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SEDIMENTARY TECTONICS AND GLACIAL RECORD IN THE WINDERMERE SUPERGROUP, MACKENZIE MOUNTAINS, NORTHWESTERN CANADA

G.H. EISBACHER

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Critical Reader

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SEDIMENTARY TECTONICS AND GLACIAL RECORD IN THE WINDERMERE SUPERGROUP, MACKENZIE MOUNTAINS, NORTHWESTERN CANADA

Abstract

The Upper Proterozoic Windermere Supergroup of the Mackenzie and Wernecke mountains, northern Cordillera, was deposited between about 800 and 570 Ma. The margin of the predominantly clastic basin was controlled by faults with a north-northeasterly to northwesterly trend. The faults record rifting in the underlying craton and were intruded by diabase dykes and sills. Faulting was accompanied by extrusion of basaltic flows and is reflected in pronounced facies and thickness changes of the highest pre-Windermere and basal Windermere units (Redstone River, Coppercap, Sayunei formations). Faulting thus began to disrupt the pre-Windermere basinal framework prior to the changeover from carbonate to clastic sedimentation which characterizes the base of the Windermere Supergroup. The lower part of the Windermere Supergroup contains the record of a regional glaciation which can also be seen in other parts of the Cordillera.

The Sayunei Formation is mainly proglacial siltstone-argillite rhythmite with dropstone laminites, till pellets (sand clasts), and characteristic iron formation near the top. The Shezal Formation has two facies: a nonmarine tillite which rests locally on polished pavement and contains abundant striated stones, and a glaciomarine diamictite facies which was deposited in complex shallow marine depositional environments. Deglaciation was abrupt. The fine grained calcareous or siliciclastic members of the basal Twitya Formation which overlie the Shezal Formation rest with knife-sharp transgressive contact on tillite and glaciomarine diamictite. The Twitya Formation is a thick clastic wedge deposited mainly on the shelf-slope transition southwest of the Mackenzie Platform and on turbidite fans of the Selwyn Basin. Locally, significant carbonate facies developed on protected platforms and adjacent slopes. An extensive regression-progradation occurred during deposition of the cyclic shallow water marine-nonmarine Keele Formation which is in gradational contact with the Twitya Formation. The basinward progradation of the Keele Formation was accompanied by contemporaneous growth faulting, slumping, and generation of carbonate olistostromes. Deposition of the Keele Formation was terminated by a second abrupt transgression followed by deposition of a monotonous shale unit of the Sheepbed Formation which is the highest Windermere formation in the region. The transgression is interpreted as eustatic and due to a second glaciation outside the Cordilleran depositional domain.

Résumé

Le supergroupe de Windermere du Protérozoïque supérieur des monts Mackenzie et Wernecke, Cordillère du Nord, fut déposé il y a entre 800 et 750 Ma. La marge du bassin composé surtout de roches clastiques résulte de failles orientées nord-nord-est à nord-ouest. Ces failles ont enregistré la formation de fissures dans le craton sous-jascent et ont subi l'intrusion de dykes et sills de diabase. La formation de ces failles fut accompagnée par l'épanchement de coulées basaltiques; elle se reflète dans les changements marqués de faciès et d'épaisseur de l'unité pré-Windermere à sa partie la plus haute et de l'unité Windermere à sa base (formations de Redstone River, Coppercap, Sayunei). Il y a donc eu formation de failles dans la structure pré-Windermere du basin avant le passage de la sédimentation carbonatée à la sédimentation clastique, caractéristique de la base du supergroup de Windermere. La partie inférieure de ce supergroupe porte des traces d'une glaciation régionale, également visibles ailleurs dans la Cordillère.

La formation de Sayunei est en grande partie composée de bandes alternées de silts et d'argilites avec des dropstones finement lités, des sphérules de till (sand clasts) et une formation de fer caractéristique près du sommet. La formation de Shezal contient deux faciès: une tillite non marine localement sus-jacente à un dallage poli, contenant de nombreuses roches striées, et un faciès glaciomarin de diamictite, déposé dans un milieu de sédimentation marine complexe et peu profond. La déglaciation fut soudaine. Un contact transgressif brusque existe entre les membres calcaires ou siliceux-clastiques de la formation basale de Twitya sus-jacente à la formation de Shezal. La formation de Twitya est une couche clastique épaisse, déposée en grande partie sur la transition plate-forme-talus au sud-ouest de la plate-forme du Mackenzie et sur les cônes de turbidites du bassin Selwyn. Des faciés carbonatés importants se sont développés localement sur les plate-formes abritées et les talus adjacents. Une importante régression-progradation a eu lieu au cours de la mise en place de la formation de Keele composée de sédiments cycliques marins et non marins, déposés en eau peu profonde. Il y a contact progressif entre la formation de Twitya et la formation de Keele. Le déplacement progressif de la formation de Keele vers le basin fut accompagnée par la formation de failles synsédimentaires, par l'effondrement et par la production d'olistostromes carbonatées. La mise en place de la formation de Keele fut terminée par une deuxième transgression brusque, suivie à son tour par le dépôt de l'unité d'argile schisteuse uniforme de la formation de Sheepbed qui constitute les couches les plus élevées du supergroupe de Windermere dans la région. On a interprété la transgression comme étant une transgression eustatique causée par une deuxième glaciation à l'extérieur du domaine de sédimentation de la Cordillère.

SEDIMENTARY TECTONICS AND GLACIAL RECORD IN THE WINDERMERE SUPERGROUP, MACKENZIE MOUNTAINS, NORTHWESTERN CANADA

INTRODUCTION

The Windermere 'Series' was first defined in the Purcell Mountains of the southern Canadian Cordillera by Walker (1926). He described the unconformity between Precambrian Purcell (= Belt) carbonates-quartzites and the overlying Windermere clastics, also of Precambrian age. Subsequent reconnaissance revealed the characteristic lithologies of the Windermere Supergroup in many other segments of the North American Cordillera. Near the type region in the southern Canadian Cordillera relevant information was first compiled by Young et al. (1973). Correlation with the northern Canadian Cordillera was established by Gabrielse (1972). Units similar in stratigraphic position and lithology have also been documented in the American Cordillera (see Crittenden et al., 1972; Wright et al., 1976). New, stimulating insight into the possible plate-tectonic setting of the Windermere succession was provided by Stewart (1972, 1976).

The Windermere Supergroup is defined as the predominantly clastic succession between older Precambrian units (i.e. Hudsonian crystalline basement or Middle (?) Proterozoic carbonate-quartzite successions) and the base of Lower Cambrian quartzites. Figure 1 shows the outcrop distribution of probable Hudsonian (older than 1600 Ma) crystalline basement in the Canadian Cordillera, the Middle (?) Proterozoic carbonate-quartzite assemblages (ranging in age from about 1600 to about 800 Ma), and the Upper Proterozoic Windermere Supergroup (ranging in age from about 800 to 570 Ma).

In discussing the Windermere strata away from the type region it is convenient to subdivide the Canadian Cordillera into the areas indicated in Figures 1 and 2. None of the areas is necessarily more representative than any other although preservation, grade of metamorphism, and outcrop conditions vary. Figure 2 is a tabulation of lithologic succession, approximate thickness, and present terminology applied to Windermere rocks. Subjacent Proterozoic carbonate-quartzite assemblages are shown in their approximate and, as yet, uncertain relative position to each other.

The base of the Windermere Supergroup is exposed in the Purcell Mountains, the Muskwa Ranges, the Mackenzie Mountains, and the Wernecke Mountains. Towards the west (Columbia Mountains, Omineca-Cassiar Mountains, and Selwyn Basin) only higher stratigraphic units of the Windermere are exposed. Metamorphism as high as sillimanite grade masks the basal relationships with crystalline Hudsonian basement in these areas. Particularly in the Columbia Mountains strong evidence exists that lower Windermere units grade into high-grade crystalline complexes which include Hudsonian and older basement (Campbell, 1973; Wanless and Reesor, 1975). It is probably also significant that the foreland to the northeast of the Columbia-Omineca-Cassiar mountains is underlain by Hudsonian basement with strong northeasterly magnetic and structural trends, transverse to the later Cordilleran trend (Burwash and Culbert, 1976; Coles et al., 1976). The trend is also expressed in the Peace River Arch (Fig. 1), a persistent transverse element throughout Cordilleran evolution (Wheeler, 1967, p. 10; Stelck et al., 1978). To the north and south of this transverse basement complex Proterozoic basins with pre-Windermere carbonate-quartzite successions intervene between the Windermere Supergroup and the crystalline basement.

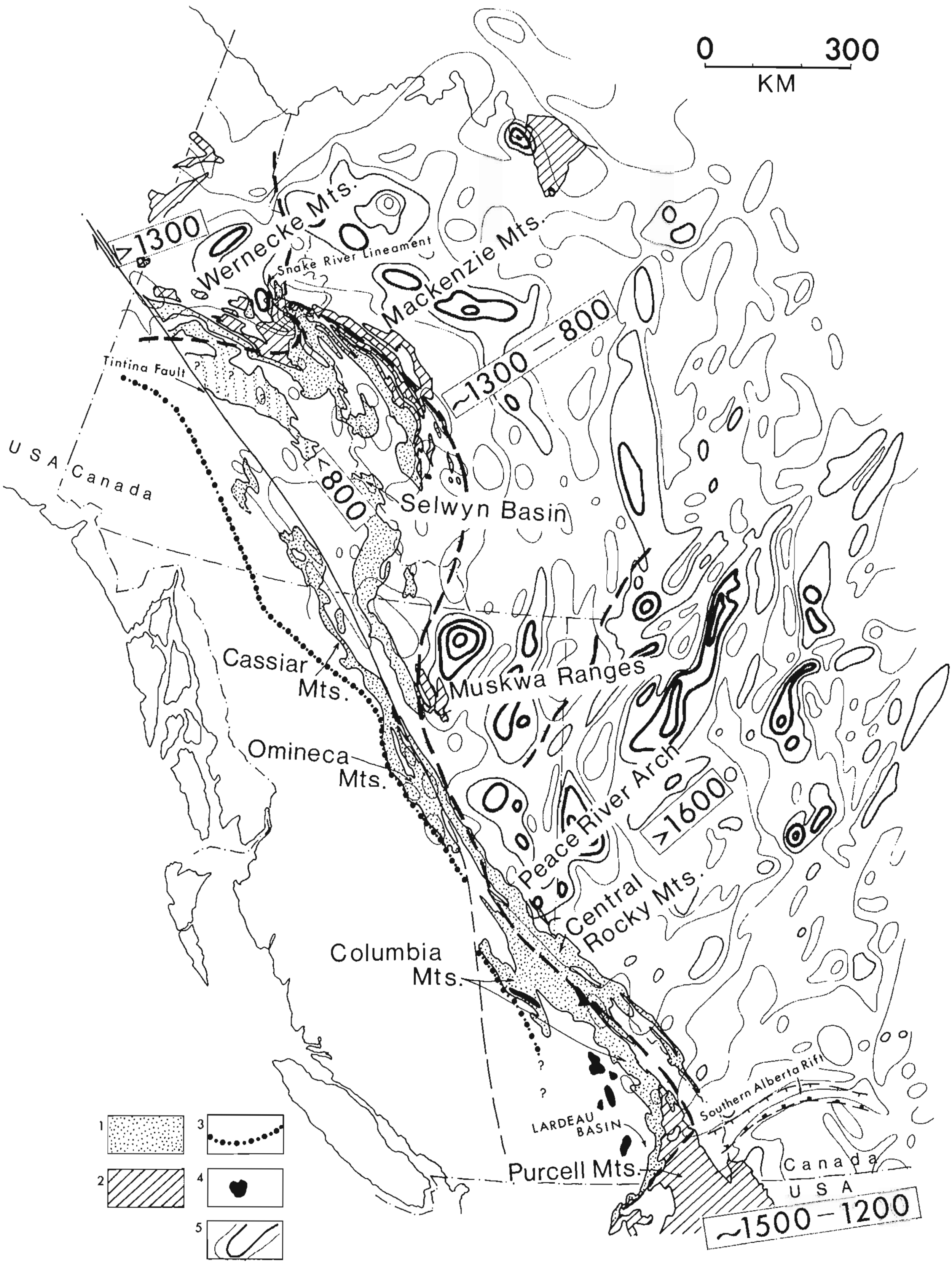
The western border of the Windermere outcrop closely follows the margin of the North American craton as defined by a tectonic contact ('Teslin Suture') between eugeosynclinal terranes accreted in late Mesozoic time on the west and the Omineca Crystalline Belt on the east (Monger and Price, 1979; Tempelman-Kluit, 1979). In addition to intense Mesozoic metamorphism and deformation the westernmost Windermere rocks were also cut by high-angle faults and translated northerly up to several hundred kilometres (Roddick, 1967; Tempelman-Kluit, 1979).

The least disturbed and best exposed Windermere succession occurs in the northernmost segments of the Canadian Cordillera, in the Mackenzie and Wernecke mountains. This report deals with the Windermere Supergroup of this region. The study focuses on the complex relationship between tectonics and sedimentation ('sedimentary tectonics') and emphasizes the effects of regional glaciation and sea level changes which also may have influenced sedimentation of the Windermere strata in other parts of the Cordillera and in time-equivalent successions of the Circum-Pacific Proterozoic.

A word on terminology. Formation terminology of the Windermere Supergroup in the Mackenzie and Wernecke mountains is generally accepted and creates few problems in description or correlation. However, several different schemes for definition of groups (and supergroups) have been proposed and general consensus is not available. All workers in the region include the Sayunei and Shezal formations in the Rapitan Group – a name widely known because of the jaspilite-hematite iron formation and glaciogenic diamictites. Gabrielse et al. (1973) included a thick clastic unit, later named Twitya Formation (Eisbacher, 1978a) in the Rapitan. Eisbacher (1978a) also included the Keele Formation in the Rapitan Group. Others have restricted the name Rapitan Group to the Sayunei and Shezal formations or would prefer the use of the term Rapitan Formation. To avoid ambiguity, therefore, the writer will use only formational terminology in the description of the rocks included in the Windermere Supergroup of the Mackenzie Mountains.

Acknowledgments

The field investigations encompassed stratigraphic reconnaissance and, locally, detailed structural studies carried out between 1975 and 1977. Most of the region is accessible only by helicopter and logistic support was provided by Drs. D.J. Tempelman-Kluit and J.D. Aitken of the Geological Survey of Canada, and C. Lord of the Department of Indian and Northern Affairs. The author acknowledges discussions with some of his colleagues of the Cordilleran Geology Division of the Geological Survey of Canada in Vancouver and wishes to thank Dr. R.A. Price, Queen's University, for his interest and encouragement. The author also benefitted from a superbly conceived field excursion to the Proterozoic sections of the western United States with Dr. M.D. Crittenden, J. Harrison, and D. Elston of the United States Geological Survey, and Dr. J.C. Crowell, University of California, Santa Barbara. The manuscript was critically read by Dr. H. Gabrielse, Geological Survey of Canada, Vancouver, who suggested several improvements.


0 300
KM
>1300
Wernecke Mts.
Snake River Lineament
Mackenzie Mts.
~1300 — 800
Tintina Fault
U S A
Canada
<800
Selwyn Basin
Cassiar
Mts.
Muskwa Ranges
Omineca
Mts.
Peace River Arch
>1600
Central
Rocky Mts.
Columbia
Mts.
LARDEAU
BASIN
Southern Alberta Rift
Purcell Mts.
Canada
U S A
~1500 – 1200
1
2
3
4
5

REGIONAL SETTING

The Mackenzie and Wernecke mountains are part of the Foreland Fold – Thrust Belt of the Mesozoic-Paleogene Cordilleran Orogen. The northwesterly to westerly trending mountain ranges are composed of marine carbonates and clastics ranging in age from late Proterozoic to Paleogene. Different Proterozoic successions, including those discussed in this report, are overlain conformably or unconformably by Paleozoic carbonates, sandstone, and shale. In the eastern and northern foothills late Mesozoic-Paleogene molasse overlaps the mountain front. A prominent Paleozoic facies change from platformal carbonates and quartzites on the northeast (Mackenzie Platform) to a basinal facies composed of fine grained clastics (Selwyn Basin) is also expressed in structural style. In the Mackenzie Mountains large-scale northwesterly to westerly trending anticlines and thrust faults define an arc which is convex to the northeast. These anticlines and northeasterly directed thrust faults such as the Plateau Fault bring Proterozoic rock units to the surface. Tight intervening synclines contain the platformal lower to middle Paleozoic carbonates. In the Selwyn Basin tightly folded shale and sandstone show a variety of structural trends although the main trend is also northwesterly. In the Mackenzie-Wernecke mountains cleavage is generally absent, in the Selwyn Basin it is generally present. Most of the northwesterly trending structures in the Selwyn Basin formed prior to the emplacement of discordant mid-Cretaceous plutons of quartz monzonite (Gabrielse et al., 1973, p. 112; Gabrielse and Reesor, 1974, p. 129). Some of the thrust faults and folds in the Mackenzie Mountains may have formed during this pre-mid-Cretaceous phase of deformation, but others may have formed during a poorly dated Upper Cretaceous – Paleogene phase of deformation which was accompanied by late-orogenic molasse deposition.

During late Mesozoic compression of the Mackenzie – Wernecke fold belt numerous Precambrian faults were reactivated along trends discordant with the overall northwesterly to westerly structures (Aitken and Cook, 1974a). Precambrian crystalline basement is not exposed at the surface and depth to basement is unknown. Some of the ramifications of late Proterozoic sedimentary tectonics on the structural pattern will be discussed in this paper. The influence of discordant basement structures is particularly prominent at the junction between Mackenzie and Wernecke mountains where the characteristic Proterozoic stratigraphy of the Mackenzie Mountains terminates abruptly at the Snake River Fault and its northwesterly extension, the Knorr Fault of Norris and Hopkins (1977).

---

1 = Windermere Supergroup

2 = pre-Windermere sedimentary assemblages

3 = western border of Precambrian rocks defined by the Mesozoic Teslin Suture between the North American craton and exotic eugeosynclinal terranes of the Western Cordillera (Tempelman-Kluit, 1979)

4 = Precambrian basement complexes in the metamorphic core zone of the eastern Cordillera

5 = aeromagnetic anomaly trends in the Precambrian Shield underneath the foreland of the Cordillera (Coles et al., 1976)

Figure 1. *Index map of the Canadian Cordillera showing the distribution of the main Precambrian rock assemblages. Approximate ages of Precambrian complexes are indicated by bold half-tone numbers. The broken lines indicate probable first-order hinge lines of late Proterozoic sedimentary basin. Note the strong magnetic anomaly trends along the transverse Peace River Arch where Hudsonian (and possibly older) basement separates the northern pre-Windermere sedimentary assemblages (i.e. Muskwa, Mackenzie Mountains, Pinguicula, Wernecke) from the pre-Windermere assemblage in the southern Canadian Cordillera (i.e. Belt-Purcell).*

GENERAL PROTEROZOIC STRATIGRAPHY OF THE MACKENZIE AND WERNECKE MOUNTAINS

Mackenzie Mountains

In the Mackenzie Mountains the Proterozoic consists of two major sedimentary successions: the Mackenzie Mountains Supergroup and the Windermere Supergroup. The Windermere Supergroup rests conformably to unconformably on a variety of formations of the Mackenzie Mountains Supergroup. It is, in turn, overlain by Paleozoic formations in conformable or disconformable contact. The following brief description uses the formation names established by Gabrielse et al. (1973), Aitken et al. (1973), Aitken et al. (1978), Aitken and Cook (1974b), Eisbacher (1978a), and Jefferson (1978). Thicknesses given are generally averages and pertinent only for the major surface exposures. Detailed relationships between the units particularly those between the uppermost Mackenzie Mountains Supergroup and the Windermere Supergroup are discussed in later sections of this report.

Mackenzie Mountains Supergroup

Map-unit H_1

This unit is about 400 m thick and consists of three members: a basal recessive silty dolostone and dolomitic shale, a middle massive dolostone with stromatolite bioherms and biostromes, and an upper massive dolostone unit composed of cryptalgal laminites.

Tsezotene Formation

The Tsezotene Formation is about 1200 m thick and consists of two units: the lower unit is composed of grey mudstone, siltstone, and mudcracked siliciclastic laminites; the upper unit consists of variegated mudstone, fine grained quartzite and minor stromatolitic bioherms.

Katherine Group (or Tigonankweine Formation)

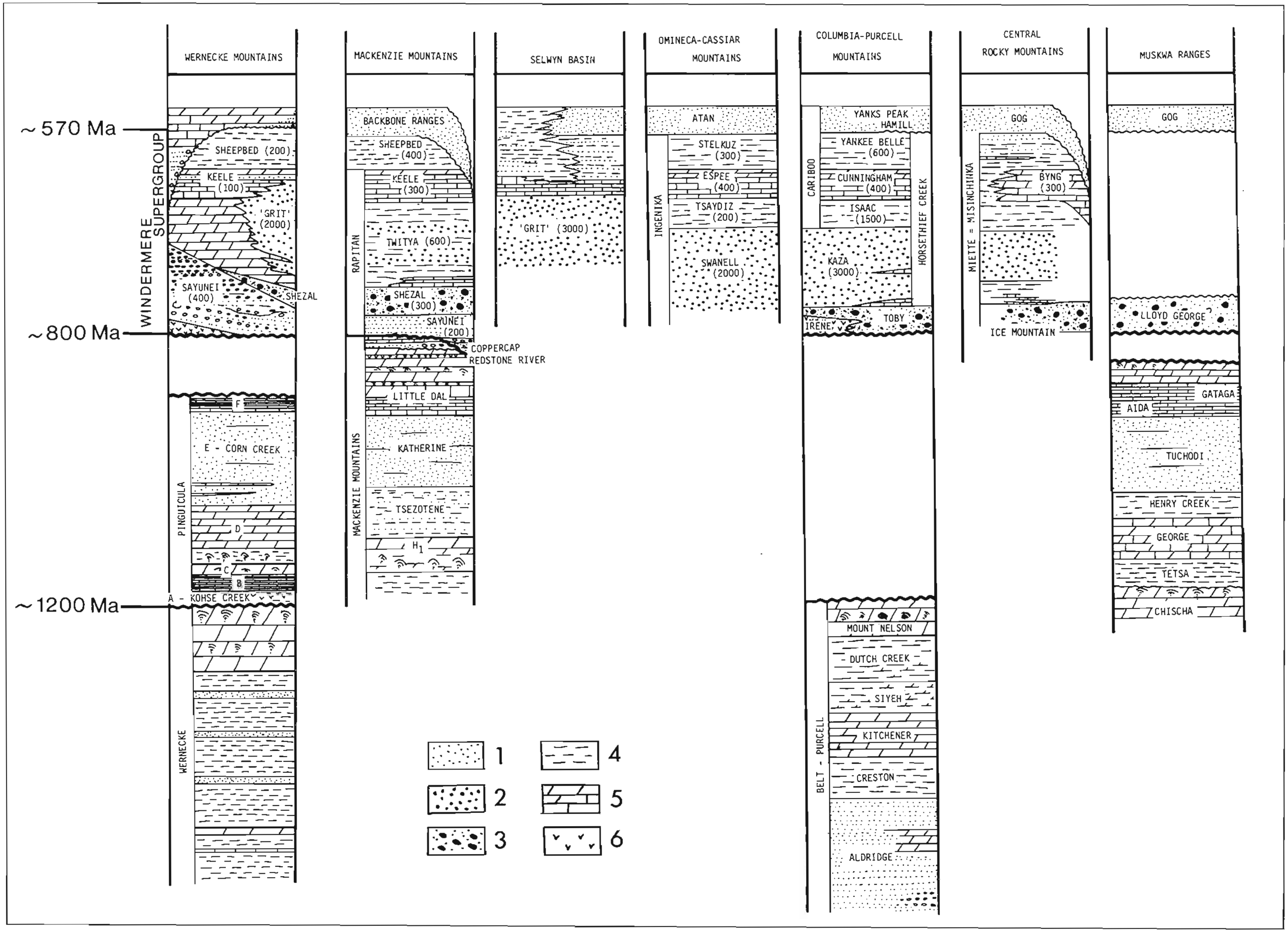
The Katherine Group is about 1500 m thick and consists of three mappable units. It is dominated by crossbedded and ripple-marked quartzite, purple to red mudstone, and contains minor stromatolitic carbonate horizons.

Little Dal Group

The Little Dal Group is about 2000 m thick and consists of six units: basal mud-cracked siltstone, thinly bedded basinal limestones, thick bedded calcareous and dolomitic grainstones, an evaporite unit, a thinly bedded rusty weathering quartzite-shale unit, and a massive dolostone unit at the top. Basaltic lava flows, several tens of metres thick are found sporadically near the top of the Little Dal Group.

Redstone River Formation

The Redstone River Formation pinches and swells from 0 to 300 m along northwesterly trending outcrops above the Plateau Fault. It is generally associated with the overlying Coppercap Formation which follows the regional pattern of thickening and thinning displayed by the Redstone River Formation. The Redstone River Formation consists of pink calcareous and dolomitic siltstone, quartzose sandstone, massive conglomerate and breccia composed of dolostone fragments, evaporites and possibly minor volcanics. In some



1 = sandstone
2 = turbiditic 'grits'
3 = diamictite
4 = shale
5 = carbonate
6 = volcanics

Figure 2. *Principal stratigraphic units of Proterozoic Windermere Supergroup and pre-Windermere sedimentary assemblages in the Canadian Cordillera. Numbers in brackets indicate approximate thicknesses in metres where known. Sources: Bell and Delaney (1977), Eisbacher (1978a, b), Gabrielse et al. (1973), Aitken et al. (1978), Gordey (1980), Mansy and Gabrielse (1978), Bell (1968), Young et al. (1973), Campbell et al. (1973), Slind and Perkins (1966), Gabrielse (1972); also includes personal observations by R.I. Thompson and the author in the central and northern Rocky Mountains.*

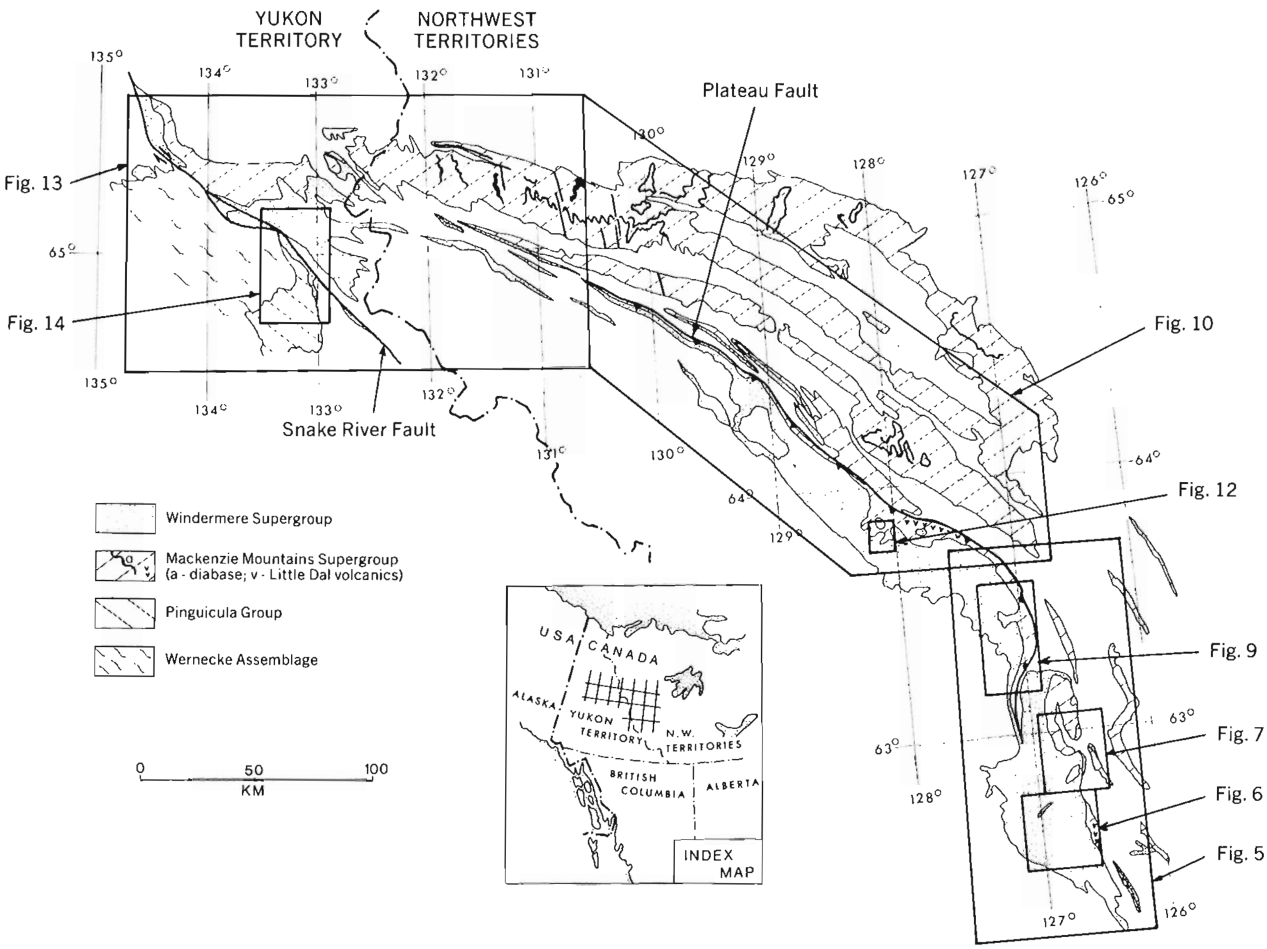


Figure 3. *Index map of the Mackenzie Mountains and eastern Wernecke Mountains showing the distribution of Proterozoic sedimentary rocks. Locations of geological sketch maps discussed in this report are also indicated.*

areas the contact with the underlying Little Dal dolostones is gradational; locally, conglomerate and breccia units up to 150 m thick rest disconformably on Little Dal Group.

Coppercap Formation

The Coppercap Formation also pinches and swells along structural trend and ranges in thickness from 0 to 500 m. In most areas it consists of two shoaling cycles of thinly bedded carbonate turbidites, delicately laminated black limestones, and massive grey dolostone. The top of the unit consists of a massive cherty dolostone, locally beds of coarse grained mass flow deposits and minor evaporite.

Windermere Supergroup

Sayunei Formation

The Sayunei Formation varies in thickness from 0 to 700 m and rests conformably, disconformably, unconformably, or in onlap on older formations (Fig. 4C). Its most prominent characteristics are monotonous thinly bedded siliciclastic laminites and turbidites which alternate with dark red – maroon or green argillite. Locally interspersed are thick beds of coarse mass-flow deposits ('sharp-clast siltstone') and glaciogenic dropstones. The top of the formation is characterized by a regionally extensive hematite-jaspilite iron formation and by abundant extrabasinal dropstones.

Shezal Formation

The Shezal Formation varies in thickness from a few metres to 500 m. In its thinner marginal facies it is a massive tillite with numerous striated and glacially polished clasts. The thicker basinal diamictite beds are interstratified with sandstone and shale. Clasts in the diamictite are up to several metres in diameter and include exotic crystalline boulders.

Twitya Formation

The Twitya Formation is up to 800 m thick and rests in sharp but generally conformable contact on the Shezal Formation. It consists of shale, siltstone, parallel-laminated sandstone, and some conglomeratic channel deposits. At the base of the unit thinly bedded to laminated dark grey particulate limestone up to 100 m thick is found in regionally restricted settings.

Keele Formation

The Keele Formation is 100 to 500 m thick and rests in gradational contact on the Twitya Formation. It consists of shoaling-upwards carbonate-quartzite cycles which grade southwestward into basinal carbonate facies and mass flow deposits. The top of the Keele Formation is defined by a laterally persistent light dolostone unit, the informally named 'Tepee' dolostone, which is about 10 m thick.

Sheepbed Formation

The Sheepbed Formation is up to 900 m thick and rests with sharp transgressive contact on the 'Tepee' dolostone of the Keele Formation. With the exception of minor thinly bedded limestone beds and some fine grained quartzose clastics the Sheepbed Formation consists of homogeneous dark grey shale.

Basal Paleozoic Formations

Precambrian units of the Mackenzie Mountains are commonly erosionally truncated and unconformably overlain by Paleozoic formations (Gabrielse et al., 1973; Aitken et al., 1973). The basal Paleozoic Backbone Ranges Formation, which possibly includes the Precambrian-Cambrian transition zone (Fritz, 1980), rests conformably or unconformably on Sheepbed Formation of the Windermere Supergroup. The Backbone Ranges Formation consists of a succession of nonmarine to shallow-water marine feldspathic sandstones, red mudstone, buff dolostone, and quartzites. Towards the east ever younger Paleozoic carbonate formations overstep Backbone Ranges Formation, Windermere Supergroup, and formations of the Mackenzie Mountains Supergroup.

Wernecke Mountains

In the Wernecke Mountains the Proterozoic succession consists of three assemblages (Fig. 2): the Wernecke Assemblage (Bell and Delaney, 1977), the Pinguicula Group, and the Windermere Supergroup (Eisbacher, 1978b). The three Proterozoic assemblages are separated from each other by profound angular unconformities and are in turn overlain conformably to unconformably by Paleozoic carbonate-shale formations. The following description uses informal terms of Bell and Delaney (1977) and Eisbacher (1978b). Local terms used here for important units are also informal.

Wernecke Assemblage

The Wernecke Assemblage consists of three conformable units: a lower unit with a total thickness of about 2000 m of carbonate and phyllitic mudstone; and middle unit with a thickness of about 5000 m of argillite, slate and quartzite; and an upper unit of about 2000 m of well bedded stromatolitic dolostone and argillite. Numerous heterolithic breccia pipes are associated with the Wernecke Assemblage.

Pinguicula Group

This brief description applies to the sequence as investigated by the author in the Pinguicula Lake region and is based on a preliminary structural – stratigraphic study along a northeast-southwest transect. In other parts of the Wernecke Mountains the Pinguicula Group may contain other facies and stratigraphically higher units.

Unit A (Kohse Creek Volcanics)

This succession grades regionally from several hundred metres of basic – intermediate volcanic flows and aquagene tuffs in the south into entirely siliciclastic red laminites up to 200 m thick in the northernmost outcrops. The Kohse Creek volcanics and equivalent rock units rest with profound angular unconformity on folded Wernecke Assemblage (Fig. 4A).

Unit B

Unit B comprises about 300 m of thinly bedded, laminated and flasered limestone which grades upward into laminated dolosiltite.

Unit C

Unit C is up to 200 m thick and consists mainly of massive white dolostone with wavy cryptalgal lamination, crossbedding, tepee structures, extensive dolomite veinlets and concretionary chert.

Unit D

Unit D is about 600 m thick and is in gradational contact with unit C. It consists of a lower rusty weathering black shale with limestone laminites and well developed stromatolite bioherms and biostromes; a middle grey dolostone with zones of flat-edge conglomerate, mudcracks and cryptalgal laminites with concretionary chert; and an upper buff dolostone with abundant black diagenetic chert, tepee and molar tooth structures.

Unit E (Corn Creek quartzite)

This succession ranges in composition from a thin, brown, parallel laminated quartzite in the north to a succession up to 2000 m thick composed of thinly bedded red dolomitic siltstone, dolostone, and quartzite. Near the top, crossbedded quartzite contains significant concentrations of hematitic cement.

Unit F

Unif F is a basinal, thinly bedded particulate limestone which is truncated by the angular unconformity below the red conglomerate of the basal Windermere Supergroup.

Windermere Supergroup

Detailed mapping along the Snake River established that the Windermere Supergroup extends from the Mackenzie Mountains into the Wernecke Mountains and that in so doing it undergoes a dramatic facies change.

Sayunei Formation

The Sayunei Formation varies greatly in thickness from 0 to about 300 m. Where studied so far, it is composed entirely of conglomerate which overlies an angular unconformity, cut deeply into folded and faulted units of the Pinguicula Group (Fig. 4B). The conglomerate changes from a red fluviatile facies on the south to buff subaqueous channel deposits on the north.

Shezal Formation

From the Snake River southwestward the Shezal Formation thins rapidly from several hundred metres to 0 metres thickness. It is a diamictite composed of greenish grey greywacke and bedded siltstone with loosely dispersed quartzite, greenstone, and dolostone clasts.

Twitya Formation (Profeit dolostone and turbiditic 'Grits')

The equivalents of the Twitya Formation are at least 400 to 800 m thick and consist of light grey, thick bedded particulate dolostone with wavy lamination, sutures, diagenetic cavities, and sporadic oolites. The unit, well exposed near Mt. Profeit, grades northward into mass-flow breccias of dolostone and turbiditic limestone interbedded with shale; the shale, in turn, grades laterally into thick siliciclastic flysch which corresponds to parts of the widespread 'Grit' unit of the Selwyn Basin.

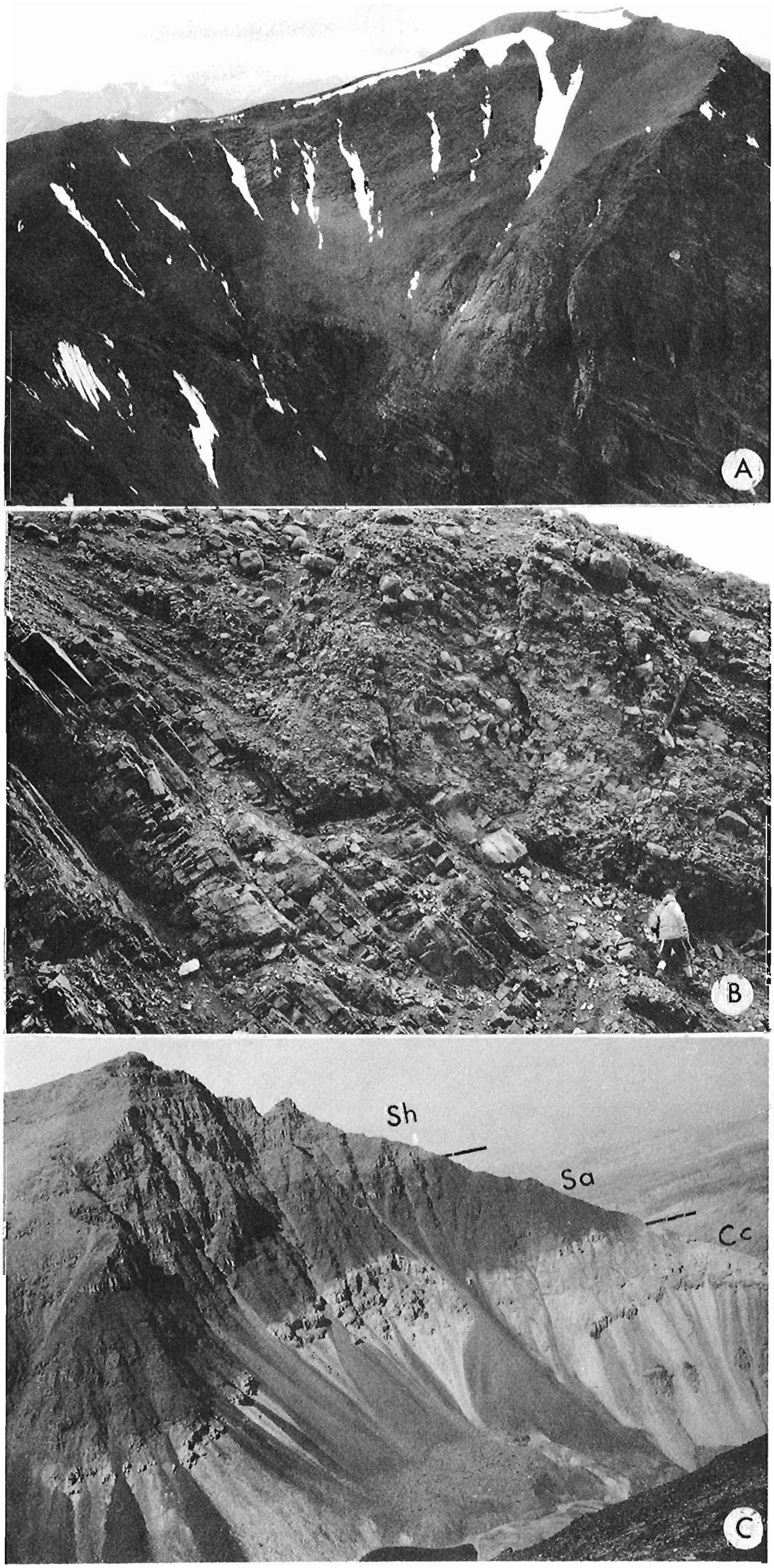


Figure 4

A - *Angular unconformity between dolostone of the upper Wernecke Assemblage and red siltstone of the basal Pinguicula Group (unit A). Photograph was taken about 10 km north of Pinguicula Lake (for location see Fig. 13) looking eastward. GSC 203631*

B - *Angular unconformity between unit D of Pinguicula Group and conglomerate of the basal Windermere Supergroup. Photograph was taken near the headwaters of Corn Creek (for locations see Fig. 13) looking northward. GSC 203631-A*

C - *Onlap of basal Windermere Supergroup (Sayunei Formation = Sa) against gently folded Coppercap Formation (=Cc). Locality is about 10 km north of North Redstone River, Mackenzie Mountains. Note the relatively planar contact between Shezal Formation (=Sh) and Sayunei Formation (=Sa). GSC 203631-B*

Keele Formation

The Keele Formation is about 40 m thick and consists of grey laminated limestone, pink recrystallized dolostone, crossbedded pebbly quartzite and a distinct white dolostone at the top.

Sheepbed Formation

The Sheepbed Formation is about 300 m thick and, except for minor thinly bedded limestone, consists of black shale. It is overlain conformably and unconformably by Paleozoic quartzite and carbonate formations.

AGE OF THE WINDERMERE SUPERGROUP OF THE MACKENZIE MOUNTAINS

From the discussion presented in the following chapters it will be seen that the Windermere Supergroup rests either conformably or unconformably on the Mackenzie Mountains Supergroup, depending on local sedimentary tectonics.

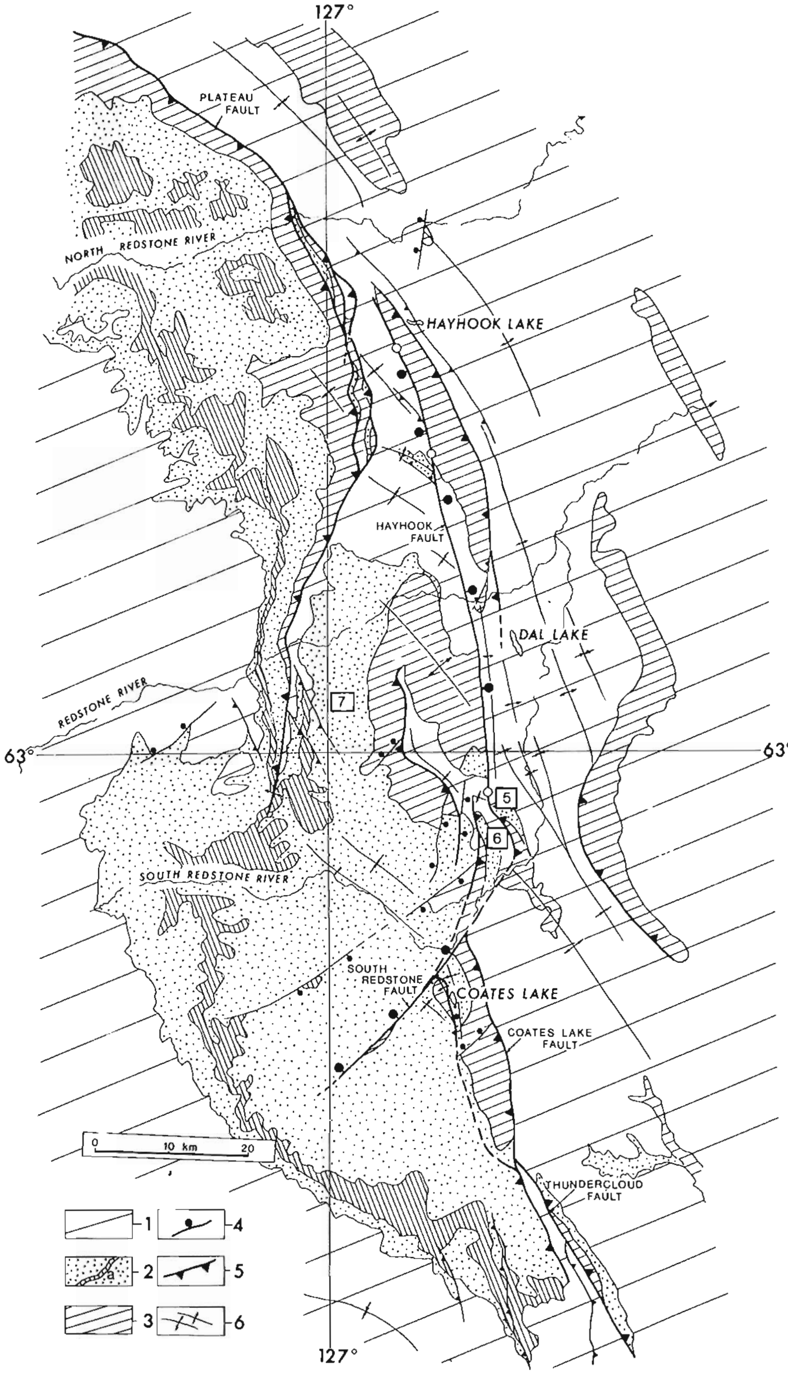
Algal microbiota and macromorphology of stromatolites suggest that the Little Dal Group of the Mackenzie Mountains Supergroup was deposited between about 1100 and 800 Ma (Hofmann and Aitken, 1979).

The Mackenzie Mountains Supergroup is cut by diabase dykes and sills. Samples of two sills in the Tsezotene Formation have been studied radiometrically and two Rb-Sr isochrons suggest ages of 769 (or 753) and 766 Ma for the time of intrusion (Armstrong et al., in press). Extrusive basaltic volcanism possibly related to these sills is known from the top of the Little Dal Group and another phase of volcanism was probably responsible for extensive deposition of hematite-japilite iron formation near the top of the Sayunei Formation of the basal Windermere Supergroup. Depending on which of these volcanic phases corresponds to emplacement of the mafic sills the basal Windermere strata are probably less than 800 Ma, and possibly less than 770 Ma old.

The top of the Windermere Supergroup is probably latest Precambrian in age. This age depends on the age assigned to the Backbone Ranges Formation, a quartzite commonly placed at the boundary between Precambrian and Cambrian strata (Fritz, 1980).

SEDIMENTARY TECTONICS

In order to describe the tectonics, which accompanied deposition of the basal Windermere units and which later influenced geometry of late Mesozoic structures, the region is subdivided into three major segments. These are the Redstone segment (North Redstone and South Redstone rivers), the Mountain River segment, and the Snake River segment. For each of these segments structural relationships and major sedimentary facies of the Windermere and subjacent Proterozoic units will be discussed with the aid of geological sketch maps and diagrams. The three principal maps (Fig. 5, 10, 13) outline the configuration of pre-Windermere units, the Windermere Supergroup (with the Keele carbonate-quartzite succession), and the Paleozoic carbonate-shale succession.



1 = Paleozoic formations

2 = Proterozoic Windermere Supergroup (2a = Keele Formation)

3 = Proterozoic Mackenzie Mountains Supergroup

4 = high-angle fault (dot on downthrown side)

5 = thrust fault (barb on upthrown side)

6 = folds

Figure 5. *Geological sketch map of the Redstone River area, Mackenzie Mountains. Numbers in boxes indicate location of selected sections discussed in text. Geology supplemented after Gabrielse et al. (1973).*

In the Mackenzie Mountains the main outcrop belt of Windermere strata is broadly parallel with the Plateau Fault, a thrust fault soled by an evaporite horizon in the middle part of the Little Dal Group. The Plateau Fault places pre-Windermere Little Dal dolostone over Paleozoic formations to the northeast. Over most of its extent the Plateau Fault zone and related faults trend northwesterly. However, upon entering the Redstone segment from the northwest the fault curves sharply to the south and finally diminishes in displacement until it dies out in a series of splays near the South Redstone River (Fig. 5). The line connecting the southern termination of the Plateau Fault and the Coates Lake Fault, another significant thrust to the southeast, is a very gentle anticlinal warp along which bedding dips are rarely more than five degrees. In the area to the southeast of the sharp deflection of the Plateau Fault the regional structural pattern is a composite of northwesterly and north-northeasterly trends some of which are the heritage of Precambrian syndepositional tectonics.

Northwestward, the Plateau Fault and related structures extend into the Snake River segment where northwesterly trends merge with northerly trends of the Richardson Fault array (Norris and Hopkins, 1977). A major fault zone, the Snake River – Knorr Fault, separates pre-Windermere sedimentary assemblages of the Mackenzie Mountains, from the distinctly different pre-Windermere assemblages of the Wernecke Mountains.

The following discussion of the Windermere Supergroup will proceed from southeast to northwest using the Redstone, Mountain River and Snake River segments to illustrate the subtle interplay of tectonics and sedimentation.

South Redstone River area

The geology of the South Redstone River area is shown in two sketch maps covering the areas south and north of the South Redstone River respectively (Fig. 6, 7).

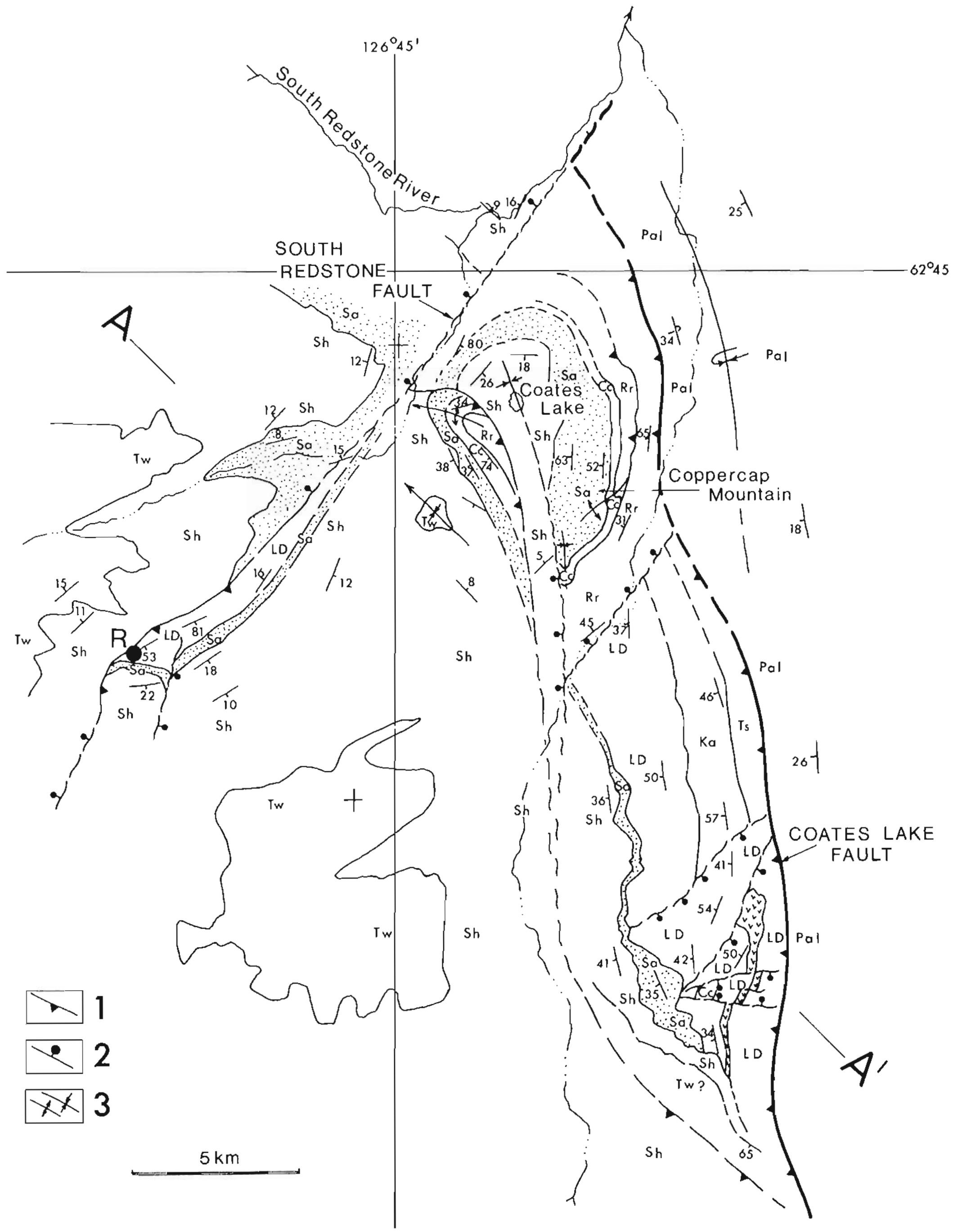
South of the South Redstone River the structure is dominated by two major faults: the northerly trending Coates Lake Fault, a thrust fault, and the northeasterly trending South Redstone Fault, a high-angle normal to high-angle reverse fault. Along the Coates Lake Fault a variety of Proterozoic rocks are thrust over an eastward overturned syncline of Paleozoic carbonate and shale (Gabrielse et al., 1973). Northeasterly trending faults within the Coates Lake thrust plate juxtapose different pre-Windermere formations against each other. About 15 km south of Coates Lake one of these transverse faults is capped discordantly by Sayunei Formation (basal Windermere Supergroup). In this area the transverse faults are closely associated with basaltic flows in the highest part of the pre-Windermere Little Dal carbonates (Fig. 6); the faults might have facilitated extrusion of the basalt flows. The basalts of the downthrown panel are about 50 m thick and are overlain by 20 m of hematitic siltstone laminites, 30 m of dolosiltites – quartzites, and about 120 m of cherty dolostone and turbiditic limestone beds of Coppercap Formation. The flows and immediately overlying pre-Windermere rocks are not preserved in the upthrown panel of Little Dal Group to the north. Thus vertical displacement along the fault was at least 200 m and occurred between latest Little Dal and earliest Windermere time. North of the upthrown fault block, in the immediate vicinity of Coates Lake, the thrust plate is composed of Redstone River and Coppercap formations with a total thickness of at least 450 m. These units are completely missing below the Sayunei Formation to the south. The inferred transverse fault between the Coates Lake section and the upthrown block of Little Dal Group probably runs north of a creek bed 7 km south of Coates Lake. Coarse sedimentary breccias indicate that this fault was active during deposition of Redstone River Formation. Angular bouldery debris in the Sayunei Formation south of Coates Lake suggest probable continued movement in Windermere time.

There is a strong possibility that the northeast trending South Redstone Fault was also active about this time: 12 km to the west-southwest of Coates Lake a minimum of 700 m of the upper Little Dal Group are missing along the south side of the South Redstone Fault and brown rusty sandstone and shale plus a few metres of dolostone of the middle Little Dal Group are overlain unconformably by basal conglomerate of the Sayunei Formation at Point R of Figure 6. North of the fault the Sayunei Formation consists almost entirely of mass flow deposits composed of angular slabs of pre-Windermere lithologies and fragments of reworked Sayunei Formation including the characteristic hematite-jaspilite iron formation. The South Redstone Fault was reactivated during late Mesozoic orogenic compression of the Mackenzies and is probably linked with a thrust fault immediately west of Coates Lake; it also truncates the Coates Lake Fault. Another expression of the South Redstone Fault, hidden underneath Paleozoic rocks 30 km to the northeast of Coates Lake, may be the distinct sigmoidal outcrop pattern of pre-Windermere rocks (Fig. 5).

North of the South Redstone River the South Redstone Fault converges against an array of north-trending faults (Fig. 7). The geology in this area is dominated by a north-westerly trending thrust fault which brings pre-Windermere units over a northeasterly verging syncline of Paleozoic carbonate and shale (S_1 in Fig. 7). However, this structure has been profoundly modified by northerly trending high-angle faults, including the Hayhook Fault. The northerly trending faults have a dramatic expression in abrupt facies and thickness changes of Windermere rocks. One of the faults (shown as F_1 in Fig. 7) displaces the contact between Little Dal Group and Katherine Group by several hundreds of metres but does not seem to extend into Windermere rocks. About 4 km to the southeast of this fault (at point PX of Fig. 7) the Little Dal Group, which here has been stripped of at least 900 m of its uppermost section, is overlain with angular unconformity by 50 m of sedimentary (Redstone River ?) boulder breccias. The dolomitic breccia, in turn, is unconformably overlapped by maroon siltstone of the Sayunei Formation which here thins rapidly towards the east (Fig. 7).

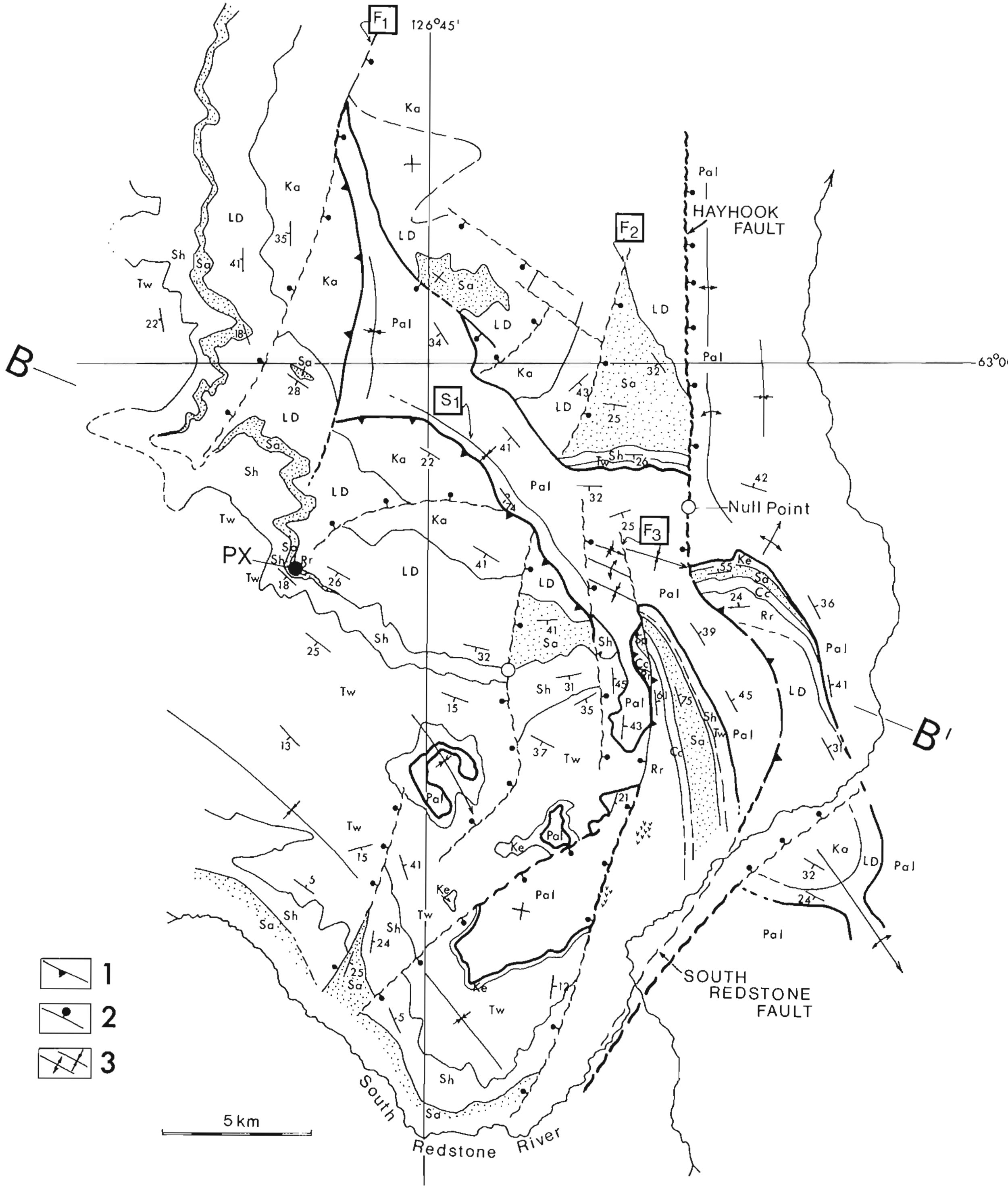
Another fault (F_2, Fig. 7) separates a block devoid of Sayunei Formation on the west from a downthrown block with about 200 m of Sayunei Formation on the east. The fault is truncated by Paleozoic rocks along the north limb of syncline S_1. Fault F_3 separates a panel with 500 m of Redstone River – Coppercap on the east from one without these formations on the west. The fault also may have served as a vent for volcanics here associated with Redstone River Formation.

The Hayhook Fault (Gabrielse et al., 1973) separates two distinct facies of the Sayunei Formation: a massive grey-pink tillite on the east and basinal maroon siltstone, mass flow diamictite, and iron formation on the west; the Redstone River Formation is characterized by sedimentary breccias on the east of the fault and pink siltstone on the west. Immediately south of these two panels, but across the South Redstone Fault Paleozoic carbonate formations lie directly on pre-Windermere Little Dal Group and all of the Windermere is missing. The Hayhook Fault cuts Paleozoic rocks and probably represents a re-activated high-angle Proterozoic Fault similar to others described here. South of a structural Null Point (Fig. 7), steeply eastward plunging hinge lines of minor folds suggest that in the final stages of late Mesozoic compression the southern limb of the syncline S_1 was sliced and tilted eastward by the re-activated fault F_3 and the Hayhook Fault.



Ts =	*Tsezotene Formation*	*Sh* =	*Shezal Formation*	*1* =	*thrust fault (barbs on upthrown side)*
Ka =	*Katherine Group (= Tigonanqueine Formation)*	*Tw* =	*Twitya Formation*	*2* =	*high-angle fault (dots on downthrown side)*
LD =	*Little Dal Group (v-pattern (indicates basaltic volcanics)*	*Pal* =	*Paleozoic formations. For restored stratigraphic cross-section AA' see Figure 8*	*3* =	*folds*
Sa =	*Sayunei Formation*	*R* =	*locality referred to in text*		

Figure 6. *Geological sketch map of the South Redstone River area (south segment).*



Ka =	*Katherine Group*	*Ke =*	*Keele Formation*
LD =	*Little Dal Group*	*Pal =*	*Paleozoic formations*
Rr =	*Redstone River Formation*		
Cc =	*Coppercap Formation*		
Sa =	*Sayunei Formation*		
Sh =	*Shezal Formation*		
Tw =	*Twitya Formation*		

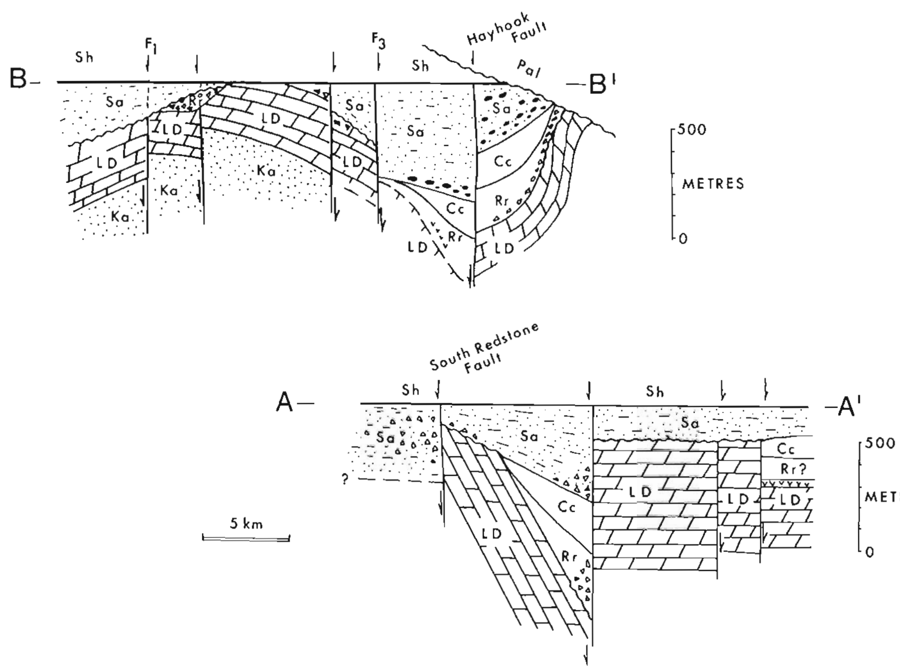
Null point = point along a reactivated fault where sense of displacement changes. For restored cross-section BB' see Figure 8. F_1, F_2, F_3 are faults referred to in text; S_1 is syncline referred to in text; P_x is locality referred to in text

1 = thrust fault (barbs on the upthrown side)

2 = high-angle fault (dots on downthrown side)

3 = folds

Figure 7. *Geological sketch map of the South Redstone River area (north segment).*



LD = Little Dal Group
Ka = Katherine Group
Rr = Redstone River Formation
Cc = Coppercap Formation
Sa = Sayunei Formation
Sh = Shezal Formation

Figure 8. *Restored stratigraphic section across the north-northeasterly trending synsedimentary faults of the South Redstone River area using the base of the Shezal Formation as datum plane (for location see Fig. 6 and 7). V-pattern indicates position of basaltic volcanics in the uppermost Little Dal Group.*

Thus northerly to northeasterly trending faults have greatly influenced the relief during deposition of Redstone River, Coppercap, and Sayunei formations in the South Redstone area and were partly reactivated as tears and high-angle reverse faults during late-Mesozoic-Paleogene southwest-northeast compression.

Figure 8 shows two restored northwest-southeast cross-sections across the contemporaneous transverse faults south (AA') and north (BB') of the South Redstone River respectively. The Shezal Formation is used as datum plane although differential movements along the faults continued to be significant during and after deposition of the Shezal Formation. From these diagrams it seems that beginning with the outflow of basaltic lava the local paleogeography was dominated by complex marine to nonmarine interfaces with deposition taking place on mud flats, small alluvial fans, and evaporitic basins to the southwest (Redstone River Formation). A relatively abrupt transgression (Coppercap Formation) converted the structurally low lying areas into basins which received carbonate turbidites and laminites. The 'transition zone' in the uppermost Redstone River Formation is characterized by red-grey-green variegated dolosiltites and cryptalgal laminites which host stratabound copper mineralization (Coates, 1964; Eisbacher, 1977; Jefferson, 1978; Ruelle, in press). The highest member of the Coppercap Formation is a massive cherty dolostone with minor evaporite lenses. In drill core at Coates Lake, the transition between Coppercap Formation and Sayunei Formation is conformable. North of the South Redstone Fault the uppermost Coppercap dolostone member is overlain by 10 to 50 m of chaotic olistostrome composed almost entirely of angular carbonate clasts which float in a calcareous matrix. This olistostrome unit grades into less calcareous tillite which probably correlates with the Sayunei Formation (see later section).

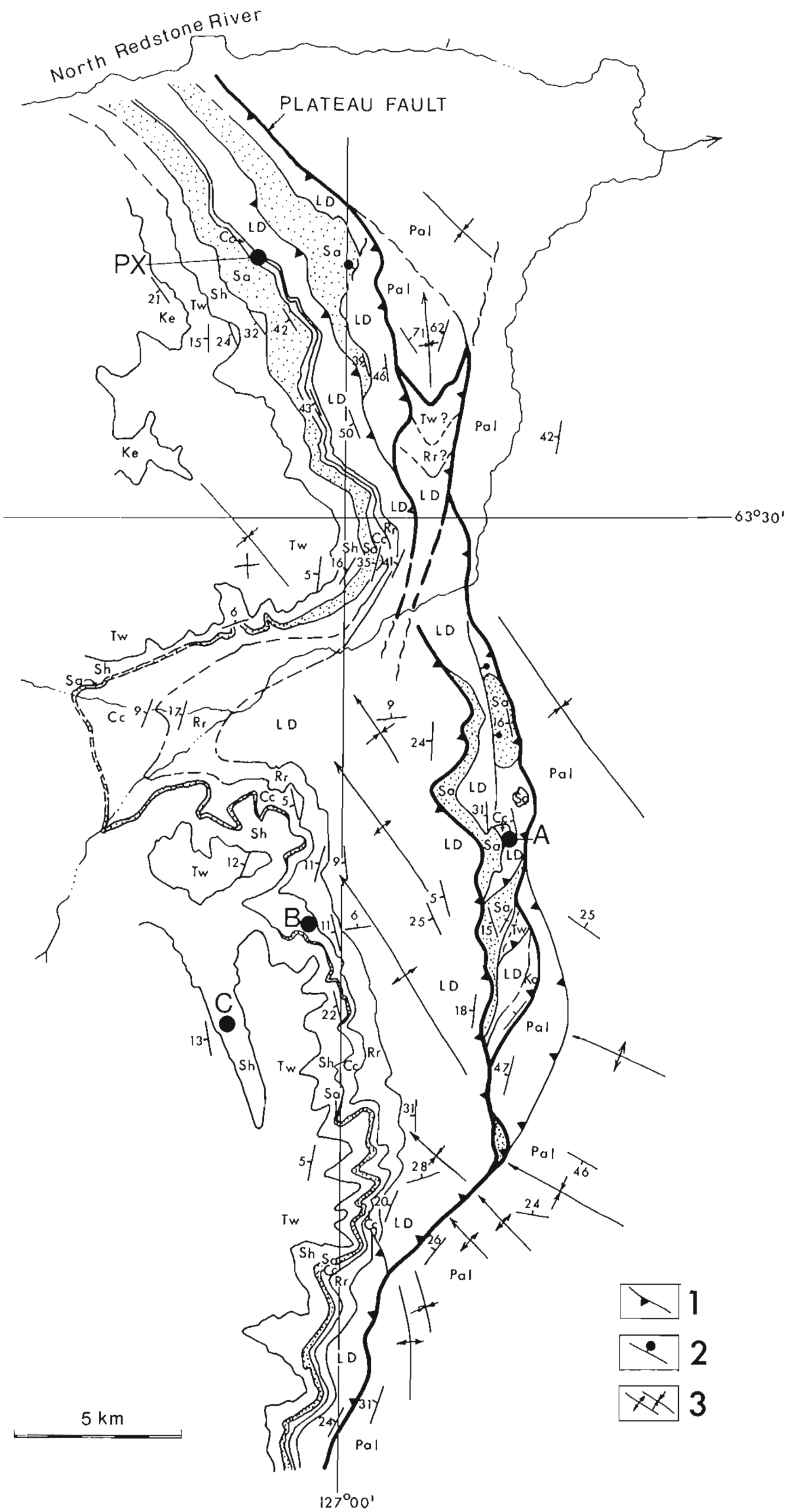
North Redstone River Area

The Proterozoic geology of this area (Fig. 9) is dominated by an abrupt change in trend of the Plateau Fault from a northwesterly to a southerly direction. Structure and stratigraphy reflect this change vividly. The Plateau thrust plate carries Proterozoic formations over Paleozoic carbonates. In the southern part of the area major and minor folds of northwesterly trend in Paleozoic carbonates east of the thrust fault are almost perpendicular to the Plateau Fault which here strikes north-northeasterly. The folds in the incompetent shale units of the footwall plunge gently underneath the thrust plate which is composed of competent dolostone of the upper Little Dal Group. On the thrust plate widely-spaced en-echelon flexures have a similar discordant trend in relation to the Plateau Fault. The Plateau Fault clearly cuts across these structures (Fig. 9). In the zone where the major change in trend of the thrust fault occurs the Plateau Fault splays into several complex imbrications involving mainly Proterozoic rocks. Near the creek at latitude 63°30'N the Plateau Fault asserts its north-northeasterly trend along a lower subsidiary splay which trends into complexly deformed Paleozoic rocks east of the main fault zone. Facies in the Proterozoic Redstone River and Sayunei formations suggest that the north-northeasterly trend was also a subsidiary fault-controlled hinge line during the deposition of these units (Eisbacher, 1978a, p. 19-20). Immediately north of the creek the Redstone River Formation is a fluviatile conglomerate, 150 m thick, consisting almost entirely of Little Dal dolostone cobbles and sporadic quartzite. The conglomerate thins northward where it is overstepped by Coppercap Formation (at point PX in Fig. 9). In the subsidiary fault panel to the east of the Plateau Fault a red breccia, possibly correlative with the Redstone River conglomerates, rests on Little Dal Group and seems to be overlain by younger Windermere rocks although the contact is not exposed. Paleocurrent flow, derived from imbricated cobbles in the Redstone River conglomerate, was to the southwest. To the south no conglomerate is found in the Redstone River Formation which is composed of pink cross-laminated siltstone with paleocurrent flow to the northwest. A hinge might also have controlled deposition of the Sayunei Formation which thickens from about 100 m to 500 m, 15 km to the north. The subsidiary hinge and others of similar trend were probably reactivated during late Mesozoic compression and caused the Plateau Fault to break southward rather than maintain a southeasterly trend. Despite the subtle expression of minor transverse faults, the Proterozoic units in general thicken dramatically in a westerly direction. This is well illustrated in the Coppercap Formation which increases greatly in thickness from point A to point C in Figure 9.

At point A about 5 m of dark grey Coppercap limestone and dolostone rest directly on buff dolostone of Little Dal Group; at point B, 6 km to the west, Coppercap Formation is about 170 m thick and rests on at least 250 m of Redstone River siltstone; at point C some 270 m of Coppercap Formation were intersected in the subsurface (L. Haines, Rio Tinto Canadian Exploration Ltd., personal communication, 1977) before drilling was abandoned after another 20 m of anhydrite were found below the Coppercap carbonates. In the creek bed north of point C, folds in the Coppercap Formation with an amplitude of about 3 m trend northerly and verge westward, apparently unrelated to a major structure in the area; they might represent slump folds along a steep paleoslope suggested by the dramatic thickness increase of the Coppercap Formation and by sudden facies changes in the underlying Redstone River Formation.

Mountain River Area

In the Mountain River area (Fig. 10) the Plateau Fault is associated with several thrust splays to the northeast and southwest of the main fault. On the northeast of this fault array pre-Windermere Mackenzie Mountains Supergroup is overlain directly by Paleozoic platformal carbonates. Mackenzie Mountains Supergroup and Paleozoic cover are deformed into broad anticlines and synclines locally disrupted by reactivated transverse structures (Aitken and Cook, 1974a). Along the Plateau Fault zone the Windermere Supergroup increases rapidly in thickness from zero to about 3000 m from the feather-edge on the northeast to its greatest exposed thickness to the southwest. In the southwesternmost thrust plate only the highest units of the Windermere succession



Ka = *Katherine Group (= Tigonanqueine Formation)*
LD = *Little Dal Group*
Rr = *Redstone River Formation*
Cc = *Coppercap Formation*
Sa = *Sayunei Formation*
Sh = *Shezal Formation*
Tw = *Twitya Formation*
Ke = *Keele Formation*
1 = *thrust fault (barbs on downthrown side)*
2 = *high-angle fault (dots on downthrown side)*
3 = *folds*

Figure 9. *Geological sketch map of the area south of North Redstone River. A, B, C, PX are localities referred to in text.*

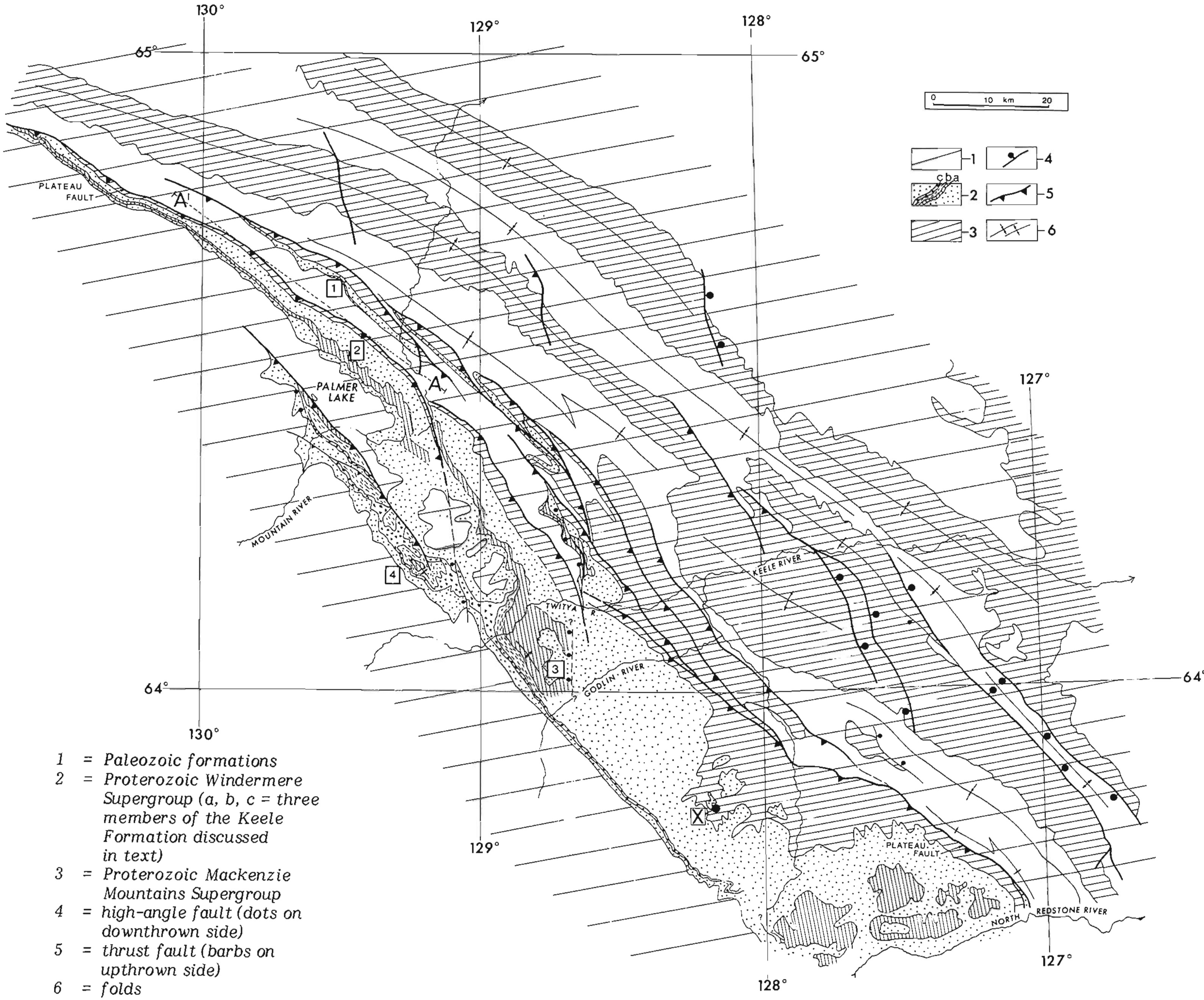


Figure 10. *Geological sketch map of the Mountain River area, Mackenzie Mountains. Numbers in boxes indicate location of sections discussed in text and shown in Figure 18; X is locality referred to text. Geology supplemented after Gabrielse et al. (1973) and Aitken and Cook (1974b, c).*

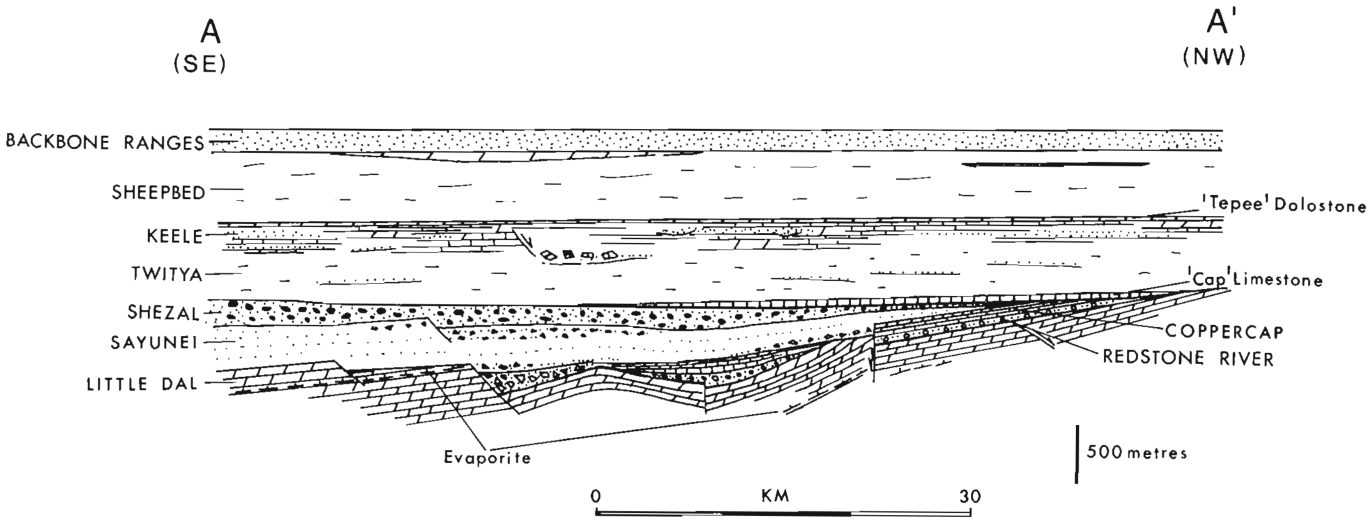


Figure 11. *Stratigraphic restoration of the Windermere Supergroup along Section AA' of Figure 10 with the uppermost Proterozoic – Lower Cambrian Backbone Ranges Formation as datum plane. For discussion see text.*

are exposed. The structural complications along this segment of the Plateau Fault are probably a reflection of both north-northwesterly trending older structural elements and the rapid increase in thickness of the Windermere Supergroup to the southwest. Some of the Precambrian structural trends are well reflected in facies and thickness changes along the trend of the Plateau Fault.

An example of these changes in the character of Windermere rocks and subjacent Redstone River and Coppercap formations is illustrated along a generalized section AA' (Fig. 10, 11). This section follows the strike of the Plateau Fault from southeast to northwest. Tracing the base of the Sayunei Formation from near point A (Fig. 10) to the northwest one first encounters evaporitic units of the middle Little Dal Group overlain unconformably by Sayunei Formation of the Windermere. Thus several hundred metres of upper Little Dal Group are missing. About 10 km to the northwest the evaporites are abruptly replaced by a section of crudely stratified breccias which consist almost entirely of angular dolostone fragments and slabs. This sedimentary breccia is almost devoid of sandy interbeds and is at least 150 m thick. It is unconformably overlain by the characteristic maroon siltstone laminites of the Sayunei Formation.

The apparent downward displacement of the evaporites at this point and their reappearance some 20 km to the northwest suggest a fault with a throw of several hundreds of metres which was overstepped by the Sayunei Formation (Fig. 11). Farther to the northwest dolostone units of the upper Little Dal Group are conformably overlain by conglomerate, mudstone and evaporite of the Redstone River Formation, and by carbonate rocks of the Coppercap Formation. However, at one point both of these units seem to have been erosionally truncated prior to Windermere deposition. From this point the Sayunei Formation thins from 300 to zero metres within a horizontal distance of 5 km (Fig. 11). In the same general area the Keele Formation, higher in the Windermere, displays a spectacular synsedimentary carbonate-platform scarp which trends north-northwest and probably reflects failure of Twitya shales over an older tectonic hinge zone with a north-northwesterly trend (Eisbacher, 1978a, p. 18). These facies and thickness changes along strike of the Plateau Fault indicate significant tectonic control of sedimentation. However, thickness changes across the Plateau Fault are even more dramatic and will be discussed in a later section dealing with the glacial record.

In the southeastern part of the Mountain River segment other deformation contemporaneous with or slightly preceding deposition of the basal Windermere strata is possibly even more abnormal with respect to simple southwestward thickening. At point X in Figures 10 and 12 a high-angle fault with vertical displacement of several hundred metres involves basal Sayunei siltstones which conformably overlie some 500 m of Coppercap Formation. Tightly appressed folds involving Coppercap and basal Sayunei are exposed east and south of the fault. Fault and folds trend north-northwesterly and the folds are overturned to the west. Fault and folds are overlain by flatlying beds of the Sayunei Formation (including iron formation) thus suggesting an intra-Sayunei unconformity, indicated in Figure 12. Copper mineralization appears to be related to this unconformity (Helmstaedt et al., 1979).

The Mountain River area thus has a record of faulting, some folding and southwestward tilting of pre-Windermere rocks which occurred contemporaneously with Windermere sedimentation. Some of the transverse contemporaneous faults were also reactivated during late Mesozoic deformation and modified first-order folds and faults.

Snake River Area

This region probably contains the most perplexing exposures of Proterozoic unconformities in the Canadian Cordillera. The regional framework map of the Snake River segment and a geological sketch map illustrate the distribution of the main Proterozoic sedimentary complexes and the important Snake River Fault which trends into the Knorr Fault zone (Fig. 13, 14).

The area is characterized by two profound angular unconformities which demonstrate two major phases of folding in pre-Windermere strata (Eisbacher, 1978b). However, the regional correlation of these deformational phases as attempted by the author (Eisbacher, 1978b, p. 57), may be more complex than suggested previously.

The relationships are documented in Figure 14. Southwest of Pinguicula Lake the upper unit of the Wernecke Assemblage is tightly folded along well defined north-northeasterly trends. These folds were first demonstrated underneath the unconformity at Pinguicula Lake by Wheeler (1954) although the regional significance of the profound truncation remained a tantalising problem after this early reconnaissance of the Bonnet Plume region. The

Rr = Redstone River Formation
Cc = Coppercap Formation
SaL = lower part of Sayunei Formation
SaU = upper part of Sayunei Formation
Sh = Shezal Formation.

Figure 12. *Geological sketch map of the area near point X of Figure 10. Local angular unconformity between tightly folded – lower Sayunei and upper Sayunei shown as bold line.*

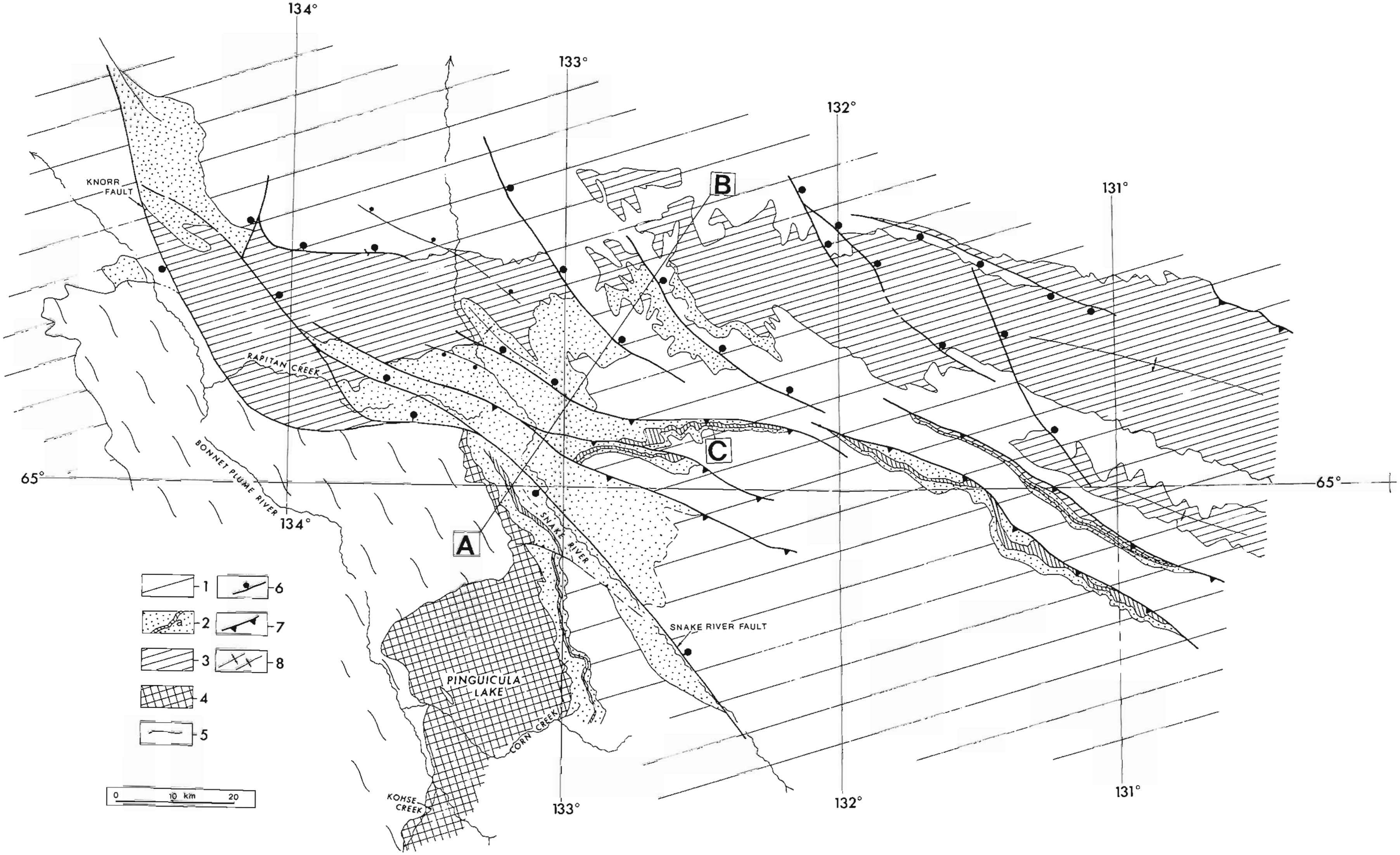
unconformity later served as a type area for the 'Racklan Orogeny' (Gabrielse, 1967) which presumably separated deposition of pre-Windermere from Windermere rocks. Re-examination of the area showed that the unconformity separates Wernecke Assemblage from the overlying Pinguicula Group, both being sub-Windermere Proterozoic sequences (Fig. 14). At Pinguicula Lake and for several kilometres to the south the folded and cleaved dolostone-slate of the Wernecke Assemblage is truncated by the angular unconformity and is overlain by the volcanics along Kohse Creek and by siliciclastics of the basal Pinguicula Group further to the north. At Pinguicula Lake the unconformity dips about 35° to the east, and the facies of the basal beds is transitional between the flows and aquagene tuffs to the south and red siliciclastic laminites to the north (Fig. 4A). Locally, conglomerate channels about 15 m thick, composed of quartzite and dolostone boulders, rest on Wernecke Assemblage (Wheeler, 1954, p. 15). From the pronounced truncation of fold limbs there is not much doubt that in the Pinguicula Lake area the north-northeasterly trending folds formed prior to deposition of the basal Kohse Creek beds. How far away from this area the pre-Pinguicula deformation can be recognized in the Wernecke Assemblage has yet to be established. Also, emplacement of extensive heterolithic breccias, described by Bell and Delaney (1977), Bell (1978), and Archer and Schmidt (1978) in the Wernecke Assemblage is of pre-Pinguicula age.

East of the regional unconformity a generally eastward dipping succession of Pinguicula units is repeated by three major east-dipping reverse faults (Fig. 14). The easternmost exposures of the Pinguicula Group reveal structures which in turn are overlain unconformably by basal conglomerate of the Windermere Supergroup. These structures are outlined mainly by unit E (Corn Creek quartzite) and unit F, the highest Pinguicula unit exposed in this area. Two easterly dipping thrust faults and an easterly trending high-angle tear are truncated by the unconformity and overlain by up to 250 m of massive bright red conglomerate which does not seem to be affected by structures which deform the Pinguicula Group (locality X in Fig. 14). North of locality X the same unconformity truncates other mappable structures outlined by quartzite of unit E and the sub-Windermere unconformity gradually approaches the sub-Pinguicula unconformity. The regional convergence of the two unconformities is caused not only by truncation of progressively lower Pinguicula units but also by the progressive northerly thinning of the Pinguicula Group. Paleocurrents, as suggested by crosslaminations measured in unit B and crossbeds in unit E, corroborate a southward-inclined paleoslope for the Pinguicula basin.

The basal conglomerate of the Windermere Supergroup correlates with the Sayunei Formation of the Mackenzie Mountains and in its northernmost exposures is overlain by diamictite of the Shezal Formation. The depositional setting of the Sayunei conglomerate was probably nonmarine in the redbed facies to the south and subaqueous in the buff channelized facies to the north. Paleocurrents, as indicated by imbricated clasts, flowed southeastward in the red facies and northeastward in the buff facies. In both facies the clasts are mainly quartzite and dolostone.

An impressive platform-basin transition from southwest to northeast is also indicated by the onlap of the glaciomarine Shezal Formation and the dramatic facies change from massive dolostone, about 300 m thick at Mount Profeit, to basinal siliciclastics in the upper Windermere Supergroup. In detail this dolostone breaks up northeasterly into several tongues of dolostone breccia separated from each other by shale, and, within a distance of a few kilometres, changes into limestone pebble conglomerate and calcareous turbidites which overlie Sayunei and Shezal formations (Fig. 15A, B, C). The most basinal facies, the calcareous rudites and turbidites are overlain by graded siliciclastic 'Grit' unit. Paleoslope, as derived from slump folds in this zone, is to the northeast; paleocurrent flow, as derived from solemarks in the turbiditic 'Grit' unit is to the southeast (Eisbacher, 1978b). The Keele Formation, which oversteps the Mount Profeit dolostone in the south, was deposited in a shoaling southeasterly deepening trough which was parallel with the Snake River Fault.

Further evidence for a fault-controlled trough comes from north of the Snake River Fault (locality Y in Fig. 14). There the Sayunei Formation is a massive red conglomerate at least 300 m thick, which rests unconformably on pre-Windermere Mackenzie Mountains Supergroup. It is composed of angular to rounded clasts of dolostone, limestone, quartzite, and greenstone in order of decreasing abundance. The conglomerate carries rare angular clasts of iron formation and grades upwards into greenish slaty diamictite of the glaciomarine Shezal Formation which contains dolostone and greenstone clasts in about equal proportions. Bedded iron formation, which is a characteristic



1 = Paleozoic formations
2 = Proterozoic Windermere Supergroup (a = Keele Formation)
3 = Proterozoic Mackenzie Mountains Supergroup
4 = Proterozoic Pinguicula Group
5 = Proterozoic Wernecke Assemblage
6 = high-angle fault (dots on downthrown side)
7 = thrust fault (barbs on upthrown side)
8 = fold axes

Figure 13. *Geological sketch map of the Snake River area, Mackenzie Mountains and Wernecke Mountains. Reconstruction of cross-section AB is shown in Figure 16. Geology supplemented after Aitken and Cook (1974c) and Norris (1975).*

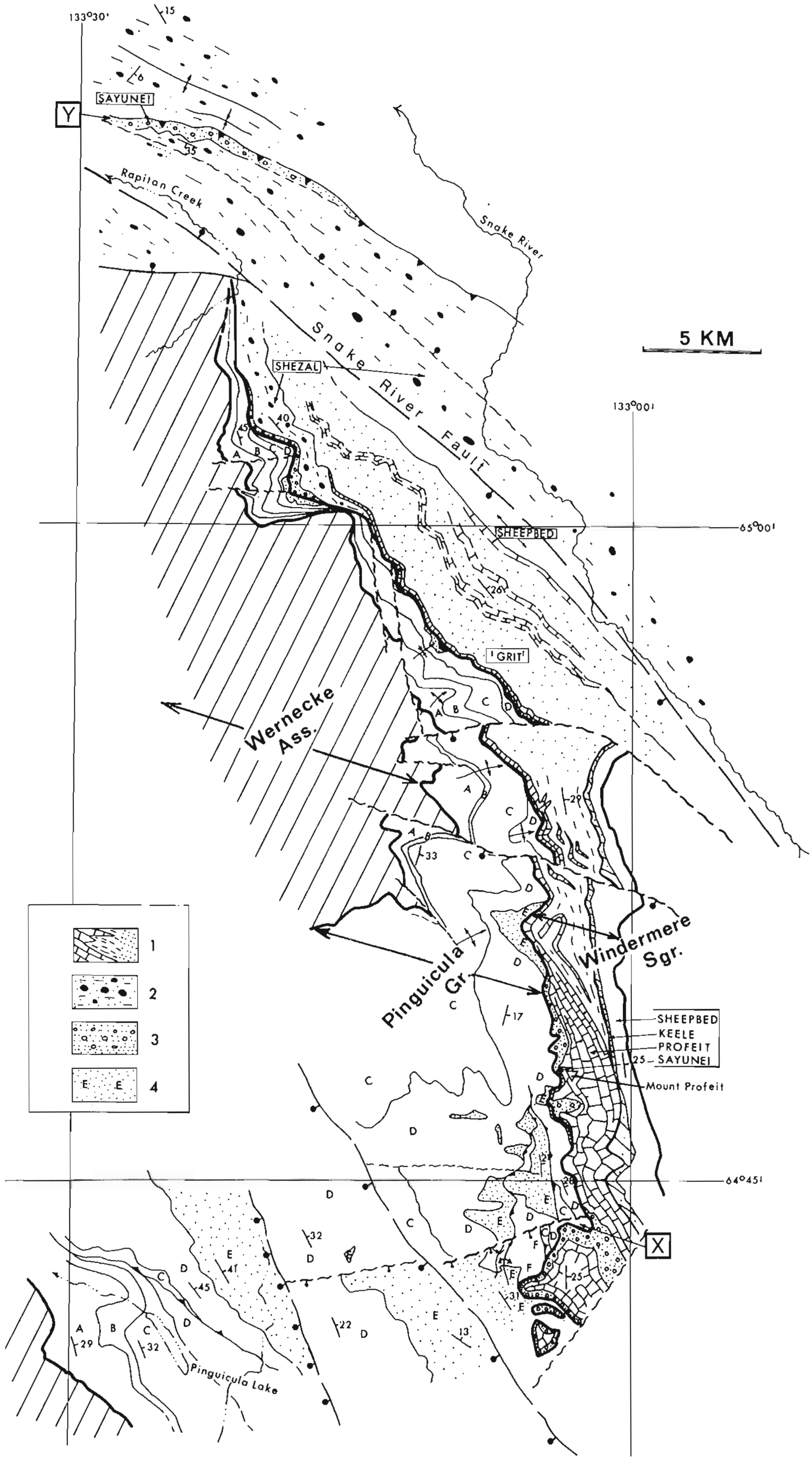
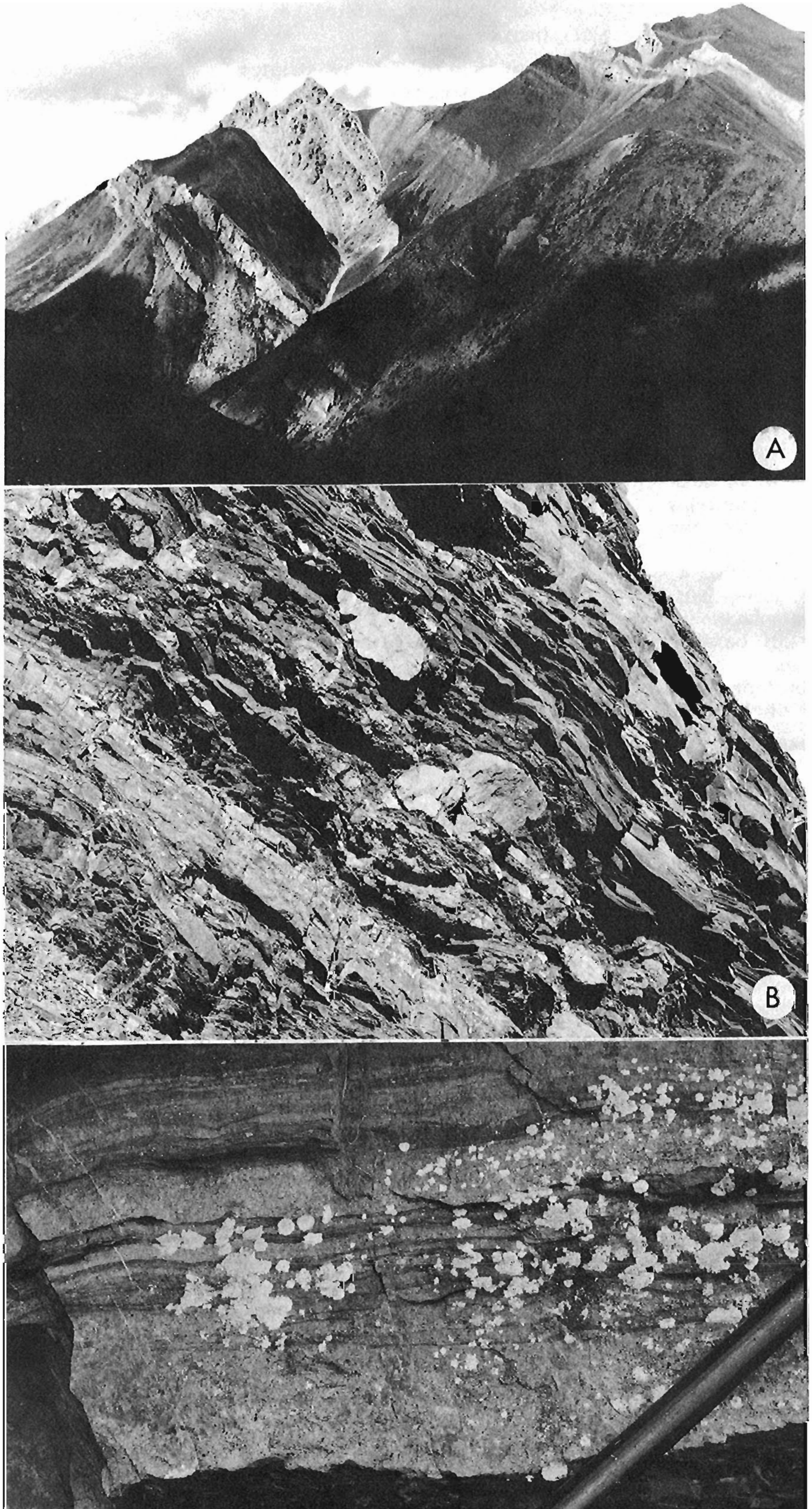


Figure 14

Geological sketch map of the easternmost Wernecke Mountains illustrating the convergence of two Proterozoic unconformities near the Snake River Fault. Units A to F are formations of the Pinguicula Group (Fig. 2). Unit A of the Pinguicula Group rests with angular unconformity on Wernecke Assemblage. Corn Creek quartzite (= 4) illustrates by its outline pre-Windermere structures underneath the angular unconformity below the basal conglomerate (= 3) of the Windermere Supergroup. Note rapid southwestward thinning of the Shezal Formation (= 2) against the Wernecke platform and the dramatic facies change in the upper Windermere from platformal dolostone near Mount Profeit to shale and siliciclastic 'Grit' unit along the Snake River (= 1). The Snake River Fault is probably a major transcurrent fault.



A - *Tongues of dolomitic breccia interbedded with shale exposed north of Mount Profeit. Breccias were deposited on a northeast-facing submarine slope adjacent to a dolomite platform. View to the north. GSC 203631-C*

B - *The dolomite breccias grade northeasterly into dolomitic-calcareous rudites and turbidites, which in turn are overlain and interbedded with siliciclastic turbidites of the 'Grit' unit. GSC 203631-D*

C - *Siliciclastic turbiditic 'grit' which is widespread throughout the Selwyn Basin. GSC 203631-E*

Figure 15

The three photographs illustrate the rapid facies change displayed in the upper part of the Windermere Supergroup southwest of the Snake River Fault (see Fig. 14).

of the upper Sayunei Formation, first appears 10 km northeast of the Snake River Fault. Paleocurrents suggest southeasterly directed axial sediment dispersal (Eisbacher, 1978b).

Thus, sedimentary facies and thickness changes indicate synsedimentary tectonics along the Snake River-Knorr Fault zone, with a basin axis parallel to the dominant fault trend of the region. A schematic cross-section through the Windermere basin across the Snake River Fault is shown in Figure 16. The formations of the Pinguicula Group do not match those of the Mackenzie Mountains Supergroup exposed just to the north of the fault. It is possible that the quartzite of unit E corresponds to the quartzite of the Katherine Group but the thicknesses, particularly along the northern pinchout of the Pinguicula Group, are so different that a reliable restoration of the pre-Windermere geology in this area cannot be attempted without further field studies.

REGIONAL TECTONICS OF THE NORTHERN WINDERMERE BASIN MARGIN AND THE ORIGIN OF SELWYN BASIN

From the foregoing sections it is inferred that in the northern Canadian Cordillera the margin of the latest Proterozoic basin was superimposed on an older basin of thick epicratonic sedimentary successions (Mackenzie Mountains Supergroup and Pinguicula Group). Unconformities along the basin margin were created by high-angle and possibly transcurrent faults which were active during deposition of the Redstone River, Coppercap, and Sayunei formations. Faulting was accompanied and/or preceded by emplacement of diabase sills and dykes, and by extrusion of basaltic volcanics. The new fault-controlled basin margin first received redbeds, evaporites, and carbonates (Redstone River and Coppercap), and then proglacial and glacial siliciclastics (Sayunei and Shezal). Faults mapped or inferred as having been active during this time interval are shown in Figure 17.

The pattern of faults suggests clockwise rotational stretching of the epi-cratonic basement; this resulted in broad subsidence of a new basin to the southwest, the Selwyn Basin (Gabrielse, 1967). The Selwyn Basin hosts a thick wedge of Proterozoic to Paleozoic clastics and carbonates (Gordey, 1980). Marginal facies of this wedge were deposited on paleoslopes that faced towards the centre of the basin.

The deeper basement of the Selwyn Basin therefore probably consists of an extremely complex assemblage of faulted and subsided Proterozoic sediments, volcanics and sills, and is probably underlain by blocks of stretched continental crust; whether or not true oceanic crust developed anywhere below the Windermere Supergroup remains a topic for speculation (see later section).

GLACIAL RECORD IN THE WINDERMERE SUPERGROUP

Studies in many parts of the world have yielded evidence for glaciation or glaciations in late Precambrian time. Several comprehensive reviews have discussed the points for or against a glacial interpretation of late Precambrian diamictites and dropstone laminites (Harland and Rudwick, 1964; Schermerhorn, 1974; Chumakov, 1978). The existing sedimentary models for glaciomarine environments have been summarized recently by Edwards (1978). Nomenclature of glaciogenic deposits is presently being revised under the auspices of the International Geological Correlation Programme Project 38 by W.B. Harland and the preliminary terminological consensus of this working group will be applied in the following sections.

Glaciomarine diamictites, particularly those deposited in deeper water are similar in texture and structure to subaqueous rudites deposited by mass flow processes along steep paleoslopes in nonglacial environments. In the regional interpretation of glaciogenic deposits it is therefore important to distinguish the possible effects of steep paleoslope, created by active tectonic environments, from direct or indirect effects of regional glaciation (or glaciations).

Many criteria such as striated or polished pavements, faceted and striated stones, 'till' pellets, clast pockets, varvites, siliciclastic rhythmites, dropstones, dropstone-laminates, and exotic (or 'extrabasinal') clasts have been used to deduce possible glaciogenic settings of diamictites. However, other criteria such as the turbidite model, slump folding, olistostrome formation, and carbonate sedimentation have been used by those looking for nonglacial interpretation of diamictites (see the three reviews cited above). The complexities of the glaciomarine depositional model are compounded in geological environments which reflect both tectonics and glaciation. In the foregoing chapters of this report it has been stressed that deposition of the Windermere Supergroup occurred in a tectonic environment characterized by faulting (and related folding) which resulted in complex onlap, overlap or unconformity at the base of the Windermere Supergroup. Steep paleoslopes therefore existed along the margin of the basin. But, in addition to the evidence for an active tectonic environment, there is also much evidence in support of a glacial paleoclimate during the deposition of the basal Windermere units (Sayunei and Shezal formations); this has been pointed out before by several workers (Ziegler, 1959; Upitis, 1966; Young, 1976; Eisbacher, 1976, 1977, 1978a, b; Yeo, 1978). Another important problem is the interpretation of extensive diamictites (and olistostromes) in the upper part of the Windermere Supergroup (Fritz, 1980).

The following discussion will attempt to demonstrate how the Windermere succession of the northern Cordillera might be explained in terms of the subtle interplay between tectonics, paleoclimate and sea level changes. The sections chosen to illustrate the dynamics of basin evolution reflect the reconnaissance nature of the present study. In particular, knowledge of the extremely complex facies relationships in the Snake River segment, which involves a transition from nonmarine conglomerates to massflow deposits, volcanogenic iron formation, dropstone rhythmites, and glaciomarine diamictites, requires much further study.

For discussion of the facies and thickness changes two 'downbasin' transects will be used, one in the Mountain River segment, the other in the Redstone River segment. For purposes of a better regional appreciation of the problem, however, extrapolations along trend will be made as well. The possible regional significance of the succession in the Mackenzie Mountains with regard to other parts of the Windermere Supergroup in the Cordillera is discussed in a final chapter.

Mountain River Segment

In the Mountain River segment the Windermere Supergroup is exposed in three thrust plates which, from northeast to southwest, bring younger and thicker formations to the surface. The sections discussed are shown in Figure 18 and their location is indicated in Figure 10. The description proceeds downbasin from Section 1 through 4, but considers some of the lateral changes as well.

Section 1 (64°36'N, 129°24'W)

The base of the Windermere Supergroup is defined by a flat and polished surface carved into a brecciated dolomitic unit of the Little Dal Group. It is exposed in a fault panel north of and subsidiary to the Plateau Fault. The polished surface is stained by a coating of brown iron-rich crust, 1 to 2 mm thick and persists along trend (Fig. 19B). It is overlain

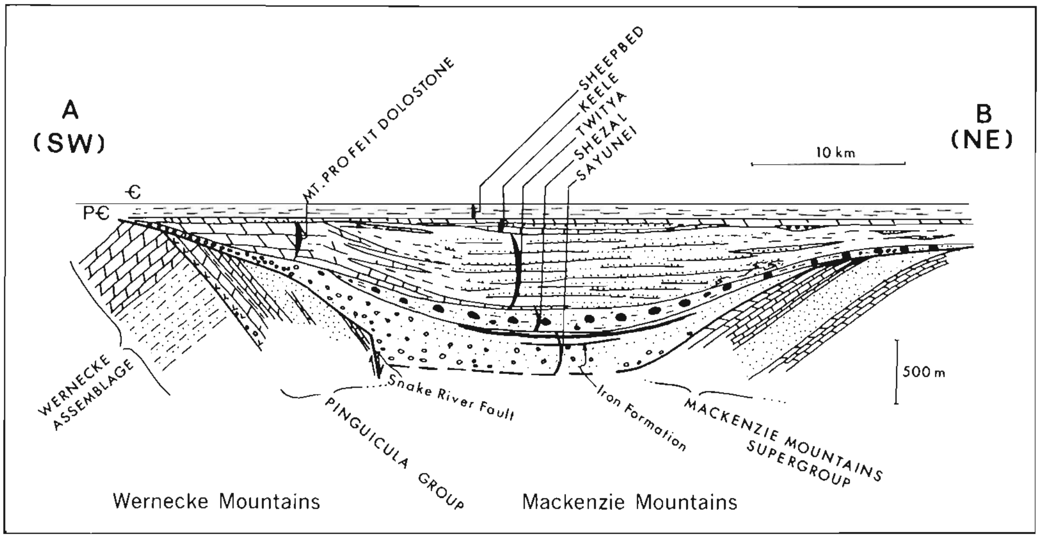


Figure 16

Schematic stratigraphic reconstruction of the Windermere Supergroup along a transect from the eastern Wernecke Mountains to the Mackenzie Mountains (for location see Fig. 13). Major displacement of pre-Windermere rocks along the Snake River Fault is suggested by mismatch of stratigraphy and facies.

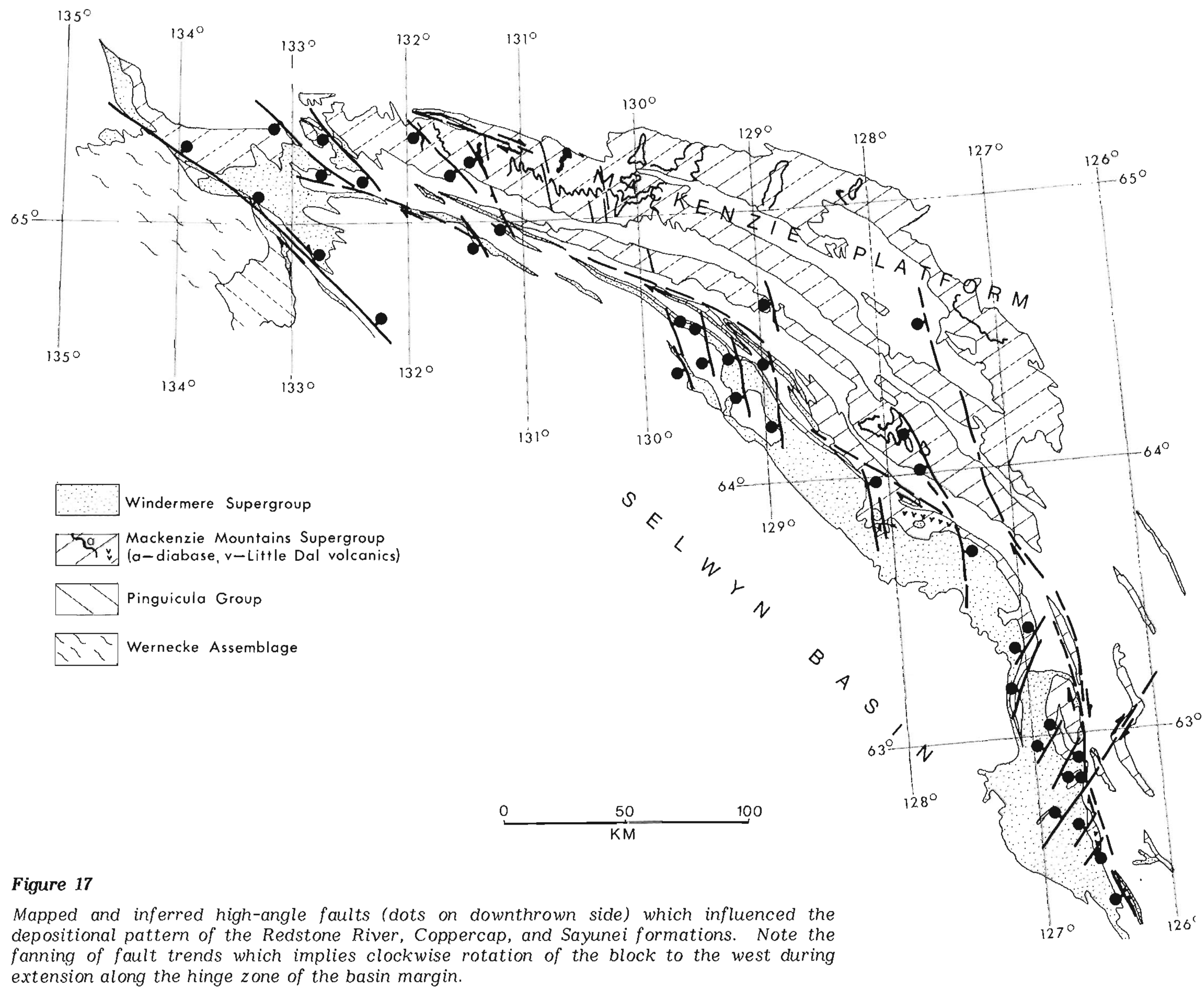


Figure 17

Mapped and inferred high-angle faults (dots on downthrown side) which influenced the depositional pattern of the Redstone River, Coppercap, and Sayunei formations. Note the fanning of fault trends which implies clockwise rotation of the block to the west during extension along the hinge zone of the basin margin.

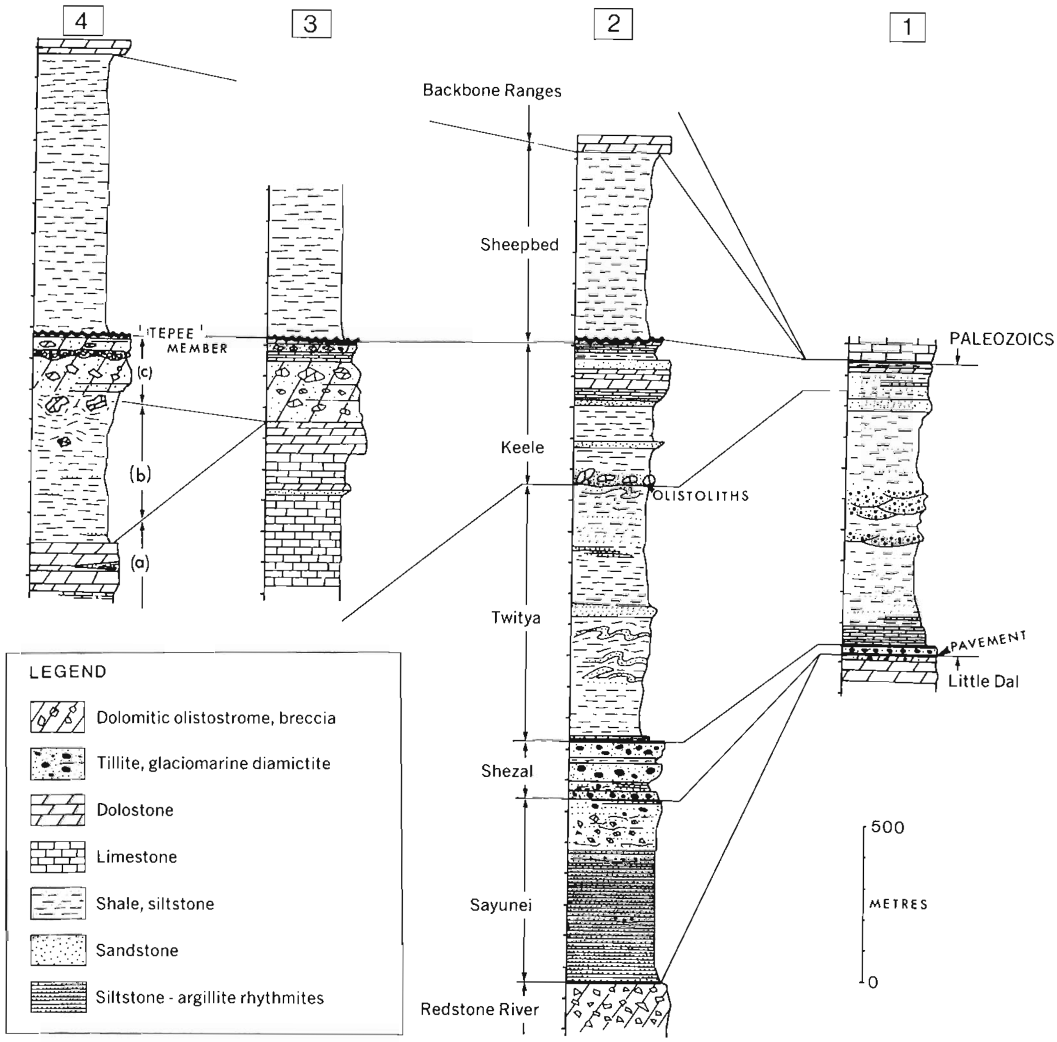


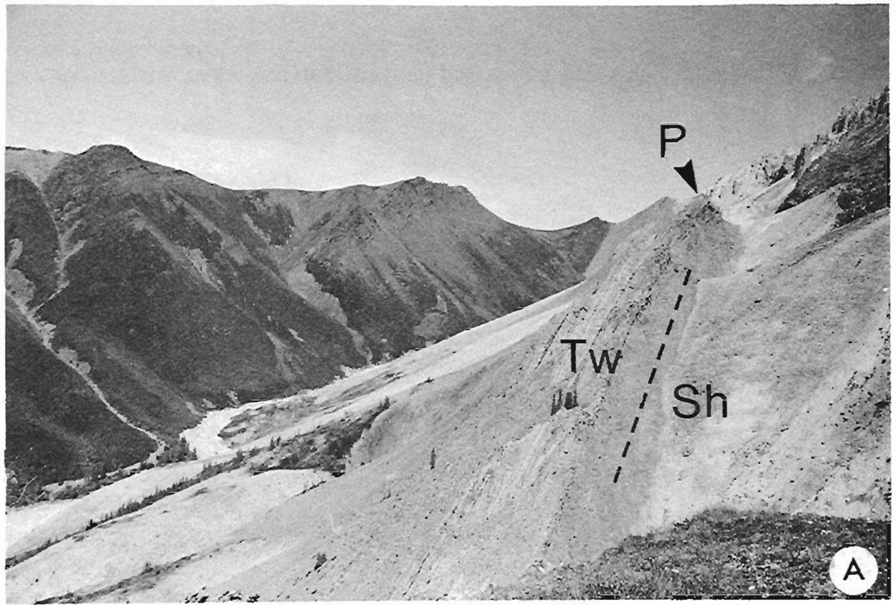
Figure 18. *Four sections of Windermere Supergroup along a northeast-southwest transect in the Mountain River area. For location of sections see Figure 10. For discussion of lithologies and facies changes see text.*

by about 20 m of massive, buff weathering tillite (Shezal Formation) with abundant striated and beautifully faceted stones, some of which are illustrated in Figure 20.

The disconformity between the polished surface of Little Dal dolostone and the massive tillite is interpreted as a glacial pavement overlain by nonmarine tillite. Southeastward along structural trend the massive tillite changes into buff weathering, but crudely stratified tillite. Stratification is defined by subtle changes in grainsize of the matrix and angularity of suspended stones (Fig. 19C). This facies probably indicates reworking of basal tillite sheets into 'flow' tillites. Stones in the tillite are mainly dolostone, quartzite, chert and some extrabasinal greenstones. The composition of the matrix reflects that of the stones.

The tillite is overlain in sharp contact by about 60 m of thinly bedded to laminated limestone of the basal Twitya Formation (Fig. 19A). The calcareous laminites separate the more resistant beds of particulate limestone, some of which display graded bedding. Along trend to the northwest of Section 1 the limestone changes into a thin unit of laminated dolosiltite. To the south the limestone unit breaks up into calcareous turbidites separated by shale intervals; bedding thickness of these turbiditic limestones ranges from 5 to 20 cm. From this relationship it is obvious that carbonate banks and shoals were established during a widespread transgression along the northeastern margin of the basin immediately after deglaciation.

The dark grey limestone unit is overlain by 30 m of black shale with a few beds of calcareous turbidites. The bulk of the overlying Twitya Formation, which in this fault panel ranges from 500 to 700 m in thickness, is composed of shale and parallel- or cross-laminated siltstone. About 300 m above the base of the Twitya Formation lenticular bodies of channelized grits and pebbly sandstones composed of well sorted quartz and chert clasts in equal proportion interrupt the monotony of the section. In the channel fill deposits slabs of siltstone and shale from the underlying finer grained rocks make up a major proportion of the coarse material; several large flutes at the bottom of the channel fills indicate transport to the southwest. These channels, which occupy as much as 200 m of the total Twitya section, in general extend no more than a few hundred metres along strike and are concentrated near the central transect of the fault panel. Like most of the Twitya Formation in the Mackenzie Mountains this facies was probably deposited on the outer shelf and upper slope of the clastic basin (Eisbacher, 1978a).



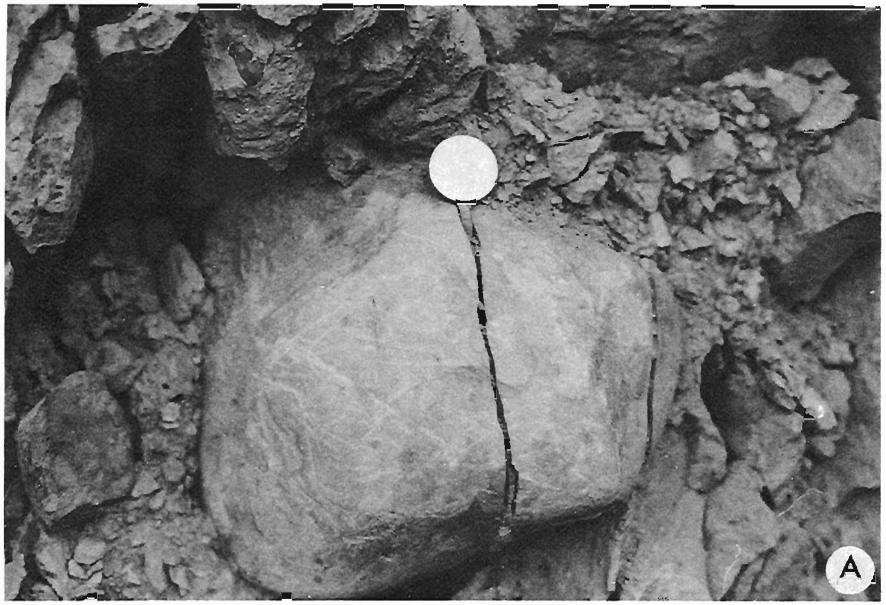
A - *Southwest dipping panel of Proterozoic rocks near Section 1 (northeast of Palmer Lake, Fig. 10). 'P' indicates position of polished pavement carved into Little Dal Group; Sh = tillite (Shezal Formation) covered by talus except along transverse ridges; Tw = limestone turbidites and laminites of basal Twitya Formation; ridges in the background are composed of siltstone and shale of the Twitya Formation. View to the north. GSC 203631-F*

B - *Polished and iron-stained pavement on brecciated Little Dal Group dolostone which is overlain by tillite of the Shezal Formation. GSC 203631-G*

C - *Massive to stratified tillite and 'flow' tillite of the Shezal Formation south of Section 1. GSC 203631-H*

D - *Limestone turbidites separated by interbeds of shale in the basal Twitya Formation near Section 1. GSC 203631-I*

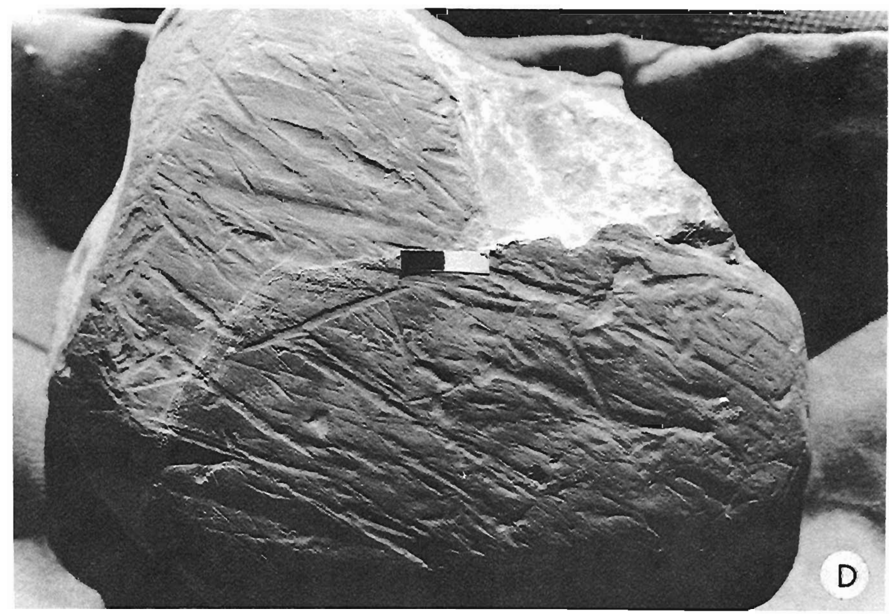
Figure 19



A - *Dolomitic stone (coin for scale). GSC 203631-K*

C - *Striated stone of cherty siltstone, about 7 cm in diameter. GSC 203631-M*

B - *Chert stone; note faceting, surface polish and crosscutting striae bar scale is 2 cm. GSC 203631-L*



D - *Deeply grooved stone of cherty siltstone (bar scale is about 2 cm).*

Figure 20. *Striated stones from Shezal tillite in the area of Section 1.*

Towards the top of the section sandstone beds are more commonly crossbedded and grade into about 50 m of quartz-granule sandstone, calcareous siltstone, and cyclic dolomite-quartzite beds of the Keele Formation. The granule sandstone contains abundant grains of jaspilite, probably derived from jaspilite-hematite iron formation of the Sayunei Formation, which must have been exposed to the northwest. In Section 1 the Keele Formation is overlain unconformably by lower Paleozoic platform carbonates.

Section 2 (64°32'N, 129°23'W)

This section is above the Plateau thrust plate and comprises the complete Windermere Supergroup. The base is an angular unconformity between Windermere Supergroup and pre-Windermere rocks. The exposed part of the succession begins with about 150 m of tightly packed, oligomictic sharpstone conglomerate which displays crude layering on a 10 m scale. The clasts are almost entirely slabs, blocks and cobbles of Little Dal dolostone. This unit is probably a local fault scarp facies of the Redstone River Formation (Eisbacher, 1977). It is overlain in abrupt and unconformable contact by maroon siltstone-argillite couplets of the Sayunei Formation. With the exception of minor lenticular beds of sharpclast pockets, channels, and lonestones the bulk of the Sayunei Formation is made up of siliciclastic rhythmites composed of graded siltstone-argillite couplets which range from 0.5 to 5 cm in thickness (Fig. 21A). They were probably deposited by density and turbidity currents along a clastic basin margin that lacked major fluvial input. Some 430 m of monotonous maroon rhythmites are followed by 150 m of sharpclast-rudites which are characterized by the same maroon argillite matrix as the fine grained rhythmites below. Bedding planes are poorly defined and individual sedimentation units grade into each other along diffuse basal and lateral contacts. Internal fabrics are generally chaotic. Angular fragments derived from Little Dal, Redstone River, and Coppercap carbonates predominate, but well rounded extrabasinal igneous clasts are found scattered throughout this sequence. Differential weathering of calcareous clasts in the dolomitic-siliciclastic matrix gives a distinct Swiss-cheese texture to outcrops (Fig. 21B). Towards the top of this unit clast size and rounding increase and striated stones of dolomite and extrabasinal igneous stones suggest a strong advance of a glacial facies (e.g. grounded shelf ice) over the proglacial subaqueous environment reflected by the underlying rhythmites of the Sayunei Formation. Northwest of Section 2 the Sayunei Formation thins rapidly and is overstepped by tillite of the Shezal Formation. In the same direction maroon rhythmites contain well defined internally cross-stratified channels composed of carbonate-sharpstone clasts and most of the siltstone layers in the rhythmites are crosslaminated (Fig. 21C). Slumping, commonly observed along these channels, may provide for one other mechanism outside pebble-rafting by ice floes to account for some of the lonestone lenticles in the Sayunei Formation (Eisbacher, 1978a). The distinct maroon colour of the Sayunei Formation is due to a considerable amount of hematite in the clay fraction. The hematite-jaspilite iron formation unit, which in other parts of the Mackenzie forms a marker near the top of the Sayunei Formation, is not well developed in the area of Section 2. It might have been removed by chaotic mass flow processes which deposited the sharpstone rudites at the top of the Sayunei Formation. Above these rudites a subtle colour change from maroon to brick red and then to buff coincides with the appearance of rounded stones, some of them with striated surfaces.

In the diamictite of the overlying Shezal Formation boulders and blocks of up to 5 m in diameter are composed predominantly of carbonate lithologies (Fig. 22) but there are also blocks of quartzite, greenstone and well founded boulders of granitic gneiss obviously derived from the Canadian Shield. The thickness of the Shezal Formation varies greatly along trend between 30 and 200 m. In the thicker sections the diamictite is crudely stratified by intervals of dark grey shale and siltstone beds of up to a few metres thick; sandstone lenses or/and pockets of monolithologic orthoconglomerate also suggest bedding in the otherwise massive deposits (Fig. 22C). The rapid vertical and lateral changes of texture in the Shezal diamictite suggest that it was deposited in a complex subaqueous environment where oscillation of the front of a grounded ice mass created a perplexing variety of grain sizes and clast shapes.

The top of the Shezal Formation is sharp and overlain by laminated or graded limestone of the basal Twitya Formation (Fig. 23A, B). The thickness of the limestone member varies from 0 to about 100 m and it pinches out along trend towards the northwest and southeast. In areas where particulate limestone was not ponded on top on the Shezal Formation its place is taken by dark pyritic shale. The black shale facies suggests a starved environment and the shale is commonly slump folded (Fig. 23C). Upwards the Twitya Formation becomes more silty and the remainder of the formation, which here is about 800 m thick, consists of silty shale and siltstone with occasional parallel-laminated sandstone beds, also commonly contorted into spectacular slumpfolds. The Twitya Formation was probably deposited along a southwestward prograding continental slope and shelf which defined the northeastern margin of the Selwyn Basin.

The Twitya Formation grades upward into the shale-quartzite-carbonate succession of the Keele Formation. The Keele Formation in Section 2 is a cyclic shallow water deposit which displays shoaling upward cycles in both carbonate and siliciclastic facies (Eisbacher, 1976). Carbonate and clastic cycles overlap along trend and are further complicated by local contemporaneous faulting along the prograding basin margin. Typically the cycles are 5 to 20 m thick. The deeper water facies includes laminated siliciclastics and thinly bedded limestone, the shallow water facies includes intertidal or fluviatile quartzites, crossbedded oolitic limestone, massive dolostone, and stromatolitic carbonate horizons. Along trend olistostromes, derived locally from failed carbonate-banks, are found as stringers in the deeper water shale-siltstone facies (Eisbacher, 1978a). The most interesting aspect of the Keele Formation is its top. It is commonly composed of quartzose clastics or granule conglomerate capped by a remarkably persistent, white to buff weathering dolostone member which is referred to informably as 'Tepee dolostone' for the characteristic internal structures (Fig. 24, 25 F). This distinct dolostone bed is generally between 5 to 20 m thick and is overlain abruptly by about 500 m of black shale of the Sheepbed Formation. The shallow water depositional environments of much of the Keele Formation and particularly the persistent Tepee dolostone at the top suggest a strong regional regression of the sea which was followed by an abrupt rise of sea level and drowning of the carbonate platform underneath hundreds of metres of Sheepbed shale. Along trend to the northwest, the Tepee dolostone can be followed to the Snake River area, where, at locality C of Figure 13, it rests on 50 m of possibly fluviatile oligomictic quartzite-cobble conglomerate of a thin section of Keele Formation.

The regressive shallow water facies of the upper Keele and the abrupt transgressive overlap of black shale of the Sheepbed Formation observed along the whole length of the basin are important in understanding the more complex relationships of Section 3 and Section 4 farther downbasin.

Section 3 (64°04'N, 128°46'W)

This section is exposed in a north-dipping structural panel between Twitya and Godlin rivers (Fig. 10). The basal units of the Windermere Supergroup are not exposed and the

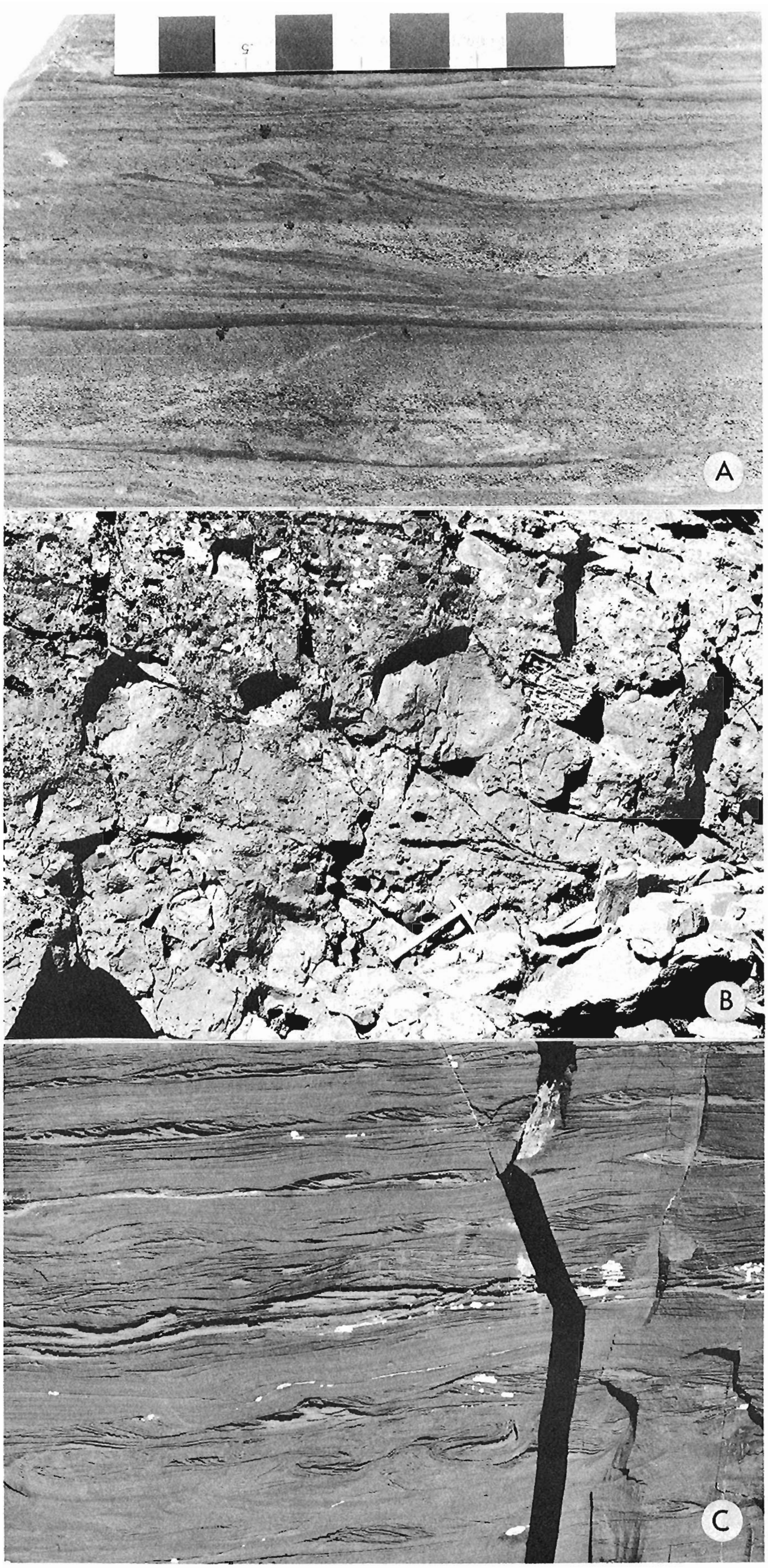


Figure 21

A - Distinctly graded, fine grained sandstone-siltstone-argillite rhythmite of the Sayunei Formation (scale in centimetres). GSC 203631-N

B - Coarse 'sharpclast-siltstones' of the Sayunei Formation, composed of a chaotic mixture of angular limestone and dolostone fragments in a matrix of siltstone – argillite. GSC 203631-O

C - Ripple-drift crosslamination and convoluted bedding in siltstone of the Sayunei Formation north of Section 2. GSC 203631-P

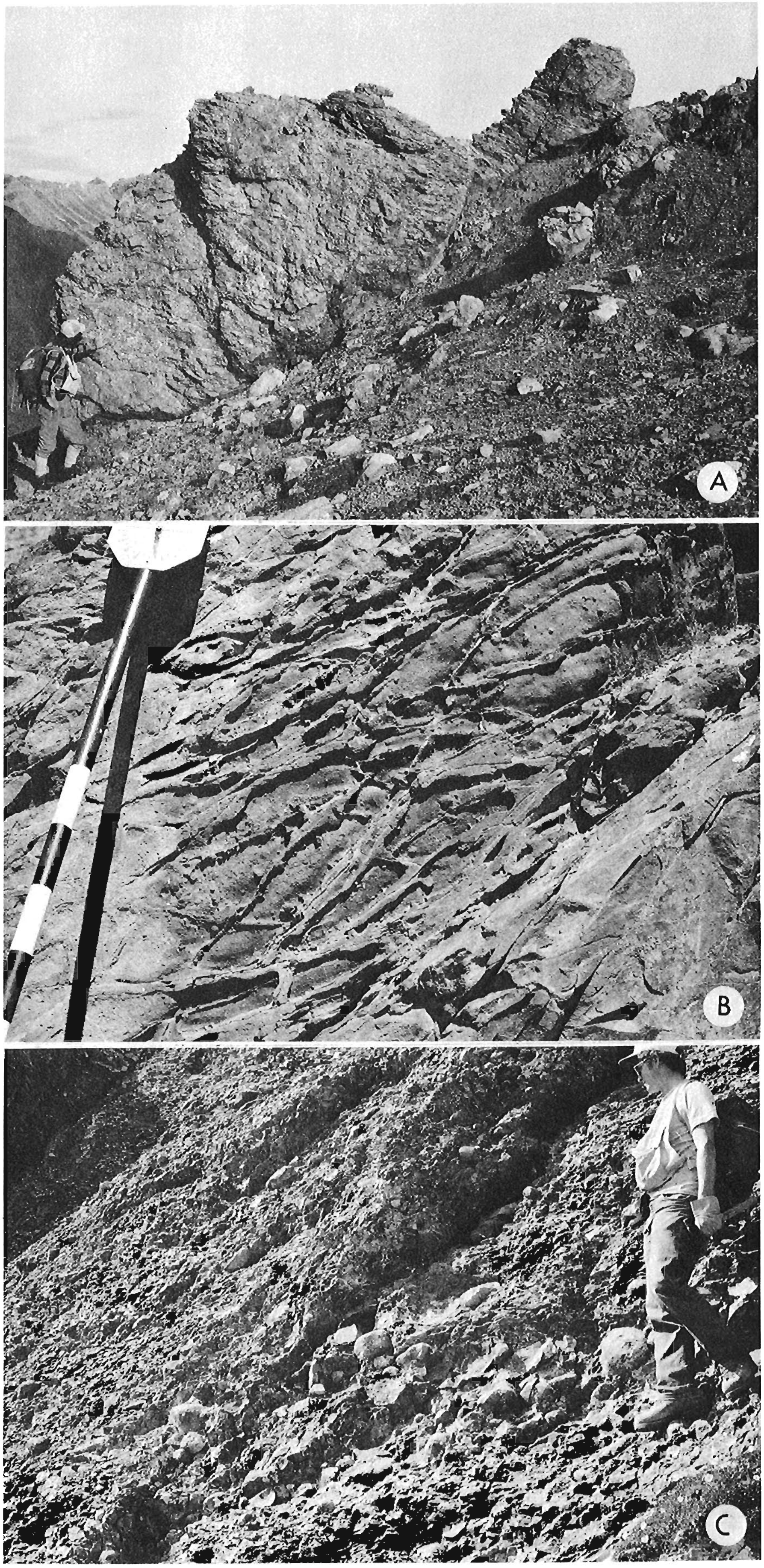


Figure 22

Shezal Formation in the area of Section 2.

A - *Rounded megaclast of dolostone derived from Little Dal Group. GSC 203631-Q*

B - *Characteristic reticulate weathering pattern of the finer grained matrix of the Shezal diamictite in the area of Section 2. GSC 203631-R*

C - *Very densely packed and crudely stratified dolostone conglomerate within Shezal Formation; this type of conglomerate grades laterally into dolomitic diamictite. GSC 203631-S*

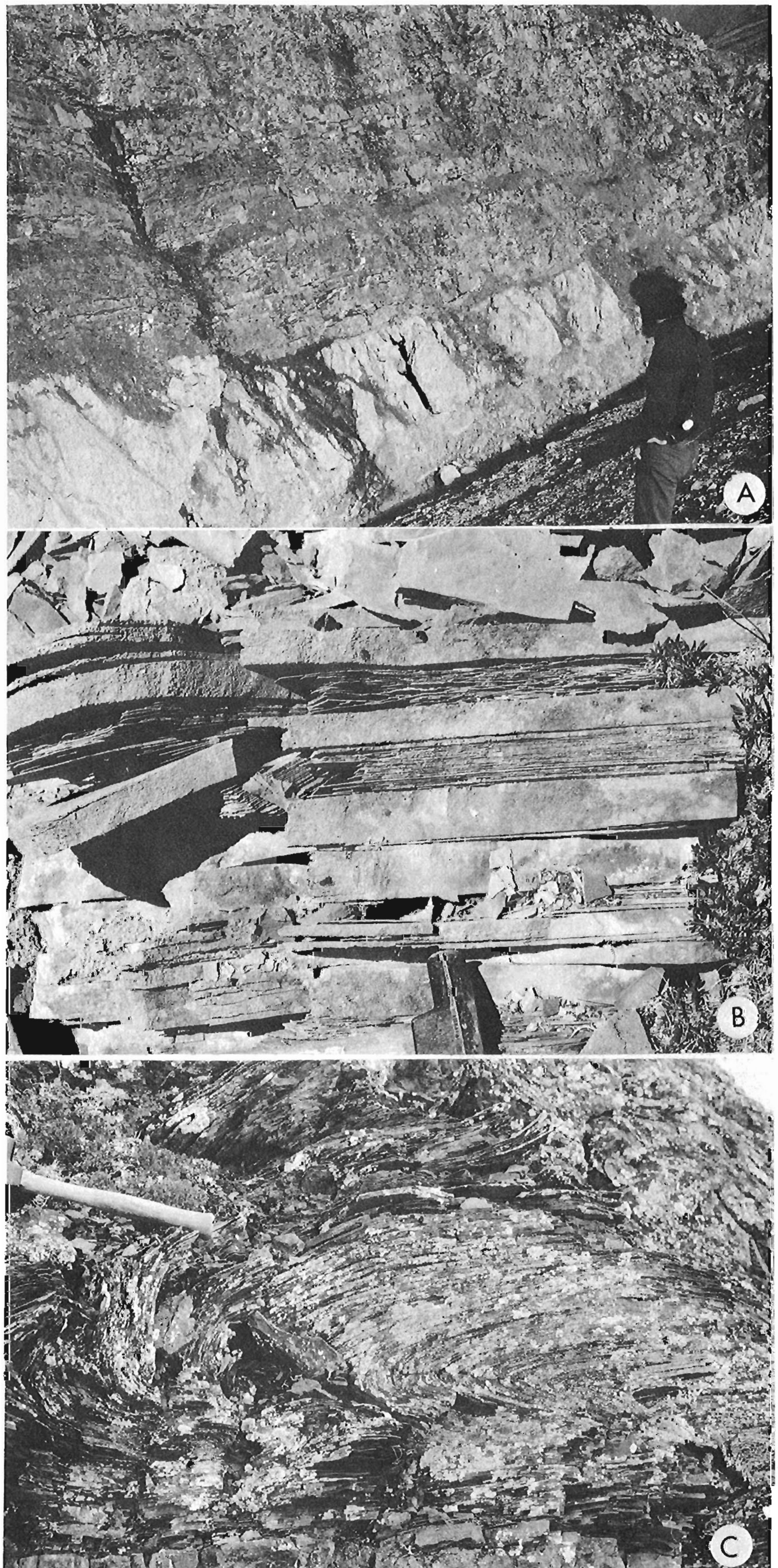


Figure 23

A - *Abrupt contact between diamictite of Shezal Formation and thinly bedded limestone of basal Twitya Formation. GSC 203631-T*

B - *Detail of the limestone in the basal Twitya Formation; note beds of particulate limestone interbedded with evenly bedded calcareous laminites. GSC 203631-U*

C - *Slump folds in black shale of the basal Twitya Formation. GSC 203631-V*

Figure 24

The 'Tepee dolostone' member at the top of the Keele Formation as seen from near Section 2 looking to the southeast. The light weathering 'Tepee dolostone' contrasts with the dark shale of the overlying Sheepbed Formation. GSC 203631-W

section begins with thin- to medium-bedded basinal limestone which grades upward into cryptalgal calcareous laminite, oolitic limestone, and a thin quartzose dolostone unit. The limestone unit is about 400 m thick and is overlain by a unit of orange-weathering, brecciated, and intensely recrystallized dolostone with traces of internal lamination, about 100 m thick. The shallow water dolostone is overlain by 200 m of massive carbonate-debris flow deposits (olistostromes) characterized by a chaotic matrix of dolomitic quartzose sand and abundant carbonate fragments of predominatly dolomitic composition. Some of the dolostone clasts are several metres in diameter. Near the top, the olistostrome is interbedded with a dark grey laminated limestone 20 m thick, which in turn is overlain by a chaotic deposit composed of angular blocks of dolostone and limestone in a matrix of dolomitic sand. The sequence is capped by a discontinuous bed of dolostone, a few metres thick, which is in sharp contact with the overlying dark shale of the Sheepbed Formation.

The section represents a carbonate facies of the Keele Formation, and although its base cannot be seen, it probably overlies siltstone of the Twitya Formation. The upper part of the section reflects deep erosion of the carbonate bank and redeposition of carbonate debris as olistostrome. No extrabasinal clasts were observed among the clasts of the chaotic debris flow deposits. The thin dolomite cap is correlated with the Tepee dolostone exposed in Sections 2 and 4.

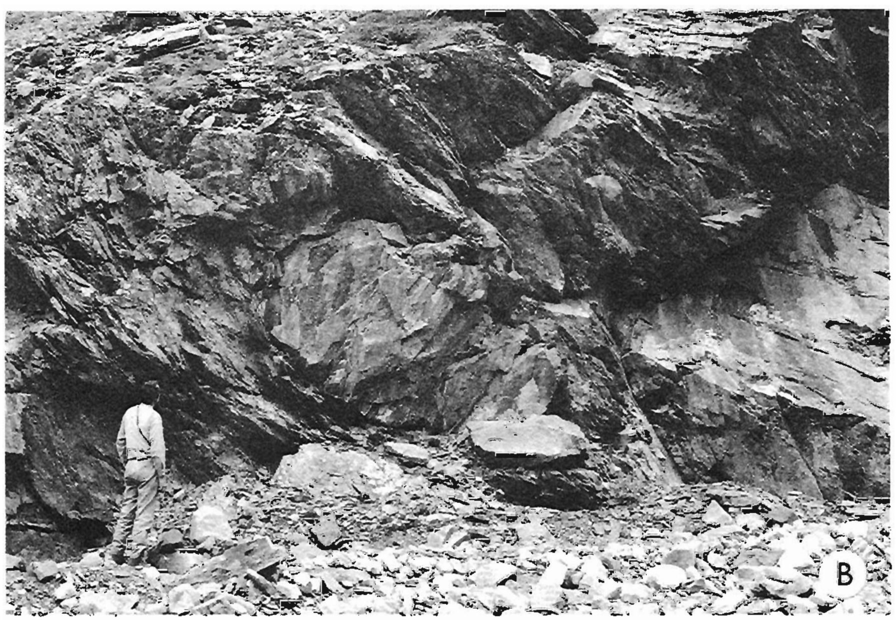
Section 4 (64°18'N, 129°30'W)

This section is in the southwesternmost thrust plate of the area that brings Windermere Supergroup to the surface (Fig. 10). The hanging wall of the thrust is a highly recrystallized orange dolostone of the Keele Formation discussed above; locally, this dolostone unit is interbedded with brick-red laminated siltstone and minor quartzite (unit (a) of Fig. 18). The dolostone is overlain by up to 450 m of silty shale with numerous slump folds and intrastratal slide surfaces (Fig. 25A and unit (b) of Fig. 18). Towards the top of member (b) large slabs and blocks of dolostone float freely in a matrix of silty shale (Fig. 25B). With the appearance of dolostone olistoliths the silty matrix becomes increasingly dolomitic until cobbles of dolostone and limestone are embedded in a matrix of dolomitic sand (Fig. 25C); the thickness of the olistostrome is about 100 m (unit (c) of Fig. 18). It is overlain by dolomitic arenite interlayered with more olistostromes which, however, are composed almost exclusively of angular clasts of dark grey basinal limestone (Fig. 25D). The chaotic internal fabric of the olistostrome displays intricate patterns of reworking of the finer grained dolosiltite matrix. The olistostrome unit is about 140 m thick and contains two monomictic limestone-pebble conglomerates 5-10 m thick (Fig. 25E); it is capped by the characteristic buff dolomite of the Tepee dolostone (Fig. 25F) which is about 10 m thick and is overlain by some 900 m of Sheepbed shale.

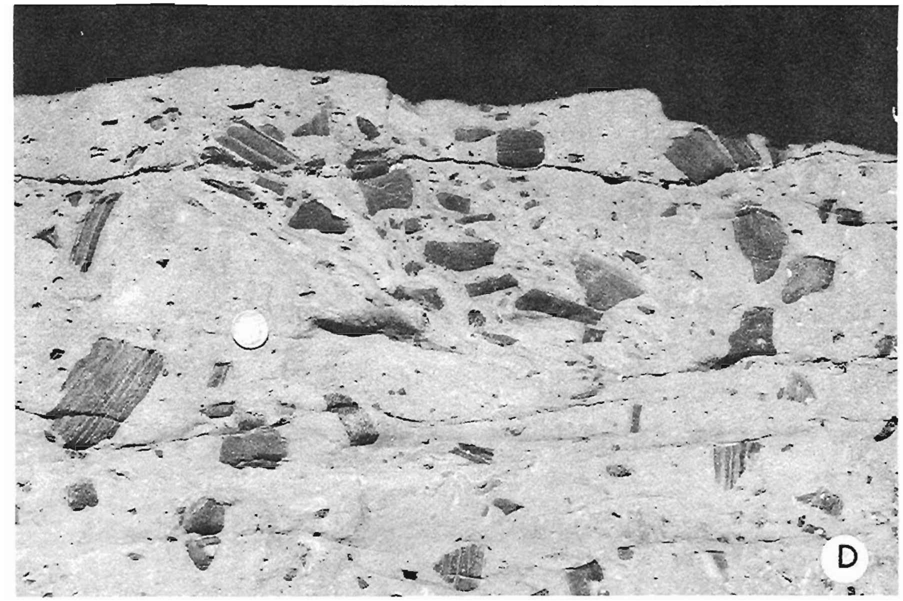
The whole succession correlates with the Keele Formation. The siltstone unit (b) probably represents a slope deposit. Its rapid increase in thickness from 0 to 450 m between Section 3 and 4 can be traced in outcrop (Fig. 10) and suggests a syndepositional scarp or hinge similar to the north-northwesterly trending scarp near Section 2 (Eisbacher, 1978a). The chaotic mass flow deposits probably originated by rapid erosion of an exposed shallow water carbonate platform. Downcutting into the platformal succession such as that in Section 3 would create the 'inverse stratigraphy' portrayed in the clast composition of the deposits: dolostone slabs appear first, limestone clasts from a deeper level appear higher in the section.

In the olistostromes of Sections 3 and 4 no exotic, extrabasinal or striated stones were observed. Apparent dropstones related to the chaotic deposits are ambiguous. Most of the internal textural and structural relationships of the chaotic deposits are characteristic of olistostromes as reviewed by Görler and Reutter (1968), Abbate et al. (1970), Cook et al. (1972), and Hoedemaker (1973). Thus, there is not much direct evidence favouring a glacial origin for the chaotic deposits associated with the Keele Formation. Nevertheless, the depositional pattern in latest Keele time requires significant and widespread lowering of sea level to accommodate progradation of the shallow water carbonate complex including the Tepee dolostone at the top. This regression of the sea was followed by an equally widespread abrupt transgression signalled by the onset of monotonous shale deposition of the Sheepbed Formation. As suggested before (Eisbacher, 1978b), this accentuated fall and rise of sea level could be related indirectly to glaciation elsewhere. Progradation of the Keele Formation and deposition of olistostromes would coincide with eustatic lowering of sea level, the transgression of the Sheepbed shales would signal the eustatic rise of sea level. A phase of sudden foundering along the length of the basin due to tectonic displacements cannot be ruled out at present as an alternate explanation but is not favoured by the author.

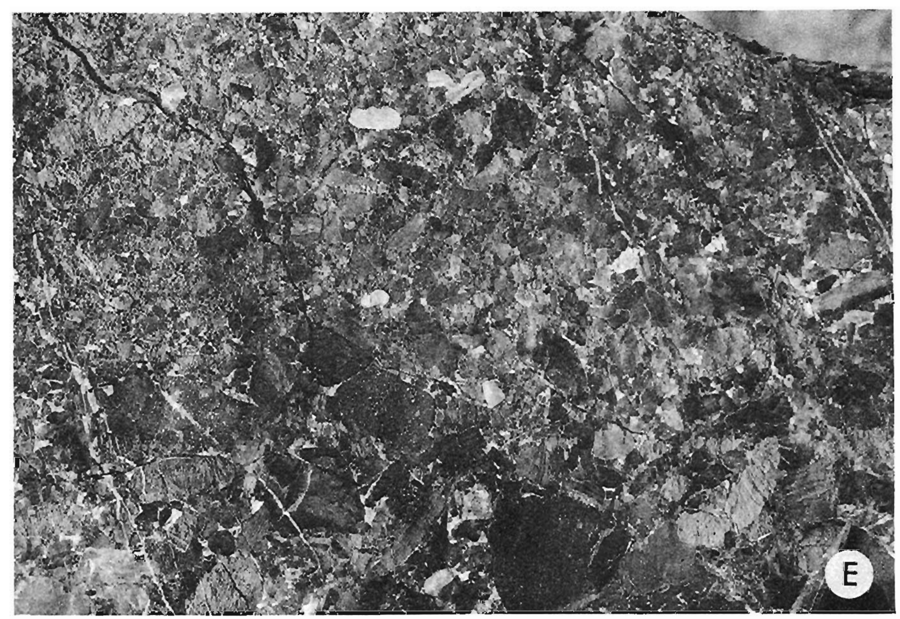
A - *Interformational soft-sediment slip surfaces within unit (b) of the Keele Formation near Section 4. GSC 203631-X*



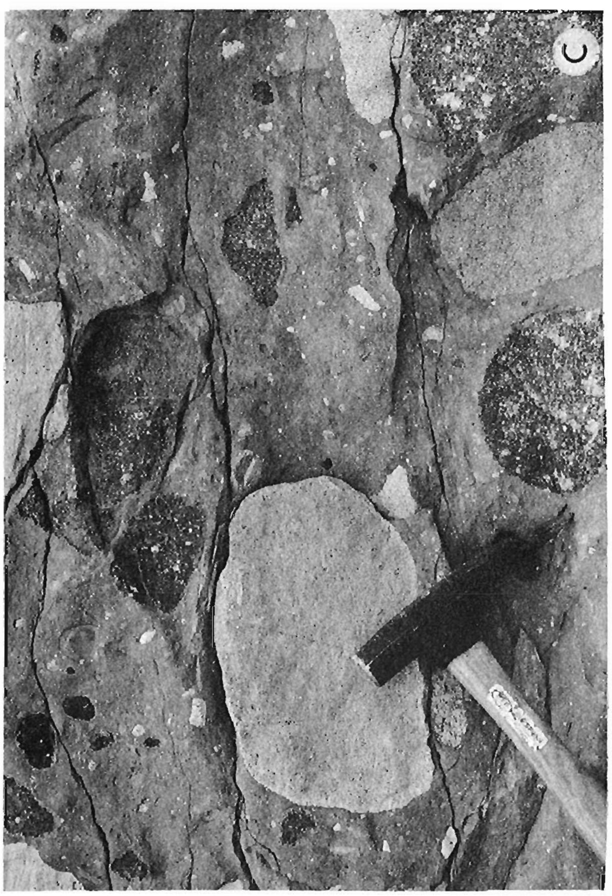
B - *Slabs of recrystallized dolostone in siltstone of unit (b) of Keele Formation near Section 4. GSC 203631-Y*



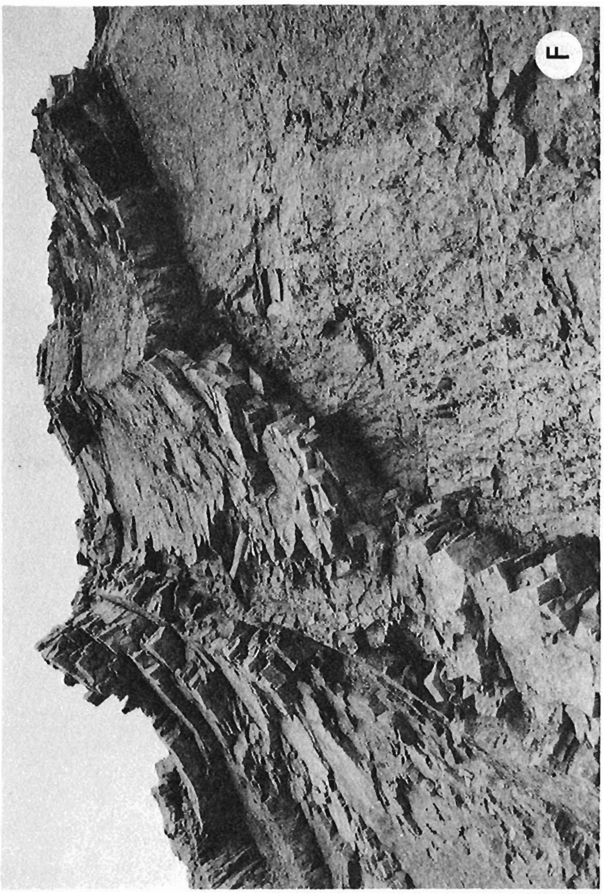
D - *Angular fragments of calcareous laminite in dolomitic matrix; note reworked composite clast with irregular border zone at the centre of the picture. GSC 203632*



E - *Channel fill composed of dark grey, predominantly pebbly limestone clasts in unit (c) of Keele Formation near Section 4. GSC 203632-A*



C - Rounded cobbles and boulders of dolostone (light) and limestone (dark) in a dolomitic matrix of unit (c) of Keele Formation near Section 4. GSC 203631-Z



F - 'Tepee dolostone' member at the top of the Keele Formation; the elongate crests of the bedding planes trend preferably to the south-southwest although no detailed study of the orientation of these features has as yet been carried out. GSC 203632-B

FIGURE 25

Redstone River Segment

Due to vigorous faulting which occurred contemporaneous with sedimentation, the facies changes across major fault panels in the Redstone River area tend to be abrupt. Three measured sections, referred to by numbers 5 to 7 in Figure 26, illustrate the transition from one facies to another and demonstrate the pronounced thickening of the Windermere Supergroup west of the basinal hinge line.

Section 5 (62°56'N, 126°32'W)

The base of the thin Windermere succession, exposed in Section 5, is a sharp erosional surface carved into massive, internally laminated, limestone-dolostone of the Coppercap Formation. The highest part of the Coppercap Formation also contains a brecciated zone, several metres thick, which is overlain by buff-weathering chaotic diamictite of the basal Windermere about 100 m thick and consisting predominantly of limestone fragments floating freely in a particulate calcareous matrix. It grades upwards into a succession of bright-red weathering massive tillite sheets with abundant striated clasts of varied lithology that rest in a dolomitic-siliciclastic matrix. Carbonate stones still predominate but quartzite and greenstone are also common. Fragments of jaspilite-hematite iron formation and blocks of Redstone River breccia indicate vigorous reworking of all other units along the hinge zone of the Windermere basin. Tillite sheets vary from 5 to 20 m in thickness and towards the top are separated from each other by several units, 1 to 10 m thick, of bright red to maroon siltstone and argillite, similar to those of the presumably coeval Sayunei Formation. The total thickness of the composite tillite succession is about 200 m; its accumulation and preservation was favoured at this locality by active tectonic subsidence. The precise correlation between the tillite of Section 5 and the glaciomarine rhythmites-diamictites of Section 6 is difficult in spite of the small distance (5 km) between the two sections. However, Section 5 contains beds similar to the rhythmites of the Sayunei Formation of Section 6 and the massive tillite contains clasts of hematite-jaspilite iron formation, probably eroded from Sayunei Formation. The red tillites therefore are interpreted as a proximal nonmarine facies equivalent of the proglacial Sayunei Formation.

The tillite is capped by 15 m of white quartzite with a stratigraphic position that is not clear (Keele Formation or Backbone Ranges Formation ?) and all units of the Windermere including the quartzite are truncated unconformably by lower Paleozoic carbonate rocks.

Section 6 (62°52'N, 126°36'W)

In Section 6 Windermere rocks rest on cherty dolostone and thickbedded limestone laminite of the Coppercap Formation. There, as in Section 5, the basal unit is a chaotic sharpstone diamictite, about 110 m thick, which is composed of locally derived limestone clasts and whose matrix changes upsection from particulate limestone to dolomite and quartz; towards the top of the unit the colour of the matrix changes from buff to bright red. The basal diamictite is overlain by about 430 m of predominantly maroon siltstone-argillite rhythmite of the Sayunei Formation which contains at least two beds of bright red polymicitic diamictite (1 and 3 m thick respectively) similar to the tillites in Section 1. The Sayunei Formation is also rich in features indicative of a proglacial setting such as dropstones and lenticular sand-clasts (or 'till pellets' of Ovenshine, 1970) which are gently depressed into underlying graded siltstone laminae or argillite (Fig. 27A, B). The top of the Sayunei Formation is characterized by argillite beds of ever higher hematite content until an interval of about 40 m contains the characteristic hematite-jaspilite iron formation. The iron formation hosts occasional extrabasinal (mainly basic volcanic) dropstones.

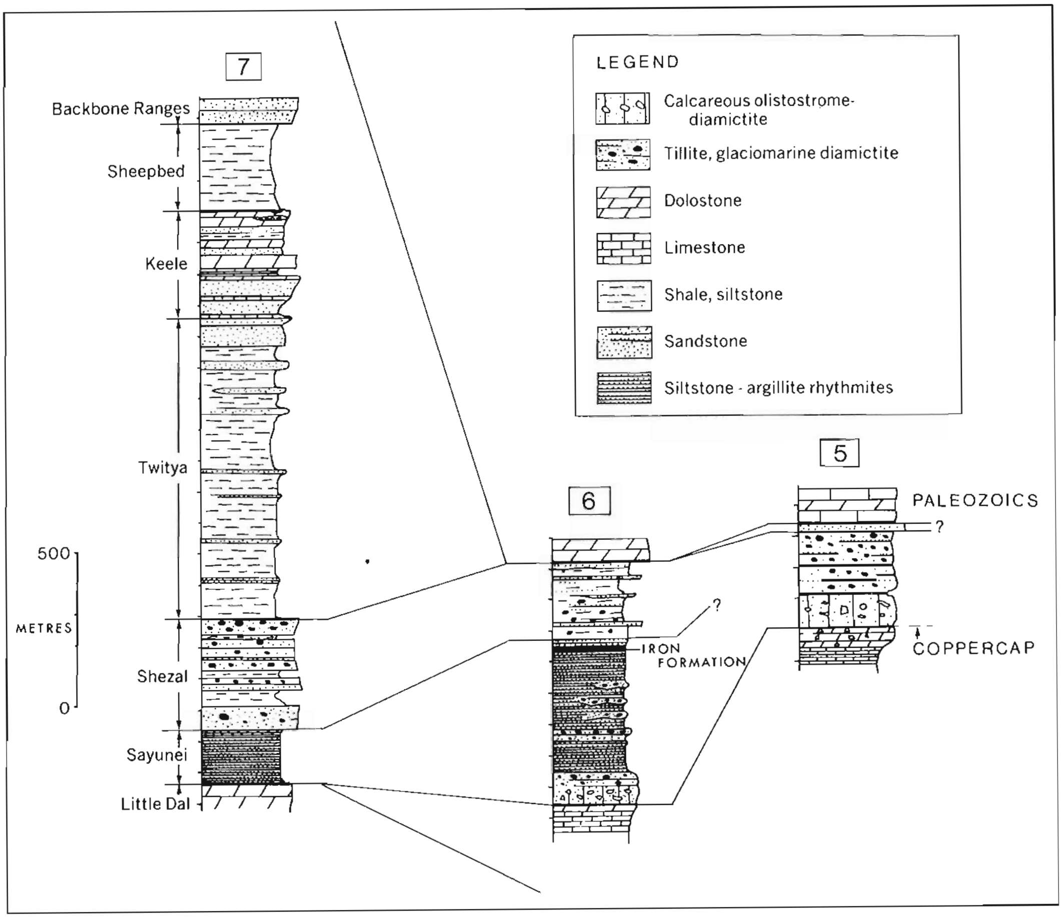


Figure 26

Three sections of the Windermere Supergroup along an east-west transect in the Redstone River area. For location of the sections see Figure 5. For discussion of lithologies and facies changes see text.

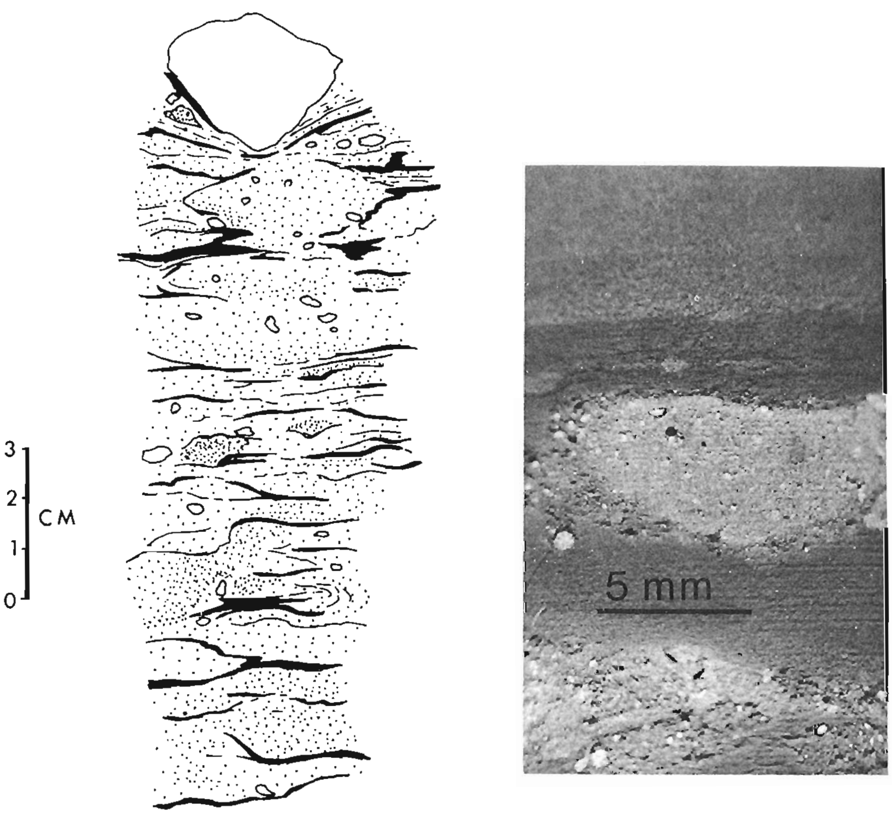


Figure 27

Siltstone-argillite rhythmite of the Sayunei Formation in the vicinity of Section 6. (A) Irregularly bedded, graded siltstone (stippled) and argillite (solid black) with lonestones of carbonate; the lonestones are probably ice-rafted dropstones as they do not seem to be associated with any particular bed (sketch from polished hand specimen). (B) Light grey-green sand clasts ('till pellet') embedded in dark maroon argillite-siltstone and overlain by graded siltstone. One possible interpretation of the sandclasts (according to observations of Ovenshine, 1970) is that they were incorporated into marine bottom sediments as frozen lumps of sand. The diffuse border between the sand clast and the silty-argillaceous matrix supports the contention that the sand clasts were poorly consolidated prior to emplacement into bottom sediment.

The maroon siltstone-argillite rhythmites of the Sayunei Formation are overlain in gradational contact by dark green siltstone matrix of the Shezal Formation characterized by rounded stones of greenstone, quartzite, and carbonate. The Shezal Formation is about 250 m thick, is well bedded and contains several members of sandstone and shale devoid of oversize stones. The change from the graded maroon rhythmites and dropstone laminites of the Sayunei Formation to the dark green-grey diamictite-sandstone-shale succession of the Shezal Formation probably reflects shoaling of the glaciomarine environment; density flows below were replaced by vigorous traction transport of sand and silt. Section 6 is capped by lower Paleozoic carbonate formations which rest unconformably on Windermere rocks.

Section 7 (63°00'N, 127°00'W)

In Section 7 the basal Sayunei Formation rests unconformably on a middle unit of the Little Dal Group and consists of coarse carbonate-sharpclast channels and graded polymicitic grits about 20 m thick. The remainder of the Sayunei Formation is made up of 140 m of monotonous maroon siltstone-argillite rhythmite and dolomitic-siliciclastic turbidites. Local sandy lenses with oversize stones are found scattered throughout the section. The jaspilite-hematite iron formation, characteristic for the upper Sayunei Formation elsewhere, is absent at Section 7 and may have been eroded by grain flows whose deposits make up the highest part of the section. The overlying Shezal Formation consists of distinctly bedded diamictite, which occurs as sheets 5 to 30 m thick, and interbedded siltstone, shale and shallow water sandstones with large scale crossbedding (Eisbacher, 1976). The diamictite sheets show all gradations from loosely scattered stones in a matrix of ripple-drifted siltstone to conglomeratic channels or loadcasted pockets of extrabasinal stones (Fig. 28). The sedimentary structures and the great textural variability indicate a complex glaciomarine environment near a grounded to floating ice-margin along which basal moraine and flow tills were vigorously reworked by traction currents. In general the composition of the matrix reflects the composition of the stones: carbonate and quartzite stones are dominant near the base, extrabasinal clasts such as greenstone and granitoids are more abundant in the upper part. The total thickness of the Shezal Formation is about 370 m thick and its top is a well defined surface along which bouldery diamictite of great compositional variety is overlain by dark grey shale and siltstone of the Twitya Formation.

The Twitya Formation consists of shale, siltstone, and quartzose sandstone. Internal structures of the sandstones include parallel lamination and dewatering structures, and siltstone beds are cross- or parallel-laminated. Graded bedding is virtually absent. Much of the Twitya Formation, which is about 900 m thick in Section 7, reflects depositional environments of an open shelf. The Twitya Formation grades upwards into distinct shallow water quartzites, limestone, and dolostone of the Keele Formation which is about 350 m thick. Near the top of the Keele Formation a thoroughly recrystallized dolostone unit contains a channel deposit made up entirely of limestone pebbles. It is capped by a thin unit of light grey dolostone – Tepee dolostone of the Mountain River area. The Tepee dolostone is in abrupt contact with 260 m of grey Sheepbed shale. The Sheepbed Formation is overlain disconformably by fluviatile sandstone of the Backbone Ranges Formation.

LATE PRECAMBRIAN PALEOSLOPES

Analysis of thickness changes, paleocurrents and slumpfolds shows that the upper Proterozoic Windermere Supergroup of the Mackenzie Mountains was deposited along paleoslopes which prograded centripetally towards the Selwyn Basin (Fig. 29).

The relationship between nonmarine tillite and glaciomarine diamictites of the Shezal Formation suggests a westward deepening of the basin in the Redstone River segment, southwestward deepening in the Mountain River segment, and southeastward deepening in the Snake River segment.

Paleocurrents in crossbedded sandstones and sliplines of slump folds in shaly beds of the Twitya and Keele formations indicate a similar direction of progradation of clastics after deglaciation. The correlation of these shelf-slope assemblages with their basinal equivalents is not yet entirely satisfactory. In the Selwyn Basin most of the upper Proterozoic clastics (and carbonates) have been grouped in a general 'Grit Unit' (Gabrielse et al., 1973; Gordey, 1980). This map unit thus includes basinal facies of Twitya, Keele, Sheepbed and Backbone Ranges formations. The turbidite facies, which overlies Shezal diamictite in the Snake River segment (north of Mount Profeit, Fig. 14), demonstrates that clastic shelf deposits and platformal carbonates of Twitya Formation correlate with at least 1000 m of turbiditic 'grits' in the Selwyn Basin. Centripetal progradation and persistent facies changes from shelf-slope to turbidite basin imply that movement along basement faults and rate of subsidence kept pace with input of clastic material some of which was probably derived from the Canadian Shield judging by the high feldspar content.

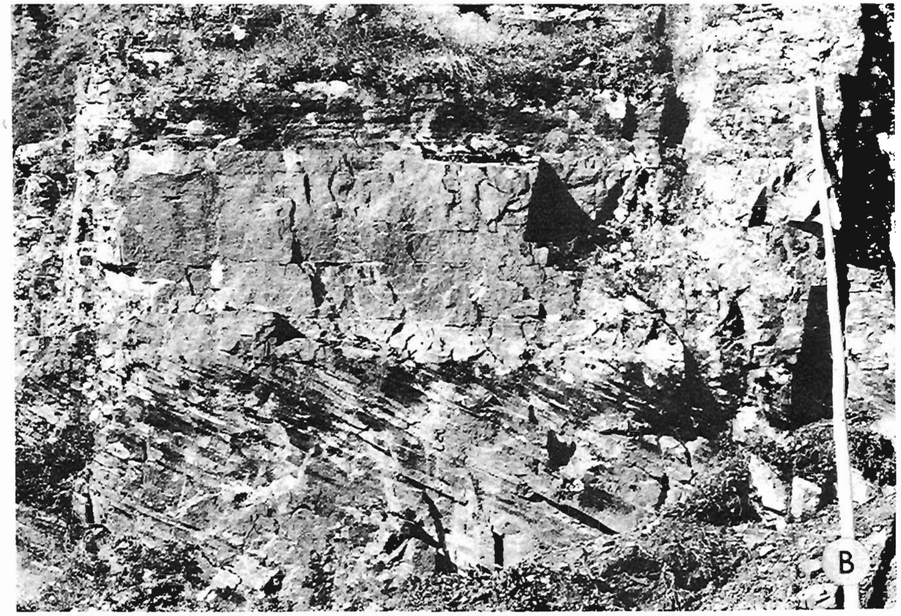
TECTONICS, GLACIATION, AND EUSTATIC SEA LEVEL CHANGES

The general stratigraphic sequence of the Windermere Supergroup as described above in seven selected sections can be seen in many other localities of the Mackenzie Mountains. The pattern permits certain speculations as to the interplay between initial rifting, subsequent glaciation, and possibly related eustatic changes of sea level. A generalized interpretation, as deduced from the data presented above, is shown in Figure 30.

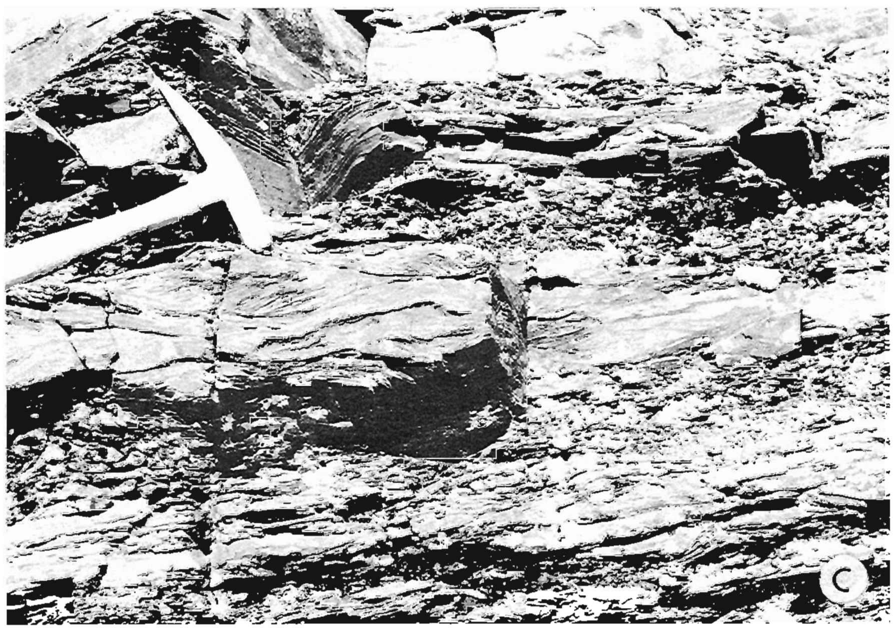
Rifting, associated with locally intense block faulting and folding began with the outpouring of basaltic lava near the top of the Little Dal Group and was most dramatic during deposition of the Redstone River, Coppercap, and Sayunei formations. Faults formed along an arcuate belt somewhat oblique to a hinge located between the Mackenzie Platform and the Selwyn Basin. Early in the history of the basin local hinges determined the boundary between glaciers or ice sheets on land, grounded shelf ice, and proglacial environments. The advance of glaciers during early Sayunei time probably depressed the crust, thus maintaining relatively deep and locally protected basins which favoured preservation of the hematite-jaspilite iron formation. This preservation factor was particularly significant just prior to the advance of ice over the shelf which was now starved of clastic input.

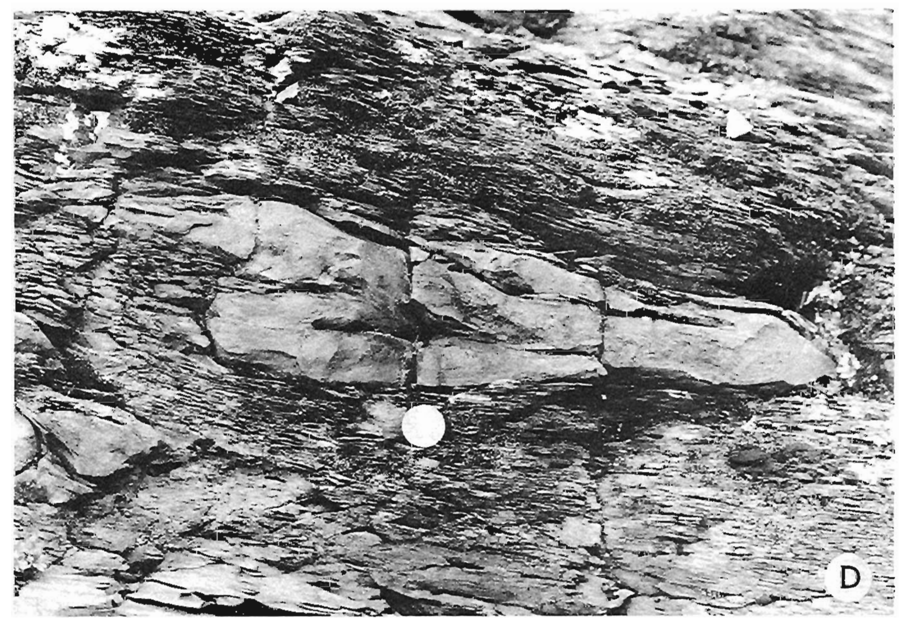
Further advance of glaciers seems to have been accompanied by (eustatic ?) shoaling of the sedimentary basin. Glaciomarine deposits of the Shezal Formation (tillite, flow-tillites etc.) are commonly interbedded with shallow water clastics; the variety of sedimentary textures and structures indicate great fluctuations of the interface between ice, water and sediment during the deposition of the unit. Deglaciation was abrupt and was followed by almost instantaneous (eustatic ?) transgression of the sea and establishment of carbonate banks along the shallow platform.

A *- Crudely layered diamictites interbedded with shale, siltstone, and minor sandstone (arrow); recessive unit above the diamictite complex is basal shale of the Twitya Formation. GSC 203632-C*



B *- Quartzose sandstone interbedded with diamictite but without oversize clasts; note large scale cross-stratification (pole for scale is about 1.5 m long). GSC 203632-D*





C *and* ***D*** *- are examples of the ripple-drift crosslaminated and smeared-out matrix of diamictites with a loose sprinkling of oversize stones. GSC 203632-E; GSC 203632-F*

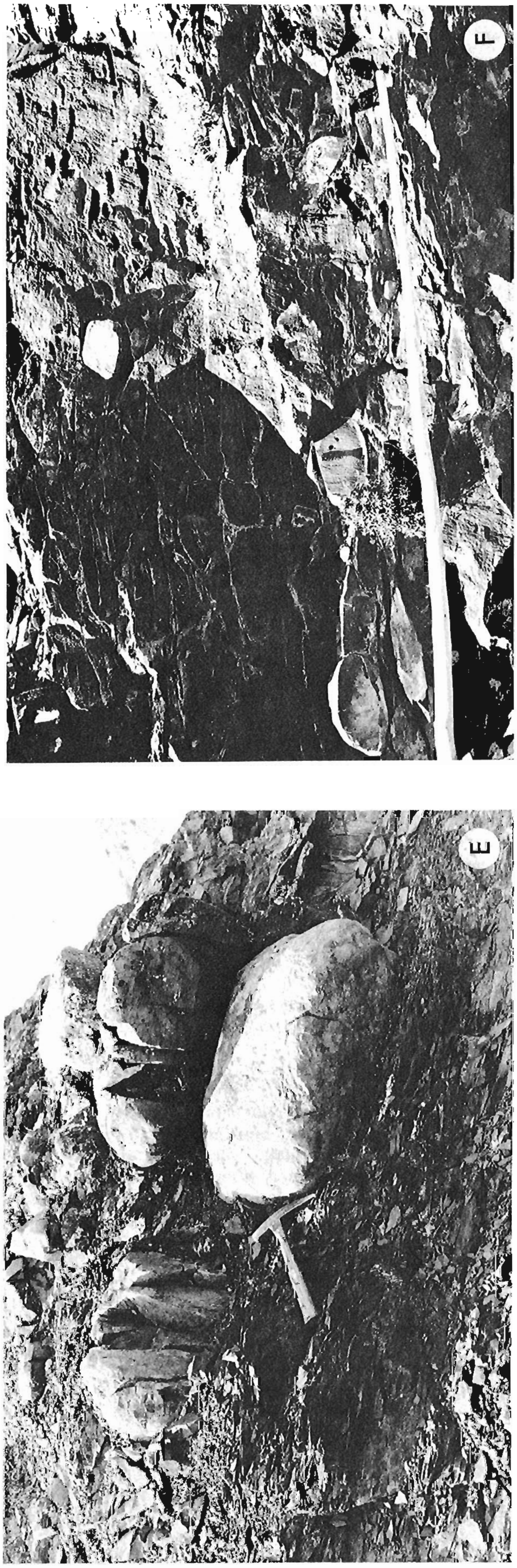


Figure 28. *Sedimentary characteristics of the Shezal Formation in the area of Section 7.*

E *and* **F** *- illustrate oversize stones arranged in an open fabric within a bedded siltstone matrix. Only a few stones in this facies of the Shezal Formation are striated.*
GSC 203632-G; GSC 203632-H

Siliciclastic debris bypassed the banks and caused vigorous progradation of the Twitya shale-sandstone assemblage towards the centre of the Selwyn Basin.

A second phase of regional (eustatic ?) shoaling is indicated by the progradation of cyclic shallow water marine and nonmarine clastics and carbonates of the Keele Formation. This progradation of shallow water deposits over unstable shelf and slope clastics was accompanied by failure of carbonate banks along old fault hinges and by erosion of exposed carbonate cliffs, resulting in deposition of extensive olistostromes along the slope of the sedimentary basin. An abrupt transgression due to a (eustatic ?) rise in sea level led to the deposition of the monotonous Sheepbed shale on top of the Keele Formation. The latest Precambrian to earliest Cambrian Backbone Ranges Formation suggests extensive bevelling of older relief along the platform hinge and indicates continued progradation of clastics towards the centre of Selwyn Basin.

In summary, the Windermere Supergroup of the Mackenzie Mountains reflects an initial phase of rifting, about 800 to 750 Ma ago; its subsequent sedimentary history was profoundly influenced by two eustatic (?) sea level changes, one related to local glaciation (Sayunei-Shezal formations), the other possibly to a glaciation elsewhere (Keele Formation).

GEODYNAMIC IMPLICATIONS

Several workers have attempted to view the late Precambrian evolution of the Cordilleran region in terms of a rifting event (or events) which eventually removed the western margin of large Proterozoic basins by processes of seafloor spreading. Timing and mode of these processes, however, are poorly understood (see models of Monger et al., 1972; Gabrielse, 1976; Stewart, 1972, 1976; Monger and Price, 1979). Data presented in foregoing sections of this report suggest strongly that a phase of rifting, accompanied by basaltic volcanism and followed by regional glaciation, set the stage for extensive asymmetric westward progradation of a clastic wedge after about 800 to 750 Ma. The Windermere basin of the northern Canadian Cordillera is superimposed on an older sedimentary assemblage composed of predominantly shallow water quartzite-carbonate-shale successions. This pre-Windermere basin probably covered broad areas of the Wernecke Mountains, Mackenzie Mountains, and Muskwa Ranges (see Fig. 1, 2), and in the Wernecke Mountains rests with profound angular unconformity on a yet older assemblage of deformed sedimentary rocks.

Considering recent paleomagnetic work in the Cordillera of the United States by Elston and Bressler (1980), which entertains the possibility that much of the Belt Supergroup might have been deposited prior to 1200 or 1300 Ma, and taking into account the intrusion of the Hellroaring Creek granodiorite complex into the Belt-Purcell rocks of the southern Canadian Cordillera at about 1260 Ma (Ryan and Blenkinsop, 1971), it is conceivable that a major orogenic event disrupted the Belt-Purcell basin and underlying crystalline Hudsonian rocks of the Canadian Shield. Subsequent to Belt-Purcell sedimentation a second set of superimposed basins were filled by a thick carbonate-quartzite-shale assemblage between about 1200 and 800 Ma (Muskwa assemblage, Mackenzie Mountains Supergroup, Pinguicula Group).

Rifting, which initiated deposition of the clastic Windermere Supergroup at about 800 to 750 Ma, was therefore preceded by at least two periods of 400 Ma each and a major intervening phase of regional deformation. All of the pre-Windermere sedimentation could have occurred in deep intracratonic basins and need not have been a manifestation of passive continental margins (Harrison, 1977).

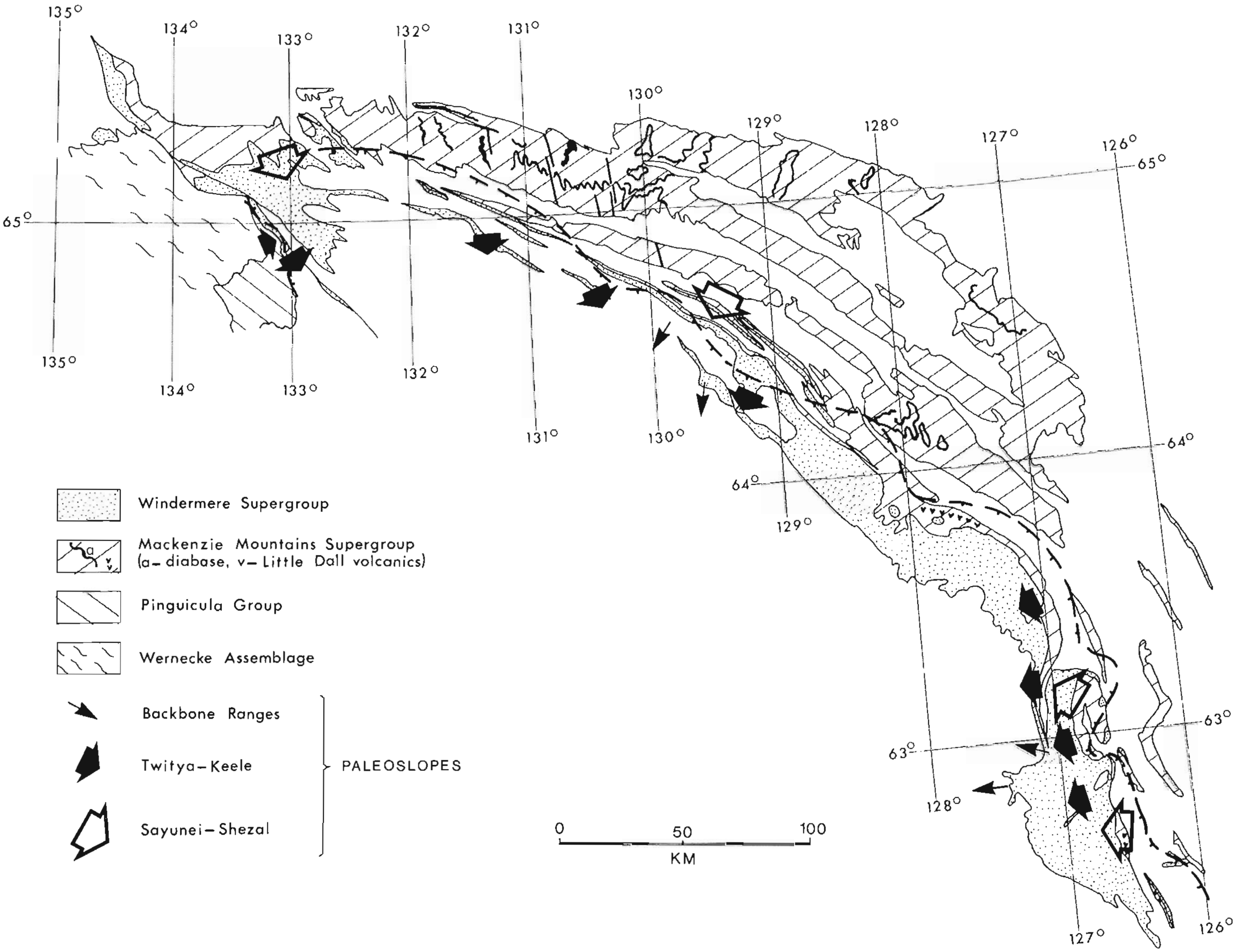
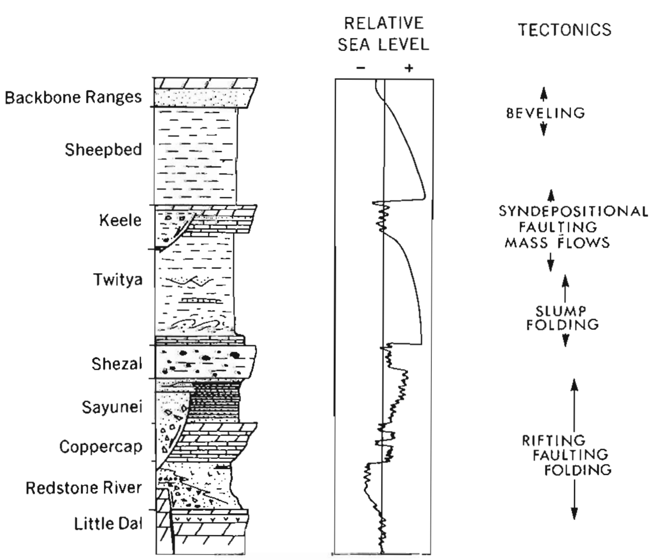
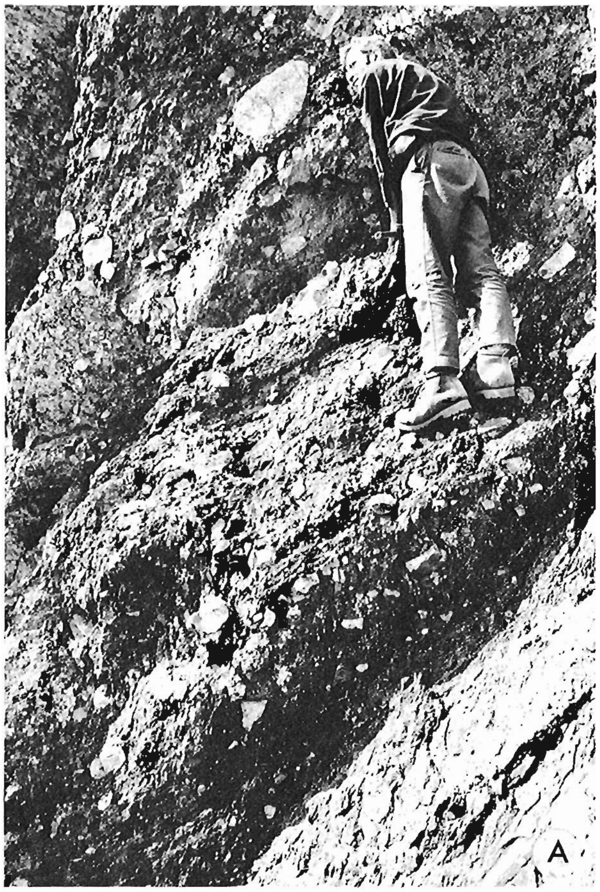


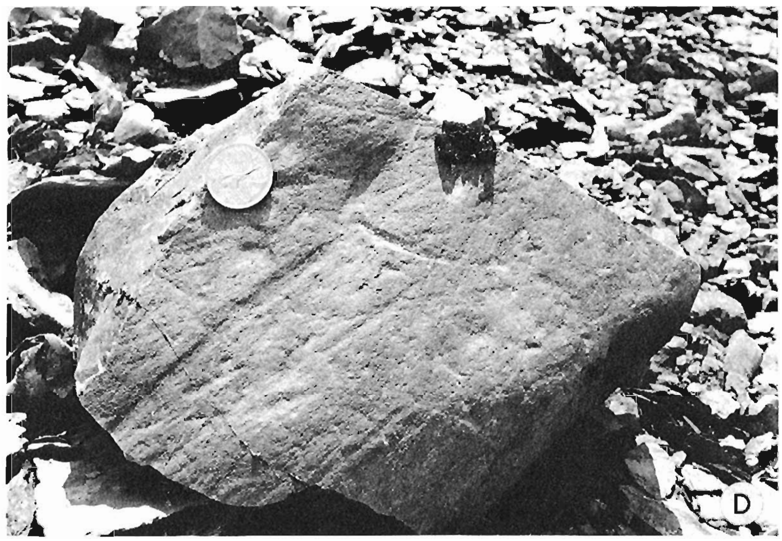
Figure 29. *Paleoslope during deposition of the Windermere Supergroup as derived from synoptic paleocurrent and slump-fold data. Broken line is the approximate position of the boundary between nonmarine tillite and glaciomarine diamictite facies of the Shezal Formation.*

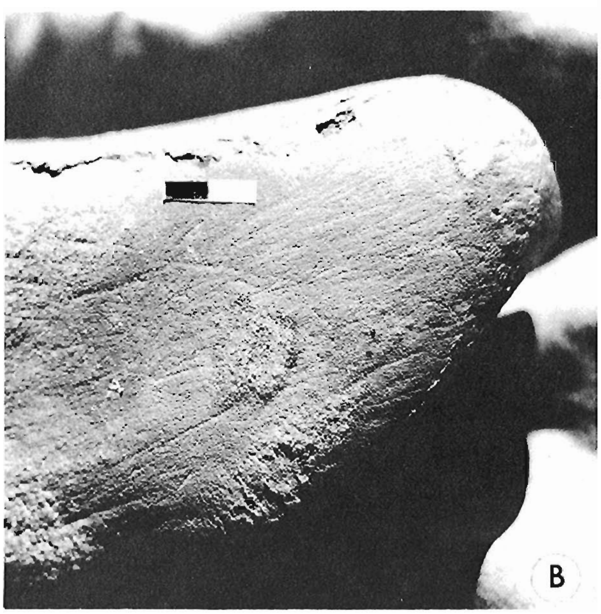


Nevertheless it is clear that when faulting initiated subsidence of the Windermere basin between about 800 and 750 Ma ago the basin floor had been weakened by foregoing subsidence, crustal stretching, and, locally, intense deformation. Rifting during early Windermere time disrupted the older basin trends and triggered progradation of a clastic wedge along a new 'miogeocline'. The characteristic facies of the Windermere have been identified along the length of the North American Cordillera, but only the eastern and northern margins of this great clastic basin have been identified in the Cordillera. The western margins may be preserved in other cratonic blocks of the Circumpacific region (Australia ?, China ?). However, whether or not the Windermere rift event created an interface between 'true' continental crust and 'true' oceanic crust cannot be answered at present: nowhere has late Proterozoic oceanic crust been

Figure 30 *Generalized relationship between sedimentation, relative sea levels and tectonics along the basinal hinge line of the Windermere Supergroup, Mackenzie Mountains, for discussion see text.*







A - Crudely stratified diamictite with exotic granitic clast of unknown provenance (boulder to the left of the head of Dr. W.H. Fritz) near Lloyd George, Muskwa Ranges, British Columbia. GSC 203632-I

B - Striated quartzitic stone from the Lloyd George diamictite (bar scale is 2 cm long). GSC 203632-J

C - Dropstone of quartzite in siliciclastic rhythmites of the Toby Formation (north of Forster Creek, Purcell Mountains, British Columbia). GSC 203632-K

D - Striated boulder of quartzite in the Toby Formation (north of Forster Creek, Purcell Mountains, British Columbia). GSC 203632-L

Figure 31. *Examples of glacial evidence for deposition of diamictites in the Windermere Supergroup of the Muskwa Ranges (A, B) and the Purcell Mountains (C, D) of the Canadian Cordillera (see Fig. 2).*

found beneath Windermere rocks and plutonic rocks, which intruded Windermere strata during the later evolution of the Cordillera, suggest mobilization of a sialic basement or of deeply buried Windermere rocks of a composition similar to sialic crust (Gabrielse and Reesor, 1974).

Another important question is the association of glacial deposits with the rifted margin. Along the whole length of the Canadian Cordillera the base of the Windermere Supergroup, where exposed, is characterized by glacial deposits: the tillite and glaciomarine deposits of the Wernecke and Mackenzie mountains (see this report); the Toby Formation in southern British Columbia (Aalto, 1971) where dropstone laminites and striated clasts have recently been found by the author (Fig. 31C, D); the 'Ice Mountain' diamictite of the central Rocky Mountains which occupies the same stratigraphic position as the Toby Formation; and the 'Lloyd George' diamictite in the Muskwa Ranges (Fritz, 1972), where exotic and glacially striated clasts have also been found (Fig. 31A, B). Diamictites of probable glaciomarine origin have also been reported near the base of Windermere correlatives in the United States (Crittenden et al., 1972; Wright et al., 1976). All of these deposits occur along a pronounced tectonic hinge line (Stewart, 1972).

In the Mackenzie Mountains rifting began prior to the onset of glacial sedimentation (i.e. Redstone River Formation). Evidence for pre-diamictite rifting has also been reported in the United States. Elston (1979) has documented a nonmarine basin in the Precambrian Grand Canyon Supergroup which, on the basis of detailed mapping and radiometric studies, has been inferred to have formed along a major high-angle fault about 830 Ma ago (Elston, 1979, p. 16). The fault-related redbed deposits (Sixtymile Formation) are unconformably overlain by Cambrian quartzites and the typical glaciogenic deposits of the Windermere are either not preserved or were not laid down in the Grand Canyon region. It is probably significant that in both the northern and southern exposures of Proterozoic units in the Cordillera rifting preceded a widespread glaciation.

After deglaciation, the middle part of the Windermere Supergroup reflects dramatic subsidence along most of the North American Cordillera. Vigorous progradation of clastic shelves and carbonate platforms supplied abundant debris to extensive turbidite basins west of the tectonic hinge line (e.g. Selwyn Basin, Rocky Mountains, Columbia and Cassiar mountains). Composition of these 'grits' depends greatly on the composition of exposed source areas to the east. In the area of the Columbia Mountains more of the debris might have been derived directly from Hudsonian crystalline basement than in the equivalent grit units of the Selwyn Basin. However, this problem has not yet been pursued.

A distinct phase of shoaling, as suggested by the sedimentary characteristics of the Keele Formation of the Mackenzie Mountains may have been responsible for regressive facies in other parts of the Canadian Cordillera as well (e.g. Espee Formation, Cunningham Formation, Byng Formation); the eustatic mechanism proposed for the Keele Formation should be tested in these, probably coeval, formations.

Because of the glacial and glacio-eustatic control of late Precambrian sedimentation interbasinal and intercontinental 'correlations' are possibly valid. Similarities in the late Precambrian successions of the United States, Canada, China, and Australia are such that they might tempt speculation on how close these areas were with respect to each other while strata of Windermere age were laid down. However, because of the eustatic sea level changes, similar stratigraphy on different crustal blocks does not imply automatically former proximity of these blocks. The resolution of the problem needs other methods – e.g. paleomagnetic.

CONCLUSIONS

In the northern Canadian Cordillera the Windermere Supergroup is a predominantly clastic succession which was deposited between about 800 Ma and 570 Ma along a basin margin controlled by northeasterly to northwesterly trending faults. The depositional basin of the Windermere Supergroup was superimposed on older sedimentary basins and the new Windermere basin developed on a strongly attenuated continental crust bounded by sheared passive margins. Basaltic volcanism was locally associated with the rifts. High-angle faults along the rifted hinge zone are expressed particularly well in rapid changes of sedimentary facies and thickness of the highest pre-Windermere units (Redstone River and Coppercap formations) and the basal Windermere succession (Sayunei Formation). Rifting was followed by climatic change, and much of the basin was overriden by ice of a regional glaciation which is expressed in siliciclastic proglacial dropstone-rhythmites, tillites, and glaciomarine diamictites of the basal Windermere Supergroup (Sayunei and Shezal formations). Following deglaciation, carbonate banks and intervening clastic shelves supplied abundant debris which was transported towards the centreof the Selwyn Basin (Twitya Formation, parts of the 'Grit' unit). Clastic deposition of the upper Windermere Supergroup was interrupted by progradation of a widespread, cyclic shallow water carbonate-clastic assemblage (Keele Formation). This progradation created olistostromes at the front of carbonate platforms. An abrupt rise in sea level (Sheepbed Formation), possibly due to eustatic sea level changes following a glaciation elsewhere in the world, resulted in the deposition of black shale of the Sheepbed Formation.

The evolution of the sedimentary succession in latest Precambrian time in the northern Canadian Cordillera is thus related to tectonic processes and eustatic sea level changes which are also expressed in other parts of the North American Cordillera and the Circum Pacific region.

REFERENCES

Aalto, R.K.
1971: Glacial marine sedimentation and stratigraphy of the Toby Conglomerate (Upper Proterozoic), southeastern British Columbia, northwestern Idaho, and northeastern Washington; Canadian Journal of Earth Sciences, v. 8, p. 753-787.

Abbate, E., Bortolotti, V., and Passerini, P.
1970: Olistostromes and olistoliths; Sedimentary Geology, v. 4, p. 521-557.

Aitken, J.D. and Cook, D.G.
1974a: Effect of antecedent faults on "Laramide" structure, Mackenzie Arc; in Report of Activities, Part B, Geological Survey of Canada, Paper 74-1B, p. 259-264.

1974b: Caracjou Canyon map-area, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Paper 74-13, 28 p.

1974c: Geological maps, northern parts of Mount Eduni and Bonnet Plume Lake map-areas, District of Mackenzie; Geological Survey of Canada, Open File 221.

Aitken, J.D., Long, D.G.F., and Semikhatov, M.A.
1978: Progress in Helikian stratigraphy, Mackenzie Mountains; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 481-484.

Aitken, J.D., Macqueen, R.W., and Usher, J.L.
1973: Reconnaissance studies of Proterozoic and Cambrian stratigraphy, lower Mackenzie River area (Operation Norman), District of Mackenzie; Geological Survey of Canada, Paper 73-9, 178 p.

Archer, A.R. and Schmidt, U.
1978: Mineralized breccias of early Proterozoic age, Bonnet Plume River district, Yukon Territory; Canadian Mining and Metallurgical Bulletin, v. 71, p. 53-58.

Armstrong, R.L., Eisbacher, G.H., and Evans, P.
Age and stratigraphic-tectonic significance of Proterozoic diabase sheets, Mackenzie Mountains, northwestern Canada; Canadian Journal of Earth Sciences. (in press)

Bell, R.T.
1968: Proterozoic stratigraphy of northern British Columbia; Geological Survey of Canada, Paper 67-68, 75 p.

1978: Breccias and uranium mineralization in the Wernecke Mountains, Yukon Territory – a progress report; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 317-322.

Bell, R.T. and Delaney, G.D.
1977: Geology of some uranium occurrences in Yukon Territories; in Report of Activities, Part A, Geological Survey of Canada, Paper 77-1A, p. 33-37.

Burwash, R.A. and Culbert, R.R.
1976: Multivariate geochemical and mineral patterns in the Precambrian basement of western Canada; Canadian Journal of Earth Sciences, v. 13, p. 1-18.

Campbell, R.B.
1973: Structural cross-section and tectonic model of the southeastern Canadian Cordillera; Canadian Journal of Earth Sciences, v. 10, p. 1607-1620.

Campbell, R.B., Mountjoy, E.W., and Young, F.G.
1973: Geology of McBride map-area, British Columbia; Geological Survey of Canada, Paper 72-35, 104 p.

Chumakov, N.
1978: Dokembriskye tilliti i tilloidi; Academy of Sciences of USSR, Transactions, v. 308, 202 p.

Coates, J.A.
1964: The Redstone bedded copper deposits; M.Sc. Thesis, University of British Columbia, Vancouver, B.C., 77 p.

Coles, R.I., Haines, G.V., and Hannaford, W.
1976; Large scale magnetic anomalies over western Canada and the Arctic: a discussion; Canadian Journal of Earth Sciences, v. 13, p. 790-802.

Cook, H.E., McDaniel, P.N., Mountjoy, E.W., and Pray, L.C.
1972: Allochthonous carbonate debris flows at Devonian Bank ('Reef') margins, Alberta, Canada; Bulletin of Canadian Petroleum Geology, v. 20, p. 439-497.

Crittenden, M.D. Jr., Schaeffer, F.E., Trimble, D.E., and Woodward, L.A.
1972: Nomenclature and correlation of some upper Precambrian and basal Cambrian sequences in western Utah and southeastern Idaho; Geological Society of America Bulletin, v. 82, p. 581-602.

Edwards, M.B.
1978: Glacial Environments; in Sedimentary Environments and Facies; ed. H.G. Reading, Elsevier, N.Y., p. 416-438.

Eisbacher, G.H.
1976: Proterozoic Rapitan Group and related rocks, Redstone River area, District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 76-1A, p. 117-125.

1977: Tectono-stratigraphic framework of the Redstone Copper Belt, District of Mackenzie; in Report of Activities, Part A, Geological Survey of Canada, Paper 77-1A, p. 229-234.

1978a: Re-definition and subdivision of the Rapitan Group, Mackenzie Mountains; Geological Survey of Canada, Paper 77-35, 21 p.

1978b: Two major Proterozoic unconformities, northern Cordillera, in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 53-58.

Elston, D.P.
1979: Late Precambrian Sixtymile Formation and orogeny at top of the Grand Canyon Supergroup, northern Arizona; United States Geological Survey Professional Paper 1092, 20 p.

Elston, D.P. and Bressler, S.L.
1980; Paleomagnetic poles and polarity zonation from the middle Proterozoic Belt Supergroup, Montana and Idaho; Journal of Geophysical Research, v. 85, p. 339-355.

Fritz, W.H.
1972: Cambrian biostratigraphy, western Rocky Mountains, British Columbia; in Report of Activities, Part A, Geological Survey of Canada, Paper 72-1A, p. 209-211.

1980: International Precambrian-Cambrian boundary working group's 1979 field study to Mackenzie Mountains, Northwest Territories, Canada; in Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 41-45.

Gabrielse, H.
1967: Tectonic evolution of the northern Canadian Cordillera; Canadian Journal of Earth Sciences, v. 4, p. 271-298.

1972: Younger Precambrian of the Canadian Cordillera; American Journal of Science, v. 272, p. 521-536.

1976: Environments of Canadian Cordillera depositional basins; American Association of Petroleum Geologists, Memoir 25, p. 492-502.

Gabrielse, H. and Reesor, J.E.
1974: The nature and setting of granitic plutons in the central and eastern parts of the Canadian Cordillera; Pacific Geology, v. 8, p. 109-138.

Gabrielse, H., Blusson, S.L., and Roddick, J.A.
1973: Flat River, Glacier Lake and Wrigley Lake map-area (95E, L, M) District of Mackenzie and Yukon Territory; Geological Survey of Canada, Memoir 366, 153 p.

Gordey, S.P.
1980: Stratigraphic cross-section, Selwyn Basin to Mackenzie Platform, Nahanni map-area, Yukon Territory and District of Mackenzie; in Current Research, Part A, Geological Survey of Canada, Paper 80-1A, p. 353-355.

Görler, K. and Reutter, K.J.
1968: Entstehung und Merkmale der Olistostrome; Geologische Rundschau, v. 57, p. 484-514.

Harland, W.B. and Rudwick, M.J.S.
1964: The great infra-Cambrian ice age; Scientific American, v. 211, p. 28-45.

Harrison, J.E.
1977: Geometry and sedimentation of the Late Precambrian Belt Basin-1977 update; Geological Society of America, Abstracts with Programs, p. 730-731.

Helmstaedt, H., Eisbacher, G.H., and McGregor, H.
1979: Precambrian copper mineralization at the Nite-Claims, Mackenzie Mountains; Canadian Journal of Earth Sciences, v. 16, p. 50-59.

Hoedemaker, Ph.J.
1973: Olistostromes and other delapsional deposits, and their occurrence in the region of Moratalla (Prov. of Murcia, Spain); Scripta Geologica, v. 19, 207 p.

Hofmann, H.J. and Aitken, J.D.
1979: Precambrian biota from the Little Dal Group, Mackenzie Mountains, northwestern Canada; Canadian Journal of Earth Sciences, v. 16, p. 150-166.

Jefferson, C.W.
1978: Stratigraphy and sedimentology, upper Proterozoic Redstone Copper Belt, Mackenzie Mountains, N.W.T.-a preliminary report; Mineral Industry Report 1975, Department of Indian and Northern Affairs, p. 157-169.

Mansy, J.L. and Gabrielse, H.
1978: Stratigraphy, terminology, and correlation of upper Proterozoic rocks in Omineca and Cassiar Mountains, north-central British Columbia; Geological Survey of Canada, Paper 77-19, 17 p.

Monger, J.W.H. and Price, R.A.
1979: Geodynamic evolution of the Canadian Cordillera-progress and problems; Canadian Journal of Earth Sciences, v. 16, p. 770-791.

Monger, J.W.H., Souther, J.G., and Gabrielse, H.
1972: Evolution of the Canadian Cordillera: a plate-tectonic model; American Journal of Science, v. 272, p. 577-602.

Norris, D.K.
1975: Geological maps, Hart River, Wind River, and Snake River, Yukon and Northwest Territories; Geological Survey of Canada, Open File 279.

Norris, D.K. and Hopkins, W.S. Jr.
1977: The geology of the Bonnet Plume Basin, Yukon Territories; Geological Survey of Canada, Paper 76-8, 20 p.

Ovenshine, T.A.
1970: Observations of iceberg rafting in Glacier Bay, Alaska, and the identification of ancient ice-rafted deposits; Geological Society of America Bulletin, v. 81, p. 891-894.

Roddick, J.A.
1967: Tintina Trench; Journal of Geology, v. 75, p. 23-33.

Ruelle, J.C.L.
Depositional environments and genesis of stratiform copper deposits of the Redstone Copper Belt, Mackenzie Mountains, N.W.T., Canada; Geological Association of Canada, Special Paper. (in press)

Ryan, B.D. and Blenkinsop, J.
1971: Geology and geochronology of the Hellroaring Creek Stock, British Columbia; Canadian Journal of Earth Sciences, v. 8, p. 85-95.

Schermerhorn, L.J.G.
1974: Late Precambrian mixtites: glacial and/or nonglacial; American Journal of Science, v. 274, p. 673-824.

Slind, O.L. and Perkins, G.D.
1966: Lower Paleozoic and Proterozoic sediments of the Rocky Mountains between Jasper, Alberta and Pine River, British Columbia; Bulletin of Canadian Petroleum Geology, v. 14, p. 442-468.

Stelck, C.R., Burwash, R.A., and Stelck, D.R.
1978: The Vreeland High: a Cordilleran expression of the Peace River Arch; Bulletin of Canadian Petroleum Geology, v. 26, p. 87-104.

Stewart, J.H.
1972: Initial deposits in the Cordilleran Geosyncline: Evidence of a Late Precambrian (850 m.y.) continental separation; Geological Society of America Bulletin, v. 83, p. 1345-1360.

1976: Late Precambrian evolution of North America: Plate tectonics implications; Geology, v. 4, p. 11-15.

Tempelman-Kluit, D.J.
1979: Transported cataclasite, ophiolite and granodiorite in Yukon: evidence of arc-continent collision; Geological Survey of Canada, Paper 79-14, 27 p.

Upitis, U.
1966: The Rapitan Group, southeastern Mackenzie Mountains, N.W.T.; M.Sc. Thesis, McGill University, Montreal, 70 p.

Walker, J.F.
1926: Geology and mineral deposits of Windermere map-area, British Columbia; Geological Survey of Canada, Memoir 148.

Wanless, R.K. and Reesor, J.E.
1975: Precambrian zircon age of orthogneiss in the Shuswap Metamorphic Complex, British Columbia; Canadian Journal of Earth Sciences, v. 12, p. 326-332.

Wheeler, J.O.
1954: A geological reconnaissance of the northern Selwyn Mountains region, Yukon and Northwest Territories; Geological Survey of Canada, Paper 53-7, 42 p.

1967: Tectonics-Canadian Upper Mantle Report 1967; Geological Survey of Canada, Paper 67-41, p. 3-30.

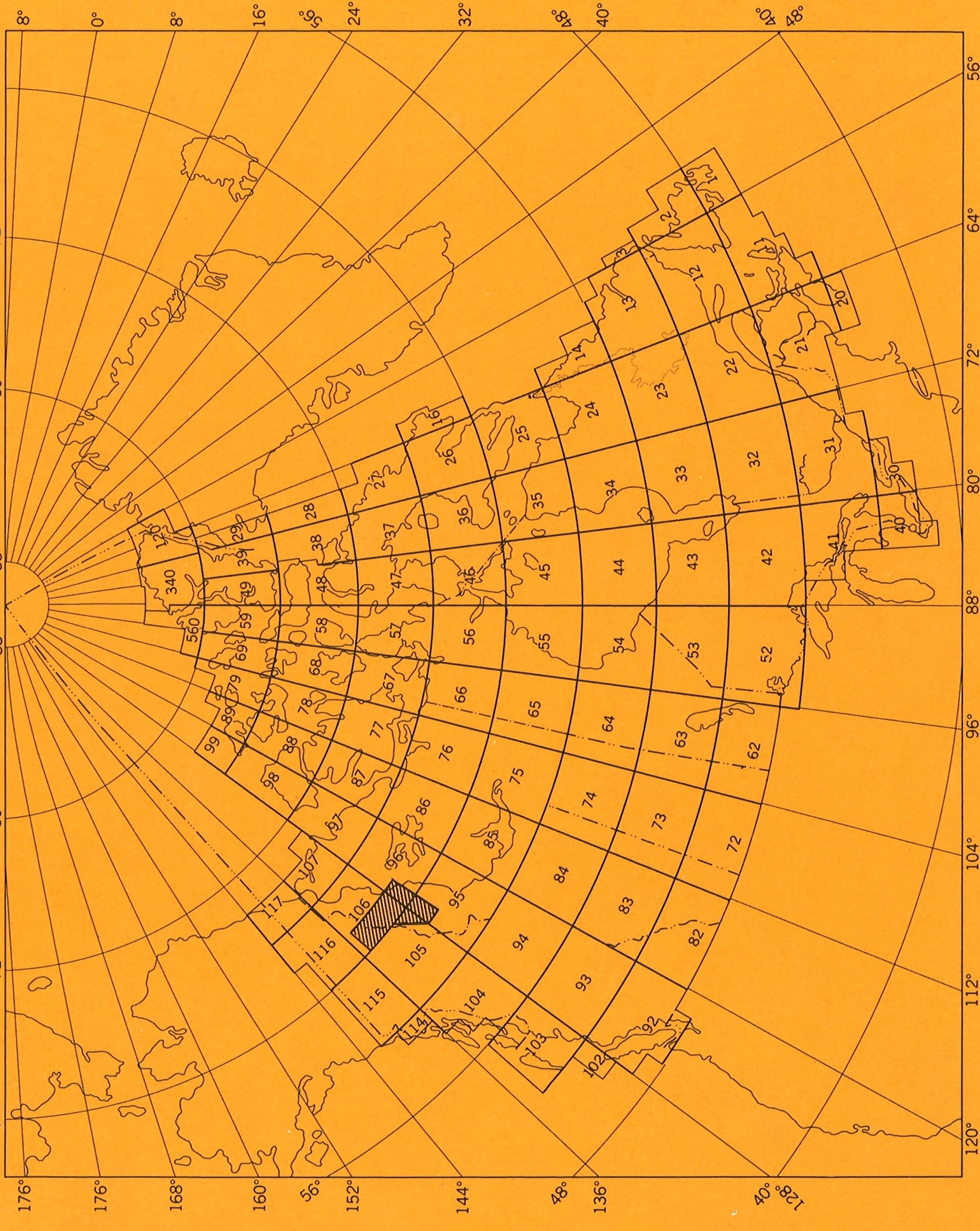
Wright, L.A., Troxel, B.W., Williams, E.G., Roberts, M.T., and Diehl, P.E.
1976: Precambrian sedimentary environments of the Death Valley region, eastern California; California Division of Mines and Geology, Special Report 106, p. 7-15.

Yeo, G.
1978: Iron-formation in the Rapitan Group, Mackenzie Mountains, Yukon and Northwest Territories; Mineral Industry Report 1975, Department of Indian and Northern Affairs, p. 170-175.

Young, F.G., Campbell, R.B., and Poulton, T.P.
1973: The Windermere Supergroup of the southeastern Canadian Cordillera; in Belt Symposium, Volume 1, Idaho Bureau of Mines and Geology, p. 181-203.

Young, G.M.
1976: Iron-formation and glaciogenic rocks of the Rapitan Group, Northwest Territories, Canada; Precambrian Research, v. 3, p. 137-158.

Ziegler, P.A.
1959: Fruhpalaozoische Tillite im östlichen Yukon-Territorium (Kanada); Eclogae Geologicae Helvetiae, v. 52, p. 735-741.



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