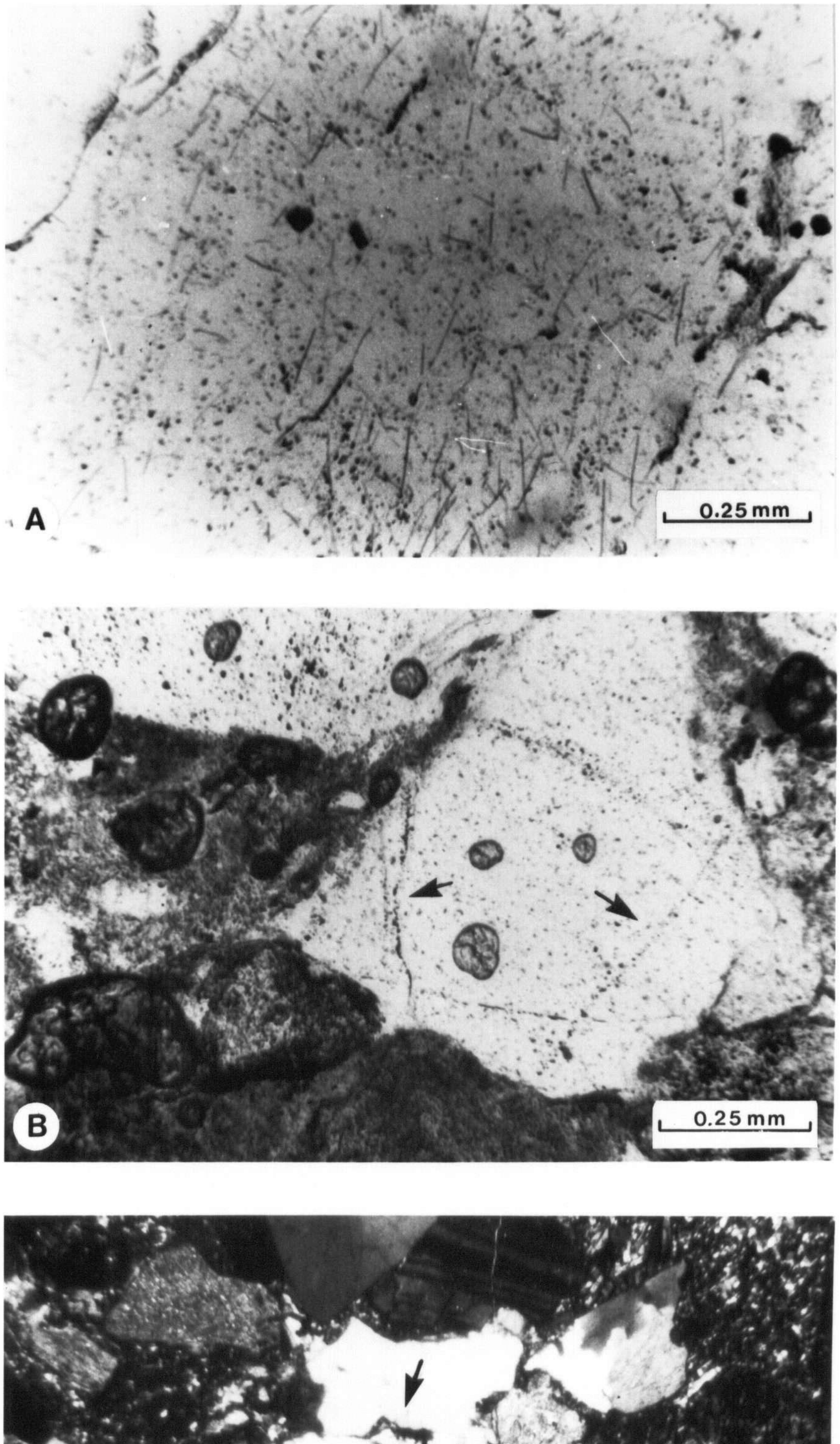
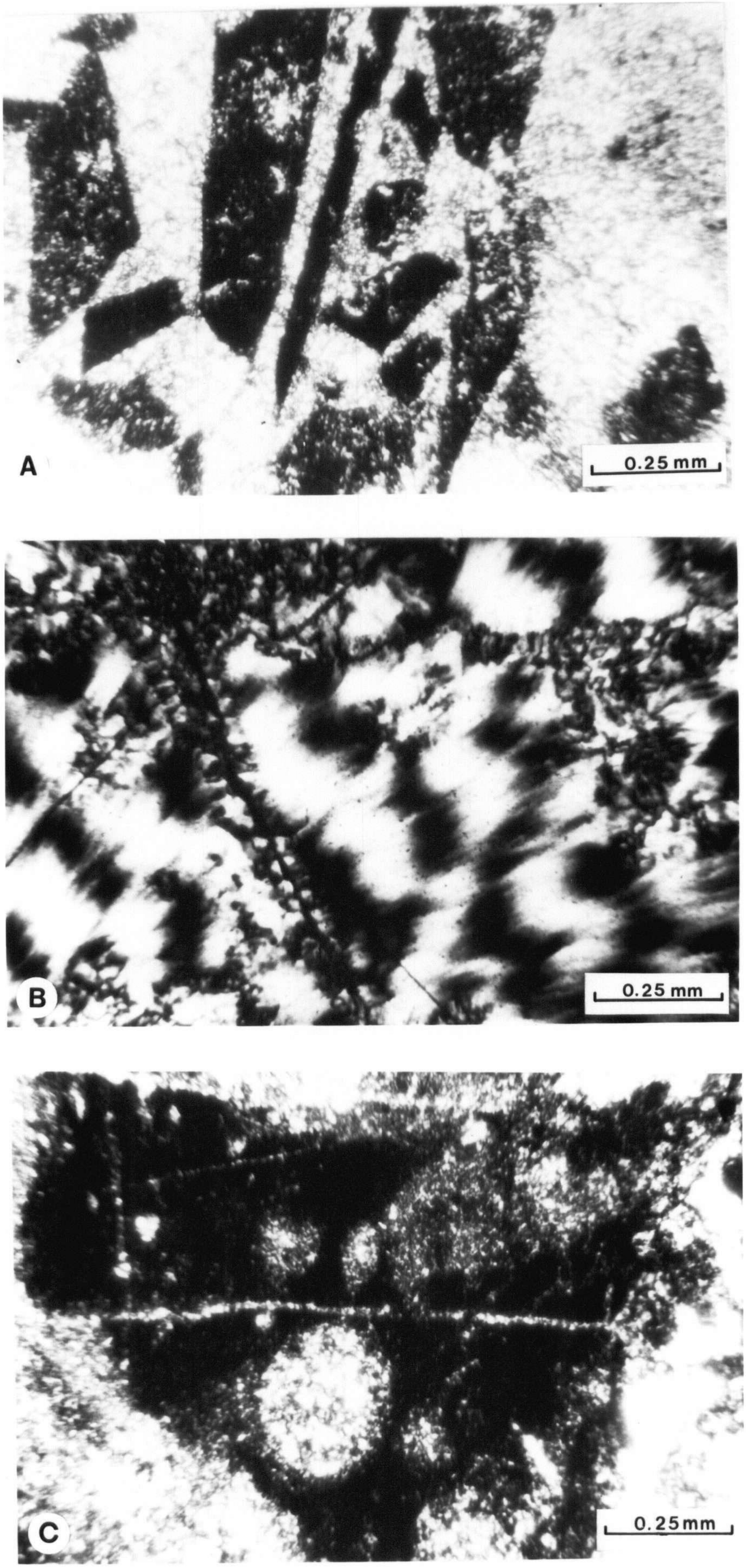

A
0.25 mm
B
0.25 mm
C
0.5 mm

Plate 9.

9a. Thin section photomicrograph of chert with argillaceous material. Nicols crossed.

9b. Thin section photomicrograph of chalcedony (zebraic?). Nicols crossed.

9c. Thin section photomicrograph of chert with circular fossil(?) remnants. Nicols crossed.


A
0.25 mm
B
0.25 mm
C
0.25 mm

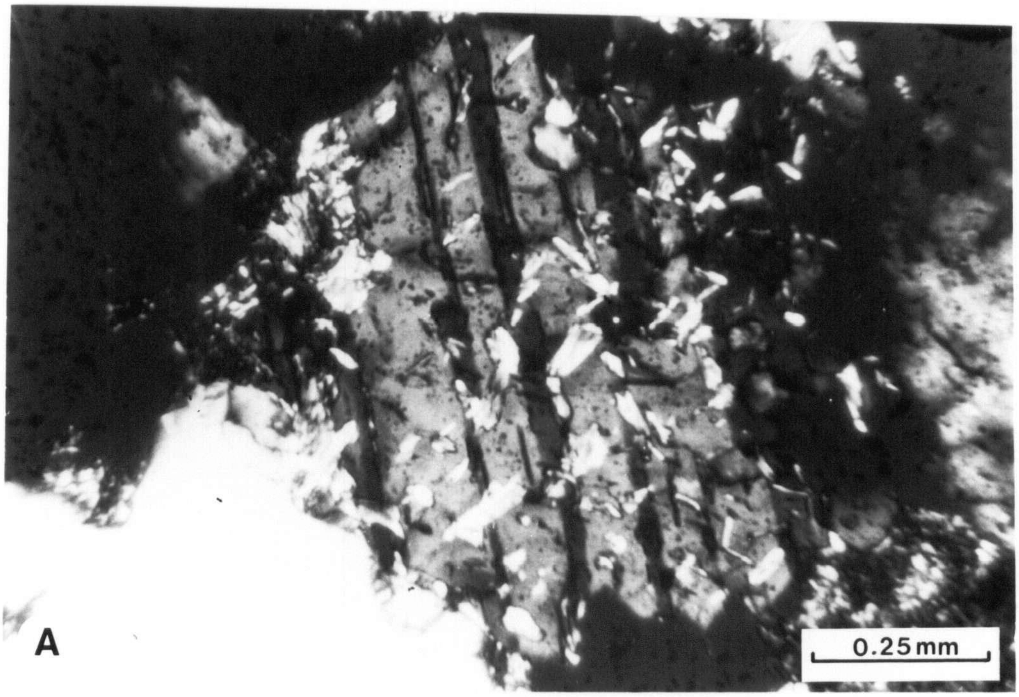
is excluded from the feldspar component, thus where volcanic rock fragments are abundant the plagioclase count may be low. Plagioclase is highly variable in habit, ranging from unaltered crystal laths to extremely altered grains without clear boundaries. Alteration is generally to mica, epidote group minerals, and calcite (Plate 10). Generally, plagioclase (An 25 - An 45) within tuffs and tuffaceous sediments is unaltered, whereas within non-tuffaceous sediments it is highly altered, making composition determinations difficult.

Orthoclase was only identified in the point counted sections, largely because of the difficulty in recognizing unstained orthoclase. Orthoclase is a minor constituent comprising less than 30% of the total feldspar. Orthoclase grains are subrounded and have moderate sphericity.

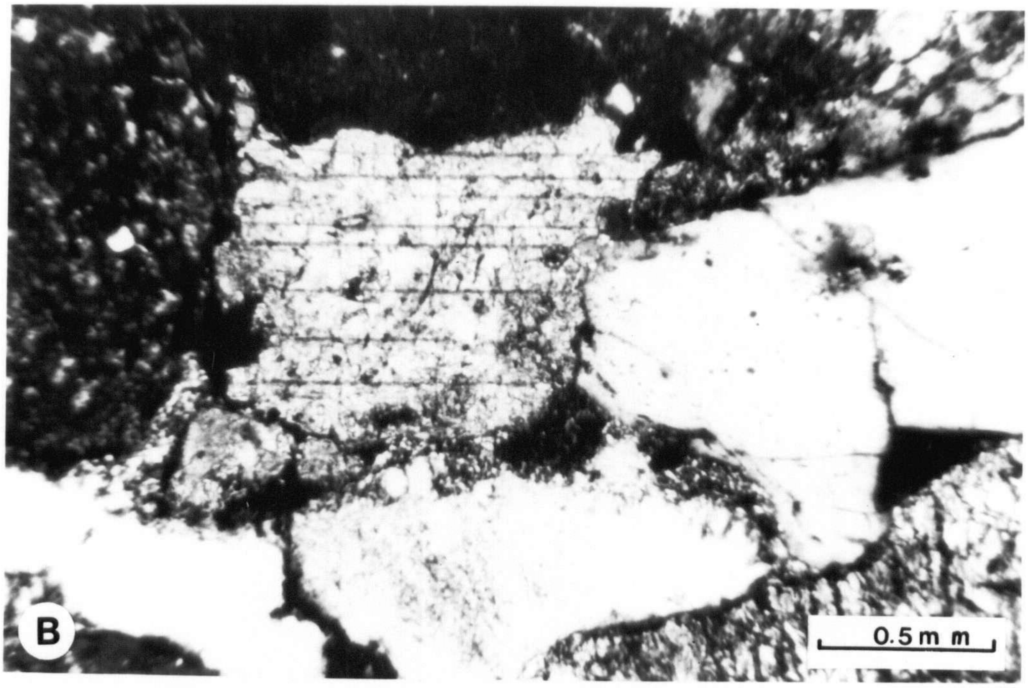
Volcanic rock fragments comprise 0 to 40% of the framework grains, averaging 20% and include mafic to intermediate rock fragments with plagioclase phenocrysts. The phenocrysts are lath-like, generally unaltered, and in some samples have a trachytic texture (Plate 11). The majority of volcanic rock fragments are round to subrounded and have a moderate to high sphericity.

Sedimentary rock fragments generally comprise from 0 to 25% of the framework grains, but may reach up to 50% in the Laslui Member. Sedimentary rock fragments are invariably clastic and dominantly mudstone, siltstone and tuff with rare fine sandstone fragments. Color ranges from brown to almost

Plate 10. Thin section photomicrographs of plagioclase feldspar.

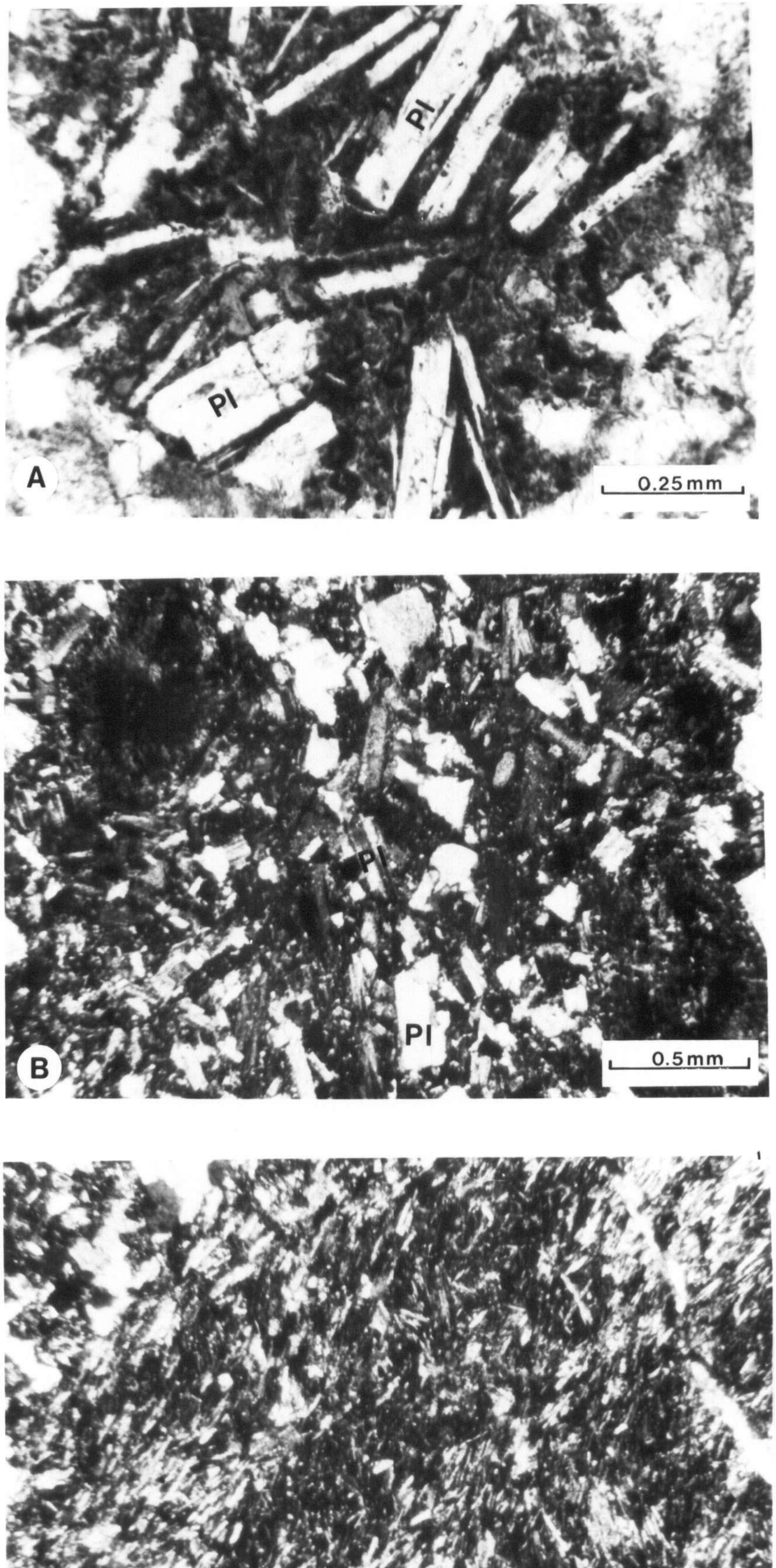


10a. Alteration to mica. Nicols crossed.



10b. Alteration to calcite. Nicols crossed.

Plate 11. Thin section photomicrographs illustrating the various textures of volcanic rock fragments Plagioclase (Pl) is the main phenocryst. 10c shows trachytic texture of the plagioclase laths. 10b. and 10c. nicols crossed.


Pl
Pl
A
0.25 mm
Pl
Pl
B
0.5 mm
C
0.5 mm

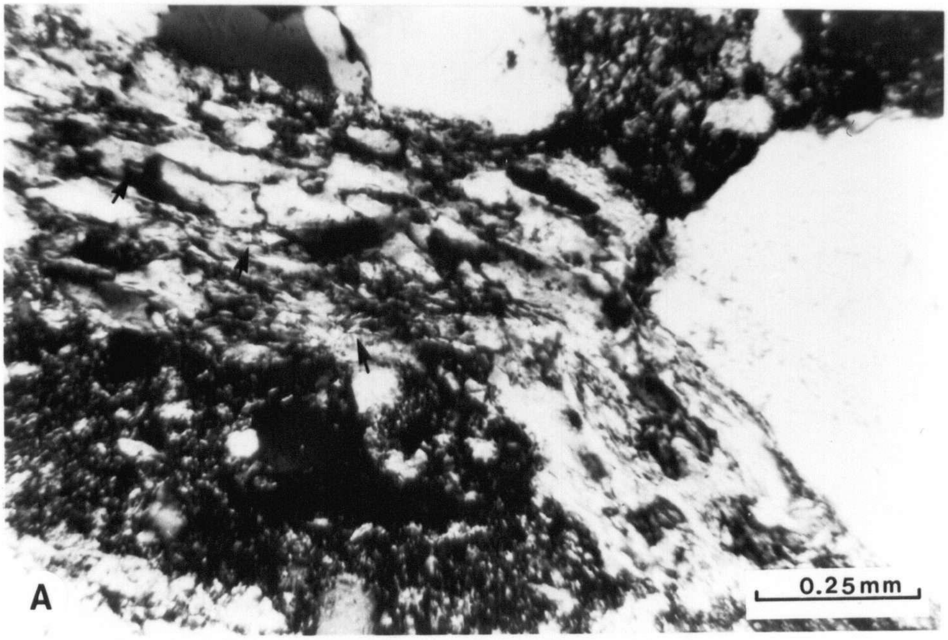
red and includes various amounts of organic matter in the mudstones, siltstones and sandstones. Tuff fragments are a variety of colors including red, maroon, green, aqua, and buff. Sedimentary rock fragments are round to subrounded and have low to moderate sphericity.

Metamorphic rock fragments are a minor constituent, reaching a maximum of 5% of the framework grains in the Spatsizi Member. Metamorphic rock fragments are limited to schist fragments composed of elongate quartz crystals, with sutured contacts, and an abundance of mica (Plate 12a). Stretched polycrystalline quartz grains with sutured contacts, and lacking mica, were not recorded here as "Metamorphic rock fragments", but rather as quartz grains. Thus the overall metamorphic rock fragment component may be underestimated. Identified metamorphic rock fragments are subrounded and have a low sphericity.

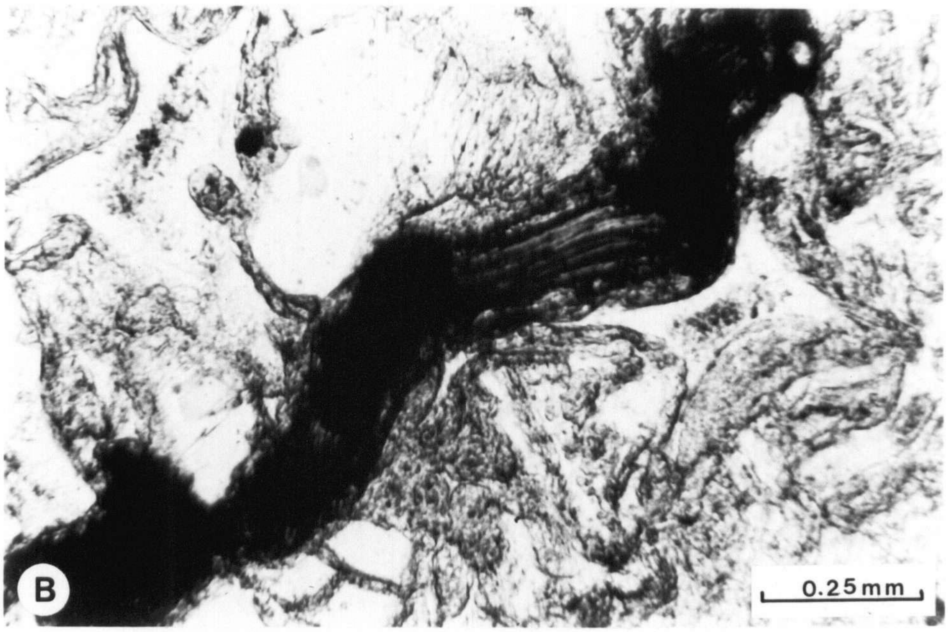
Granitic rock fragments are limited to conglomerate and coarse sandstone where they comprise less than 5% of the clasts. Granitic rock fragments tend to disintegrate on transport, which explains their absence in finer sediments. Composition ranges between granodiorite and granite.

Accessory detrital framework grains include mica, chlorite, calcite and heavy minerals. Mica is present in nearly all samples, but generally comprises less than 1% of the total grains. The main accessory minerals in the Laslui Member are chlorite and muscovite, and in the Tatlatui and Spatsizi Members are chlorite, muscovite and biotite. Typically, the original habit of mica grains is hard to

Plate 12.



12a. Thin section photomicrograph of a metamorphic rock fragment. Note the elongate and stretched internal grains. Arrows point to mica flakes within the rock fragment. Nicols crossed.



12b. Thin section photomicrograph of a bent or kinked mica (biotite).

distinguish owing to diffuse grain boundaries. Also, color appears to have been "leached" from biotite grains due to weathering (Folk, 1968). In the Spatsizi Member, detrital biotite and muscovite are invariably kinked and show sharp grain boundaries (Plate 12b). Detrital chlorite is pleochroic in shades of green and has anomalous blue-brown interference colors. Only a few grains of blocky detrital calcite were found, and within a limited number of samples.

Heavy Minerals

Results of the heavy mineral analysis are listed in Table 1. The heavy minerals are divisible into the following four suites based on probable origin.

1) STABLE SUITE: zircon, rutile, tourmaline

2) VOLCANIC SUITE: apatite, clinopyroxene, hornblende, magnetite, ilmenite, and zircon(?).

3) PLUTONIC SUITE; augite, hornblende, sphene.

4) METAMORPHIC SUITE; garnet, clinopyroxene, hornblende, epidote (group).

The stable suite is composed of minerals resistant to weathering and recrystallization to some degree. Thus zircon, rutile, and tourmaline may be polycyclic, derived from pre-existing sediments. Minerals of the stable suite are present in all the sections analyzed. Zircon is the most abundant stable mineral. It is colorless to light brown and is subhedral to euhedral in shape (Plate 13a). Rutile, the next most abundant, is angular with an orange brown color in plane polarised light. Tourmaline is less abundant occurring in trace amounts or up to 10's of grains per sample. It is pleochroic in shades of brown or green and is well rounded.

Overall, minerals of the volcanic suite are the most abundant. Apatite is abundant in a few samples but represented by only 1 or 2 grains in other samples. It is generally euhedral and weakly pleochroic. Apatite is thought to be indicative of an eruptive volcanic source (Folk, 1968), although may occur in other igneous rocks and in some sediments. Magnetite and ilmenite are ubiquitous and by far the most abundant heavy minerals ranging in grain shape from angular to well rounded. Augite is of minor abundance and generally subrounded in shape (Plate 13b). Also, zircons showing an idiomorphic crystal outline are likely derived from a volcanic source (Folk, 1968).

The plutonic suite is poorly represented with sphene the only characteristic mineral (Plate 13c), and furthermore, some of the sphene may have formed authigenically. Sphene is of minor abundance and generally occurs as large grains with irregular crystal outlines, which are presumed to be authigenic. The few sphene grains with good crystal outlines are smaller and interpreted as detrital. All sphene grains are characteristically brown in plane polarised light. Augite is of variable abundance and distribution, in the plutonic suite, and is subangular to subrounded in shape. Hornblende is of minor abundance, typically pleochroic from brown to green and has subrounded form.

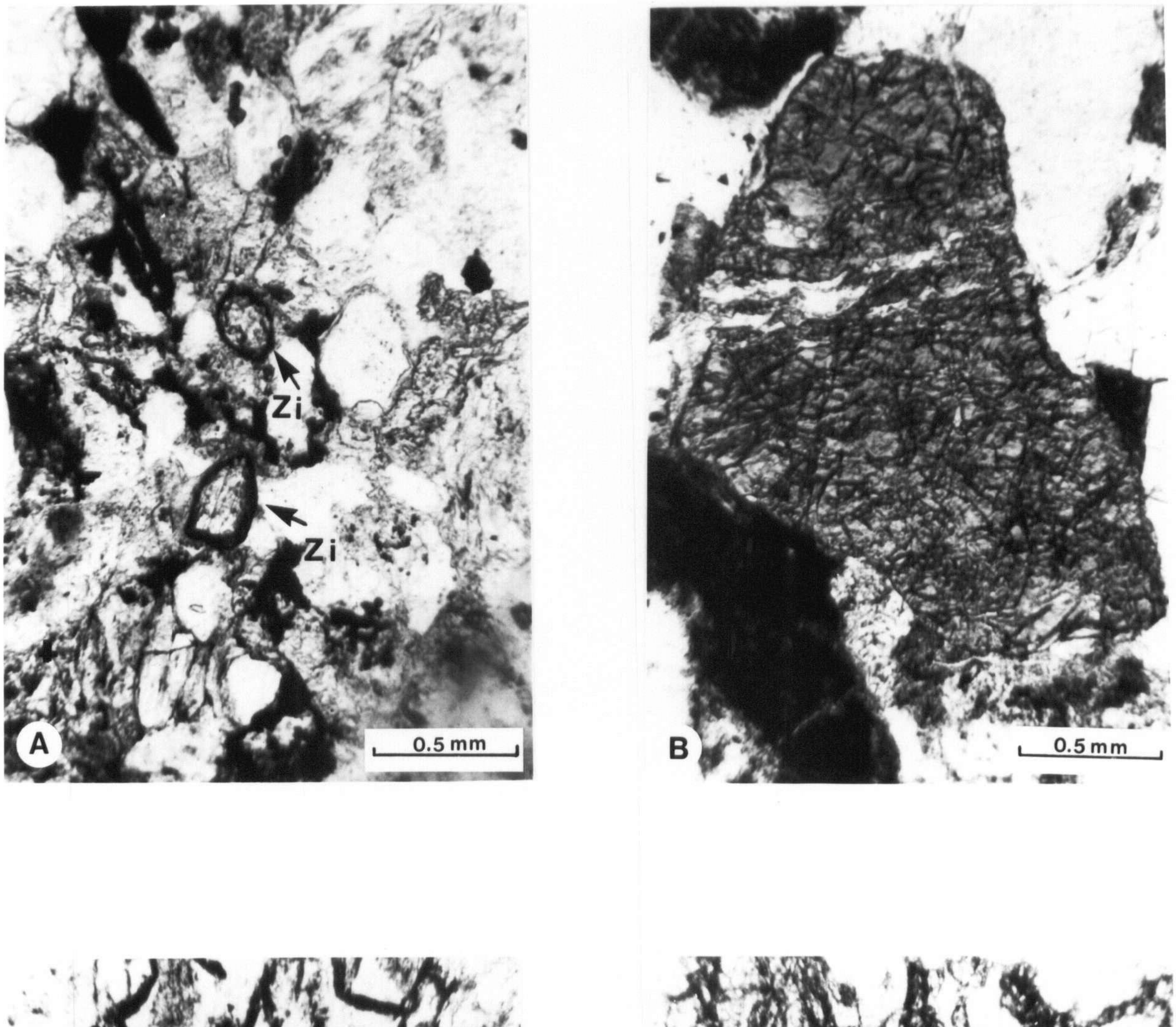
The metamorphic suite is characterized by garnet and epidote (group), whereas clinopyroxene, hornblende and sphene

Plate 13.

13a. Thin section photomicrograph of subhedral zircon (Zi) grains.

13b. Thin section photomicrograph of augite.

13c. Thin section photomicrograph of a hornblende grain. Pleochroic green to brown.


Zi
Zi
A
0.5 mm
B
0.5 mm
C
0.5 mm
D
0.5 mm

may also represent an igneous source. Garnet ranges from very angular to well rounded and is colorless to pink in thin section. Garnet, probably almandine, is of moderate to minor abundance, but is nearly ubiquitous. Epidote and clinozoisite are invariably present and commonly abundant. Epidote is colorless, and clinozoisite is pleochroic yellow-green in thin section. The grain shape of epidote and clinozoisite is either subrounded or a fine aggregate. Clinozoisite is likely derived from saussuritization of feldspars, based on appearance. Hornblende generally comprises less than 10 grains of any one sample but is present in most samples (Plate 13d). It is subrounded to subangular and shows green to brown pleochroism. Clinopyroxene (augite predominantly) is generally subangular.

Diagenesis

Volcanogenic sediments are characterized by highly reactive materials such as glass, plagioclase and volcanic rock fragments, all of which are very susceptible to hydration reactions. Diagenetic minerals common in volcanogenic sediments are clay minerals, zeolites, albite and calcite (Surdam and Boles, 1979). Early work concerning the diagenesis of volcanogenic rocks related the alteration mineralogy with stratigraphic position (Coombs et al., 1959). However more recent work by Boles and Coombs (1975); and Read and Eisbacher (1974) has demonstrated that the distribution of diagenetic minerals in volcanogenic sediments depends largely on fluid flow and original composition of the sediments, rather than stratigraphic position.

In the strata of the southern Sustut Basin the main diagenetic minerals are heulandite, laumontite, albite, smectite, celadonite, kaolinite, quartz and calcite. Identification was done optically and by X-ray diffraction. In the samples analysed there is a close correlation between sample composition, cementing agents and diagenetic history.

In the tuffs and tuffaceous mudstones the main framework grains are originally vitric shards, plagioclase, quartz and minor biotite. The originally vitric shards have been completely altered: most commonly to heulandite, less commonly to albite, and in one fine grained tuff sample laumontite replaces the vitric shards. Thin coatings of smectite, kaolinite and/or celadonite outline the originally vitric shards and vesicles. The shards and most vesicles are infilled with blades of heulandite (Plate 14a) and laumontite, or laths of albite, all oriented perpendicular to the clay rims. The vesicles are locally infilled with celadonite (Plate 14b). The non-vitric framework grains in tuffs and tuffaceous mudstones remain unaltered, except for biotite which has locally altered to celadonite.

In tuffaceous sandstones the framework grains consist mainly of unaltered plagioclase, quartz, chert, potassium feldspar, volcanic rock fragments, and lesser amounts of altered vitric shards. Quartz and albite are common as pore filling cement, with local occurrences of heulandite, and calcite. Smectite and celadonite commonly rim the framework grains and also locally fill pore spaces (Plate 14c,d).

In the non-tuffaceous sandstones the main framework grains are quartz, chert, plagioclase, sedimentary rock fragments, and volcanic rock fragments, with minor amounts of metamorphic rock fragments, micas and heavy minerals. Clay minerals and finely disseminated quartz-albite(?) are common as pore filling cement (Plate 14f). Laumontite occurs as a minor pore filling cement. Read and Eisbacher (1974) found laumontite to be more wide-spread in the non-tuffaceous sediments of the Sustut Group in the northern Sustut Basin.

Surdam and Boles (1979) outlined three basic types of reactions for the formation of zeolites, calcite, clays, albite and potassium feldspar as diagenetic phases in volcanogenic sediments: (1) hydration; (2) carbonatization (formation of carbonates); and (3) dehydration. Commonly

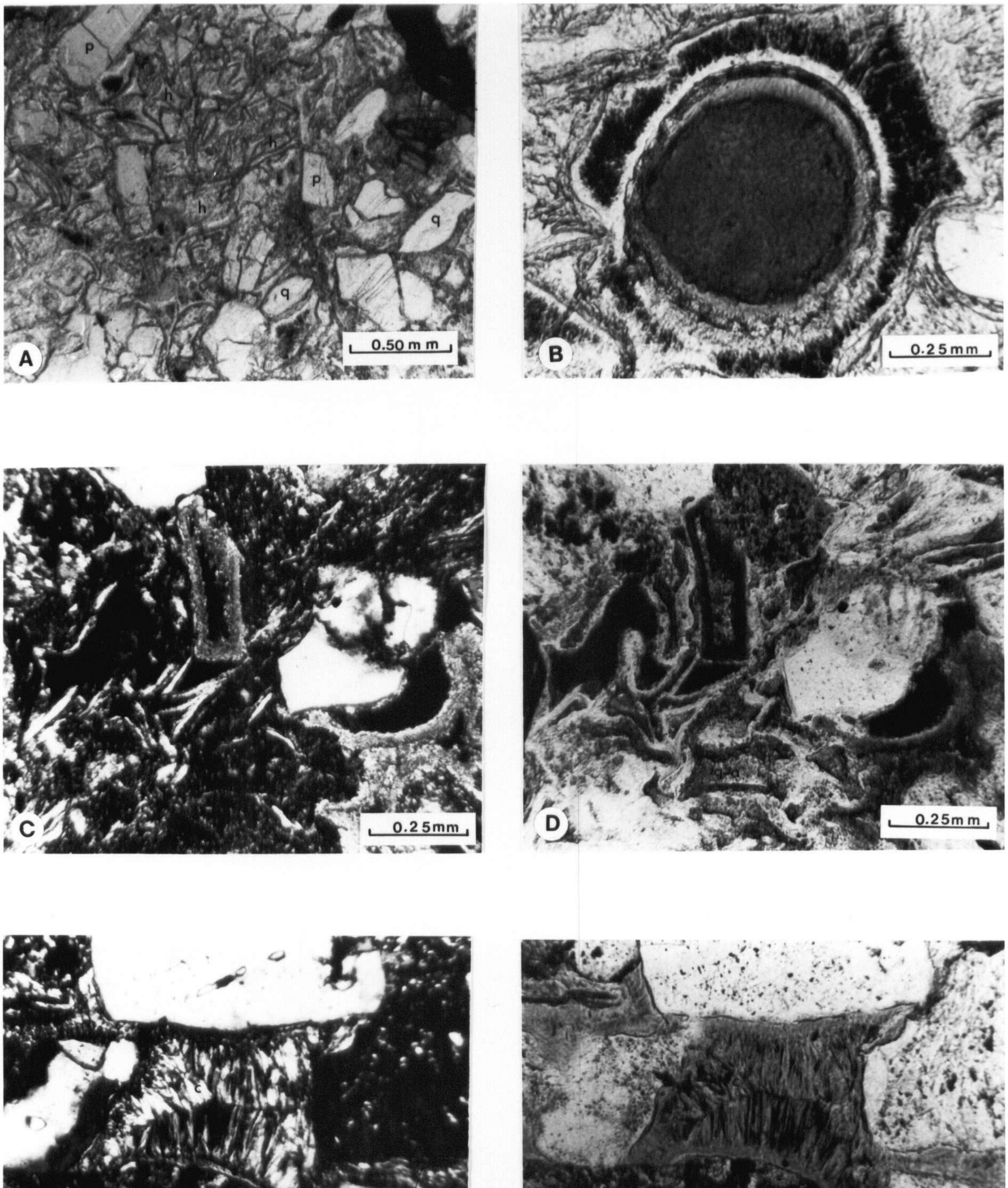
Plate 14. Thin section photomicrographs of cements.

14a. Tuff showing clay cement outlining originally vitric shards. Heulandite infills the shards (h). Other grains include quartz (q), and plagioclase (p).

14b. Excellent example of fibrous clay cement around an original vesicle in a tuff which is infilled with bright green celadonite.

14c-d. Tuffaceous sandstone showing clay rimming cement infilled with quartz (q) and albite(?) (a). 14a crossed nicols.

14e-f. Non-tuffaceous sandstone showing excellent fibrous celadonite (c) infilling pore spaces. 14e crossed nicols.


A
p
h
q
0.50 mm
B
0.25mm
C
0.25mm
D
0.25mm
E
0.25mm
F
0.25mm

hydration and carbonatization characterize early diagenesis, and dehydration characterizes later diagenesis.

In the Sustut Group, initial hydration reactions formed the nearly ubiquitous clay rimming cement, followed by open space filling by zeolites, albite, quartz, clay minerals and calcite. The permeability and porosity within the sediments resulted from primary porosity in matrix poor sandstones, secondary porosity from the dissolution of vitric shards and local fracture porosity. Virtually all of the porosity has been infilled by this "early" phase of diagenesis.

The alteration mineralogy is related to the proximity to tuffs or tuffaceous sediments. Heulandite generally occurs only in tuffs, and albite is most prevalent in the Brothers Peak Formation, suggesting that the formation of albite is also spacially related to tuffs and tuffaceous sediments. Laumontite and calcite occur throughout the Sustut Group, but particularly in non-tuffaceous sediments. Clay minerals and quartz are present throughout the Sustut Group.

The ubiquitous alteration of vitric shards released cations and silica into solution, supplying calcium for the formation of heulandite (and possible the anomalous occurrence of laumontite), and sodium for the formation of albite. Further calcium for the formation of laumontite, calcite and clay minerals in the non-tuffaceous sediments may have been supplied by the dissolution of fresh water shells (Read and Eisbacher, 1974).

K-Ar, whole rock age determinations of tuffs yielded dates of 53 and 49 Ma (Read and Eisbacher, 1974). These ages likely reflect the timing of alteration in the Sustut Group as opposed to the age of deposition because of the extensive alteration of tuffs, the low amount of biotite present, and in light of the Campanian to Maastrichtian palynological age dates.

In summary the following relationships typify the alteration within the Sustut Group:

1) the proximity to tuffs ultimately controls the type of alteration;

2) heulandite, albite, quartz and clay minerals typify altered tuffs and tuffaceous sediments;

3) laumontite, albite, calcite, quartz and clay minerals typify non-tuffaceous sandstones;

4) early hydration of vitric shards supplied the calcium for heulandite and some laumontite, and supplied sodium for the formation of albite; and

5) dissolution of fresh water shells may have supplied the remainder of the calcium for laumontite, smectite and calcite in the non-tuffaceous sediments.

PALYNOLOGY

An overall age range of Campanian to Maastrichtian is indicated by the palynomorphs present in the southern Sustut Basin. This age range is based on the presence of *Aquillapollenites* which does not occur in rocks older than Campanian and disappears at the end of the Maastrichtian (Rouse, pers comm., 1985). Other palynomorphs identified in samples located through out the study area by A. Sweet (pers comm., 1984) and G. Rouse (pers comm., 1985) are listed in the Appendix, and include; angiosperm pollen, gymnosperm pollen, spores, algal cysts, and recycled dinocysts of Late Cretaceous age. This assemblage suggests a very warm and humid climate existed at least in part during deposition of the Sustut Group (Rouse, pers comm., 1985).

COALIFICATION LEVEL

Six representative samples of carbonaceous mudstone and phytoclasts concentrated from sandstones, of the Tango Creek Formation and Brothers Peak Formation were analyzed for mean maximum vitrinite reflectance (Ro max). The lack of coal seams in the measured sections confined the number and type of samples available for organic maturation studies. Table 5 lists the determined value and location of each sample. The samples were composed dominantly of structureless vitrinite and minor inertinite, except for sample S4-129 which has a higher percentage of inertinite relative to the other samples. Vitrinite grains with dark oxidation rims and fractures were present in all samples. Ro max values ranged from 0.89% to 1.30%, corresponding to a coal rank of high volatile bituminous A to medium volatile bituminous coal (Teichmuller and Teichmuller, 1982). An anomalous value of 1.6% Ro max from sample S4-129 is attributed to local heating from a dike.

Assuming a normal geothermal gradient of 25-30°C/km and a maximum depth of burial for the Sustut Group of 2 000 m, a temperature in the order of 80° C would be expected. Such a temperature, with an effective heating time of 30 Ma, however should result in a coalification level of 0.59% Ro max (Bustin et al., 1983), substantially lower than the determined values of up to 1.3% Ro max. Thus in order to produce Ro max values of 1.3%, the maximum temperature would have been in the order of 122°C-147°C. Samples collected in the northern Sustut Basin by G. Eisbacher, yielded similarly high Ro max values, ranging from 0.99% to 1.7% (Bustin, 1984). Coal bearing sediments of a similar age to the Sustut Group, located to the north and south of the Sustut Basin, are of a lignite rank (Coal Resources of British Columbia, 1975), corresponding to an Ro max value of between 0.28% and 0.39%. Coal samples analyzed from the Middle to Upper Jurassic Bowser Lake Group, underlying the Sustut Group, yielded anomalously high values of up to 5.8% Ro max corresponding to a meta-anthracite rank (Bustin, 1984). These regionally high values indicate both the prolonged time period and regional extent over which high heat flow must have been present at least in part of the Canadian Cordillera. Anomalously high coalification levels for both the Sustut and Bowser Lake Groups, as suggested by Bustin (1984), may have resulted from: 1) exposure to high temperatures as a result of igneous intrusion accompanying the collision of the Stikine terrane, of composite terrane I, to the North American margin in Mesozoic time; and/or 2) regionally high heat flow in a back-arc basin associated with an easterly-dipping subduction zone underneath the coastal plutonic-volcanic arc complex to the west. Presently, both theories are feasible for explaining the regionally high heat flow during Mesozoic time in the Canadian Cordillera.

SAMPLE NO.	%Ro max	METRES ABOVE BASE
S3-92	0.89 ± 0.09	583
S4-129	1.50 ± 0.08	460
S4-140	1.12 ± 0.1	535
S7-188	0.97 ± 0.12	130
S7-192	1.08 ± 0.10	170
S7-211	1.20 ± 0.12	670

Table 5. Coalification level of samples from the southern Sustut Basin

PALEOCURRENT ANALYSIS

Paleocurrent measurements were determined on tabular and trough cross-stratification, and imbricated conglomerate clasts. Too few measurements were made in the Tatlatui Member and thus will not be considered here.

In the Brothers Peak Formation, a total of 286 measurements were made of which 119 were from imbricated pebbles in the lower Laslui Member, 99 were from cross stratification mainly in the upper Laslui Member and 68 were from cross-stratification in the Spatsizi Member. The principal paleocurrent direction was from the north or northwest during deposition of the lower Laslui Member. However, the principal paleocurrent direction during deposition of the upper Laslui Member was from the southwest. During deposition of the Spatsizi Member paleocurrent direction was from the west to northwest, similar to the lower Laslui Member.

PROVENANCE

Sandstones and conglomerates of the Sustut Group are characterized by low compositional stability and a submature to immature texture. Thus the composition of sandstones and conglomerates reflect the composition of the source and, combined with paleocurrent data, suggest probable source rocks. Results of the heavy mineral analysis were not diagnostic for determining a specific source rock or area. Further, results of the heavy mineral analysis did not show any trends between the Members of the Tango Creek and Brothers Peak Formations. Figure 15 illustrates the location and distribution of the principal lithological units of the inferred source areas and paleocurrent directions throughout deposition of the Sustut Group in the southern Sustut Basin.

In the Tatlatui Member of the Tango Creek Formation sandstones and conglomerates are relatively enriched with quartz, chert and granitic rock fragments. The Omineca Belt to the east of the Sustut Group is a likely source for the sediments, specifically from the unroofing of granitoid plutons that intruded the Omineca Belt, and from the Cache Creek assemblage, which is rich in chert and argillite.

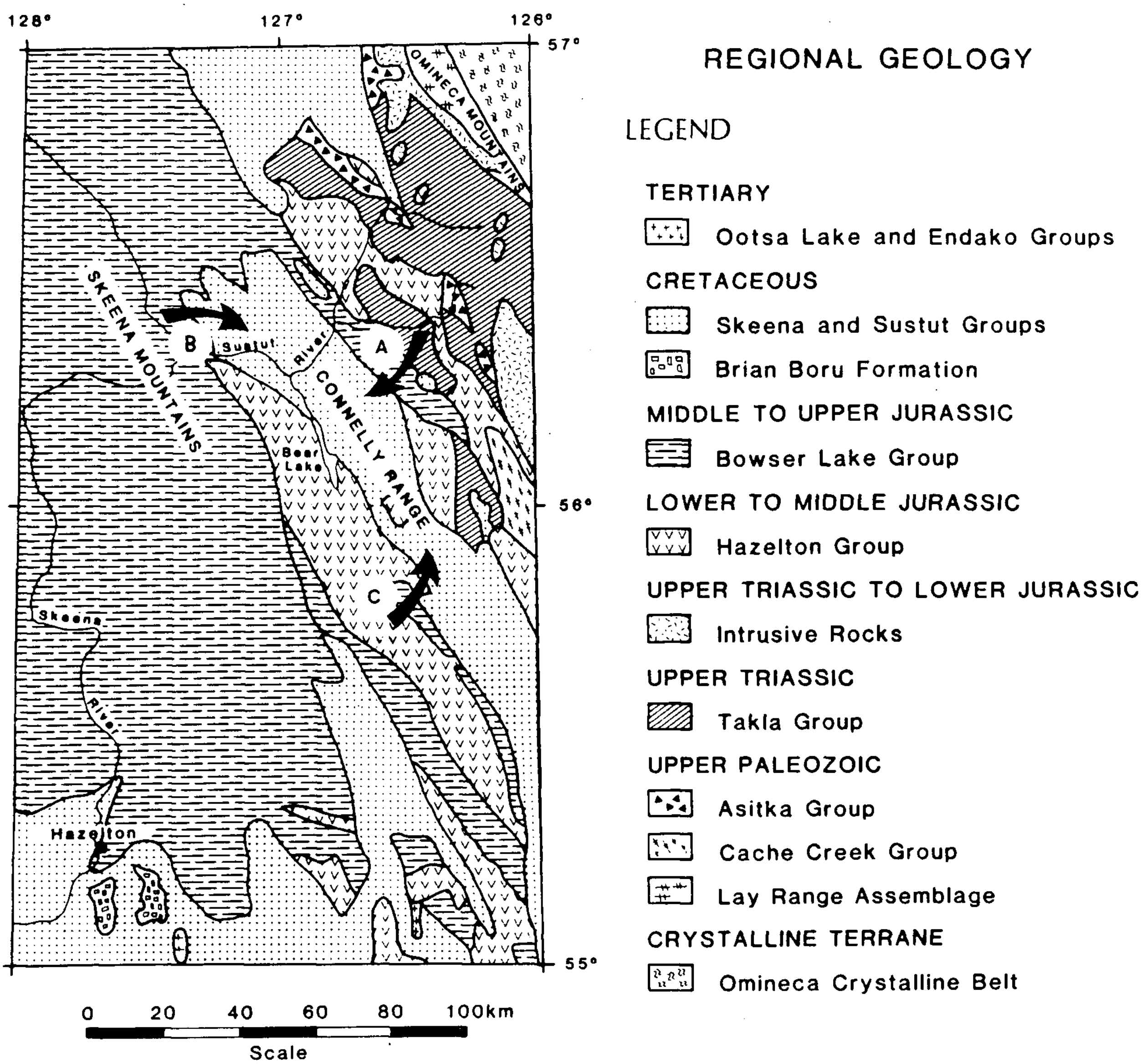
Sediments of the lower Laslui Member are rich in chert, especially the conglomerates, plus plagioclase feldspar and quartz. Paleocurrent direction during deposition of the lower Laslui Member was towards the southeast, suggesting the Bowser Group as a source rock. The Bowser Group consists predominantly of chert pebble conglomerates and quartzose sandstones, volcanics and argillites (Tipper and Richards, 1976), similar to the composition of the lower Laslui sandstones and conglomerates.

Sediments of the upper Laslui Member are composed of a high percentage of varicolored andesitic to basaltic volcanic fragments, varicolored tuff fragments as well as tuff horizons, in contrast to the lower Laslui and the Tatlatui Members. Plagioclase feldspar, quartz and chert are also common in the upper Laslui Member, but are not as diagnostic for source determination. Orientation of cross-stratification in the upper Laslui Member indicates an east to northeast dipping paleoslope, which is a significant change from the southerly dipping paleoslope of the lower Laslui Member. Both the abundance of varicolored volcanic rocks and the northeasterly paleocurrent direction suggest the Lower to Middle Jurassic Hazelton Group as the source rocks. The Hazelton Group is composed of basaltic to rhyolitic volcanic rocks, their tuffaceous equivalents, sedimentary rocks and minor limestone (Tipper and Richards, 1976). The uplifted Bowser Group may have continued to supply chert and rock fragments to the Sustut Basin during deposition of the upper Laslui Member.

The upper Laslui Member also contains abundant fine grained tuffs and tuffaceous horizons. The abundance of tuff present, together with the fine grain size would suggest that the volcanic center was: 1) very active over a long period of time; and 2) significantly removed from the Sustut Basin. The volcanic Brian Boru Formation, presently exposed south and west of the study area, is basaltic to rhyolitic in composition; plagioclase - hornblende porphyry being the commonest lithology. These volcanic rocks are cogenetic with Late Cretaceous intrusions that yielded K-Ar dates of 70 - 80 Ma (Woodsworth et al., 1983). The Brian Boru Formation and related volcanic and plutonic rocks are thought to represent part of a continental volcanic arc (Souther, 1975; Woodsworth et al., 1983) and is the most probable eruptive volcanic source responsible for the tuff horizons in the upper Laslui Member.

Detrital grains of the Spatsizi Member are dominantly chert, quartz, plagioclase feldspar and lesser amounts of volcanic rock fragments. Paleocurrent data indicates an east to southeasterly transport direction, similar to the lower Laslui Member. Composition and paleocurrent direction suggests once again the Bowser Group as the principal source rocks with minor contributions from the Hazelton Group sediments.

Recycled dinocysts of Turonian age found throughout the section indicate input from a marine environment coeval with the Sustut Group. However, there is no evidence of these rocks having been preserved within the stratigraphic record in the surrounding area.



A. Tatlatui Member

B. lower Laslui Member and Spatsizi Member

C. upper Laslui Member

Figure 15. The inferred source areas and paleocurrent directions of the Sustut Group in the southern Sustut Basin

DEPOSITIONAL HISTORY AND TECTONIC SIGNIFICANCE OF THE SOUTHERN SUSTUT BASIN

Figure 16 is a generalized stratigraphic section of the Sustut Group in the southern Sutut Basin, illustrating the changing paleocurrent directions and interpreted source rocks. The depositional history of the Late Cretaceous Sustut Basin is directly related to the tectonic evolution of the Canadian Cordillera. Composite terrane I accreted to the North American continent in mid-Jurassic time (Monger, 1984). In mid-Cretaceous time, the Sustut Basin is thought to have formed in response to high angle normal faulting accompanying extensive right-lateral strike slip faulting. The uplifted portions of the accreted terrane and the Omineca Belt, resulted in the shedding of fine and coarse grained sediment westward into the basin, depositing the Tango Creek Formation. In the southern Sustut Basin, the mainly fine grained Tatlatui Member of the Tango Creek Formation is interpreted as a distal alluvial fan to alluvial plain deposit. Periodically, braided streams migrated across the alluvial plain in response to higher energy levels and deposited coarse sandstone and conglomerate, relatively enriched in quartz, with lesser amounts of chert and igneous rock fragments, including granitic clasts. The composition of the Tatlatui Member suggest that the high grade metamorphic rocks comprising the Omineca Belt supplied much of the quartz to the southern Sustut Basin. The presence of igneous rock fragments and chert clasts possibly represent the unroofing of plutonic rocks within the Omineca Belt, and the erosion of Takla-

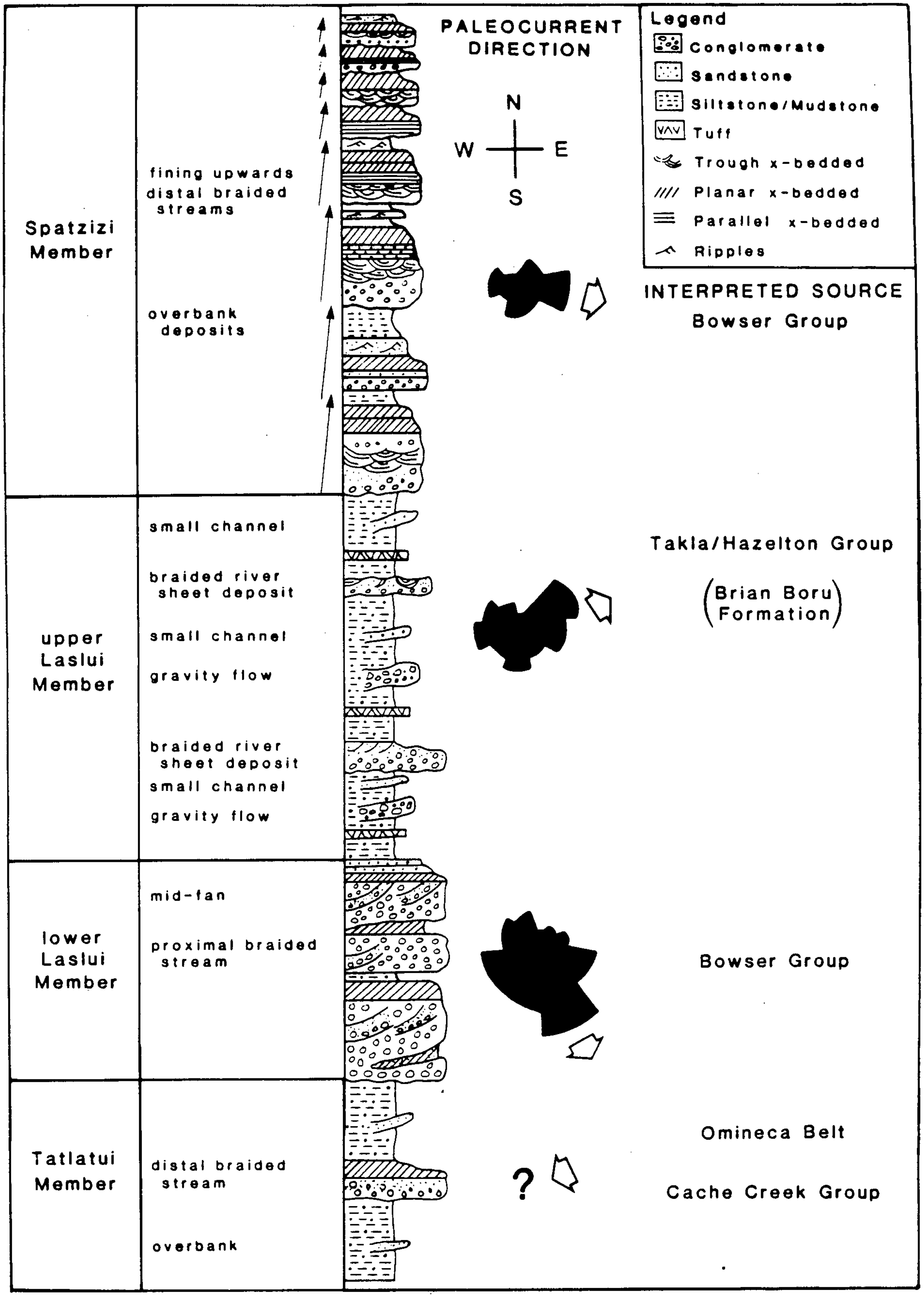


Figure 16. Generalized stratigraphic section of the Sustut Group illustrating the paleocurrent directions and inferred source rocks

Hazelton volcanics and Cache Creek chert. Paleocurrent data from the Tatlatui sediments is sparse and could not be utilized to support the proposed source localities east of the Sustut Basin.

Accretion of composite terrane II to the North American margin in mid-Cretaceous time formed the volcanic-plutonic Coast Plutonic Belt to the west of the Sustut Basin (Monger, 1984). Consequent Late Cretaceous uplift of the Coast Plutonic Belt and related folding and faulting of the Bowser Lake Group, terminated the deposition of easterly derived fine grained Tatlatui sediments, and triggered the progradation of alluvial fan complexes which deposited the thick conglomerate sequences of the basal Brothers Peak Formation (Figure 17a).

Thick fining upward sequences of the lower Laslui Member indicate deposition in several pulses by high energy braided streams. Clasts of the lower Laslui sandstones and conglomerates are mainly varicolored chert, quartz, plagioclase and volcanic rock fragments. Such a composition combined with a principal north-northeast paleocurrent direction, indicated by cross-stratification and imbricated clasts, suggests that lower Laslui sediments were mainly derived from the uplifted, chert rich, Bowser Lake Group.

With denudation of the source area, coarse grained sediments of the lower Laslui Member were progressively replaced by thick sequences of fine grained sediments, including tuff beds, of the upper Laslui Member. The fine grained sediments are thought to have accumulated on an alluvial fan distal to the lower Laslui Member or on an

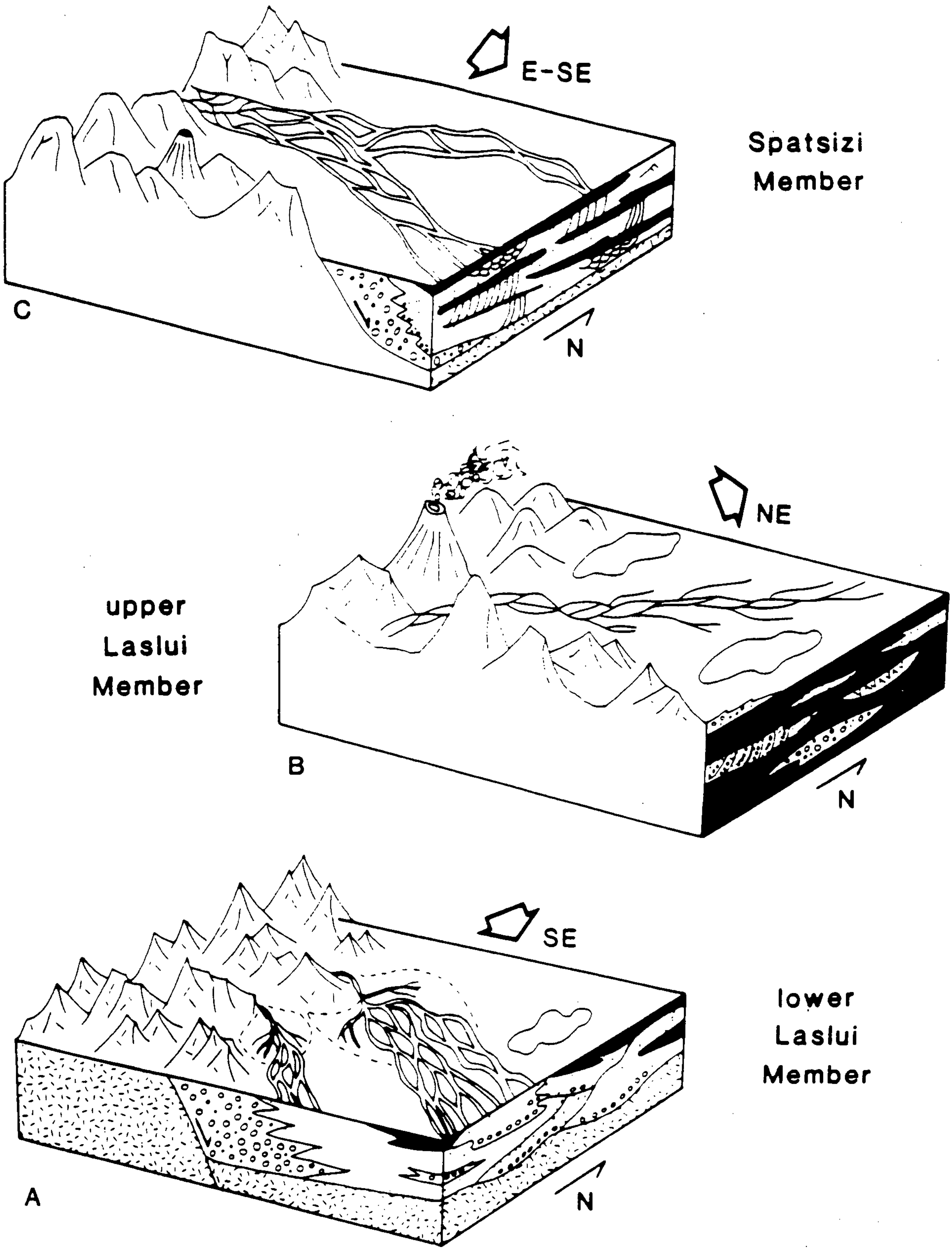


Figure 17. Depositional model of the Brothers Peak Formation

alluvial plain (Figure 17b). Small tributaries transported silt and fine sand which, during flood stages, deposited sheet-like units. In ephemeral lakes volcanic ash, which emanated from volcanic centres to the southwest accumulated. One likely volcanic center coincides with the upper Cretaceous Brian Boru volcanics. Periodically larger distributaries and high energy braided streams migrated over the alluvial plain, depositing thin units of coarse sandstone and conglomerate. Locally, gravity flows representing matrix supported conglomerate interfinger with the fine grained sediments of the upper Laslui Member. Compositionally, clasts of the coarse grained sediments are mainly varicolored volcanic rock fragments- similar to the composition of both the Takla and Hazelton Formations, as well as plagioclase, chert, and quartz. Cross-stratification in conglomerate, sandstone and tuff beds indicate a principal paleocurrent direction from the west to southwest, supporting both the proposed volcanic and sedimentary source areas.

Cyclical sandstone and mudstone sequences of the Spatsizi Member, which are gradational from the upper Laslui sediments, are thought to represent an entrenched sandy braided stream complex distal to an alluvial fan. The braided streams migrated across the alluvial plain depositing channel and overbank sediments (Figure 17c). Volcanic activity had decreased significantly during deposition of the Spatsizi Member as evident by the lack of tuffs. Similar to the lower Laslui Member, Spatsizi sandstones are mainly composed of chert, quartz, plagioclase and volcanic rock fragments which suggests that the Bowser Lake Group and possibly the Takla and Hazelton Groups were source rocks. Cross-stratification within the Spatsizi Member sandstones indicates that the main paleocurrent direction was from the west to northwest. The Bowser Lake Group is presently exposed in this direction.

SUMMARY AND CONCLUSIONS

The Sustut Group of north-central British Columbia is a non-marine succession of alternating fine and coarse grained clastics which is divisible into the Tango Creek and Brothers Peak Formations. In the southern Sustut Basin the total thickness of the Sustut Group is at least 1 500 m.

The Tango Creek Formation and the Brothers Peak Formation are conformable within the study area and are entirely Late Cretaceous (Campanian to Maastrichtian) in age, based on palynological evidence. An entirely Late Cretaceous age for the Sustut Group is significant as previous work by Eisbacher (1971, 1974), defined the Tango Creek Formation as Upper Cretaceous and the Brothers Peak Formation as Eocene.

In the southern Sustut Basin only the uppermost 400 m of the Tatlatui Member of the Tango Creek Formation is exposed. The Tatlatui Member is mainly composed of fine grained sediments interpreted as distal alluvial fan-alluvial plain deposits. The fine grained sediments are interbedded with coarse grained sandstones and conglomerates that represent the periodic migration of braided stream deposits across the alluvial plain.

The Brothers Peak Formation comprises 1 000 m of diverse clastics and tuff beds, and is divisible into a lower and upper Laslui Member and the Spatsizi Member. Sediments of the lower Laslui Member are composed mainly of thick sequences of conglomerates and coarse grained sandstones resulting from the progradation of alluvial fans. The upper Laslui sequence is composed mainly of fine grained distal alluvial fan-alluvial plain sediments, including tuff beds, which are interbedded with coarse grained distributary, sheetflood, and debris flow deposits. Cyclical sandstone/mudstone sequences comprise the Spatsizi sequence and are interpreted as sandy braided stream deposits on an alluvial plain.

Detrital components of the Tango Creek and Brothers Peak sandstones are mainly chert, quartz, plagioclase and volcanic rock fragments. Cementation by clay minerals and alteration of vitric shards to zeolites is common. The sandstones are classified as litharenites, feldspathic litharenites, and lithic arkoses.

Anomalously high coalification levels, corresponding to a rank of high volatile bituminous A to medium volatile bituminous coal (Teichmuller and Teichmuller, 1982), were found throughout the Sustut Group. Such regionally high coalification levels may have resulted from exposure to high temperature as a result of igneous intrusion and/or regionally high heat flow associated with a Jurassic to early Tertiary back-arc basin.

The depositional history of the Sustut Basin can be correlated to the tectonic evolution of the Canadian Cordillera. The Sustut Basin formed in response to extensional faulting resulting from strike-slip faulting subsequent to the accretion of composite terrane I to the North American Continent in Mid-Jurassic time (Monger, 1984). Based on composition, the Tatlatui sediments of the Tango Creek Formtaion are interpreted as originating from the uplifted Omineca Belt and other Paleozoic rocks east of the Sustut Basin. Paleocurrent measurements and provenance considerations suggest that deposition of the Brothers Peak Formation was triggered by tectonic uplift and volcanic activity west of the Sustut Basin resulting from the accretion of composite terrane II to the North American continent. Source areas to the west continued to supply sediment throughout Brothers Peak deposition.

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APPENDIX

PALYNOLOGY

Sample No.	No. Above Base	Palynomorphs	Age Range
S3-81	390	Angiosperm pollen:	Campanian-Maastrichtian
		Aquillapolenites sp. cf. A. dolium Complexiopollis? sp. Cupaneidites sp. Liliacidites sp. Nyssapollenites albertensis	Based on the presence of Aquilapollenites.
		Spores:	
		Cyathidites sp. Gleicheniidites sp.	
		Algal cysts:	
		acritarchs Sigmopollis sp.	
		Dinocysts-recycled	
		Palaeoperidinium pyrrophorum Isabelidinium acuminata Amphidiodema nucula Alterbia recticornis	
S3-100	715	Angiosperm pollen:	Indeterminate other than Albian or younger
		monosulcate pollen tricolpate pollen	
		Gymnosperm pollen:	
		Ephedripites sp.	
		Algal cysts:	
		acritarchs	

S3-106	1055	Angiosperm pollen: *Aquilapollenites pulcher* *Aquilapollenites* sp. *A.*sp. cf. *A. reductus* *Erdtmanipollis* sp. *Liliacidites* sp. tricolpate pollen triporate pollen Gymnosperm pollen: *Classiopollis* sp. *Ephedripites* sp. Spores: *Laevigatosporites* sp. *Librunisporis* sp. *Lycopodiumsporites* sp. *Stereisporites* sp.	Campanian-Maastrichtian Based on the presence of *Aquilapollenites* and *Erdtmanipollis*
S4-124	310	Dinocysts-recycled: *Palaeostomocystis laevigata*	Campanian-Maastrichtian
S4-143	550	Spores and pollen: *Gleicheniidites senonicus*	Upper Cretaceous
		Dinocysts-recycled: *Isabelidinium acuminata*	Santonian-Maastrichtian
S6-171	60	Angiosperm pollen: *Aquilapollenites* sp. Spores: *Cyathidites* sp. *Microreticulatisporites* sp. *Tauorcusporites* sp.	Campanian-Maastrichtian Based on the presence of *Aquilapolenites*

S6-182	660	Angiosperm pollen: *Aquilapollenites* sp. cf. *A.reductus* Cranwellia*sp.* *Erdtmanipollis* sp. *Liliacidites* sp. *Retitricolpites* sp. cf. *R. hepaticulus* triporate pollen *Ulmipollenites* sp. Spores: *Foraminisporis* sp. fungal spores *Gabonisporis* sp. ?*Ghoshispora* sp. *Gleicheniidites* sp. *Laevigatosporites* sp. *Lycopodiumsporites* sp. *Rouseisporites* sp.	Campanian-Maastrichtian Based on the combined presence of *Aquilapollenites, Cranwellia,* and *Erdtmanipollis*
S6-183	890	Angiosperm pollen: *Aquilapollenites* sp. *Cranwellia* sp. tricolpate pollen triporate pollen *Ulmipollenites* sp. Spores: *Gabonisporis* sp. *Ghoshipora* sp.	Campanian-Maastrichtian Based on the presence of *Aquilapollenites* and *Cranwellia*
S7-185	15	Angiosperm pollen: *A.* sp. cf. *A. ceriocorpus?* *Erdtmanipollis* sp. *Proteacidites* sp. tricolpate pollen Gymnosperm pollen: bisaccate pollen	Campanian or Campanian-Maastrichtian Based on the combined presence of the species listed

		Spores: *Appendicisporites problematicus?* *Cicatricosisporites* sp. *Foraminisporis* sp. *Fovaeosporites labiosus* *Ghoshispora* sp. *Librunisporis* sp. *Lycopodiumsporites* sp. *Neoraistrickia* sp. *Rouseisporites* sp. *Selaginella* sp.	
S7-196	320	Angiosperm pollen: *Aquilapollenites* sp. Spores: *Cyathidites* sp. *Distaltriangulisporites* sp. *Gleiichenidites* sp. *Laevigatosporites* sp. *Lycopodiumsporites* sp.	Campanian-Maastrichtian Based on the presence of *Aquilapollenites*
S7-197	305	Angiosperm pollen: *Aquilapollenites* sp. cf. *A. dolium* Gymnosperm pollen: *Eucommiidites* sp. Spores: *Cyathidites* sp. *Gleicheniidites* sp.	Campanian Based on the probable presence of *A. dolium*
S7-206	605	Spores: *Cyathidites* sp. *Laevigatosporites* sp.	no age diagnostic palynomorphs
S8-223	360	Angiosperm pollen: *Aquilapollenites* sp. cf.*A. pulcher* tricolpate pollen	Campanian-Maastrichtian Based on the presence of *Aquilapollenites*

Spores:

<u>Cyathidites</u> sp.
<u>Foraminisporis</u> sp.
fungal spores
<u>Gabonisporis</u> sp.
<u>Lycopodiumsporites</u> sp.