THE NATURE AND ORIGIN OF THE DEPOSITS IN CANYONS OF THE RAM PLATEAU NORTHWEST TERRITORIES CANADA

By

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NATURE AND ORIGIN OF DEPOSITS

IN RAM PLATEAU CANYONS, N.W.T.

FRONTISPIECE: Ram Plateau from the air
(Photo by Linda Jordan)

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ABSTRACT

Geomorphological mapping and sediment analysis of unconsolidated deposits in the canyons of Ram Plateau, Mackenzie Mountains, N.W.T. was undertaken during the summers of 1976 and 1977. Evidence was found for four major Laurentide ice advances. Ice-dammed proglacial lake phases are associated with each of the latter three.

During the early stages of canyon development, a massive ice sheet covered the area (Nahanni Glaciation) depositing a till with shield erratics on the plateau surface. After a lengthy erosional phase, ice passed through breaches in Nahanni Range and advanced to the eastern flank of Ram Plateau (Sundog Glaciation). This impounded Lake Sundog in Sundog Basin and Ram Canyon, resulting in infilling to 730 m a.s.l. Following a period of extensive dissection, a third ice sheet advanced to Ram Plateau, and alluvium was deposited up to 550 m a.s.l. in Ram Canyon and its tributaries by the impounded Lake Ram. Two stands during withdrawal are evidenced by deposits along the eastern flank of the plateau at 460 m a.s.l. and 380 m a.s.l. The most recent ice sheet advanced as far as Nahanni Range (Tetcela Glaciation) and sediment was deposited to 210-275 m a.s.l. in Tetcela Basin by the impounded Lake Tetcela. This ice sheet is attributed to the "Classical" Wisconsinan glacial stade.

Because Ram Plateau was situated at the front of the last three fluctuating ice masses, remnants of sediments dating from lakes impounded

by pre-Wisconsinan ice sheets are preserved, and there has been enough time since the plateau and canyon areas were glaciated for the effects of glacial scour to have been obliterated and the alluvium to be intensely dissected and massively slumped.

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CHAPTER ONE

INTRODUCTION

1.1 Nature of the Study

Ram Plateau is a small part of a large region in northwestern Canada and Alaska that is generally considered to have been unglaciated during the most recent (or Classical Wisconsinan) glaciation (Prest *et al.*, 1967, Plate 1.2). The absence of freshly glaciated topography has sparked a great deal of geomorphological interest for those who wish to study an assemblage of high latitude landforms that were unaffected by the ice masses which covered the major portion of Canada during the Wisconsinan. Ram Plateau was located along the western boundary of the fluctuating Laurentide ice masses (Prest *et al.*, 1967), which suggests the presence of evidence for earlier Pleistocene ice limits and glaciations. The glacial record is, however, complicated by the sequence of infilling events from successive ice sheets which melted and used the ice-free troughs between the north-trending chains of the Mackenzie Mountains as drainage routes to the north (Aitken and Cook, 1974).

The purpose of this study is to determine the nature and origin of unconsolidated deposits within the canyons of Ram Plateau and adjacent areas. The area itself has not been the subject of any detailed investigations and very little is known about it except by inference from other regions in the Mackenzie Mountains which have been studied. A greater understanding of the geomorphological history of the area during the Quaternary Period is gained by determining the nature and sequence of events which were responsible for infilling the canyons.

The study and interpretation is based upon:

1) geomorphological mapping of terraces and channel diversion features using 1:50,000 topographic maps and 1:59,000 air photos,
2) field mapping of canyon infill and surficial features, and
3) analysis of the internal morphology of the unconsolidated deposits, grain size and fabric, with a detailed description for selected profiles.

Chapter 1 provides a basic description of the geography of the study area and a review of previous morphological and Quaternary work in the Mackenzie Mountains. The geomorphological features and the laboratory analysis are discussed in Chapters 2 and 3. Chapter 4 is an interpretation of results and a comparison with other studies conducted elsewhere in the Mackenzie Mountains.

1.2 Description of the Map Area

1.2.1 Location and Extent

Ram Plateau is located along the eastern periphery of the Canyon Ranges of the Mackenzie Mountains in the southwestern region of the District of Mackenzie, Northwest Territories. It lies to the west of the Mackenzie River and 150 km north of the British Columbian border (Plate 1.1). The study area (Figure 1.1) of 3,700 sq km is bounded by longitudes 123° 30' and 124° 30' W and latitudes 61° 30' and 62° 00' N.

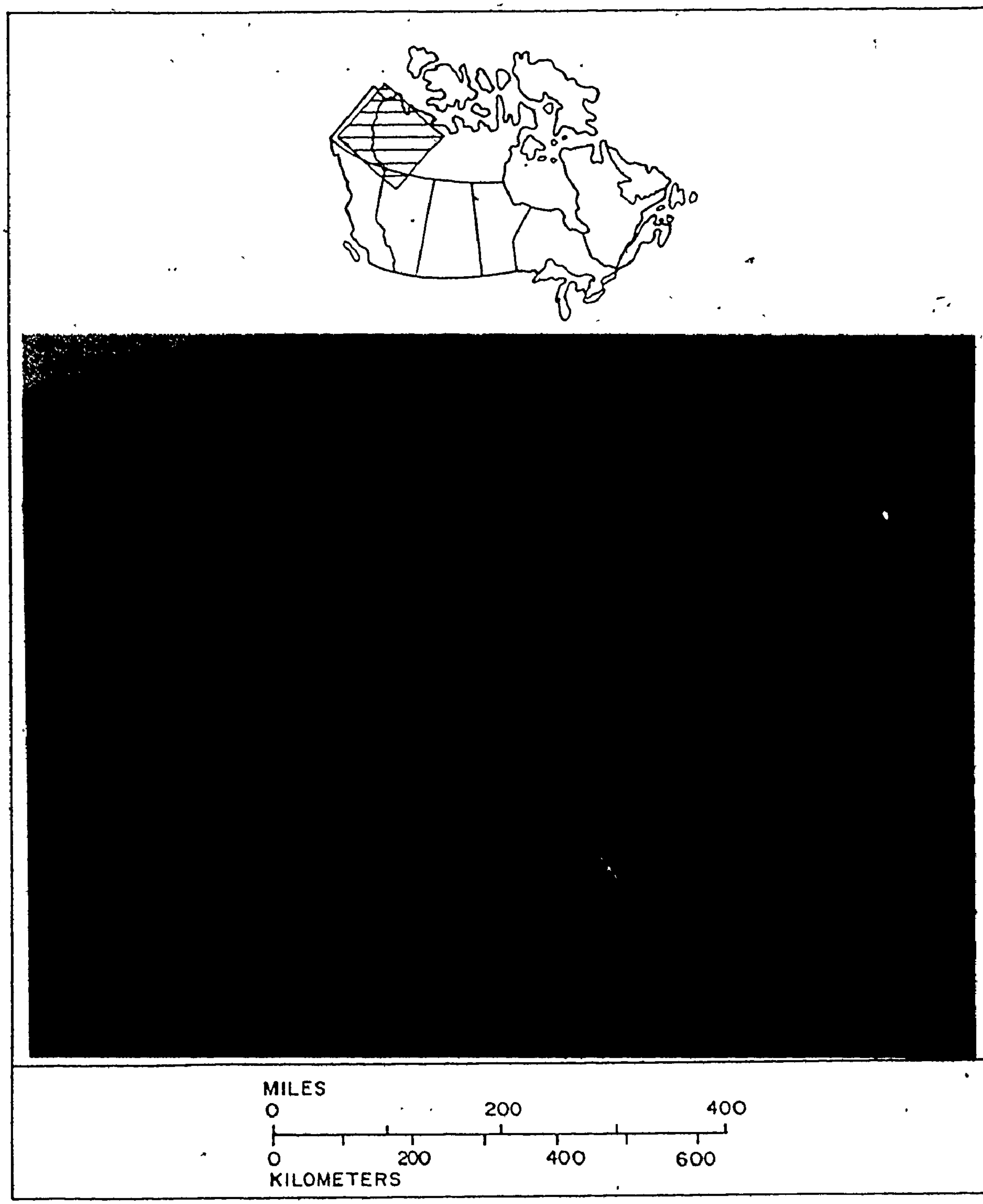
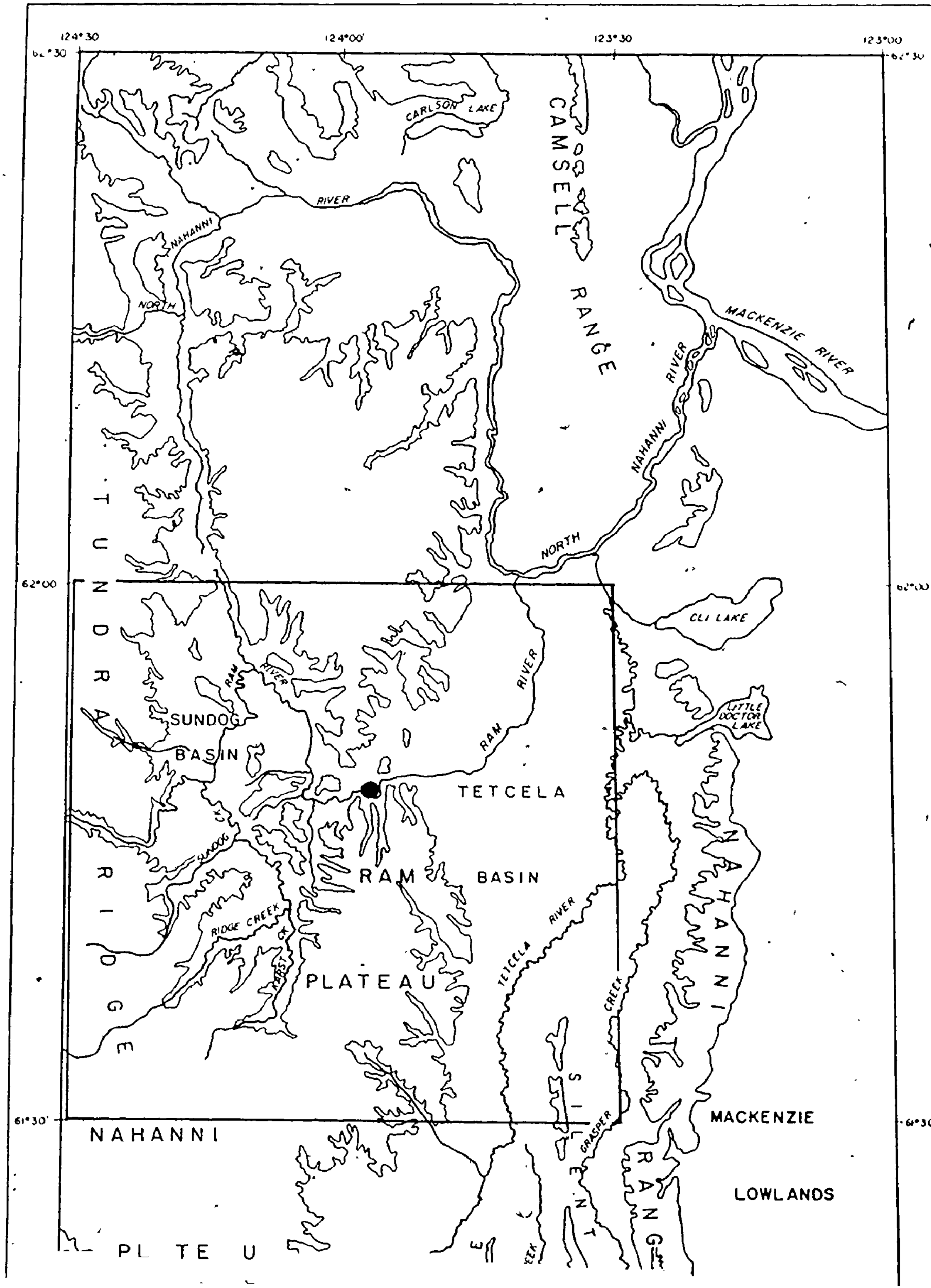


Plate 1.1: Location of Ram Plateau map of Physiographic Regions of northwestern Canada (Bostock, 1967).

1 of


124°30
124°00'
123°30
123°00
62°30
62°00
61°30'
CARLSON LAKE
CAMSELL RANGE
NORTH NAHANNI RIVER
MACKENZIE RIVER
NAHANNI RIVER
NORTH
CLI LAKE
LITTLE DOCTOR LAKE
TUNDRA RIDGE
SUNDOG BASIN
RAM RIVER
RAM RIVER
TETCELA
RAM BASIN
SUNDOG CK
RIDGE CREEK
FIRST CK
PLATEAU
TETCELA RIVER
CREEK
NAHANNI RANGE
SILENT
GRASPER
MACKENZIE
LOWLANDS
NAHANNI
PL TE U

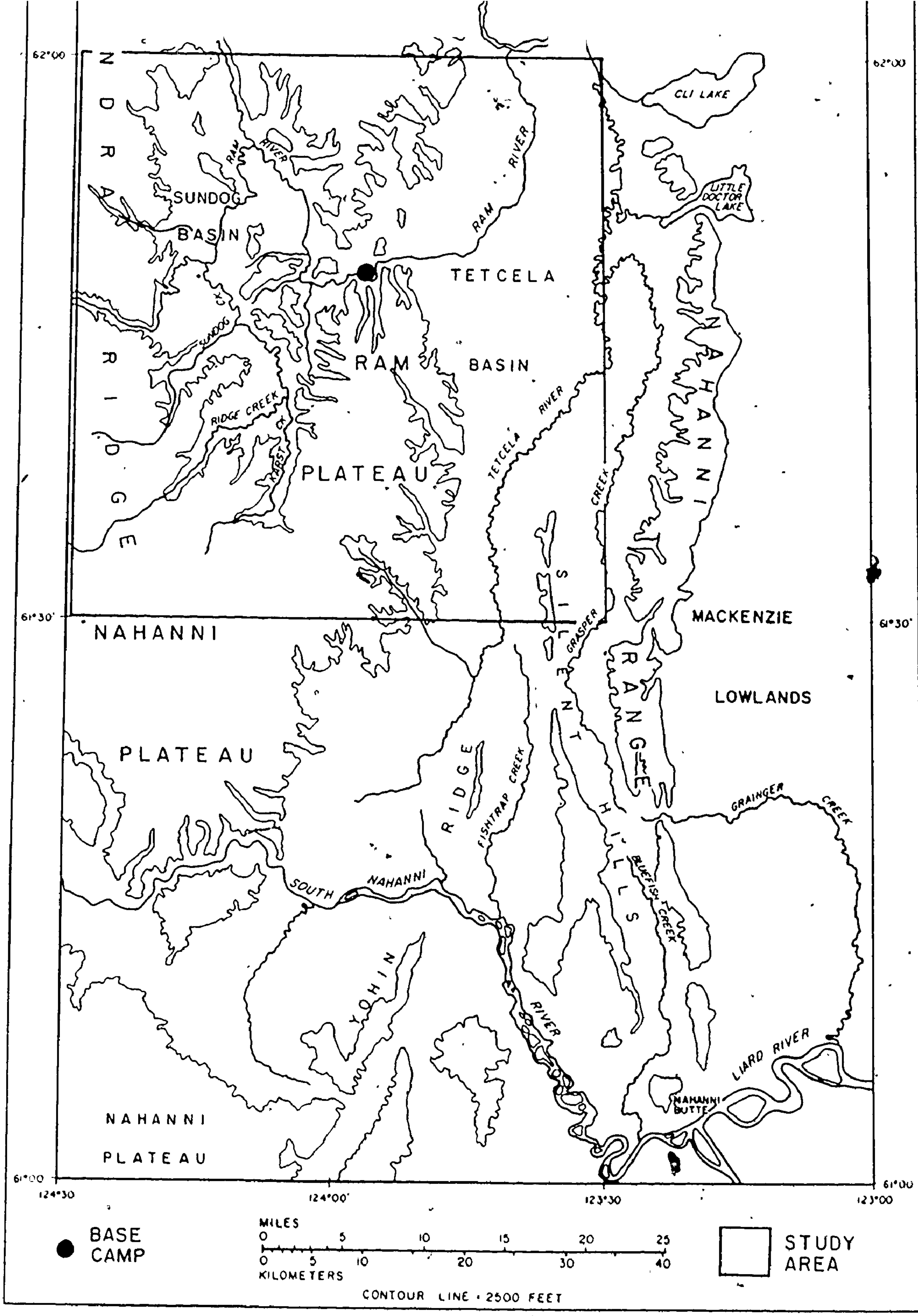


FIGURE 1.1 RAM PLATEAU STUDY AREA AND PHYSIOGRAPHIC REGIONS

A plan view of Ram Plateau shows that it has an elliptical shape with Ram River flowing through the central upland region from east to west. The upland area has a length of 43 km and a general width of 17 km. The plateau surface ranges in altitude from 1525 m (5,000 ft) in the southern half to 915 m (3,000 ft) to the north. The flanks dip to the west and east to elevations of 610 m (2,000 ft) and 305 m (1,000 ft) respectively. Along the central section of Ram River, where the base camp is situated, the elevation is 295 m (970 ft).

1.2.2 Bedrock Geology

A general account of the geology of Ram River area has been given in Canadian Geological Survey Paper 60-19 "Virginia Falls and Sibbeston Lake map-areas, Northwest Territories" (Douglas and Norris, 1960) and included in other publications by Ford (1974) and Brook (1976) so only a brief summary of the major features is presented here. A map and cross sections of the geological formations are presented in Figures 1.2, 1.3 and 1.4. A chronology of Geologic Formations is shown in Table 1.1.

The geological strata are composed primarily of Paleozoic carbonates with inter-bedded shales that were deposited over a period of 460-360 million years B.P. The oldest beds which outcrop only at Nahanni Range include the finely crystalline dolomites of the Ordovician (Mount Kindle Formation), the Silurian and early Middle Devonian (Arnica Formation). The succeeding strata (Funeral Formation) are exposed at the base of many of the canyons of Ram Plateau. This 750 m thick formation is comprised predominantly of platey calcareous shale inter-bedded with recessive limestones. The overlying dolomitic Manetoe Formation is 95 m

TABLE 1.1 GEOLOGICAL TIME SCALE

ERA	PERIOD	EPOCH	YEARS B.P. ×10^6
Cenozoic	Quaternary	Holocene	
		Pleistocene	
			1.5-2.0
	Tertiary	Pliocene	7
		Miocene	26
		Oligocene	37-38
		Eocene	53-54
		Paleocene	
			65
Mesozoic	Cretaceous		136
	Jurassic		195
	Triassic		
			225
Paleozoic	Permian		280
	Pennsylvanian		325
	Mississippian		345
	Devonian		395
	Silurian		430-440
	Ordovician		500±
	Cambrian		
			570
Precambrian			

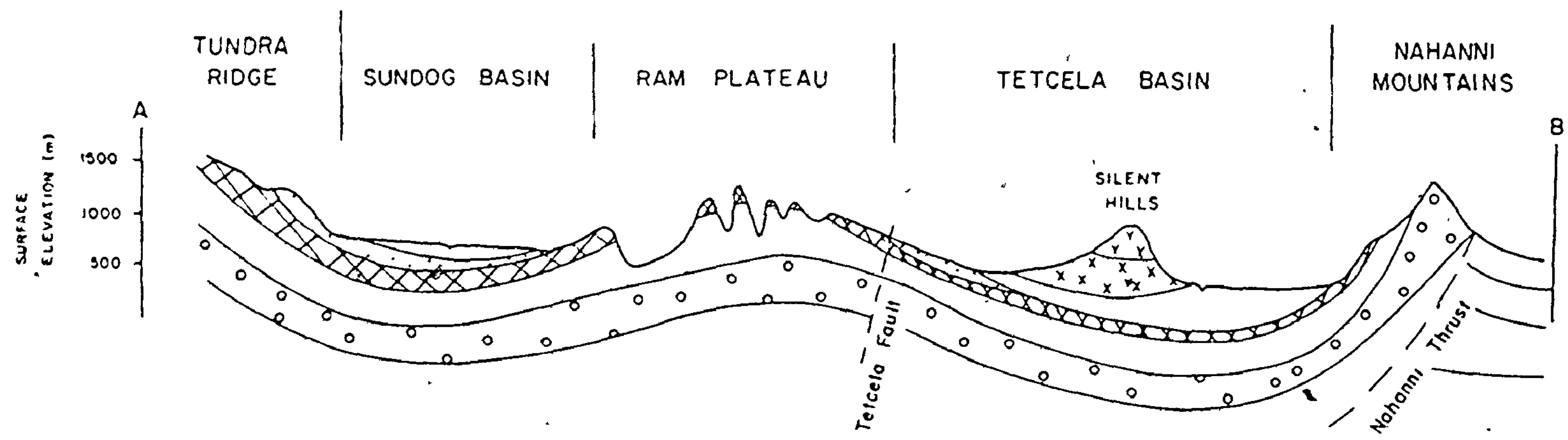
(after Douglas et al., 1970)

ERA	PERIOD		FORMATION	ROCK TYPE	
MESOZOIC		Z		shale	MILES 0 2 4 6 / 0 4 8 KILOMETERS
PALEOZOIC	MISSISSIPPIAN	Y		shale	
	UPPER DEVONIAN	X		shale, siltstone	
			FORT SIMPSON	shale	FAULT
	MIDDLE DEVONIAN		HORN RIVER	shale	
			NAHANNI	limestone	THRUST
			HEADLESS	shale	
			MANETOE	dolomite	SYNCLINE
			FUNERAL	limestone, shale	
			ARNICA	dolomite	ANTICLINE
	SILURIAN			dolomite	
	ORDOVICIAN			dolomite	

FIGURE 1.2 RAM PLATEAU AREA, N.W.T., GEOLOGY

(DOUGLAS AND NORRIS, 1960)

FIGURE 1.3 SCHEMATIC GEOLOGIC CROSS SECTION ACROSS THE RAM PLATEAU



REFER TO FIGURE 1.2 FOR LEGEND

(DOUGLAS AND NORRIS, 1960)

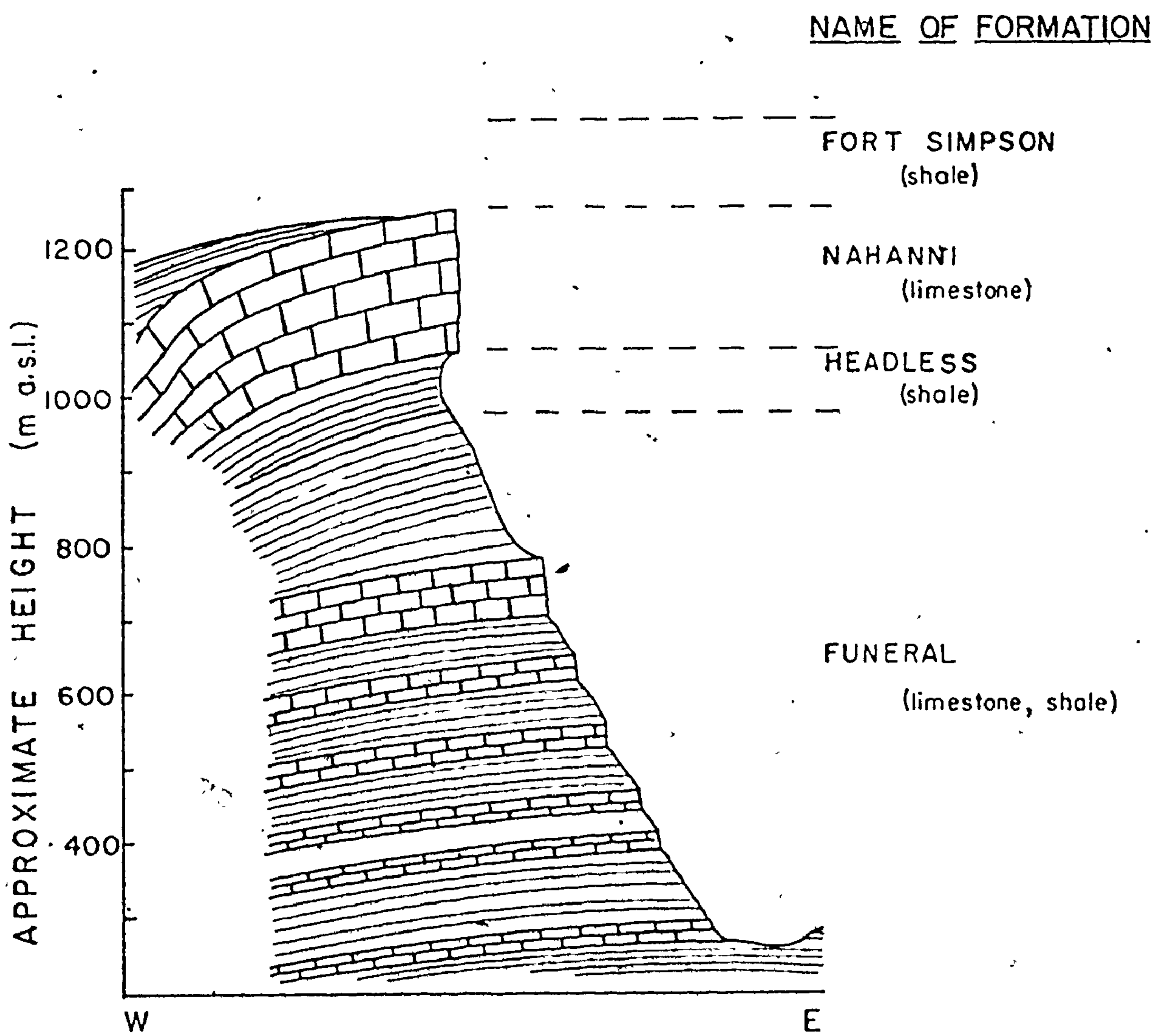


FIGURE 1.4 SCHEMATIC PROFILE OF GEOLOGY FOR RAM RIVER CANYON

(after DOUGLAS AND NORRIS, 1960)

thick and is present only along the western slope of Nahanni Range. In the canyons of Ram Plateau, the 45-150 m thick Headless Formation succeeds the Funeral Formation and is essentially a calcareous shaley recessive unit at the base of the cliff-forming beds of the Nahanni Formation. The Nahanni Formation (of late Middle Devonian age) is 200 m thick in Ram Plateau and consists of massive to thick-bedded limestones which are generally exposed as a single massive cliff unit. The later Horn River Formation of shales dating from the top of the Middle Devonian and Fort Simpson Formation of shales from the early Upper Devonian remain only along the flanks of Ram Plateau and Tundra Ridge and throughout Tetcela and Sundog Basins. The 70 m thick Horn River Formation is considered to be the basal layer of the 550 m thick Fort Simpson Formation. The two succeeding shaley units of Upper Devonian age and two of Mississippian age (Yohin and Clausen Formations) outcrop along an anticlinal structure in the Tetcela Basin, the Silent Hills. The most recent formation consists of shales dating from the Mesozoic and is only found east of Nahanni Range.

The complex nature of the strata is due to rapid facies changes at several stratigraphic levels from the Ordovician to the late Middle Devonian. Great thicknesses of dolomitic shelf sediments comprising the Funeral Formation were formed in a shallow, restricted, lagoonal environment prior to clastic sedimentation of the Headless Formation during a period of transgression. A subsequent regression resulted in widespread deposition of shallow-shelf carbonates and evaporites followed by a second major transgression which spread clastic sediments in the form of Middle and Upper Devonian shales of the Horn River and Simpson

Formations over the Nahanni Limestone (Noble and Ferguson, 1971).

The shale and carbonate strata underwent widespread deformation during the Cretaceous and early Tertiary, removing the upper layers of weak shales of the Horn River and Simpson Formations and possibly planating the surface. Ram River probably flowed eastward across an erosional plain of little relief following a course similar to that at present. The Laramide Orogeny, during the Tertiary resulted in upwarping of the region and structural doming of the Ram Plateau while the Sundog and Tetcela Basins were depressed (Douglas and Norris, 1960). Warping must have been gradual because the Ram River was able to cut an antecedent canyon with entrenched meanders into the rising mass. This produced the high degree of relief which presently characterizes the plateau. North-south canyons were gradually incised down to the base level of Ram River following the north-south jointing pattern of the carbonate bedrock.

The five main areas of differing geology and physiography will be discussed as they occur from east to west (Figure 1.1).

Nahanni Range, the southernmost extension of the Franklin Mountains, along the eastern border of the study area is an homoclinal thrust that dips 20°-35° to the west. This steep westward-dipping cuesta marks a fault where the older Devonian formations abruptly sink beneath the nearly flat-lying Cretaceous and Tertiary sediments that cover much of the Mackenzie Lowlands (Douglas and Norris, 1960). It is a spectacular instance of a 'front range', appearing as an abrupt wall when viewed from the east. Two salient re-entrants at the northern end of the range are occupied by Little Doctor and Cli Lakes.

Between Ram Plateau and Nahanni Range lies the structurally depressed Tetcela Basin. It appears to be a strip of the Interior Plains left almost undisturbed within the Mackenzie Mountain area when the Franklin Range emerged from the plains far out in front of the main area of deformation (Bostock, 1948). Centrally located within the basin is a simple fold, (Silent Hills) 100 km in length trending north from the South Nahanni to North Nahanni Rivers. It is a broad structure with flanks dipping at 20°.

Ram Plateau is a broad, dome-shaped structural upland that is oval in plan with its long axis trending north. Minor structural complications are gently plunging folds at the north end and northeast-trending faults with either west or east sides relatively downdropped. At the south end is a small uplifted block with what appear to be compressional fractures within it. A low, narrow, heavily fractured structural col joins the south end of Ram Plateau to Nahanni Plateau at an elevation of 870 m (2,850 ft)(Douglas and Norris, 1960). Ram Plateau is a stripped structural surface on Nahanni Limestones. The more easily eroded shales of the Simpson Formation were probably removed before or during an early period of Pleistocene glaciation. All that remains today are occasional small rounded hillocks standing above the surrounding plateau surface (Ford, 1974).

The Sundog Basin, a shallow syncline, is bounded on the west, south and east by Tundra Ridge, Nahanni Plateau and Ram Plateau. The strata on its flanks dip approximately east to west at between 5°-10° and the shales which remain on this lowland surface are blanketed by an unknown but certainly substantial depth of unconsolidated sediment.

The Mackenzie Mountains impart a pronounced north-south grain to the country. Tundra Ridge along the easternmost flank of the Mackenzie Mountain system is an east-dipping homocline that merges with Nahanni Plateau marking the southern limit of Sundog Basin. Both are steeply incised by tributaries of the Sundog and Ram Rivers to expose the early- to mid-Devonian carbonate strata (Douglas and Norris, 1960).

1.2.3 Climate, Permafrost and Vegetation

The southeastern Mackenzie Mountains have a cold, continental interior climate (Siberian type, Köppen Dfc-E) characterized by short, warm summers and long, cold winters. The estimated mean annual temperature is -1.66°C and the mean annual precipitation of approximately 521 mm falls mainly as rain during the summer months. Burns (1972) has classified this part of the Northwest Territories as Alpine (Forest-Tundra) in his discussion of the climate of the Mackenzie Basin. The area lies in the rainshadow of the Coastal and Interior mountain ranges so it does not experience any maritime influence of the Pacific Ocean or the large amounts of precipitation that characterizes regions to the west.

The closest station with a reasonably long period of climatic observation is Fort Simpson, at the junction of the Mackenzie and Liard Rivers, 140 km east of Ram Plateau. The temperature and precipitation means for this station (Figure 1.5) cannot be directly applied to Ram Plateau because of the lower altitude (130 m (423 ft) as compared to 305-1,200 m (1,000-4,000 ft)) and the enhanced rainshadow effects of the Mackenzie Mountains due to its more easterly location. The mean annual temperature at Fort Simpson is -3.83°C and the mean daily temperature ranges from -30.39°C to -26.0°C during January, the coldest month,

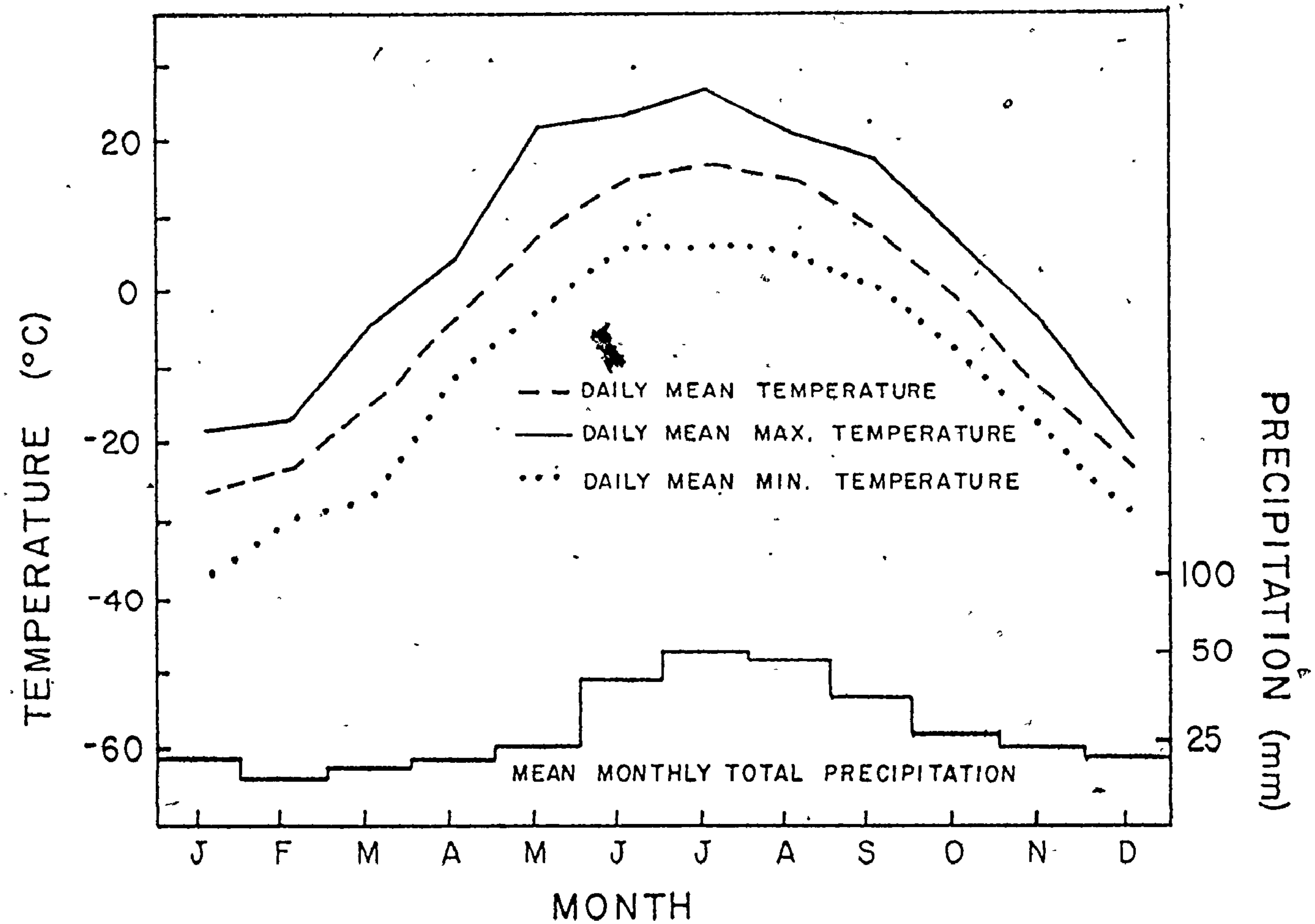


FIGURE 1.5 TEMPERATURE - PRECIPITATION MEANS
FORT SIMPSON, N.W.T. (1941-1963)

and from 10.61°C to 16.83°C during July, the warmest month. Mean annual precipitation is 345 mm.

Due to the longer and more reliable record, Fort Simpson data is preferred to that of Tungsten which is located on the Flat River at an altitude of 1,295 m (4,250 ft) and approximately 300 km west of the study area (Figure 1.6). At Tungsten the mean daily temperature ranges from -31.67°C to -27.67°C in January and from 4.8°C to 16.39°C during July. Observations for 1970 at Cadillac Mine on Prairie Creek 50 km WSW of Ram Plateau indicate that on the average the Mackenzie Mountains receive considerably more precipitation than does Fort Simpson and that the major portion of this falls as rain during the summer months. The incomplete record from Cadillac Mine (Figure 1.7) shows that during the eight month period of record some 52.63 cm fell, including 20.63 cm of rainfall during August alone.

Temperatures in Ram Canyon vary with elevation. The data shown in Figure 1.8 show that at the base camp (295 m (970 ft)) the mean minimum and mean maximum daily temperatures for July and August, 1975, were 5.6°C and 15.7°C respectively. The corresponding temperatures on top of the plateau, at 1,200 m (4,000 ft), were 4.1°C and 11.7°C. Not only are the temperatures lower and the diurnal variation greater on top of the plateau surface, but the precipitation is greater also.

The mean date of complete freezeover for the Ram River is early November and probably earlier for small tributary creeks. This corresponds closely to the November 15 date when the Mackenzie and Liard Rivers freeze over at Fort Simpson (Table 1.2). The average date that major rivers are clear of ice is approximately May 15. The date for

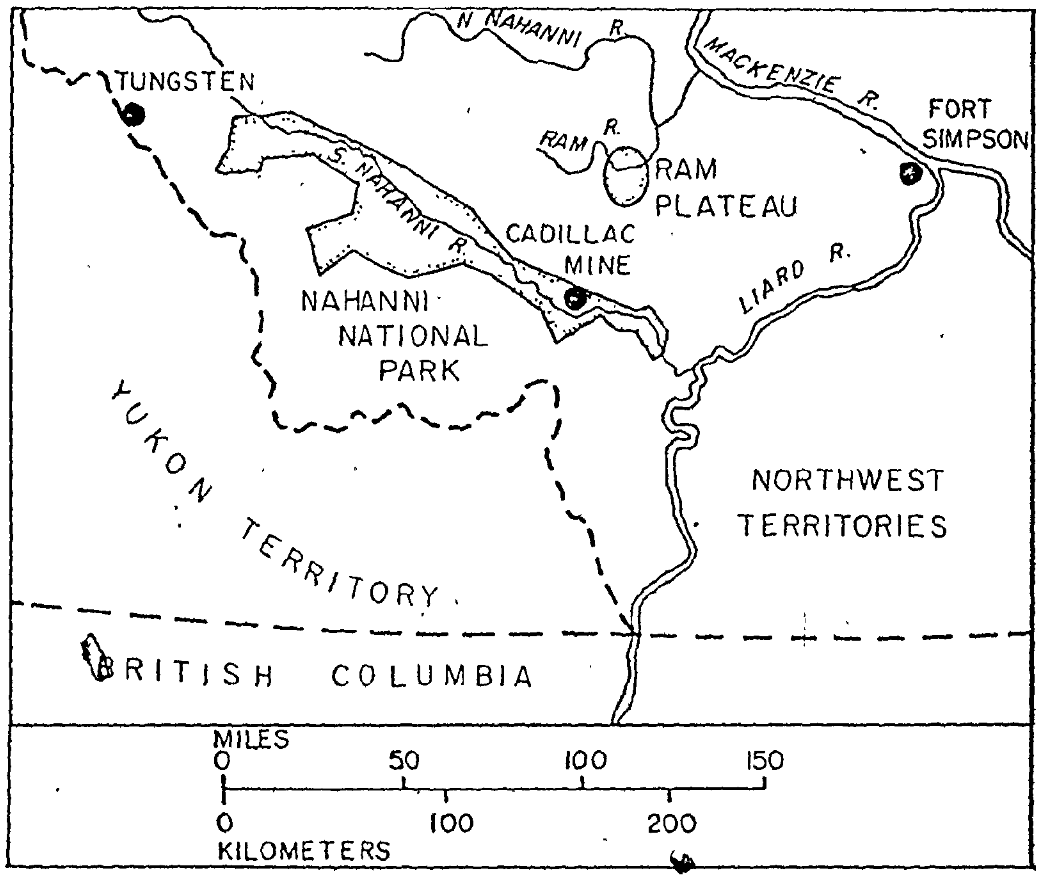


FIGURE I.6 LOCATION OF CLIMATE STATIONS

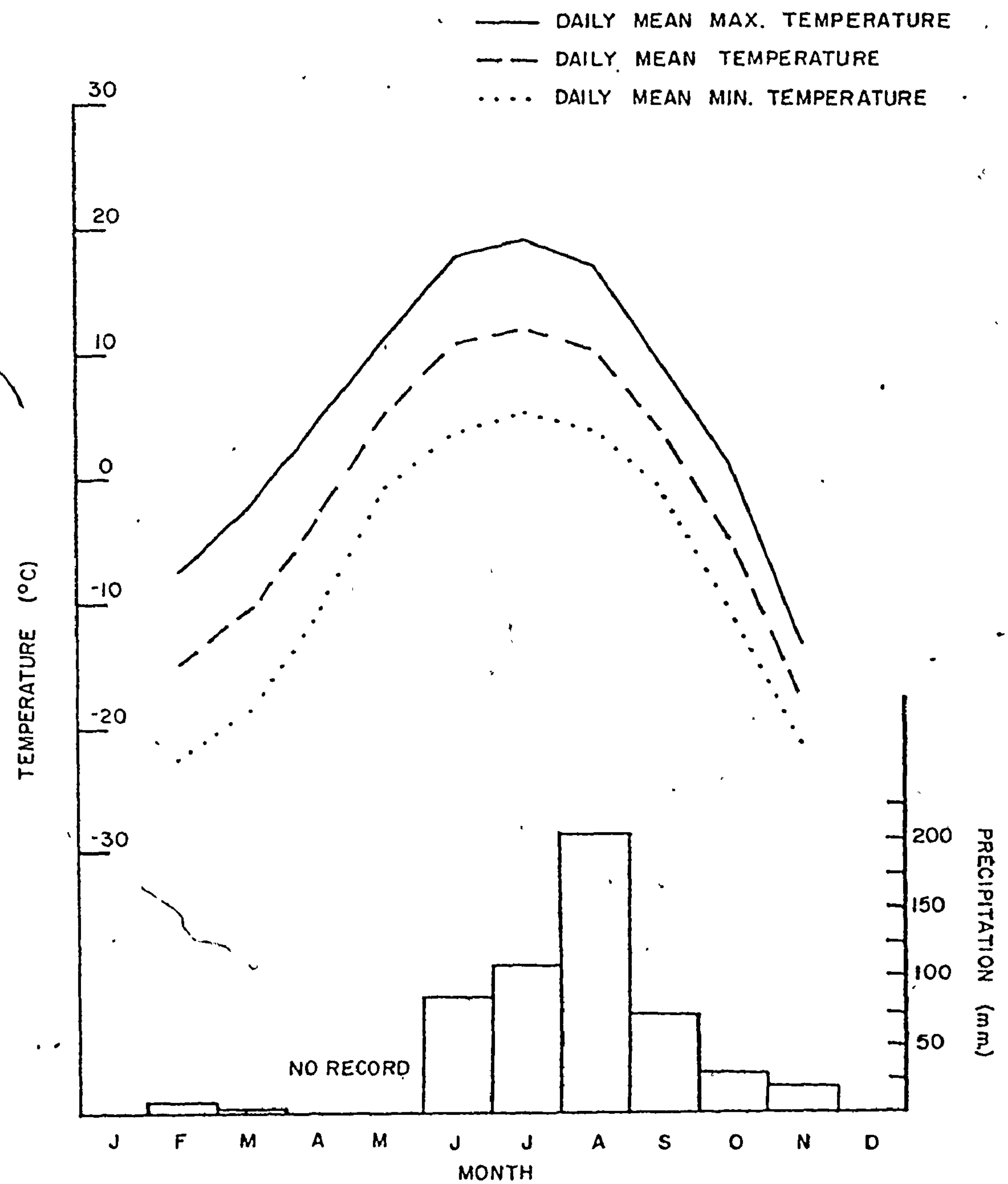


FIGURE I.7 TEMPERATURE - PRECIPITATION MEANS
CADILLAC MINE, N.W.T.
FEB. TO NOV., 1970

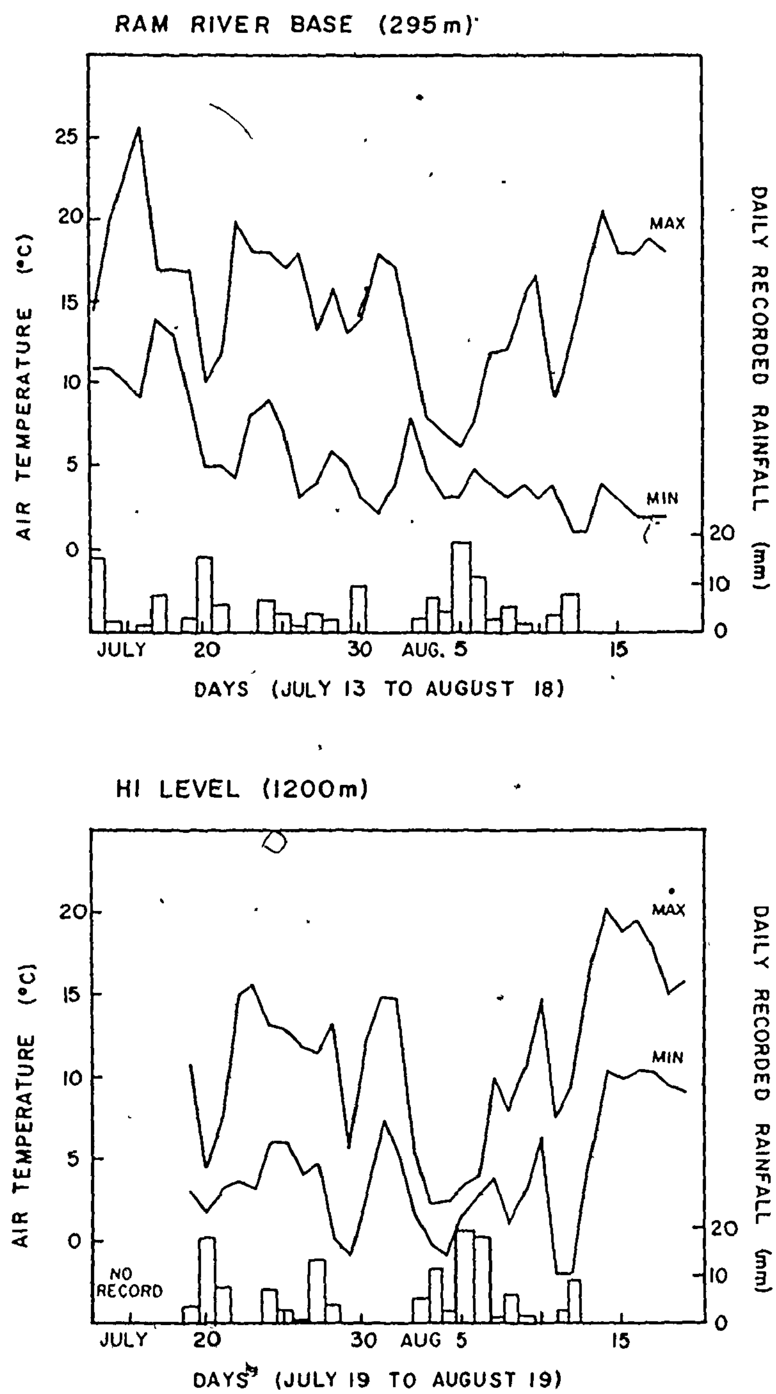


FIGURE 1.8 RAM RIVER CLIMATIC DATA
SUMMER, 1975

(NICHOLS, 1976)

TABLE 1.2

BREAKUP AND FREEZEUP DATES FOR LIARD AND MACKENZIE RIVERS NEAR FORT SIMPSON, N.W.T.

1974	LIARD RIVER	MACKENZIE RIVER
Ice bridge closed	Apr 19	Apr 19
Ferry service opened	May 17	May 20
Ferry service closed	Nov 6	Dec 10
Ice bridge opened	Dec 2	Dec 20
1975		
Ice bridge closed	Apr 21	Apr 21
Ferry service opened	May 12	May 14
Ferry service closed	Oct 29	Nov 15
Ice bridge opened	Nov 21	Dec 1
1976		
Ice bridge closed	Apr 16	Apr 12
Ferry service opened	May 6	May 9
Ferry service closed	Oct 31	Dec 9
Ice bridge opened	Dec 13	Dec 14

(from "Explorers' Guide" for Canada's Arctic, 1977) break up of the Ram River in 1977 was mid April, however, winter and spring temperatures were higher than average for that year (Gauthier, Department of Lands and Forests, Fort Simpson, N.W.T., pers. comm.).

Because the mean annual temperature is below freezing, frozen ground phenomena are common, especially at higher altitudes. Permafrost at depth is highly dependent on the surficial material as shown by the presence of permafrost at depths greater than 3 m in coarse sands and gravels at Ram base camp, at less than 2 m in finer sands and gravels close to the river (e.g. Ram River stilling well and Subject Creek stilling well), and at depths of less than 15 cm in silty material underlying peat at 18 m above the present river level. On top of the plateau at elevations of 915-1,070 m (3,000-3,500 ft) frozen ground phenomena (e.g. stone circles) are common where there is sufficient unconsolidated material covering the limestone surfaces.

The low temperature extremes and the presence of permafrost at shallow depths allow only the hardiest of boreal and tundra species to survive. Freezing temperatures which last at least half the year limit tree height and trunk diameters. Permafrost limits root networks. Vegetation types of the Ram Canyon can be divided into three main classes (Brook and Ford, 1974). On the plateau surfaces at elevations greater than 915 m (3,000 ft), alpine grasses, reindeer moss, ericaceous shrubs and dwarf conifers are common in areas where the limestone bedrock is covered by shallow depths of unconsolidated material. Within the lower reaches of the canyons and on flood plains where there is much more sediment there is a dense growth of tall trees with white spruce, balsam and poplar the dominant species. A dense shrub layer of alder is often present. Slumping is common in these areas as evidenced by slump faces and curved tree trunks. A third form of vegetation which is found at intermediate elevations where the soil cover is thin is comprised of stunted open tree and alder growth surrounding clearings of grasses, reindeer moss and coniferous scrub. There is usually a distinct boundary between this vegetation type and loose scree material except in areas where the angle of screes is least. Over much of Mackenzie Plain and Sundog Basin a widely occurring forest type is open black spruce and reindeer moss (Brook, 1976).

1.2.4 Topography and Drainage

The five main topographic elements of the Ram River study area as shown in Figure 1.1 include the eastern slope of Tundra Ridge and the northeastern slope of Nahanni Plateau of the Mackenzie Mountains, Sundog Basin, Ram Plateau, portions of Tetcela Basin, and Nahanni Range.

The carbonate strata of Tundra Ridge and Nahanni Plateau are deeply incised by the headwaters of Ram and Sundog Rivers, producing high cliff faces, extensive scree slopes and deep canyon valleys.

The Sundog Basin is a broad, alluviated plain 25 x 10 km that has been well dissected by the Ram and Sundog Rivers and tributaries. The two rivers have created wide flood plains between 670 m (2,200 ft) at the upstream ends and 550 m (1,800 ft) downstream. The gradient of Ram River here is approximately 4.4 m/km. The river drains to the north end of the Sundog Basin and then turns abruptly southwards to flow through the very narrow, vertically walled Scimitar Canyon at an elevation of 460 m (1,500 ft), making a spectacular entry into the broader

Ram Canyon. Ram River may have at one time flowed on northwards through a wide channel that is now occupied only by a small tributary, and thence drained into the North Nahanni River.

The Ram River presently follows a meandering course having a gradient of 4.8 m/km through the centre of Ram Plateau. This antecedent river became deeply incised into the massive grey and dark grey carbonate strata as the land mass domed upwards. That the river is antecedent in origin is evidenced by the profusely meandering nature of the river through a bedrock upland. If it were not antecedent, it would be much straighter, as are the tributary canyons.

Downstream from Scimitar Canyon the river has exposed its bedrock base in only two places: 2.5 km upstream of base camp at an altitude of 300 m (980 ft) and 4.8 km downstream of base camp at an altitude of 275 m (900 ft). It is apparent that a great amount of sediment derived from infilling events after initial downcutting, still covers most of the original bedrock river channel. After flowing eastward out of the plateau area at an altitude of 250 m (820 ft) the river adopts a braided channel northwards until it empties into the North Nahanni River.

Between Ram Plateau and Nahanni River lies the flat, expansive lowland of the Tetcela Basin at an elevation of 210-270 m (700-900 ft). The unconsolidated deposits in this basin have not been as deeply incised as those of Sundog Basin. The Tetcela River, draining the eastern flank of Ram Plateau and the western slope of Nahanni Range follows a meandering course northwards and joins the North Nahanni River 8 km east of the junction of the Ram and North Nahanni. The North Nahanni subsequently discharges into the Mackenzie River at Camsell Bend.

The Nahanni Range, the southernmost extension of the Franklin Mountains, is some 125 km long and up to 16 km wide. Within the study area it forms a remarkably narrow wall 6-7 km in width and rises abruptly from the Interior Plains to an elevation of 1,200-1,525 m (4,000-5,000 ft). Near the northern end there are two narrow breaches which are occupied by Little Doctor Lake (10 km long) and Cli Lake (13 km long).

1.3 Previous Morphological and Quaternary Work

1.3.1 Evidences for Glaciations

As early as 1938 Cameron and Warren recognized that evidence of glaciation in the South Nahanni region of the Mackenzie Mountains is not strongly marked. Bostock, in 1948 detected a lack of glacial features in some areas north of Peace River and suggested that this was due to relatively light precipitation during the Pleistocene, such as characterizes this region today.

Two large areas of the Mackenzie Mountains were delimited as having escaped extensive glacial cover during the Wisconsinan by Wilson *et al.* (1958) in the first "Glacial Map of Canada". These areas were enlarged by Prest *et al.* (1967) who recognized that parts of the Mackenzie Mountains may not have been glaciated at any time during the Pleistocene while other parts may have been covered by ice during one or more of the Pleistocene glacial events (Plate 1.2).

Craig and Fyles (1960) found evidence for three principal ice sheets (Laurentian, Cordilleran and High Arctic) that partly coalesced during their maximum stands. There may have been only limited and

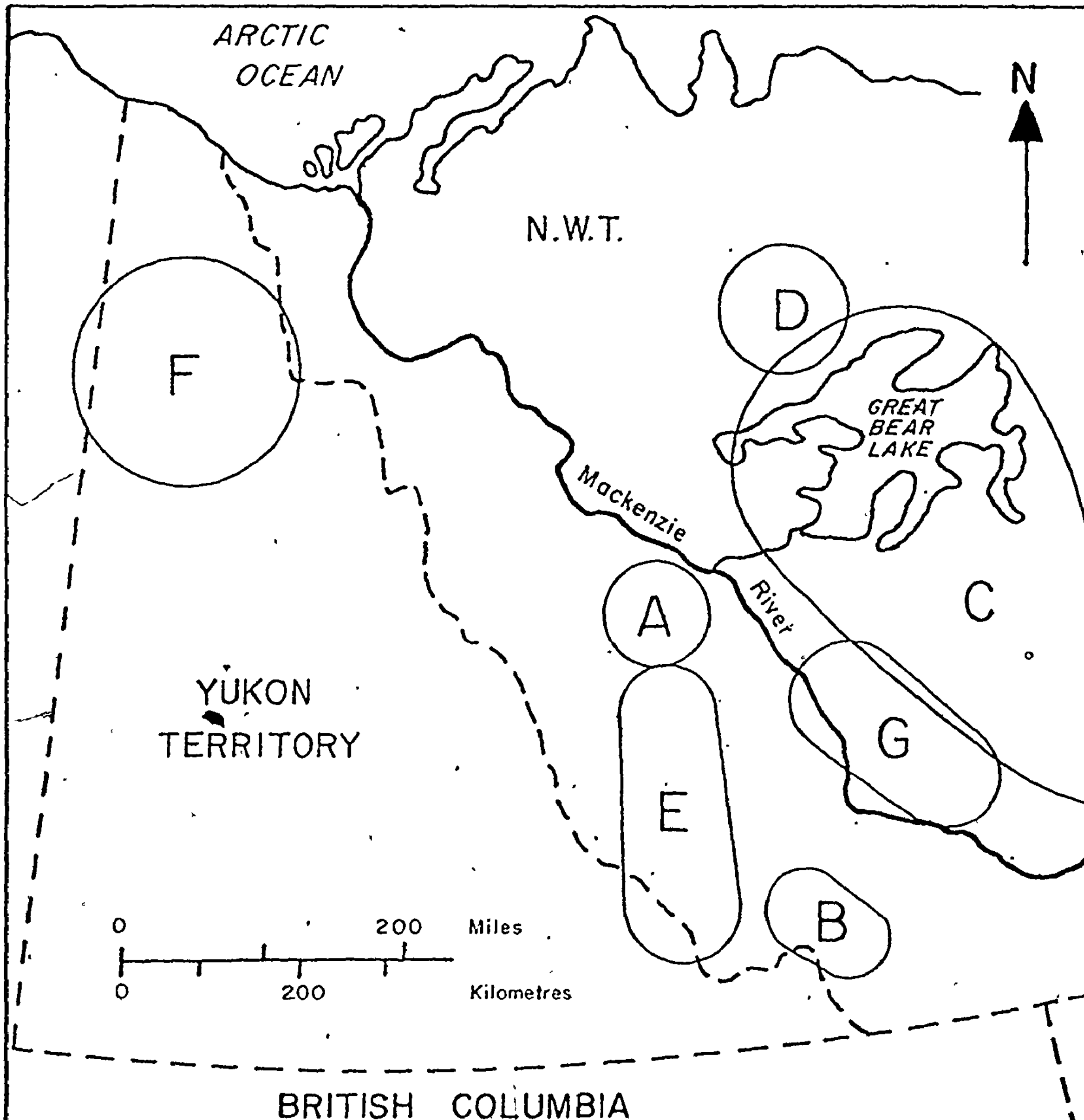
SCALE	1:9,000,000
LEGEND	
Green	Maximum Glacial Lake coverage
Orange	Hummocky Terrain
White	Area of Wisconsinan ice
Light Purple	Area in part unglaciated
Purple	Area of pre-Wisconsian glaciation beyond the limit of last glaciation.
Dark Purple	Unglaciated area

Plate 1.2: Glacial Map for the northwestern area of Canada (Prest *et al.*, 1967)

localized contact between the Laurentian and Cordilleran ice sheets north of 60°N due to blocking of Laurentide ice by the Mackenzie Mountains.

At least two advances of Laurentide ice crossed the Interior Plains east of the Franklin Mountains and covered the eastern ranges of the Mackenzie Mountains to elevations of 1,200-1,525 meters (4,000-5,000 ft) according to Craig (1965). He found no evidence to suggest that Cordilleran ice from the west entered the area east of the Mackenzie Mountains. The Franklin Mountains may have increasingly impeded and eventually stopped the flow of Laurentide ice during early stages of deglaciation, diverting it instead to the north and south along the mountain front.

Gabrielse *et al.* (1973) reported that the entire Flat River, Glacier Lake and Wrigley Lake map areas, west of Ram Plateau (Figure 1.9), were glaciated by alpine and valley glaciers and two or more ice sheets. Cordilleran ice covered areas to altitudes of more than 1,955 m (6,415 ft) and then retreated in a southwesterly direction. That Laurentide ice from the east reached the east side of Wrigley Lake is evidenced by a large moraine containing granitic rock derived from the Shield and with a crest of 760 m (2,500 ft). Erratics also believed to have been derived from the east were found at an elevation of 1,370 m (4,500 ft) south of North Redstone River opposite the southeast end of Tigonankweine Range. The minimum upper limit of an ice sheet is well-defined by abandoned marginal channels on the northeast slope of Tigonankweine Range at elevations of 1,370 m with slopes that suggest a southerly retreat of Laurentide ice. Other indications of the westerly extent of Laurentide ice are believed to have been obliterated or greatly subdued by a late-



A Aitken and Cook, 1974
B Brook, 1976; Ford, 1976; Weirich, 1978
C Craig, 1965
D Fulton and Klassen, 1969
E Gobrielse *et al*, 1973
F Hughes, 1969
G Rutter, 1974

FIGURE 1.9 LOCATION OF OTHER AREAS STUDIED IN THE MACKENZIE MOUNTAIN REGION, N.W.T.

stage ice movement from the west.

Rutter and Boydell (1973) found evidence for two Laurentide ice advances in the Upper Mackenzie River area. A grey-black stoney till is exposed as the basal unit in many tributary valleys of the Mackenzie system, and glacial erratics on the summit areas of the Mackenzie Mountains up to elevations of 1,525 m are evidence of the first advance. A second ice advance which was much thinner and topographically controlled, with the centre of deflection at the Nahanni Range, is recorded at the surface by a light, grey-brown stoney till separated in section from the lower till by stratified sands and gravels up to 30.5 m (100 ft) thick. Deposits relating to the most recent advance are not found above an elevation of approximately 670 m (2,200 ft).

Strong evidence of multiple Laurentide glaciation in the northwestern District of Mackenzie was found by Fulton and Klassen (1969). Three tills lying outside the moraines built by the last ice advance were found in a tributary valley of the Horton River. Dating of a peat layer above the two lower tills indicated that this region of the Anderson Plain was covered by ice on at least two separate occasions prior to 38,100 years B.P. and at least once after this time.

Hughes (1969) noted extensive Laurentide invasions of the northern Yukon Territory and northwest District of Mackenzie. The ice may have reached 1,070 m (3,500 ft) on the east flank of the Richardson Mountains and 1,200 m on the north flank of the Mackenzie Mountains during two or more separate early advances or only once during an early glaciation. Dating indicated that the maximum advance of Laurentide ice on to the Peel Plateau took place more than 31,000 years ago. Two or more different ages of depositional landforms were found within the area glaciated by Laurentide ice. The well-preserved landforms in the area east of the Richardson Mountains and north of latitude 66°N are considered to be of late Wisconsinan age while the more subdued features farther west may relate to older Laurentide glaciations during early Wisconsinan or even pre-Wisconsinan time.

Rutter's (1974) work in the northern and southwestern District of Mackenzie yields evidence of two Laurentide ice advances in both areas. In the Wrigley Lake map area the "Classical" Wisconsinan limit is at 1,295 m (4,250 ft) and the earlier limit is at 1,525 m. In the Sibbeston Lake map area eastern erratics have been found up to elevations of 1,525 m.

Ford (1976) found strong evidence for multiple glaciation by Laurentide ice in the South Nahanni River region of the Mackenzie and Selwyn Mountains. The oldest of the three Laurentide ice advances is indicated by the lag of an ancient till up to altitudes of 1,400-1,615 m (4,600-5,300 ft) on the east flank of Nahanni Plateau and everywhere on Ram Plateau. The till was emplaced by the ice sheet of the First Canyon Glaciation which submerged Nahanni Range, Ram Plateau and Yohin Ridge and finally came to rest on the east flank of Nahanni Plateau prior to 300,000 years B.P. A subsequent Laurentide ice sheet during the Clausen Glaciation came to rest against the lower slopes of Nahanni and Ram Plateaux and is considered to have been responsible for the well-preserved knob and kettle terrain north and south of Nahanni River west of Yohin Ridge at 655 m (2,150 ft). The limits of the most recent Laurentide incursion are marked by a large and complex lateral moraine on the northeast flank of Mattson Mountain which descends the mountain flank from 804 m (2,640 ft) to 523 m (1,716 ft). Ford believes that during this glacial advance, the Jackfish Glaciation, ice occupied the steep-walled breach between Mattson and Twisted Mountains and that west of this the ice thinned rapidly. The Clausen and Jackfish events are tentatively ascribed to the Illinoian and "Classical" Wisconsinan periods respectively.

Brook (1976) proposes a series of five Laurentide ice advances into the Nahanni and Ram Plateaux areas. The date for the First Canyon Glaciation (Ford, 1976) at approximately 400,000 years B.P. is based on calcite dating of stalagmite growth layers above glacial winnowings incorporated into stalagmites in Grotte Valerie and Speleothem Cave. Periods of enhanced speleothem growth (indicative of interglacials) occurred approximately 310,000, 210,000 and 125,000 years B.P., with Death Canyon and Sundog Glaciations during the intervening periods when growth rates decreased. A Death Canyon glaciation with an ice surface at between 1,000-1,070 m (3,300-3,500 ft) is evidenced by glacial end moraines and delta-like complexes in several of the deep canyons which dissect the eastern flank of Nahanni Plateau south of Sundog Basin. During the Sundog Glaciation ice came to rest against the eastern flank of Nahanni Plateau north of First Canyon at an elevation of between 820-915 m (2,700-3,000 ft). Terraces in Ranger Canyon at 820-850 m (2,700-2,800 ft) are remnants of former valley fill to this level and the glacial material on Nahanni Plateau between Lafferty Creek and First Canyon up to altitudes of 820 m contrasts with the bare limestone surface above. Evidence of the later Clausen Glaciation includes depositional terraces at 640-670 m (2,100-2,200 ft) on the extreme southeastern flank of Nahanni Plateau west of Clausen Creek and similar terraces on the eastern flank of Ram Plateau where a tributary canyon south of Ram River has been alluviated to 580 m (1,900 ft). Brook (1976) ascribes this glaciation to the early Wisconsinan because the sediments laid down by Lake Nahanni which was impounded by this ice sheet are too well preserved in the fluvially active South Nahanni River drainage basin to be of Illinoian age as Ford (1976) suggested. The most recent ice advance during the "Classical" Wisconsinan came to rest against the eastern flank of the Nahanni Range. Due to blocking by this topographic barrier the only evidence west of Nahanni Range of this, the Jackfish Glaciation, is alluviation to 460 m (1,500 ft) by the impounded Lake Tetcela where two streams flowing eastward off the flank of Ram Plateau have changed course, cutting down through the bedrock walls of the original channels after they were infilled to 460 m (1,500 ft) and 300 m (1,000 ft).

1.3.2 Evidences for Ice-Dammed Lakes

There is a great deal of evidence for ice-dammed lakes and ice-marginal drainage in the easternmost ranges of the Western Cordillera and Yukon, viz., at the fronts of Laurentide ice sheets.

Prest *et al.* (1967) have marked the boundaries of a former ice-dammed lake occupying the North Redstone River valley upstream of Wrigley Lake. This was ponded by the Laurentide ice sheet that deposited the terminal moraine at the eastern end of Wrigley Lake (Gabrielse *et al.*, 1973). More recent discoveries of deposits that appear to have been laid down in ice-dammed lakes in many of the stream valleys which dissect the eastern ranges of the Richardson and Mackenzie Mountains and the Peel

Plateau suggest that many such lakes were ponded all along this mountain front during periods of Laurentide ice incursion.

Rutter and Boydell (1973) have identified glaciolacustrine sands and silts in river valleys west of the Liard valley, in mountain valleys west of Liard, Nahanni and Camsell Ranges, and in the Bulmer Lake and Wrigley Lake map-areas. The glacial lakes are thought to have reached a maximum elevation of 396 m (1,300 ft) and ultimately drained northwards. Consistent northward deflections of Carcajou River and other major streams in the Carcajou map-area and the presence of numerous abandoned spillways aligned northeasterly also suggest drainage to the north along the ice margin (Aitken and Cook, 1974).

Further evidence for glacially impounded lakes has been found by Hughes (1969) in Bonnet Plume, Bell, Old Crow and Bluefish Basins. The latter three basins are of structural rather than erosional origin, having been formed by warping or faulting in the Tertiary or early Pleistocene. Drainage out of these lakes appears to have been to the north. Palynological analysis of the sediments in Hugh's Porcupine River section and radiocarbon dating of organic matter contained within them by Lichti-Federovich (1974) has established that an early or pre-Wisconsinan Laurentide ice sheet which advanced onto the Peel Plateau and came to rest against the Richardson Mountains was followed by a "Classical" Wisconsinan Laurentide ice advance which commenced before 32,000 years B.P. and ceased by at least 10,740 years B.P.

In the South Nahanni region two distinct glaciolacustrine deposits have been reported by Ford (1976). Analysis of sediments found west of Third Canyon in the South Nahanni River valley, the Flat River valley and in tributary canyons suggests deposition in a lake with a surface at between 580 m (1,900 ft) and 650 m (2,130 ft). Ford ascribes these to the Illinoian glacial period when Clausen ice impounded Lake Nahanni. More recent sediments identified in Deadman Valley and in the Mackenzie Plain area immediately east of First Canyon, South Nahanni River, appear to have been laid down in a lake with a level at approximately 400 m (1,320 ft). Ford suggests that these were deposited by the younger Glacial Lake Tetcela that was impounded by Jackfish ice during the "Classical" Wisconsinan. Lake Tetcela is considered to have overflowed northwards across a low col into the valley of the Tetcela River.

Brook's (1976) work in the South Nahanni karst region suggests a more complex history. The extreme flatness of the upper surfaces of sediment in the Sundog Basin suggest lake deposition. In the extreme southeast portion of Sundog Basin in the region of the Nahanni poljes are terraces up to an altitude of 945 m (3,100 ft) that are interpreted as being dissected sandurs and kame terraces both laid down by a tongue of glacier ice occupying the region around what is now the labyrinth and polje karst belt. West of the Nahanni Poljes the 915 m (3,000 ft) surface appears to be of glaciofluvial origin. Lake Sundog I, impounded by Death Canyon ice resulted in alluviation of Hiller and Texas Canyons to 790-850 m (2,600-2,800 ft). These canyons presently drain underground. After a period of fluvial erosion, Lake Sundog II impounded by Sundog ice created terraces at 730-760 m (2,400-2,500 ft). These contain sands and gravels transported into the basin largely by the Ram and Sundog rivers prior to ice retreat. Lake Sundog II is believed to have drained northwards along the ice margin against the eastern slope of the northern section of Nahanni Plateau into the North Nahanni River region. Two later lakes, Lake Nahanni at 610-650 m (2,000-2,130 ft) impounded by Clausen ice and Lake Tetcela at 400 m impounded by Jackfish ice during the early and late Wisconsinan are recognized. Brook suggests that Clausen ice is of early Wisconsinan age, and not Illinoian as Ford proposed, for two reasons. The deposits of Lake Nahanni are not extensively dissected and it is likely that they correspond to the early Wisconsinan sediments studied by Hughes (1969) and dated by Lichti-Federovich (1974) as having been deposited during a glaciation which commenced before 32,000 years B.P. and ceased by at least 10,740 years B.P.

Weirich (in litt.) has concluded that a proglacial lake (Lake Cariboo) infilled the canyons of South Nahanni River to at least 610 m (2,000 ft) prior to infilling by Lake Nahanni to 610-650 m. That an extensive erosional phase separated the two events is evidenced by the presence of an unconformity between the dark grey silts of Lake Cariboo and the overlying buff-coloured silts of Lake Nahanni.

In summary it is evident that many parts of the Mackenzie Mountain area were not glaciated during the last glaciation. Studies agree that the first Laurentide ice sheet covered the mountains up to elevations of more than 1,370 m (4,500 ft) and that subsequent Laurentide advances were topographically limited in extent so that the upland areas were not glaciated. Reports concerning meltwater channels and glaciolacustrine deposits within the valleys and canyons indicate that the lakes impounded by the ice drained northwards as the ice retreated to the southeast.

The precise number of glacial advances reported differs among authors. This may be attributed to the different localities which were studied and later ice advances which removed traces of earlier glacial events. It is possible that all of this work is fundamentally correct, but its correlation is evidently difficult.

CHAPTER TWO

REGIONAL EVIDENCES OF TERRACES AND CHANNEL DIVERSION FEATURES

Larger regions both up and downstream must be studied in order to better understand the complex series of depositional events within the Ram Canyon area. Air photo and topographic map interpretation are relied upon as the best means of study. Aerial reconnaissance by helicopter over much of these adjoining areas and the region farther south along the South Nahanni River was undertaken by the author and Dr. D.C. Ford so that interpretation would be more accurate. In Chapter 3 the results of two seasons of detailed fieldwork within the Ram Canyon area and at one location in the Sundog Basin provide greater detail and further substantiate general hypotheses proposed in this chapter.

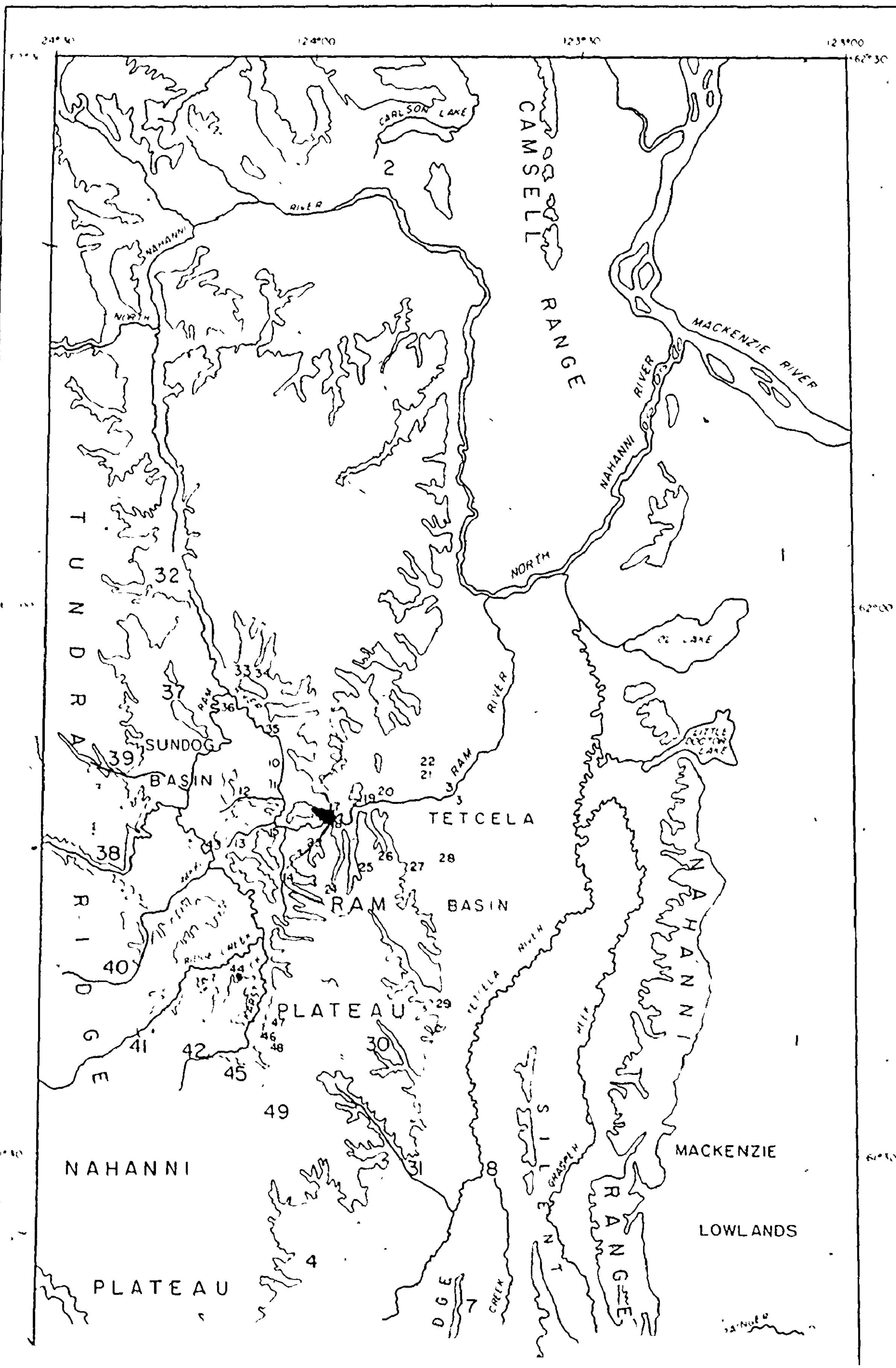
2.1 Mapping Procedures

The topographic maps and air photos for the map area bounded by Tundra Ridge, North and South Nahanni Rivers and Nahanni Mountains contain important indicators of the events thought to be responsible for the infilling of the Ram canyons. Such indicators include the location, extent and elevation of unconsolidated material, terraces and channel diversion features. The information shown on Figure 2.2 (in pocket) was initially mapped on the 1:50,000 topographic series using information derived from aerial photographs at a scale of 1:59,000, and the solid geology mapping of Douglas and Norris (1960), published by the Geological Survey of Canada at a scale of 1:250,000. In the following discussion each feature has been assigned a number which corresponds to that on Figure 2.1. The features which have not been numbered are named.

As noted, the region east of Tundra Ridge and west of Nahanni Range is generally considered not to have been glaciated during the most recent continental and alpine glacial period. Large proglacial lakes may have infilled basin areas. The limits of Laurentide ice advances were mapped from indicators such as fluted ground moraine, terminal moraines and channel diversion features resulting from the erosion of canyon walls and subsequent alluviation. The altitude and extent of proglacial lakes infilling the basins and canyons to the west of the ice margins were determined on the basis of the location and elevation of unconsolidated infill, terraces and alluvial fans. These were correlated with abandoned spillways, breaches and fluvial terraces at corresponding locations and elevations. Gradients were calculated from topographic map data. The extent of lithological control was inferred using such criteria as: scale of feature, slope, vegetation and drainage pattern, and verified in some instances by the geology maps. Unconsolidated deposits over limestone usually have sinkholes and are often surrounded by vertical limestone cliffs. Those underlain by shales at shallow depth show recent solifluctual movement which is readily detected on the air photos.

2.2 Description of Features

The large-scale features are described in terms of the four distinct geographical sub-regions of the study area: 1) Nahanni Range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123°30
CARLSON LAKE
CAMSELL RANGE
NAHANNI RIVER
NORTH
MACKENZIE RIVER
NAHANNI RIVER
NORTH
TUNDRA RIDGE
SUNDOG BASIN
RAM RIVER
RAM RIVER
TETCELA
RAM BASIN
PLATEAU
TETCELA RIVER
NAHANNI RANGE
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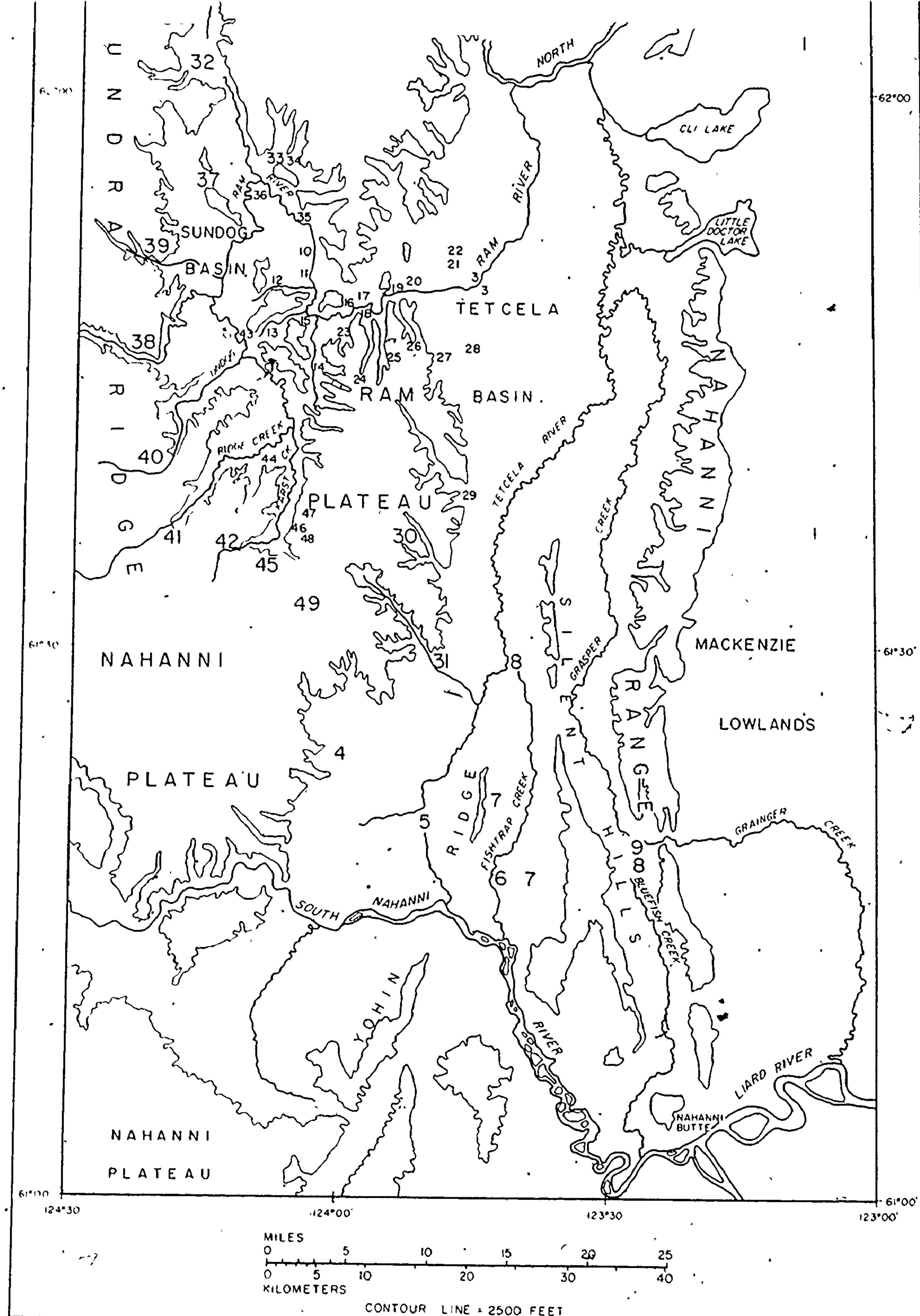


FIGURE 2.1 NUMBERED LOCATIONS OF GEOMORPHIC FEATURES

and Mackenzie Lowlands, 2) Tetcela Basin, 3) Ram Plateau, and 4) Sundog Basin.

2.2.1 Nahanni Range and Mackenzie Lowlands

Nahanni Range separates the Mackenzie Lowlands from the Interior Plain. East of the mountain range the surface of ground moraine (1) exhibits well-defined glacial flutings, some of which are filled with water. These flutings are oriented in a WNW-ESE direction indicating that Laurentide ice advanced from the ESE during the most recent glaciation. There are no flutings west of the mountains, which suggests that the most recent ice sheet did not enter the Tetcela Basin. If any terminal moraines were formed along the steep eastern slope of Nahanni Range they have been subsequently eroded.

The mountains are principally drained by rivers flowing to the west which have incised deep V-shaped valleys into the dip slope of the cuesta. The valleys show no glacial features such as cirques, truncated spurs, U-shape or hanging mouths. Unlike the canyons of Ram Plateau they are not choked with unconsolidated deposits. Alluvial fans at the mouth of each valley coalesce as they spread out into Tetcela Basin. They are probably composed of a mixture of sediment derived from the local bedrock and paleofill that has been washed out of the valleys. The fans are presently being incised, implying that they were deposited during periods of much greater detrital production.

There are two sizeable breaches through the northern section of the mountain range. That occupied by Cli Lake is 1.2 km wide and 3 km long. The western shoreline of Cli Lake extends across the midpoint of the breach, and the lake is very shallow for a distance of 1.0 km offshore, implying deposition subsequent to glacial scour. The narrower breach occupied by Little Doctor Lake is 0.5 km wide and 3.5 km long. The western shore of the lake is 2.2 km west of the western front of the mountain range and the lake is much deeper close to shore suggesting that a tongue of ice occupied the breach. This is independently indicated by the presence of a large, dissected alluvial fan at the western end of the breach. The fan deposits range in elevation from 275-365 m (900-1,200 ft).

To the south, Nahanni Range terminates at Nahanni Butte. South of this, a continental ice sheet covering Mackenzie Plain would not be diverted away from Tetcela Basin by any topographic barriers. This area is considered to be the major entrance for ice masses occupying Tetcela Basin prior to the last glaciation. Lesser amounts of ice would have entered Tetcela Basin via the large gap through which North Nahanni River flows, between Nahanni and Camsell Ranges, and via the breaches at Cli and Little Doctor Lakes.

2.2.2 Tetcela Basin

Tetcela Basin, between Nahanni Range and Ram Plateau is a very flat, extensive lowland area having a general elevation of 210-275 m (700-900 ft). The modern flood plain of the profusely meandering Tetcela River (Plate 2.1) is incised 10 m below this level. The lowland area is interrupted only by the Silent Hills, which are isolated, elongate segments of the N-S ridge of shales, central to the Yohin syncline. To the south, the western fork of this formation is the northern extension of Yohin Ridge.

Plate 2.1: Tetcela River meanders northward through the flat-floored Tetcela Basin

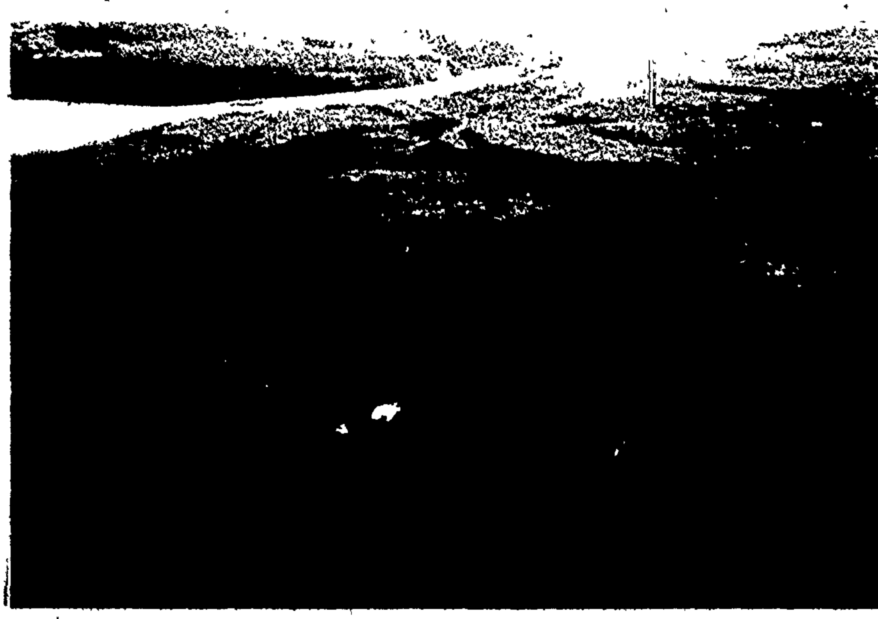


Plate 2.2: Terraces at 245-275 m at the mouth of Ram River Canyon

At the mouth of Ram Canyon there is a series of fluvial terraces (3) in unconsolidated deposits (Plate 2.2) with elevations ranging from 245-275 m (800-900 ft). These are attributed to recent erosion by Ram River. At the southern end of the basin, west of Yohin Ridge, there is a low col (5) at an elevation of 380 m (1,250 ft) between the South Nahanni and Tetcela Rivers, suggesting that at one time these two drainage systems were linked. From this col, Tetcela River drains northward, descending to 275 m at a mean gradient of 6.3 m/km. West of it, flanking Ram Plateau, there is a horizontal terrace (4) at an elevation of 425-460 m (1,400-1,500 ft). Between Yohin Ridge and the Silent Hills there are horizontal terraces (7, Plate 2.3) at 365 m (1,200 ft) on both sides of the southward-draining Fishtrap Creek. The creek flows through a lower channel having a flood plain (6) at 245 m. East again, between the Silent Hills and Nahanni Range, there is alluvium (9) up to 530-560 m (1,750-1,850 ft). It supports the headwaters of Grasper Creek, which drains to the north, Grainger Creek which drains to the east through a breach in Nahanni Range, and Bluefish Creek which drains to the south. The section of Grasper Creek north of 61° 30' N has a steep mean gradient of 15.2 m/km down to the general level of Tetcela Basin.

The basin is so flat that the marshy areas (8) in the central part drain both northward into Tetcela River and southward into Fishtrap and Bluefish Creeks.

North Nahanni River flows to the east along the northern flank of Ram Plateau, across the northern end of Tetcela Basin and then flows northward through the gap between Nahanni and Camsell Ranges to empty into the Mackenzie River. Just north of the southward diversion there

Plate 2.3: Terraces at 365 m on both sides of Fishtrap Creek (photo by Ford)

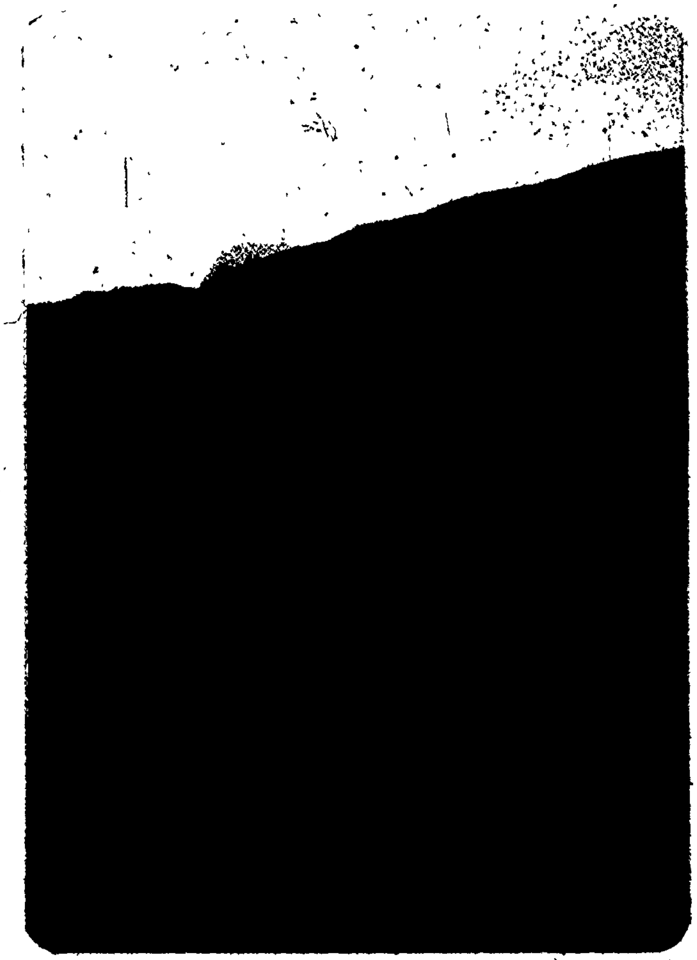


Plate 2.4: The narrow, vertically walled Scimitar Canyon (photo by Dale Leckie)

is a breach (2) at an elevation of 260 m (850 ft) which is presently occupied by Carlson Lake, the source of the northward-flowing Carlson Creek. It is possible that a lake occupying Tetcela Basin drained via Carlson Creek at a time when the lower outlet between Nahanni and Camsell Ranges was blocked, perhaps by ice.

2.2.3 Ram Plateau

The canyons of Ram Plateau are characterized by 180 m high vertical cliff faces of Nahanni Limestone with extensive blocky scree slopes below, building out onto infill at the base along their entire lengths. The scree has a slope ranging from 25°-29° and there are rock glaciers in Camp, Fault and Subject Canyons. Many of the canyons have widths greatly exceeding their depths. Due to the likelihood of lengthy periods of uninterrupted cliff recession this is not believed to be a result of erosion by valley glaciers, even though the creeks draining these immense canyons look like misfit streams and the extensive scree slopes impart a rough U-shape to the canyon's cross sections.

Ram River enters Ram Canyon via Scimitar Canyon (10) an extremely narrow, deep gorge cut into limestone (Plate 2.4). The head of the modern gorge at the northern end is a waterfall on limestone at 460 m (1,500 ft). The mouth of the 4 km long gorge is at 365 m (1,200 ft).

Ram Canyon is a complex feature. It is straight at the eastern and western ends but meanders acutely in the central portion (Plate 2.5), where the net up-doming of Ram Plateau is greatest.

Abandoned bedrock meander scars alongside Ram River with Ram Plateau are partially infilled with unconsolidated sediment up to an

Plate 2.5: Air photo of the central Ram Canyon area showing the antecedent meandering channel of Ram River

elevation of 550 m (1,800 ft). The most notable examples of filling are Golden Bowl (15) (Plate 3.19), Western Bowl (17) (Plate 3.4) and Eastern Bowl (20) (Plate 3.1). Slumping is common in all three.

The bed of the modern Ram River rests on unconsolidated infill and bedrock is exposed at only three places along its course:

1) at Scimitar Canyon (10),

2) at a chute (16) (Plate 2.6), at an elevation of 300 m (980 ft), 2.5 km upstream from base camp (18), and

3) at a small gorge (19), 4.8 km downstream from base camp where the elevation is 275 m (900 ft).

The tributary canyons draining northward into Ram River (e.g. Raynor, Camp, Subject, Mike and Lake Canyons (23-27)) have infill other than scree up to a maximum elevation of 730 m (2,400 ft) at their upstream ends, and terraces at 550 m.

On the western side of the plateau (Plate 2.7) the broad canyons which drain into Ram River (e.g. Leckie, Footloose and Butler Canyons) (12-14) have alluvium up to 730 m. As the limestone bedrock dips west, the canyon walls pass beneath the infilling (Plate 2.8). The downstream portions of the canyons are being excavated by small local creeks which empty into Ram River at elevations of 350 m (1,150 ft), 335 m (1,100 ft) and 330 m (1,080 ft) respectively.

Along the eastern flank of Ram Plateau the rivers generally drain to the east following the dip of the bedrock. North of Ram River there is an abandoned channel feature (21) at an elevation of 460 m lying between the edge of the plateau and a northward-trending series of shale outliers. The channel is oriented N-S and has a gradient of 8 m/km to the north.

Plate 2.6: Chute upstream from base camp where Ram River has re-excavated its original bedrock channel

Plate 2.8: The cliff-forming Nahanni Limestone dips west under the unconsolidated sediment infilling Sundog Basin

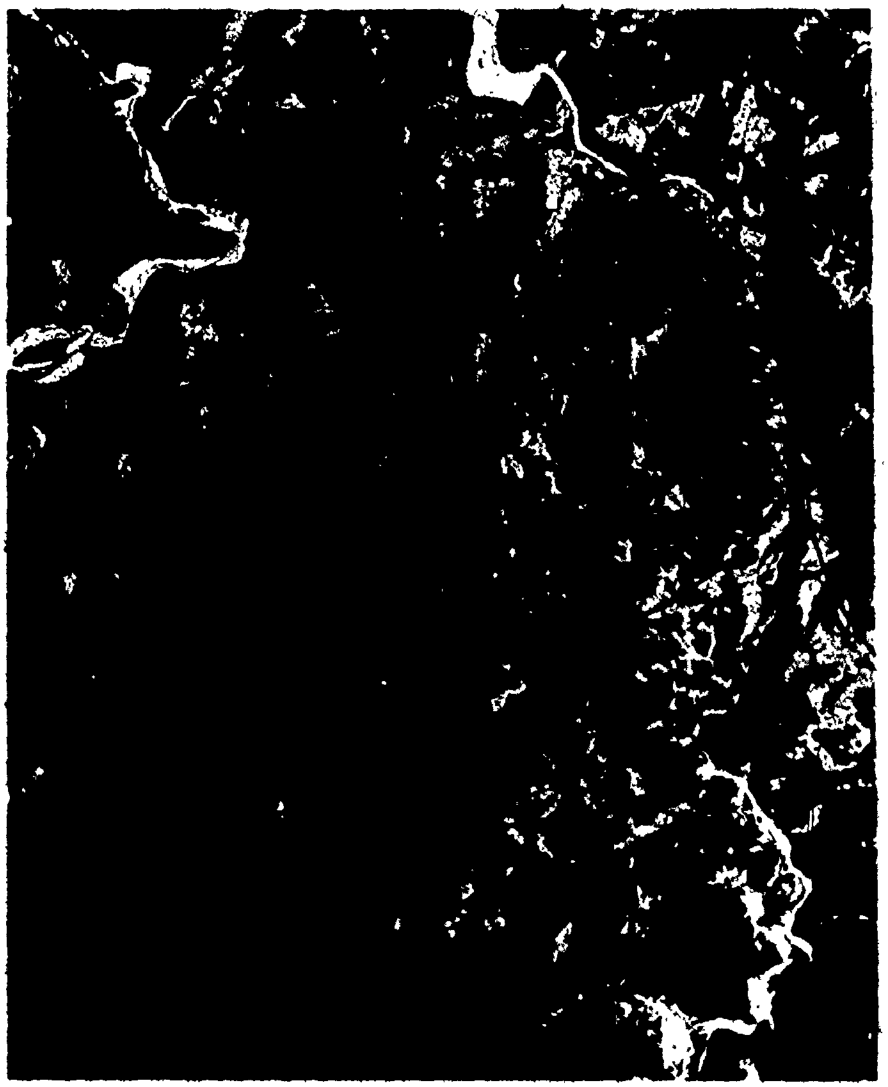


Plate 2.7: Air photo of Western Ram Canyon area showing paleochannel above Scimitar Canyon (at 'A')

A ridge of unconsolidated material (22) links two of the shale outliers. This may be a terminal or recessional moraine, indicating the western extent of an ice sheet or a stationary front during recession.

Immediately south of Ram River, Lake Canyon and Karpuk Canyon (27, 28) exhibit modifications to their original forms. Their northern halves drain north to Ram River, and air photos show that the southern halves once drained to the north. The midpoints of the canyons have been alluviated to 565 m (1,850 ft) and 460 m respectively. The vertical canyon walls of Lake Canyon obviously pass below this infill, indicating deposition after the bedrock canyon was incised. A lake, 500 m in length, occupies part of the level portion of the canyon floor (Plate 2.9). The eastern walls of Lake and Karpuk Canyons were either eroded or buried by sediment and the rivers draining the southern halves were diverted down the dip slope to the east, as shown in Figures 2.3 and 2.4.

Farther south, Latham and Tucker Canyons (29, 30) have infillings to elevations of 850 m (2,800 ft) and 1,000 m (3,300 ft) respectively. The original, broad outlet of the latter was filled to 460 m. Its river was diverted onto the eastern canyon wall as is indicated in Figure 2.5 and now flows through a recently incised, narrow channel into Tetcela Basin. In Tetcela Canyon there are unconsolidated deposits at the headwaters of Tetcela River. These may be till over shales. Their elevation is above 945 m (3,100 ft). Downstream, Tetcela Canyon contains no apparent unconsolidated material.

2.2.4 Sundog Basin

The Sundog Basin is bordered by Tundra Ridge to the west, Nahanni

Plate 2.9: A lake occupies a 500 m long section of the flat-floored Lake Canyon (photo by Nichols)

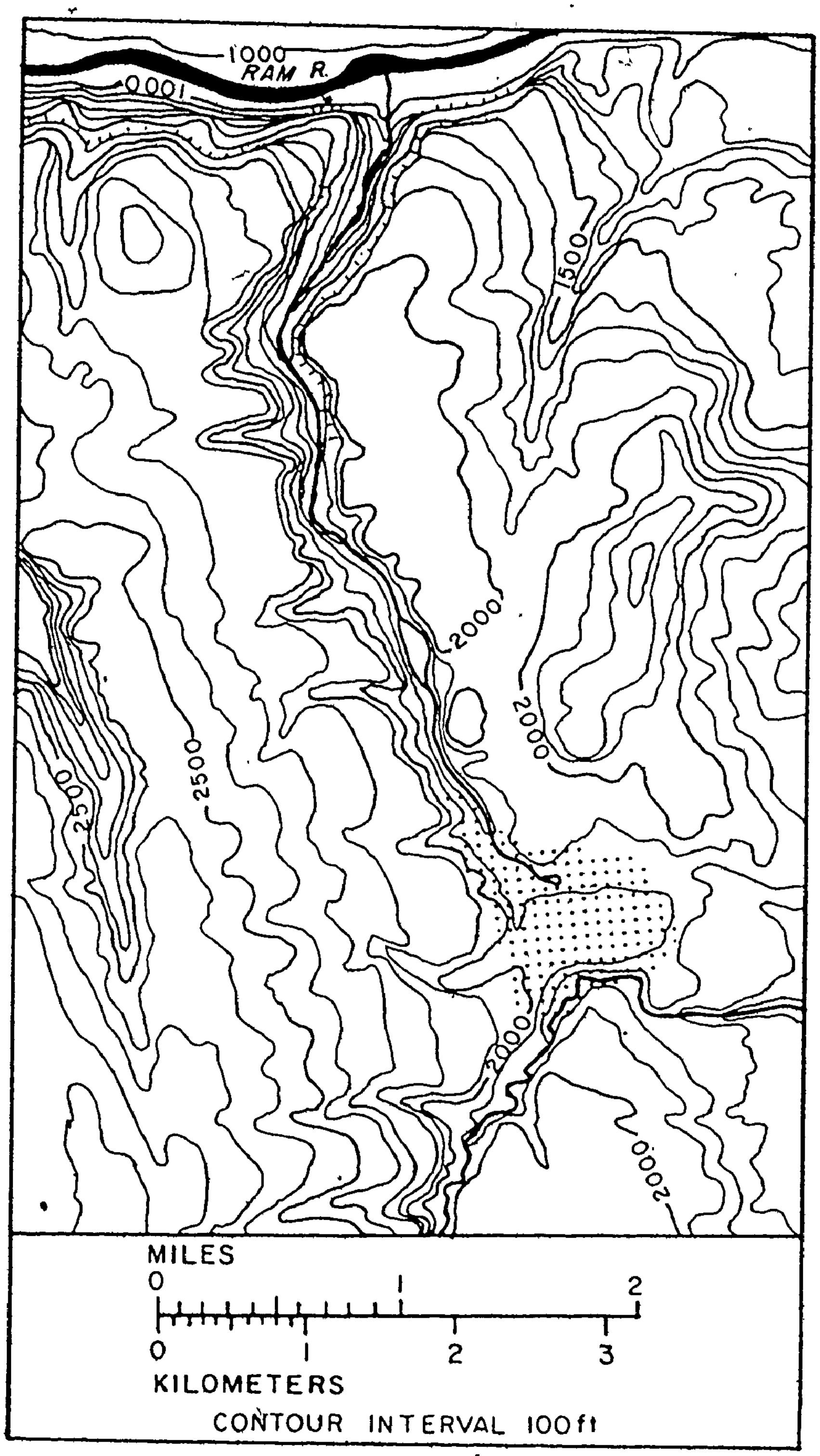


FIGURE 2.3 LAKE CANYON ALLUVIATION TO 565 m (1850 ft)

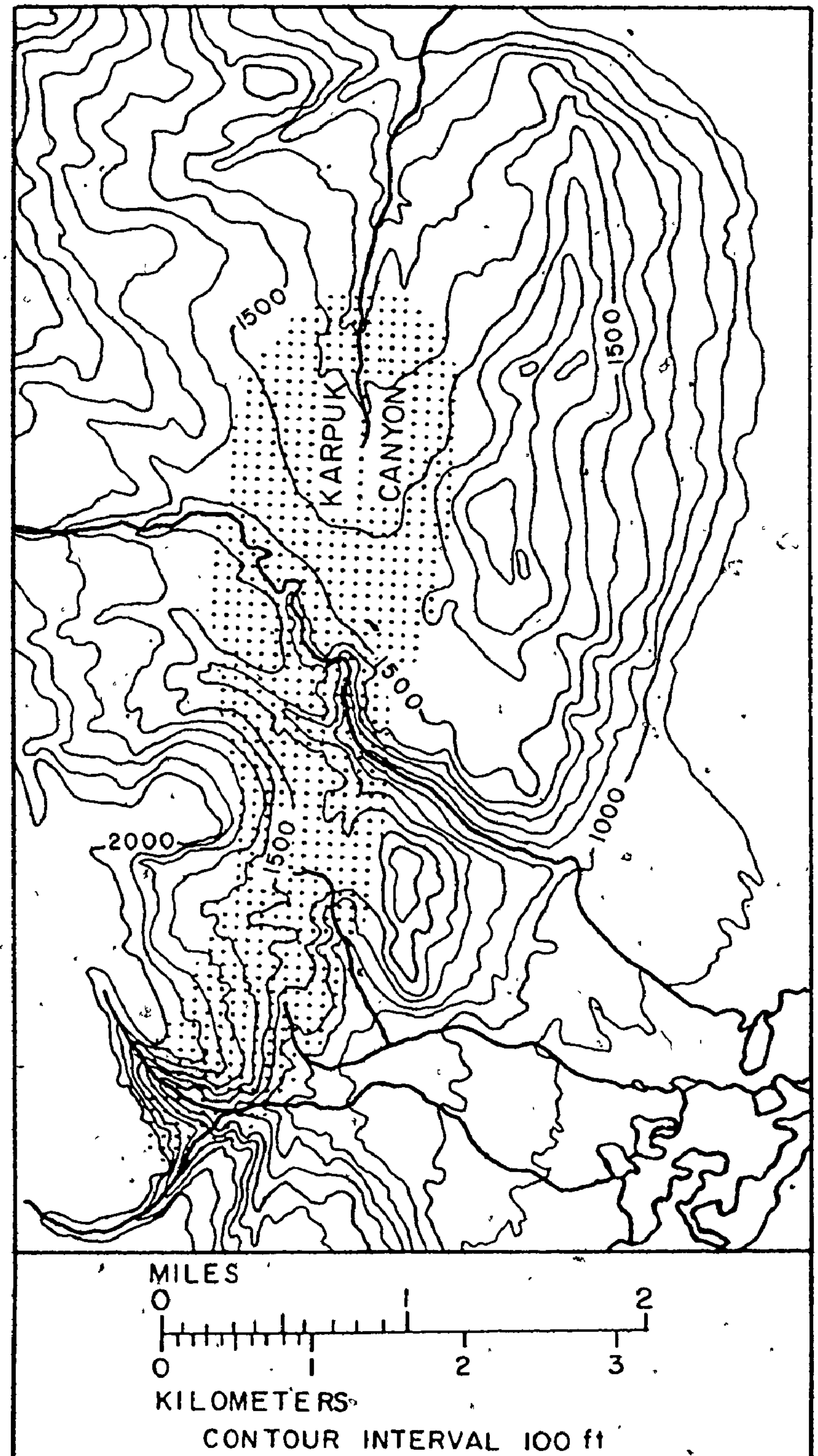


FIGURE 2.4 KARPUK CANYON ALLUVIATION TO 460 m (1500 ft)

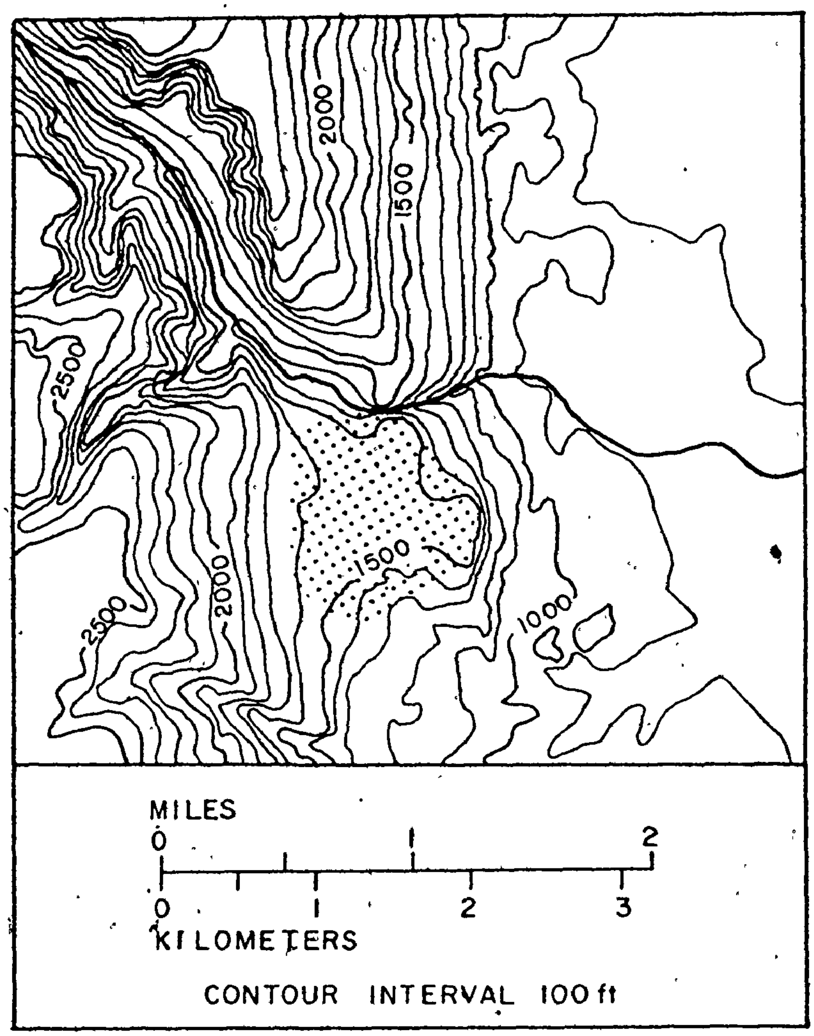


FIGURE 2.5 TUCKER CANYON ALLUVIATION TO 460 m (1500 ft)

Plateau to the south and Ram Plateau to the east. Trending across the northern portion of the basin is a linear ridge of shales (37) extending out from Ram Plateau in a northwesterly direction. Only elongate remnants of this ridge can be detected above an infilling.

The basin is mantled by great thicknesses of unconsolidated sediments which have been variably dissected. The limestone bedrock along the western edge of Ram Plateau clearly passes beneath this material (shown in Plate 2.8), indicating its deposition after Sundog Basin was structurally depressed. Many terrace fragments at a consistent elevation of 730 m (2,400 ft) intimate a lengthy period of alluviation to at least this altitude. The headwaters of Ram River and Tundra, Sundog, Ridge and Karst Creeks (38-42) are entrenching this infill, causing large-scale slumping at many places along their courses. One of the largest slump faces found in the centre of the basin (43) is more than 90 m high.

The creeks draining the northern flank of Nahanni Plateau and the eastern flank of Tundra Ridge have cut very large canyons which correspond in position, size and orientation with large, filled canyons of the western flank of Ram Plateau, viz. Leckie, Footloose and Butler Canyons. It is believed that Tundra, Sundog Ridge and Karst Creeks originally cut these three canyons as they drained eastward into Ram Canyon. The most plausible paleodrainage pattern is shown in Figure 2.7.

The modern drainage pattern of Sundog Basin is highly anomalous. The creeks (38-42) join before flowing northward through a narrow, meandering canyon (Sundog Canyon, 36) that is cut into the elongate ridge of shales. The river then turns abruptly southward to flow through the narrow Scimitar Canyon and into Ram Canyon. The narrowness of Sundog and Scimitar Canyons implies that they are the result of a relatively recent downcutting phase(s). They are the consequences of radical diversions of the paleochannels.

From the abrupt bend in Ram River there is a wide, flat-floored valley (Glew Spillway, 32) extending north for 40 km to North Nahanni River. The valley is presently alluviated to a maximum height of 585 m (1,920 ft). It is drained to the north and south by small streams having headwaters in marshy ground south of the midpoint. The size of the valley clearly indicates that this spillway feature was originally cut by a uni-directional river of much greater magnitude.

Plate 2.5 shows that above the modern, limestone Scimitar Canyon there are traces of an older channel (11) which descends to the north following the dip of the top of the limestone bedrock. The present elevation of the highest portion of the remaining channel feature is 670 m (2,200 ft) at the southern end. The channel was presumably even higher in the past (perhaps 730 m) when allowance is made for erosion of the overlying shales. Farther north, the downstream portions of two south-draining canyons (Jackson (33) and Pratt (34) Canyons) have been filled to 670 m. Their streams have been diverted westward and are presently cutting down into unconsolidated sediment, leaving the original canyon mouths infilled, as shown in Figure 2.6.

Evidence of filling above 730 m is found only around the southern perimeter of Sundog Basin. A lithologically-controlled col (49) with an elevation of 870 m (2,850 ft) joins the southwestern edge of Ram Plateau to the northeastern edge of Nahanni Plateau. It is the lowest part of the divide between Sundog Basin and the South Nahanni Basin. Its elevation

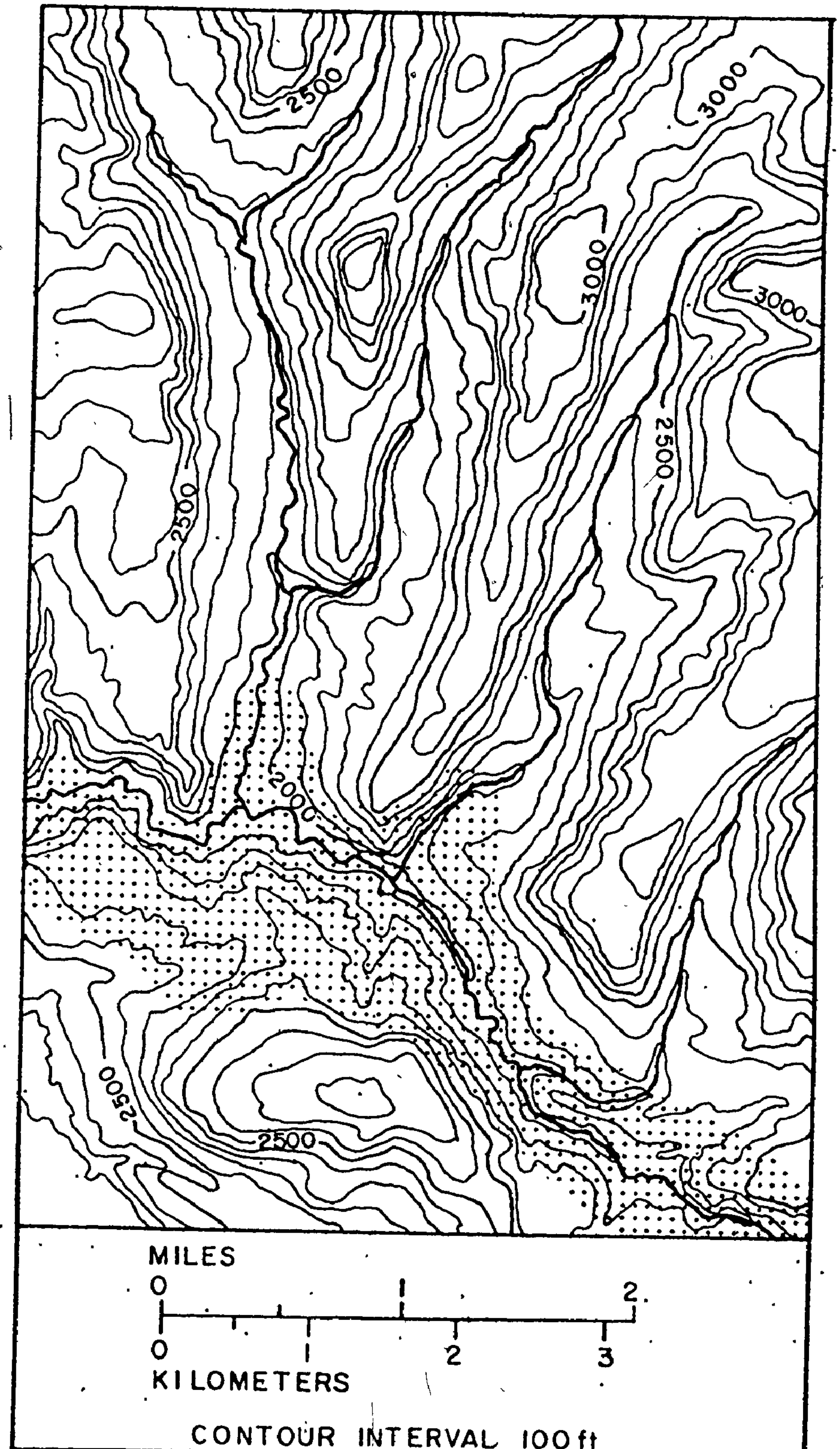


FIGURE 2.6 ALLUVIATION OF JACKSON AND PRATT CANYONS TO 670m (2200 ft)

is apparently too high for the two drainage basins to have ever been linked because the highest lake level in Nahanni basin cited by Ford (1974) and Brook (1976) is at 650 m (2,130 ft) and any lake impounded in Sundog Basin would have drained northward at lower elevations.

North of the col there is a series of depositional and erosional terraces (46) along the western flank of Ram Plateau. The terraces descend regularly to the north from 945 m (3,100 ft) to 760 m (2,500 ft) at a mean gradient of 10 m/km. The lower reaches of Hiller (47) and Texas (48) Canyons draining the southwestern flank of Ram Plateau have been alluviated to 850 m (2,800 ft). Farther west is an expansive terrace over limestone (45) at an elevation of 915 m (3,000 ft) flanking the northern edge of Nahanni Plateau. North of this (44) a much larger area of unconsolidated material shows signs of massive solifluctual descent to the northeast to a present elevation ranging from 790-700 m (2,600-2,300 ft). It follows the dip direction of underlying shale bedrock.

2.3 Tentative Outline of Events

The topographic features found in each sub-region of the map area must be related in some way to a succession of events responsible for their formation. The sequence discussed below is thought to best explain the evidence presented.

2.3.1 Evolution of the Paleodrainage System

Before upwarping of Ram Plateau, Ram River and its principal tributaries (Karst, Ridge, Sundog and Tundra Creeks) drained eastward from Tundra Ridge and Nahanni Plateau across a plain of little relief.

As Ram Plateau was gradually upwarped, drainage continued eastward due to blocking to the north by the ridge of shales and to the south by the Nahanni-Ram Plateaux bedrock col. The tributaries crossed the western flanks of the plateau (the present positions of Butler, Footloose and Leckie Canyons) and joined to flow through the central plateau area (Figure 2.7) incising the meandering, antecedent channel of Ram Canyon into the rising dome there. The canyon is straight at the eastern and western ends, but meanders acutely in the central portion where the net up-doming of Ram Plateau is greatest. This suggests an early history of antecedent effect (when only the central portion was emergent), followed by more conventional (linear and high gradient) channel entrenchment on the flanks.

According to Ford (pers. comm.), this pattern is markedly different from that of the First, Second and Third Canyons of South Nahanni River. Although lengthier than Ram Canyon, these display sinuous antecedent form throughout their length. This suggests a lesser measure of differential updoming at Ram Plateau and one that has been terminated for a long while. This is reasonable because Ram Plateau is farther from the center of the plutonic injection presumed to have triggered the uplift (Douglas, 1972, p.467). Deformation of Nahanni Plateau at First Canyon, 60 km southwest of Ram Canyon may still be continuing (Ford, 1973).

2.3.2 Glacial Advance and First Infilling Event

The 730 m (2,400 ft) terrace fragments in the northern and central portions of Sundog Basin and unconsolidated sediment found in the tributary canyons (12-14 and 23-27) of Ram Canyon up to the same altitude are

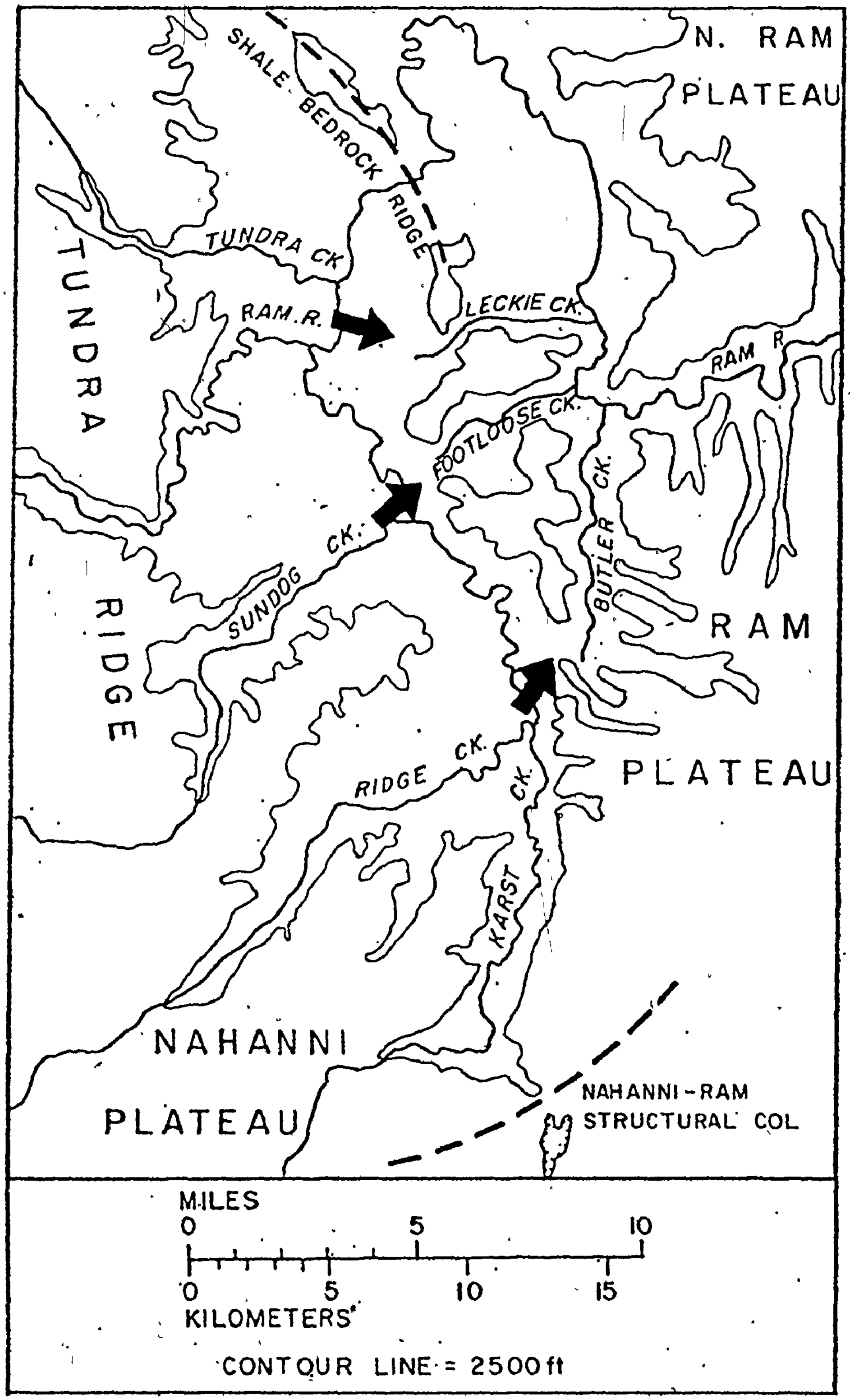


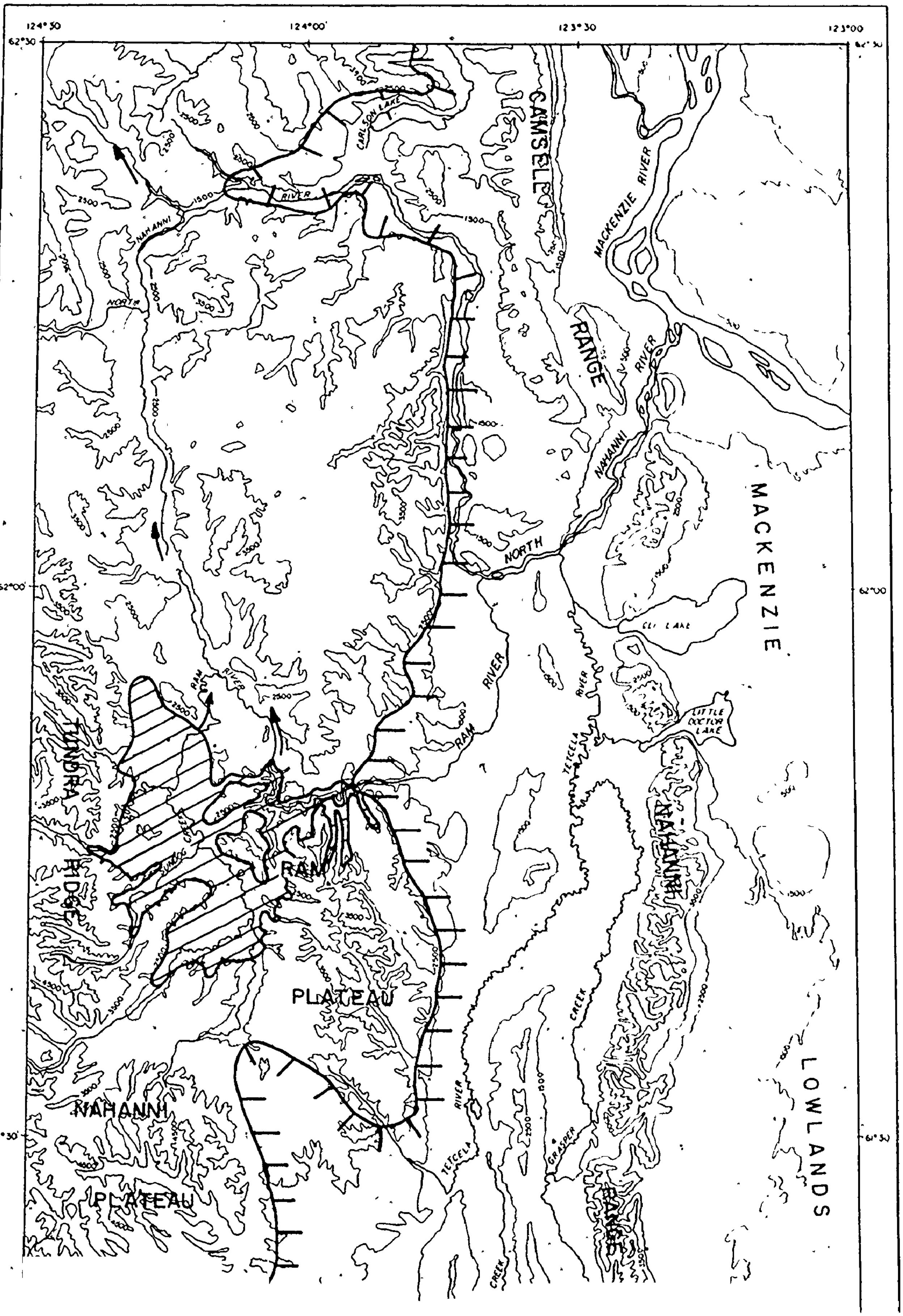
FIGURE 2.7 PALEODRAINAGE PATTERN OF RAM R. AND TRIBUTARIES IN SUNDOG BASIN

substantial evidence of infilling of Sundog Basin, Ram Canyon and its tributary canyons to a general elevation of 730 m. This rises steadily to 945 m (3,100 ft) at the southern end of Sundog Basin. Because most of the remaining fill surfaces have consistent terminal elevations of 730 m it is proposed that they were deposited in a lake basin having an outlet at 730 m. The impoundment is best attributed to Laurentide ice flanking the eastern slope of Ram Plateau to an elevation of at least 730 m (Figure 2.8).

Major deposits above this elevation are found in southern Sundog Basin. These imply a different depositional environment or different, presumably earlier, events. North of the 870 m (2,850 ft) Ram-Nahanni col they compose a series of depositional and erosional terraces that descend to the north from 945 m to 760 m (3,100-2,500 ft). Although fragmented by dissection their surface gradient is quite consistent. Because they have an upper elevation greater than that of the col and a steep northward gradient, the most feasible agent of deposition is water flowing off of the surface of an ice lobe occupying the col, building an expansive outwash fan down to the 730 m lake level. A terrace over limestone at 915 m (3,000 ft) and the unconsolidated material at an elevation of 790-700 m (2,600-2,300 ft) which is presently being affected by solifluctional processes are also remnants of the glaciofluvial outwash.

It is reasonable to postulate a substantial glacier tongue at the Nahanni-Ram Plateaux col because large quantities of ice could have entered the South Nahanni Basin via the great breach south of Nahanni Range.

Ice also entered Tetcela Basin from the South Nahanni Basin and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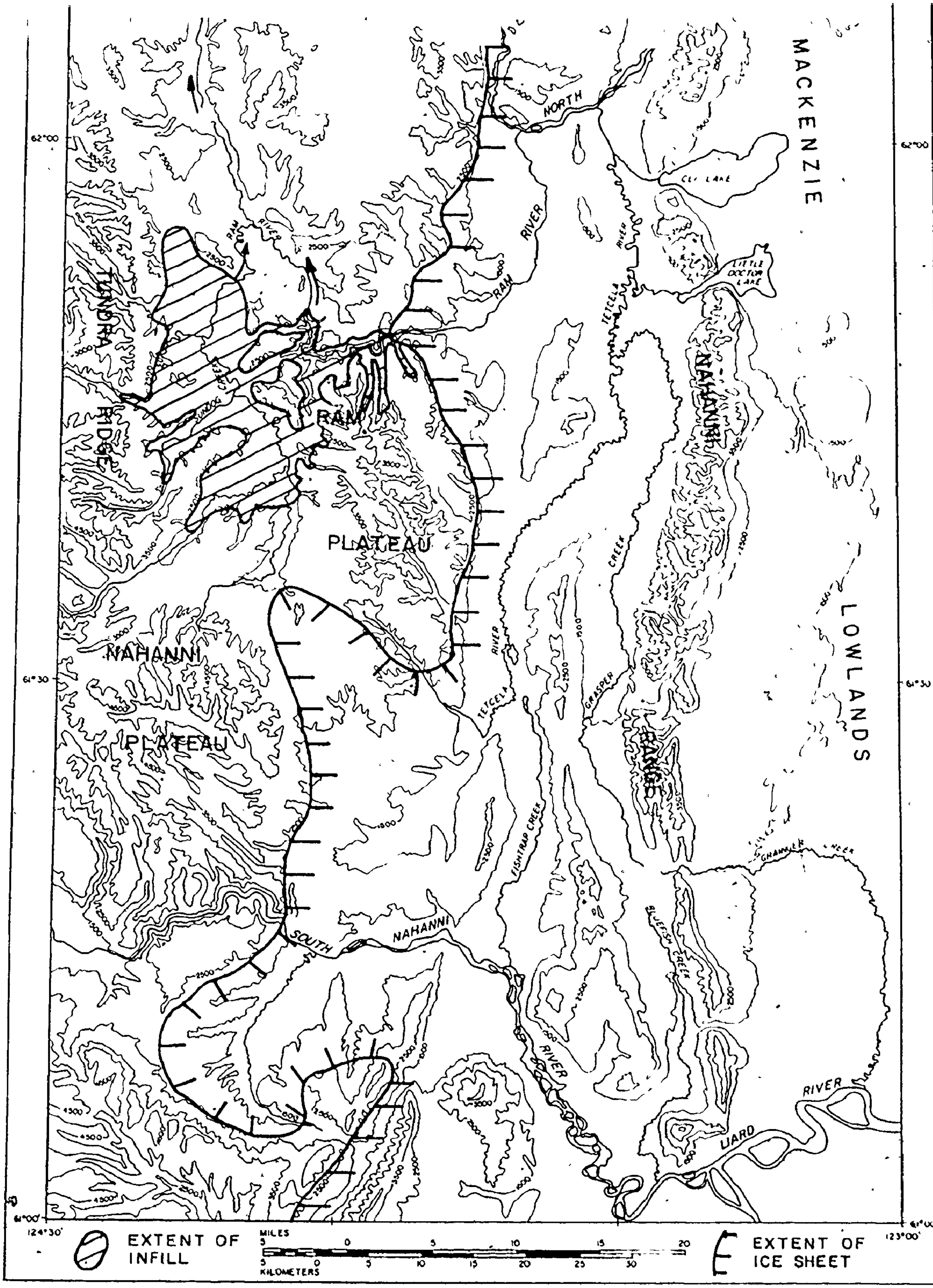


FIGURE 2.8 GLACIAL ADVANCE AND FIRST INFILLING TO 730m (2400ft)

through the smaller breaches at the northern end of Nahanni Range. Meltwater issuing from discrete tongues of ice extending westward into Tetcela, Tucker and Latham Canyons to varying elevations resulted in alluviation of their upstream portions to 945 m, 1,000 m (2,200 ft) and 850 m (2,800 ft) respectively. Farther north along the eastern flank of Ram Plateau there is no evidence of infilling above an elevation of 730 m. It is probable that the ice did not reach greater elevations because of the narrowness of the breaches at Camsell Bend, Cli Lake and Little Doctor Lake.

Meltwaters pouring into Ram Canyon from ice at its mouth and into Sundog Basin from ice occupying the col between Ram and Nahanni Plateaux accumulated in the Basin and canyons of Ram River, creating one large lake. When the lake reached an elevation of 730 m it began to drain via two newly initiated channels. Water overtopped and began cutting down into the ridge of shales which extends across the northern end of Sundog Basin, thereby establishing the route through Sundog Canyon, while a second channel developed along the north-dipping slope of limestone bedrock above the present-day Scimitar Canyon. The direction of flow through the latter is evidenced by:

1) the northward gradient of the traces of this channel, and
2) the northward-sloping abandoned terraces north of Scimitar.

The elevation of these channels must have been at least 730 m in order to alluviate Sundog Basin and the tributaries of Ram Canyon to this altitude and to infill Jackson and Pratt Canyons farther downstream to 670 m (2,200 ft). The two rivers then joined to flow northward through Glew

Spillway into the North Nahanni River.

2.3.3 First Re-excavation

After the ice receded from Tetcela Basin the lake drained to the east, leaving Sundog Basin, Ram Canyon and its tributaries alluviated to an elevation of 730 m (2,400 ft). In Sundog Basin, Karst, Sundog, Ram and Tundra Creeks did not revert to their original channels because Butler, Footloose and Leckie Canyons had also been alluviated. Instead, they joined before flowing north through the recently established breach over Sundog Canyon. From there, drainage either continued on to North Nahanni River or turned south into Ram Canyon via Scimitar. Due to limited excavation of the sediment infilling Sundog Basin even today, it is more probable that the basin drained south via Scimitar where the base level was limited by bedrock, thus establishing the present, highly anomalous, diversion course. During this presumed interglacial it is likely that the channels at Scimitar and Sundog Canyons were eroded to less than 730 m.

Local streams draining the alluviated Butler, Footloose and Leckie Canyons were not competent to clear the fill from their upstream sections so the paleodrainage routes could not be resumed. The other tributary canyons were not completely excavated either. Much of the sediment in Ram Canyon was removed because the discharge of Ram River had not been reduced by any permanent capture, and there was no new downstream limit to erosion. Evidence of the first infilling event, therefore, remains in Sundog Basin and tributary canyons of Ram River but not in Ram Canyon.

On the eastern flank of Ram Plateau, Latham and Tucker Canyons have not been completely excavated by their creeks. The more competent

Tetcela River, however, apparently has been able to remove the infill along the lower sections of its canyon.

In addition to excavation of the sediment within the canyons by the rivers, cliff recession and further development of scree slopes continued.

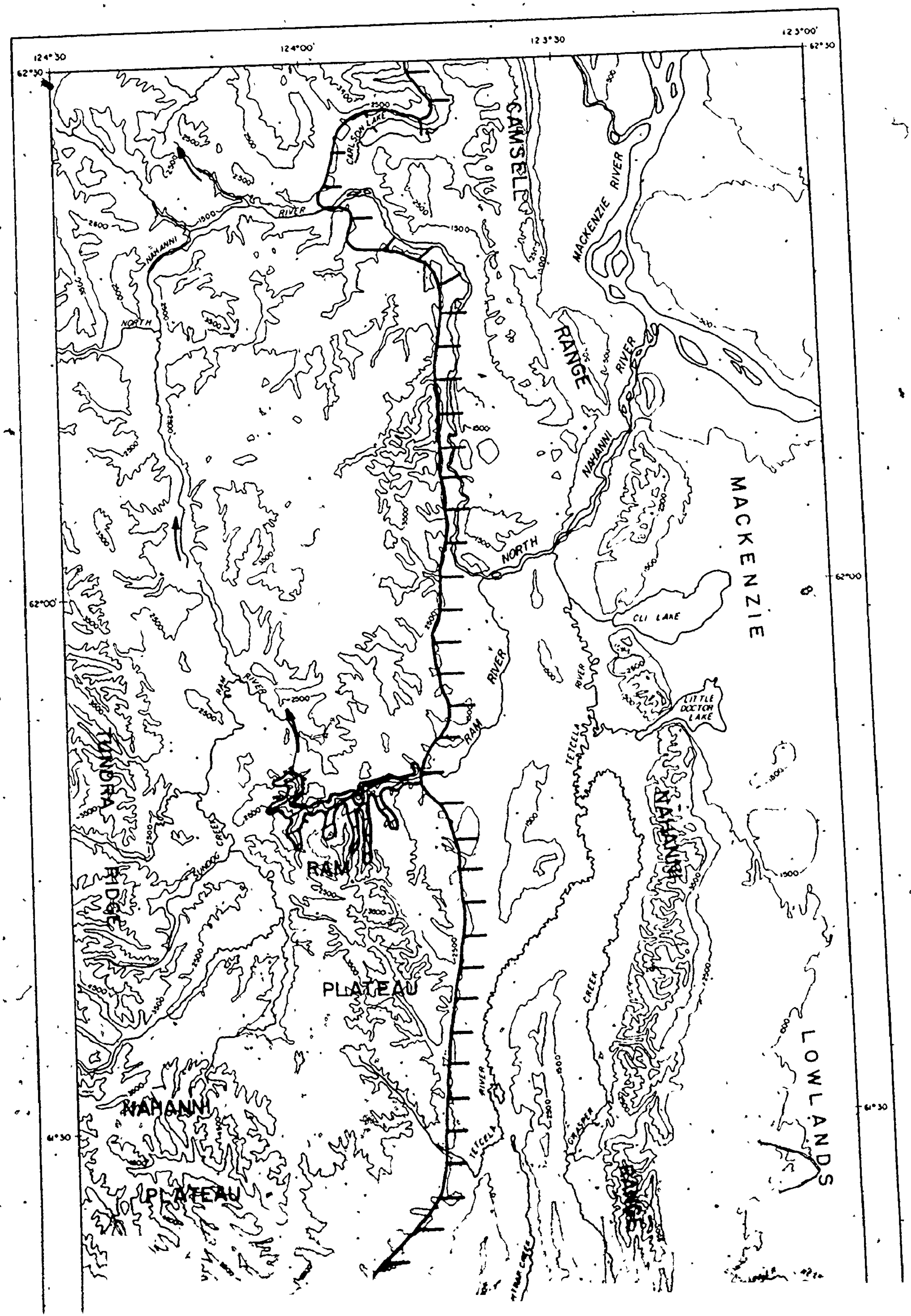
2.3.4 Glacial Advance and Second Infilling Event

Alluviation of Lake Canyon to 565 m (1,850 ft), erosion of its eastern canyon wall, and the subsequent diversion provide evidence for either: withdrawal of the ice sheet responsible for the first infilling to a stationary position along the eastern flank of Ram Plateau at an elevation of 565-580 m (1,850-1,900 ft); or introduction of another ice sheet which advanced into Tetcela Basin through the breaches in Nahanni Range (Figure 2.9).

Evidences within Ram Canyon and its tributaries of impoundment and infilling to an elevation of 550 m (1,800 ft) include terraces in Raynor, Camp, Subject and Lake Canyons at 550 m, and unconsolidated deposits up to the same altitude in Golden, Western and Eastern Bowls.

Impoundment to this elevation would not have affected Sundog Basin because the previous infilling to 730 m (2,400 ft) at the heads of Footloose, Leckie and Butler Creeks prevented water from draining west into Sundog Basin. There is no evidence of waters entering the Basin from the south. This suggests that any southern ice front did not advance high enough to occupy the Ram-Nahanni col.

With "First Fill" barring drainage to the west and ice blocking drainage to the east, it is most likely that the lake in Ram Canyon drained via Scimitar, which had been eroded to an elevation of 550 m since the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MACKENZIE LOWLANDS
CLI LAKE
LITTLE DOCTOR LAKE
RAM RIVER
TETCELA RIVER
TUNDRA RIDGE
SUNDOG CREEK
RAM PLATEAU
NAHANNI PLATEAU
NAHANNI RANGE
CREEK

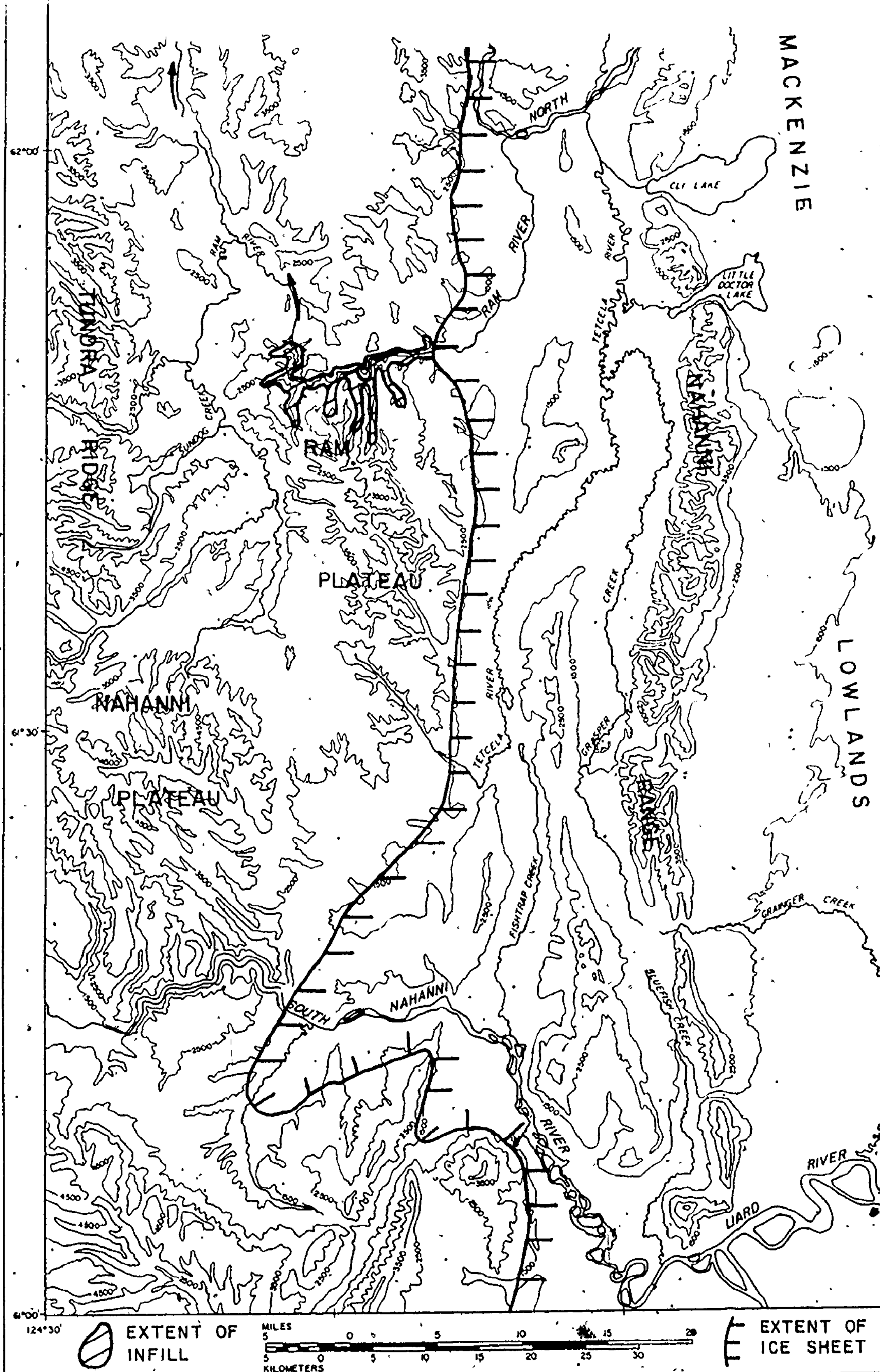


FIGURE 2.9 GLACIAL ADVANCE AND SECOND INFILLING TO 550m (1800 ft)

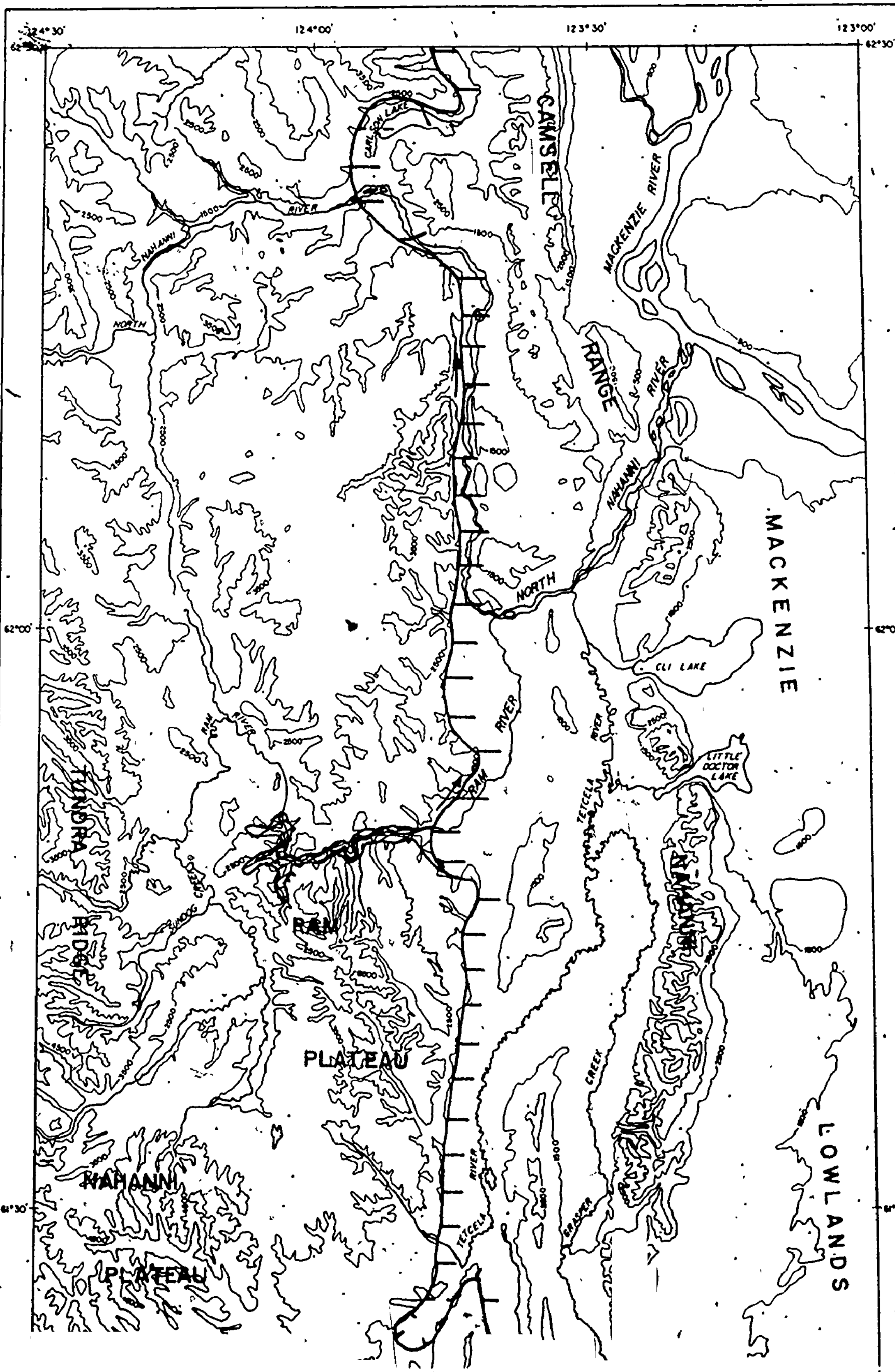
previous 730 m lake phase. The extent of this channel erosion implies that impoundment took place long after the First Infilling and therefore, the Second Infilling represents a different glaciation.

2.3.5 Second Re-excavation

Erosional effects following the withdrawal of the second ice sheet were very similar to those outlined for the first re-excavation, except that evidence of alluviation to 550-580 m (1,800-1,900 ft) is still preserved in Ram Canyon, notably in Eastern, Western and Golden Bowls. Again, Sundog Basin drained north through Sundog Canyon and then south to Ram Canyon via Scimitar instead of continuing north as it had done during the second infilling event. Because the diversion route (Glew Spillway) to North Nahanni River is presently alluviated to 585 m (1,920 ft), the Scimitar channel was preferred. The underfit streams draining Glew Spillway have not yet been able to excavate the infill.

2.3.6 Glacial Advance or Stand at 460 m

There is evidence for another ice advance through the breaches in Nahanni Range, or recession of the previous ice sheet to a stationary position with an elevation of 460 m (1,500 ft) along the eastern slope of Ram Plateau impounding a lake to this altitude in Ram Canyon (Figure 2.10). The position of the ice front is evidenced by alluviation of Karpuk Canyon, resulting in erosion of its eastern wall and subsequent diversion of the southern half of its drainage into Tetcela Basin. The mouth of Tucker Canyon has also been alluviated to 460 m and its stream has cut into the eastern canyon wall leaving the original mouth infilled.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GRASER CREEK

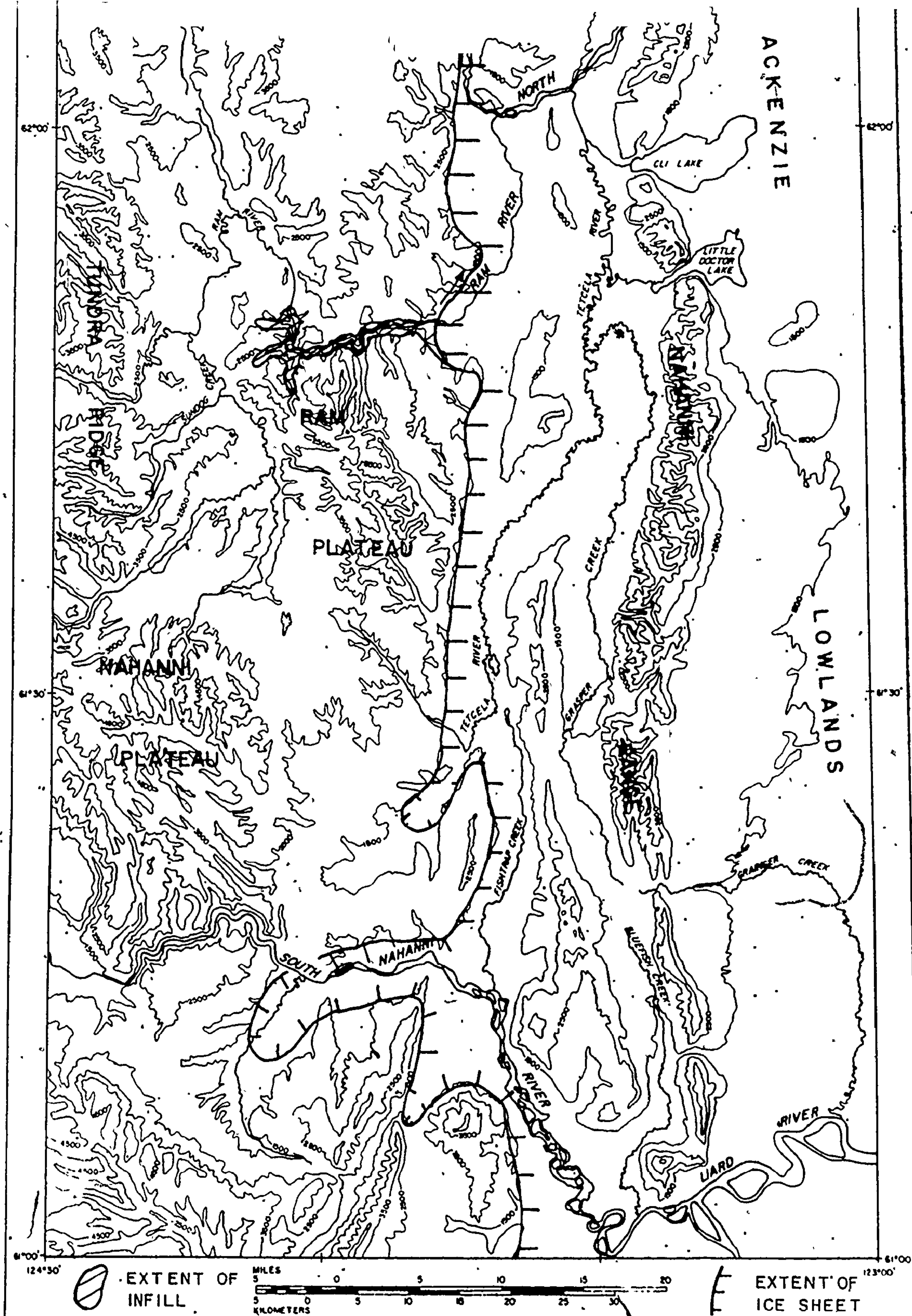


FIGURE 2.10 GLACIAL ADVANCE OR STAND AT 460 m (1500 ft)

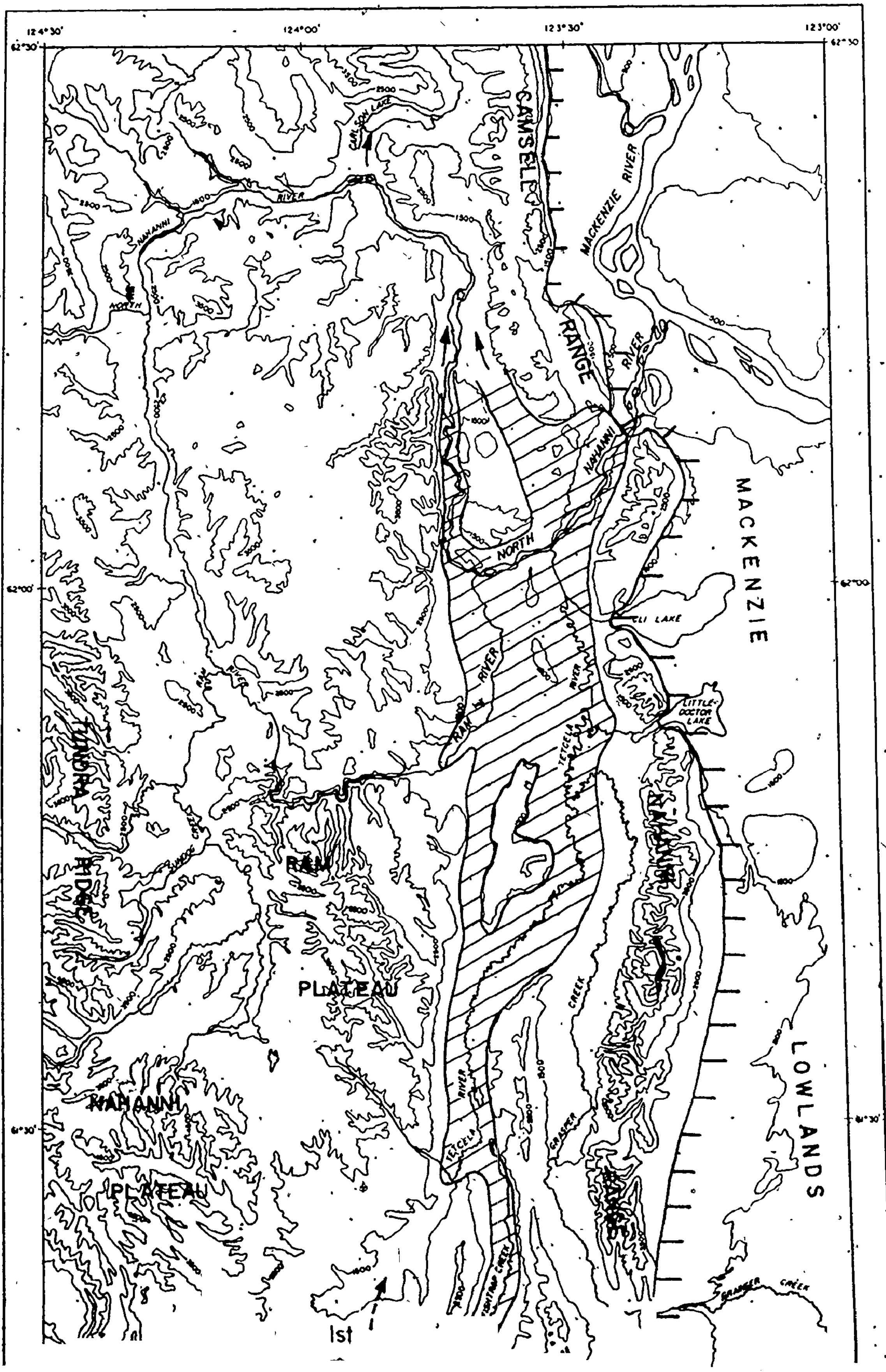
At location #21 there is an abandoned channel-like feature at 460 m descending to the north. This is considered to be the outlet for waters impounded in Ram Canyon. The adjacent terminal or recessional moraine (22) is most probably of this phase and indicates that ice blocked lower drainage outlets.

Terraces (4) along the southeastern flank of Ram Plateau at 425-460 m (1,400-1,500 ft) are further evidence that water was retained at this altitude for a lengthy period, permitting an extensive, almost level lacustrine type of deposit to accumulate. When the ice mass retreated, a lower lake level is suggested by terraces (7) between Yohin Ridge and Silent Hills at 365 m (1,200 ft).

2.3.7 Final Glacial Event

The fluted ground moraine east of Nahanni Range but not found west of it suggests that the last and most recent Laurentide ice sheet advanced as far as the Range (Figure 2.11). This impounded a lake in Tetcela Basin which drained northward via North Nahanni and Carlson Rivers over a col at 260 m (850 ft) at Carlson Lake. That the deposits in the basin are either lacustrine in origin or indicative of a past spillway to the north is strongly suggested by the flatness of the basin floor at 210-275 m (700-900 ft) and underfit channels. The abundance of marshy areas and poor drainage may be indicative of an impervious clayey deposit.

To the south, ice entered South Nahanni River Basin and occupied the gap between Yohin Ridge and Silent Hills. A lake impounded along the South Nahanni River (Ford, 1976) drained into the Tetcela Basin via a col (5) at 380 m (1,250 ft) between Yohin Ridge and Ram Plateau. Subsequent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GRAINGER CREEK
FISHTRAP CREEK
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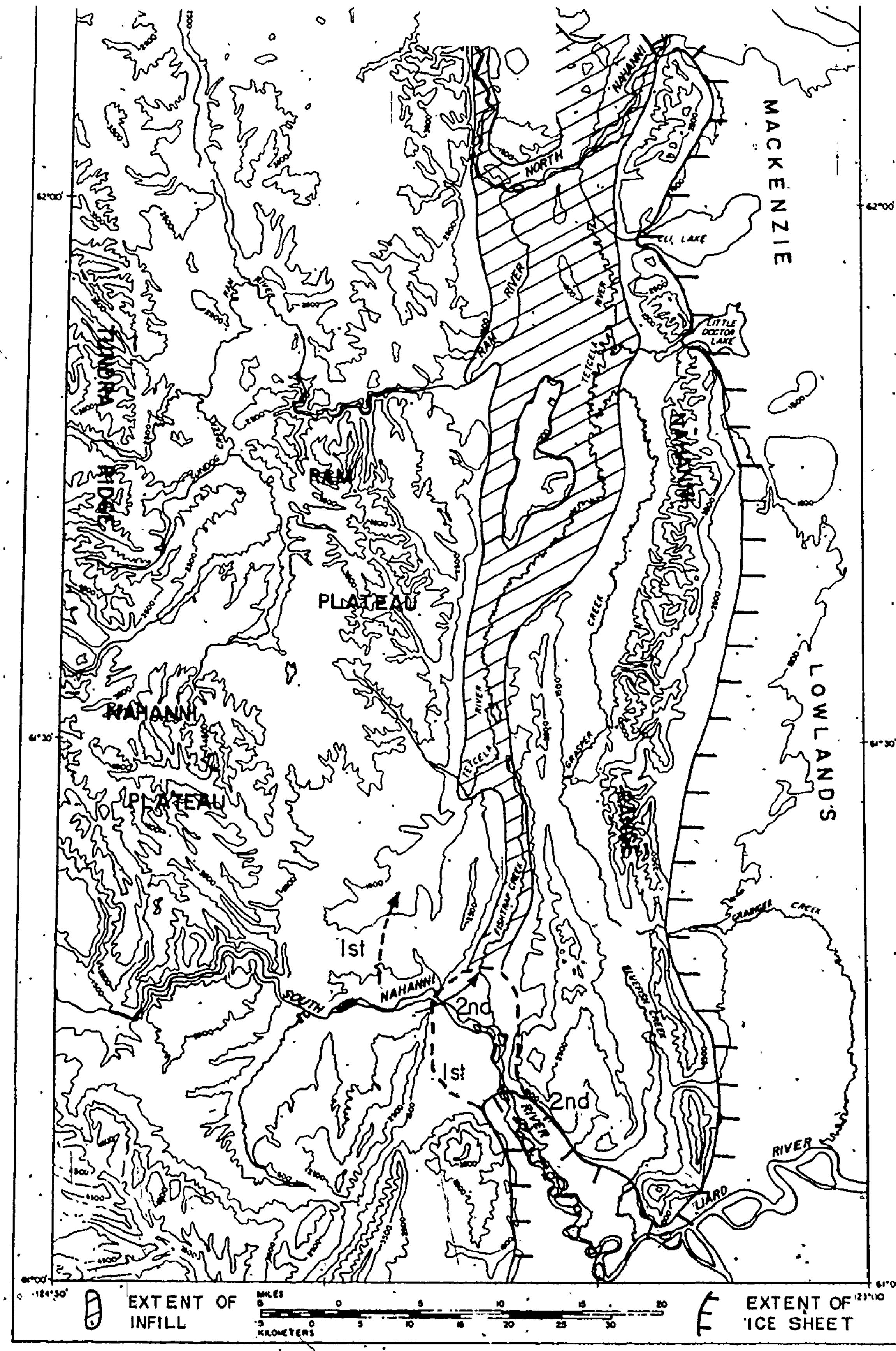


FIGURE 2.11 FINAL GLACIAL ADVANCE AND INFILLING TO 210-275m (700-900ft)

ice recession opened up a lower outlet into Tetcela Basin (6), allowing water to incise a flood plain with an elevation of 245 m (800 ft) into the terraces on both sides of Fishtrap Creek which are at an elevation of 365 m (1,200 ft).

With ice abutted against the eastern slope of Nahanni Range tongues of ice occupied the breaches at Cli and Little Doctor Lakes, as indicated by the remnants of an alluvial fan west of Little Doctor Lake. If there were a similar deposit west of Cli Lake then it has since been eroded because no evidence remains.

Meltwater flowing through Grainger Creek breach (9) deposited material up to an elevation of 560 m (1,850 ft).

Alluvial fans at the mouths of the many valleys draining the western slope of Nahanni Range coalesced as they spread out above the 210-275 m lake in the Basin. The fans are presently being incised, suggesting deposition when the base level was raised by a lake and erosion after the lake drained. The valleys themselves are not choked with sediment because their elevations are greater than 305 m (1,000 ft).

2.3.8 Post-Glacial Events

The major characteristics of the post-glacial period are continuing excavation of sediment, cliff recession and scree development. The most notable processes affecting the infill in all parts of the map area are slumping and other mass wasting processes due to undercutting by streams. Ram River has cut terraces (3) into the Tetcela Basin infill at the mouth of Ram Canyon.

The Sundog Basin deposits are much more dissected than those of the flat Tetcela Basin due to the more recent alluviation of the latter. The base level of erosion for Sundog Basin is still determined by a bedrock sill at Scimitar Canyon and the heads of Leckie, Footloose and Butler Canyons remain infilled to 730 m (2,400 ft). If these three canyons were to be cleared by their small creeks then the paleodrainage pattern would likely be resumed because Leckie, Footloose and Butler Creeks empty into Ram River at elevations lower than Scimitar Canyon.

CHAPTER THREE

ANALYSIS OF THE DEPOSITS IN SUNDOG BASIN AND THE CANYONS OF RAM PLATEAU

3.1 Procedures

3.1.1 Geographical Design of Sampling

Detailed analysis and sampling of sediment profiles were undertaken during the summers of 1976 and 1977. Locations of sediment profiles studied were limited to areas that could be attained on foot away from the base camp and from a brief fly camp at the junction of Ram River and Footloose Creek, plus one notable site in the Sundog Basin which was reached by helicopter. The locations of sample sites are shown on Figure 3.1. Traverse on foot was severely limited by the high relief and vertical cliff faces which are characteristic of Ram Plateau and the velocity and depth of Ram River. Many key areas that were noted on the air photographs were, therefore, inaccessible for detailed study.

Due to the great thicknesses of sediment infilling the canyons and dense vegetation cover, all of the sections chosen had been naturally exposed by past or present slumping or landsliding processes and the faces were cleared as much as was necessary in order to view a profile that was unaffected by slopewash. The majority of profiles studied were close to Ram River and its tributaries because fluvial undercutting has been the major initiator of recent slumping. In addition there were a

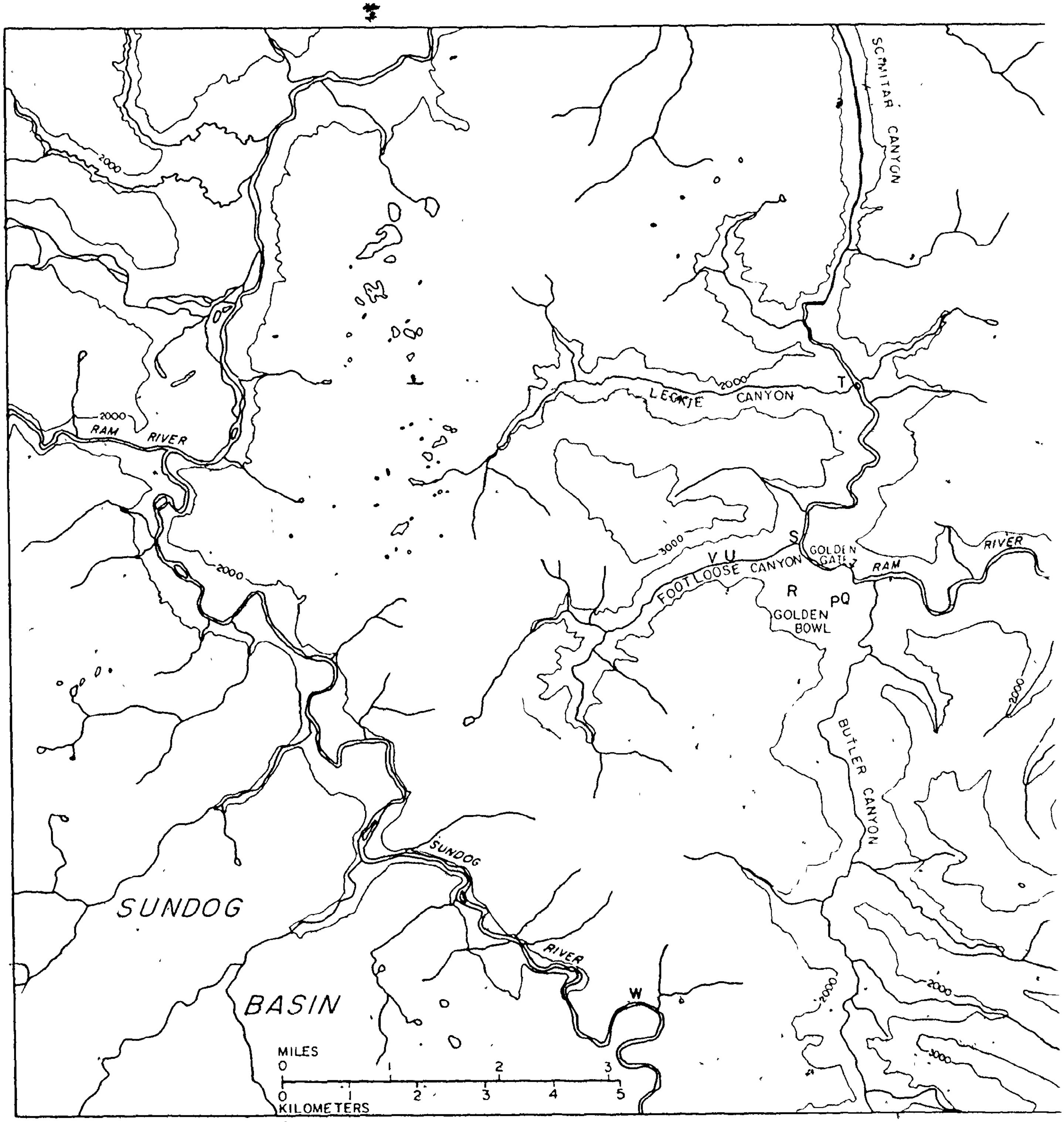
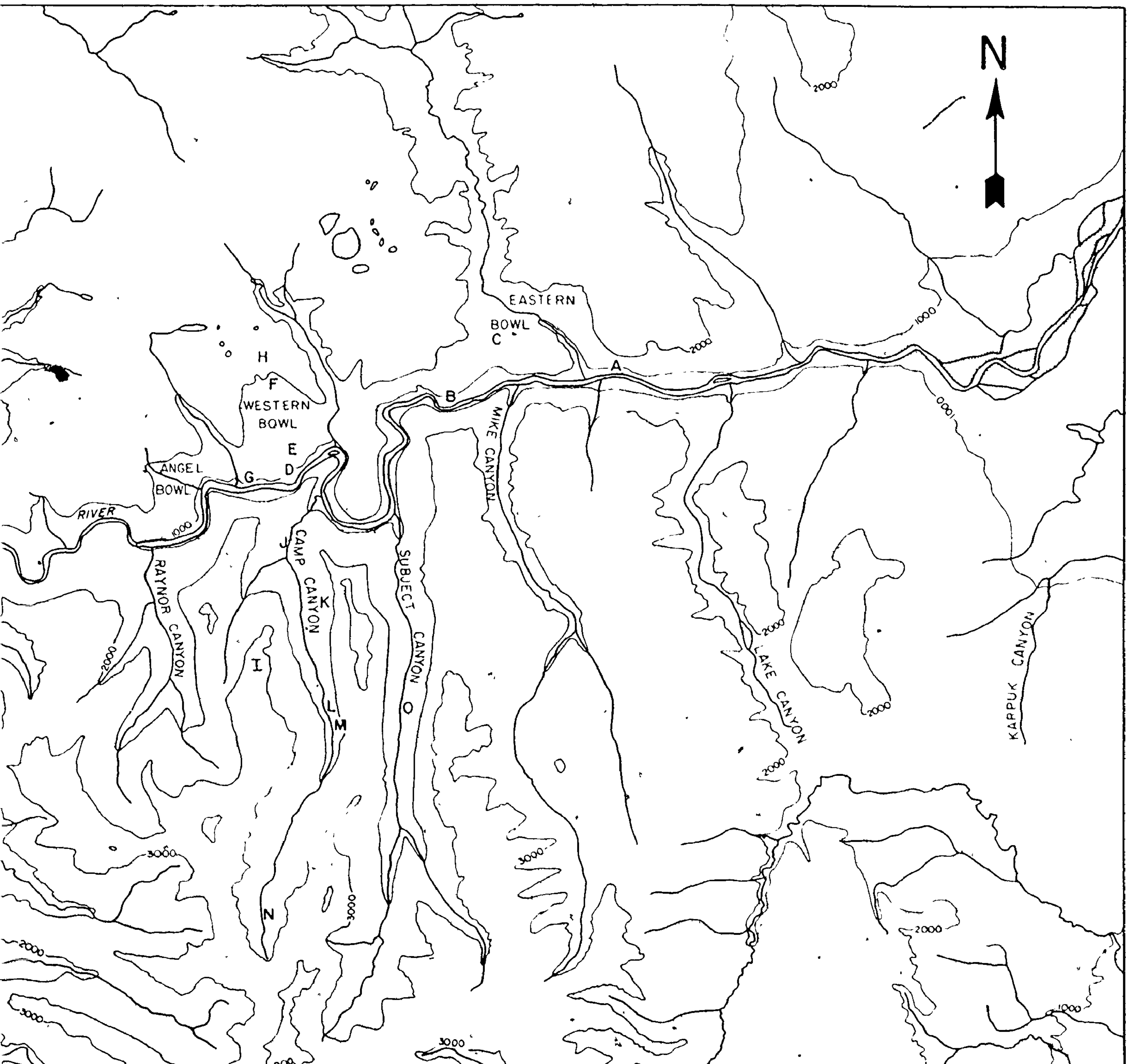


FIGURE 3.1 LOCATION



ATION OF SAMPLE SITES

few exposures studied at higher elevations where massive slope failure had resulted in slumping of sediments. Core sampling proved to be an ineffective technique due to the presence of large clasts within the sediment.

The sections sampled have been grouped into four areas (shown on Figure 3.1) to facilitate discussion: Eastern Canyons, Central Canyons Western Canyons and Sundog Basin. After presenting results of analyses for each site and establishing the relationships among sites within an area, a sequence of events correlating the sequences of deposition for all areas is formulated. In Chapter 4 the depositional environments inferred from the sediment analysis are correlated with the sequence of events established by the air photo interpretation and mapping of large scale features presented in Chapter 2.

3.1.2 Field and Laboratory Methodology

At each sediment section chosen, the face was cleared of recent slope waste deposits and a vertical profile was dug to a depth of at least 1.5 m. The strike and angle of dip of the beds were measured with a Brunton Compass. A sketch was drawn, together with a description of each unit or bed. A representative sample of each bed or unit was removed with care so as to maintain homogeneity. Granulometric studies were carried out according to the method outlined by Folk (1974) and described in detail in Appendix A. The statistical data presented in the following discussion were calculated using Folk Statistics unless otherwise stated. Moment Measure Statistics are denoted by an "MM" after the value. All data are presented in Appendix C in alphabetical order.

Fabric analysis was completed for five of the profiles in the

Central Canyon area. Bearing and plunge were measured for the long (A) axis and intermediate (B) axis of elongate clasts using a Brunton Compass. The lengths of the A, B, and C axes, the shape, angularity or roundness and type of rock were also noted. Details of fabric analysis are outlined in Appendix B, and all data are presented in Appendix C in alphabetical order.

3.2 Results of Analysis

3.2.1 Eastern Canyon Area

Eastern Bowl, in the Eastern Canyons area, is an ancient meander scar of Ram River which was entrenched into bedrock as the Plateau was upwarped, and subsequently infilled with unconsolidated material. Sections A and B are along the north bank of Ram River at the southern end of the bowl. The large arcuate feature (Section C, Plate 3.1) in the centre of the bowl was traversed by Jackson and Pratt during the 1974 field season and found to be composed of unconsolidated sediments to its top at an elevation of 490 m (1,600 ft). The creek presently draining Eastern Bowl has incised a valley on the north side and Ram River has cut a meander scar on the south side, leaving the arcuate residual. That it is composed entirely of unconsolidated sediment and is not a bedrock-controlled feature is evident from its location within a relict meander bend and further evidenced by the geological maps (Douglas and Norris, 1960). The elevation of this feature and of the sediments around the edges of Eastern Bowl implies that the bowl has been alluviated to at least 550 m (1,800 ft).

On the north bank of Ram River at the eastern edge of the Eastern

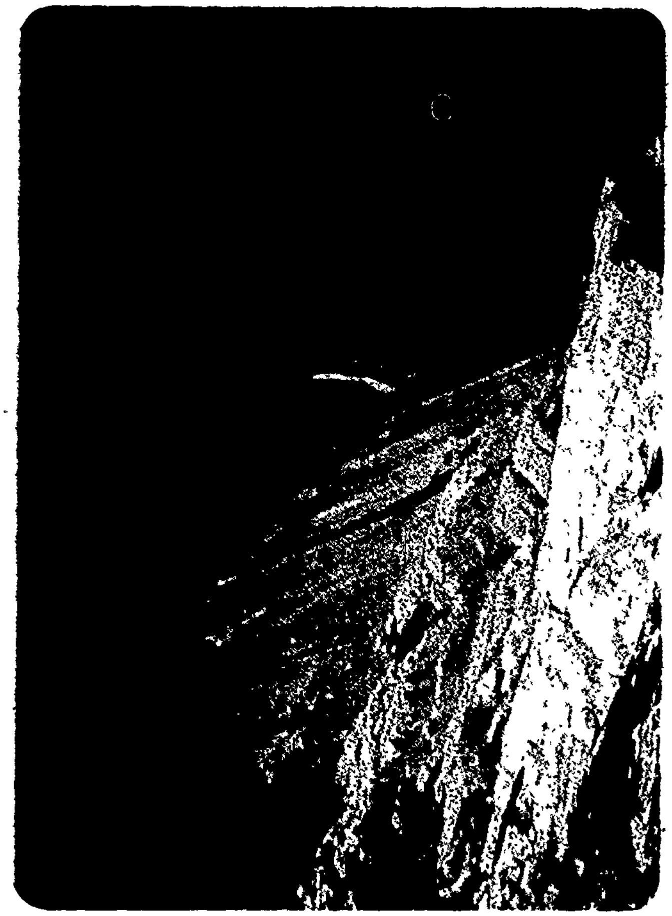
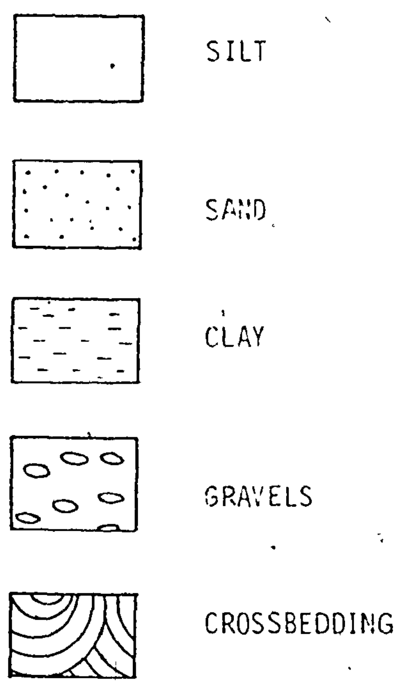


Plate 3.1: Arcuate ridge of unconsolidated infill in Eastern Bowl showing location of Section C

Bowl, sand and gravel deposits extend from the river level at 270 m (880 ft) up to approximately 290 m (950 ft). Local screes are gradually encroaching over the upper layers of sediment and in some places there is a veneer of scree down to the river. Ram River has cut into these deposits and left a 12 m high exposure at Section A (Plate 3.2).

Most of the contacts between the beds in Section A have an apparent rake with an azimuth of 265° (upriver) and a plunge of 15-20°. At the base of the section (A1) there is a 4.5 m band of rounded-subrounded gravels with a sand matrix that shows no obvious signs of cross-bedding. Above this is a 2 m thick unit (A2) of alternating fine sands and sub-rounded gravels having a sand matrix. The sand beds have a mean grain size of 2.4ϕ (fine sand) and are moderately well sorted (σ = 0.96ϕ). The sandy, matrix-supported gravel beds have two distinct populations. The mode of the gravel population is -4.25ϕ and the mode of the matrix is 1.05ϕ. Each population appears to be well-sorted. In the lower half of the A2 unit the fine layers range in width from 5-10 cm and the coarse layers are approximately 30 cm; however, in the upper half the fine layers are 40 cm thick and the coarser layers are 35 cm thick. Above this there are two units (A3 and A4) composed entirely of fine and coarse sands, each having a thickness of approximately 1 m. No internal bedding structures were apparent; however, the upper unit (A4) pinches out towards the western side of the exposure and the lower unit increases in thickness. This may be evidence of large-scale cross-bedding. Above A4 there is a 1.5 m bed (A5) of large, well-rounded cobbles dispersed throughout a matrix of sands. Many of the cobbles are erratics derived from the Canadian Shield. The coarse, sandy layer of A6 is approximately 1.5 m thick and marks the upper

LEGEND FOR DETAILED SEDIMENT PROFILES



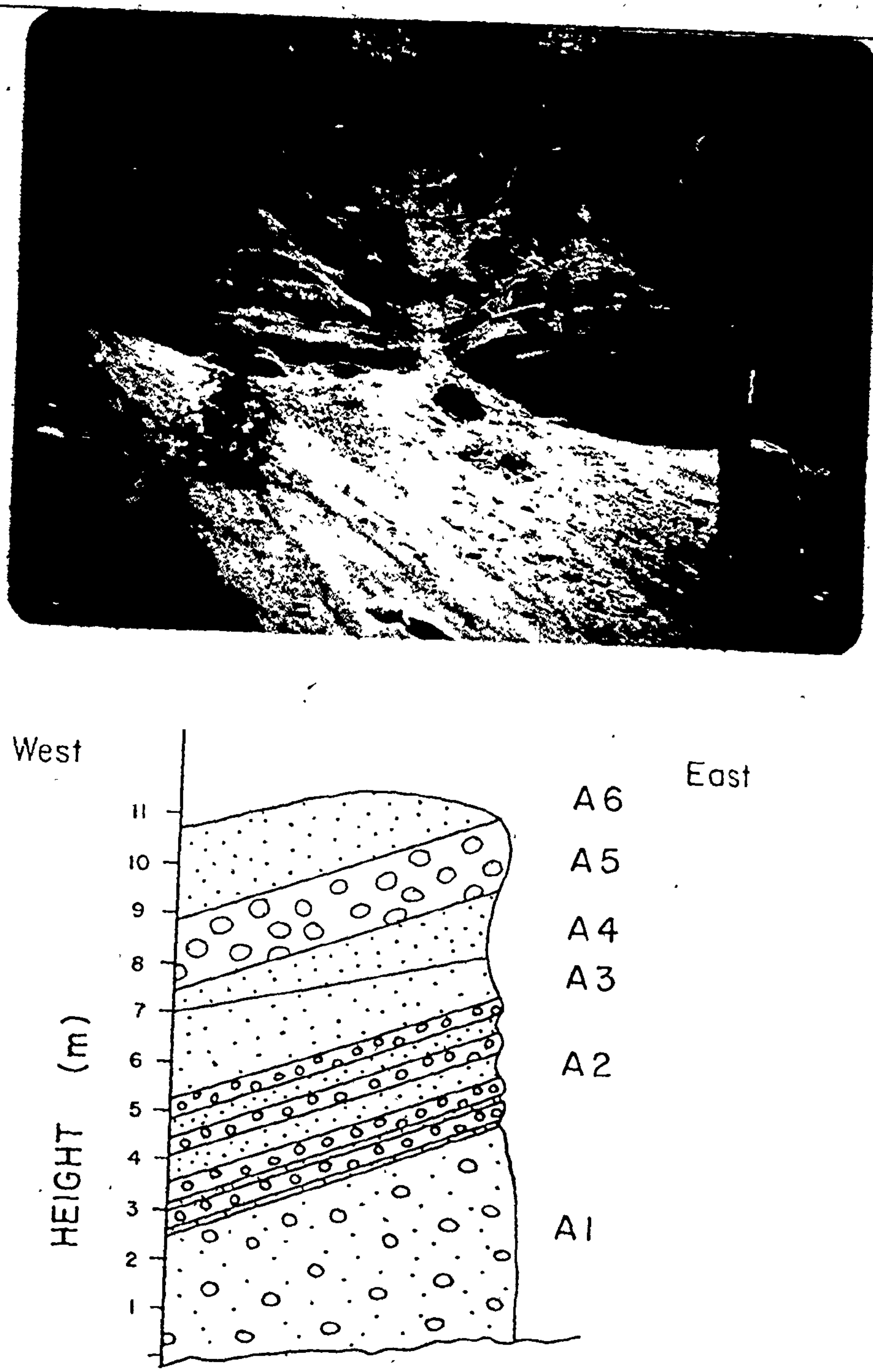


Plate 3.2: Section A

limit of the exposure.

At the western edge of Eastern Bowl on the north bank of Ram River is Section B, (at 320 m (1,050 ft)) a 20 m exposure of sand and gravel beds alternating with silts and sands which was viewed from across the river (Plate 3.3). The scree is building out over this section of infill also. The Ram River has eroded a 10 m section parallel to the river. A gully at right angles to this face has exposed an expansive section giving a rough idea of the three-dimensional characteristics of the bedding structures.

Detailed photographs taken by Brian Pratt during the 1974 field season show that the lowest exposed unit (B1) has a thickness of 8 m and is comprised of cobbles and boulders in a matrix of sand. Bedding within this unit is parallel having a rake with an azimuth of 240°, plunging 15°. Above this is a 3.5 m bed (B2) composed predominantly of sands with a few matrix supported gravel inclusions. This unit is characterized by large-scale lenticular cross-bedding, having a rake with an azimuth to the north and plunging 15°. This is succeeded by B3, a bed of sandy, matrix-supported gravels 2.5 m thick which has parallel beds having an azimuth to the north, plunging 30°. An erosional contact separates this unit from a fine-grained sandy silt layer (B4) 3.4 m thick which is massively cross-bedded. Above is a coarse sand and gravel unit (B5) with parallel beds plunging north. It shows evidence of recent slumping at the surface.

The most noticeable features of bedding for Sections A and B are the dip upriver and an alternating coarse/fine sequence exhibiting cross-bedding in the finer beds. The most reasonable explanation for this is a river flowing to the west and having alternating competence. During fast

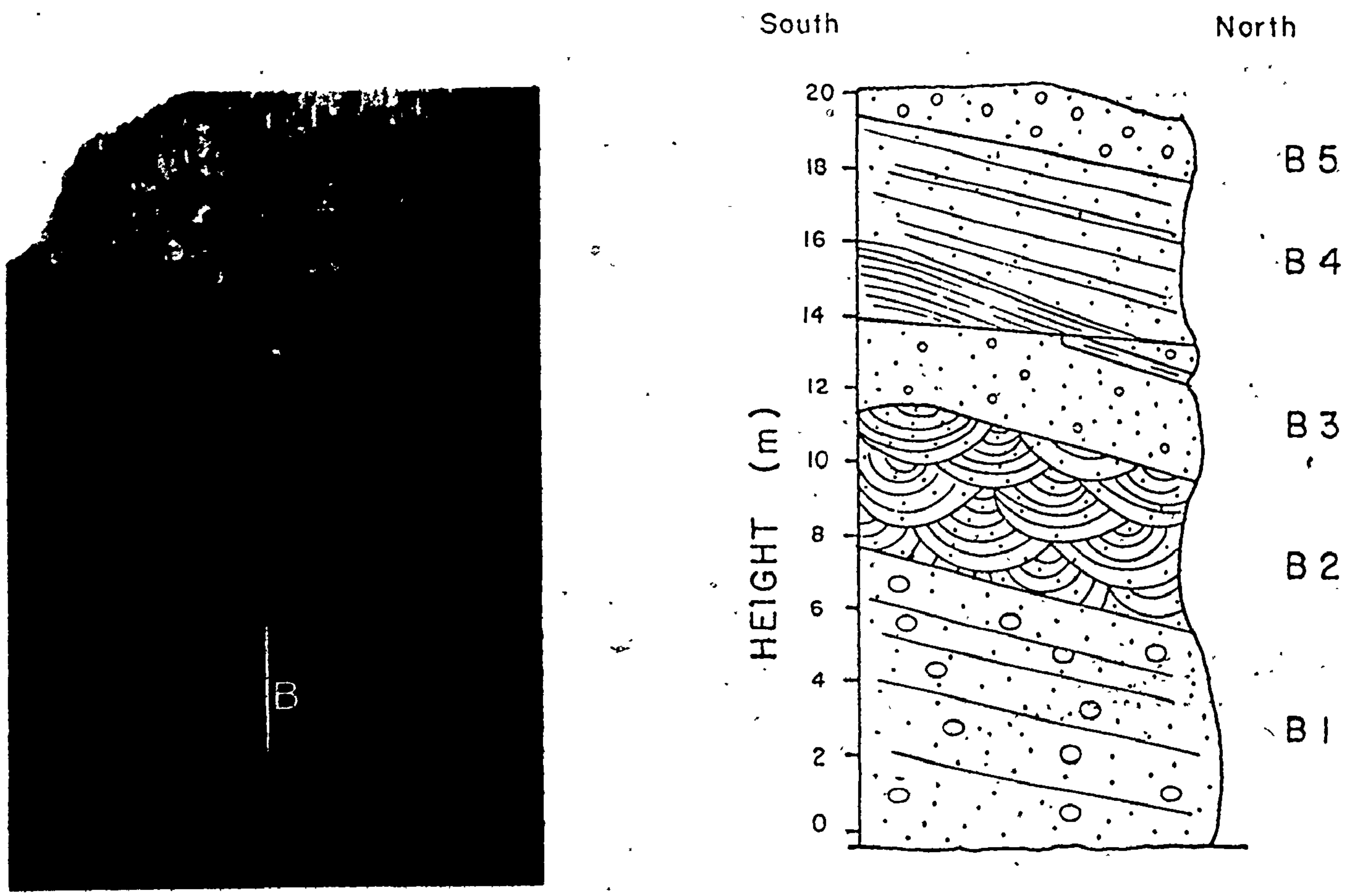


Plate 3.3: Section B

flow massively bedded sands and gravels were deposited and during low flow the cross-bedded sands and fine gravels were deposited as the river course shifted from side to side, creating mid-channel bars.

3.2.2 Central Canyon Area

On the north side of Ram River across from base camp there are two more ancient meander scars cut into bedrock by Ram River, and subsequently infilled with unconsolidated sediments to an elevation of 550 m (1,800 ft). The vertical limestone cliff face above the infill is 120 m high. The sediments in the two bowls, Western Bowl (Plate 3.4) and Angel Bowl (Plate 2.6), have undergone extensive large-scale slumping. Around the rim of Western Bowl is a series of conical slump mounds at an elevation of 490 m (1,600 ft). The only slump face showing bedding structures was Section F near the eastern side of the bowl. All slumps appeared to be composed of coarse sands and gravels. At the base of these slumps is a broad, almost flat, terrace dipping southeasterly at a low angle before dropping more steeply down to the river level. Sections D and E are located on the lower series of slump faces next to Ram River (Figure 3.5).

Section D (Plate 3.5) is a 2 m section at the top of a 6 m high slump face on the north bank of Ram River at an elevation of approximately 300 m (975 ft). At the base of the section (D1) is a bed of silty clays having a thickness of more than 30 cm with fine, gravel-sized limestone clasts dispersed throughout. This grades upwards into a 33 cm thick bed (D2) of silty clays containing a smaller number of clasts. The four beds above this (D3, D4, D5, and D6) are alternately narrow beds of sands and fine gravels and thicker beds of silty clays, with or without gravels. The

Plate 3.4: Unconsolidated sediment infilling Western Bowl, a relict meander scar of Ram River (note locations of Sections D, E and F) (Photo by Arsenault)

meter above this shows no signs of bedding but there are differences in colour and texture at various depths, possibly a result of weathering. Samples taken from the upper meter all had polymodal distributions with at least one mode in the fine to medium-sized gravel range (-2.5ϕ to -4.5ϕ, MM) and a mode in the medium-sized sand range (2.0ϕ to 1.0ϕ, MM). Beds D7 and D8 had a component of silts and clays comprising 18% of the sample whereas D9, D10 and D12 had a silt component of less than 5% of the samples.

One large cobble measuring 23 x 15 x 10 cm was embedded near the top of the exposure. Several pieces of conglomerate measuring up to 10 x 6 x 5 cm, containing rounded and subrounded clasts indigenous to the plateau area and cemented with calcium carbonate, were found in D1. This is an obvious indication that these are secondary deposits that have been moved only a short distance without much fluvial action, otherwise the cement would have dissolved or the structure disintegrated.

Fabric analyses of the A and B axes and the plane of each of 50 clasts taken from D1 show no preferred dip orientation. This may be due to either the type of deposition or to post-depositional alterations by root development or melting of permafrost after the face slumped.

Approximately 23-25 m above the river and farther back into the bowl from section D is another series of slump faces, one of which was studied in detail: Section E (Plate 3.6). These roughly bedded deposits dip 17° SE (downslope) towards Ram River and strike 60°. At the base of the 1.5 m section is E1, comprised of dark grey clays. The light brown, stony sands of E2 have a lens of light brown, coarse to very coarse sands containing coarse gravels up to -2.5ϕ. Bed E3 contains moderately well-sorted, (σ = .9) fine sands (Mn = 2.17) and increases in thickness down-

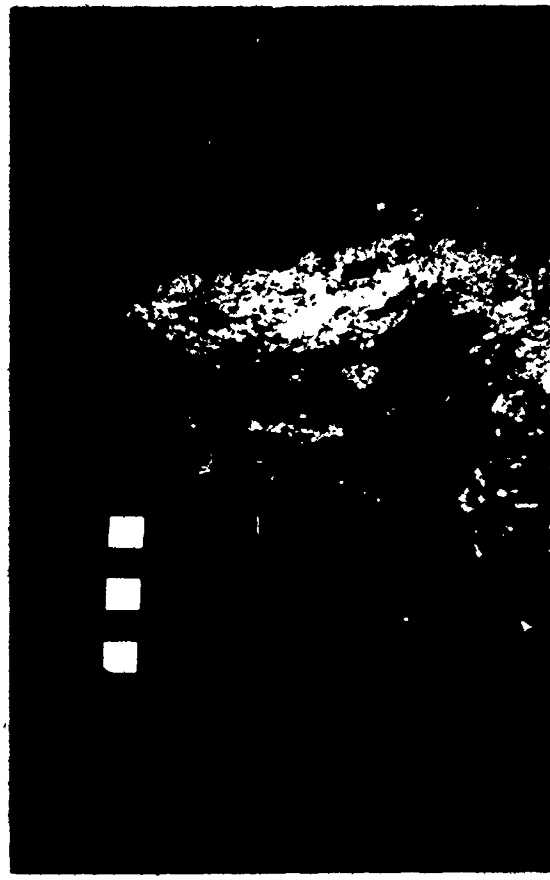


Plate 3.5: Section D

Plate 3.6: Section E

slope. The contact between E3 and E4 is irregular and indistinct. The coarse sand (Mn = -.68) matrix of Bed E4 grades upwards into silty clays. No laminae were observed. Angular and subangular limestone clasts ranging in length from less than 1 cm up to 25 cm (the average being 5.25 cm) are dispersed through E4. Bed E5 has a matrix of moderately well-sorted medium sands with a small percentage of clasts ranging in size up to -3.5 (medium gravels), which are responsible for the poorly sorted distribution (σ = 1.5) with negative skewness (Sk = -.24). Above, is a bed (E6) of very poorly-sorted, coarse sands and gravels. The deposits at the top of the section show signs of recent surficial slumping and for this reason they were not analysed.

Fabric analysis of the clasts in E2 shows that the planes of the clasts dip to the south, with a strike of 105 $\pm$ 54°, which is very similar to the direction of the dip of the beds.

Because the deposits of Sections D and E are roughly bedded and both the beds and the clasts dip out of the bowl to approximately the same direction, it is probable that they are slope waste deposits over fine-grained sediments. These characteristics are often noted in till deposits, so before assuming that Sections D and E are not of till origin, further analysis is required.

It has been suggested by several authors (Landim and Frakes, 1968; Buller and McManus, 1972; Passega, 1964) that the intensity of depositional processes may be determined by plotting pairs of Folk Statistics, such as Standard Deviation vs Mean, Skewness vs Standard Deviation and Coarsest 1 percentile vs Median. When plots of statistics for samples taken from unknown depositional environments are compared with those from known deposition environments some insight may be gained. It must be remembered that statistical analysis of grain size actually indicates the processes of deposition rather than the exact environment and that the two need not be the same (Solohub and Klovan, 1970).

Following Landim and Frakes (1968) the plot of Coarsest 1 percentile vs Median Diameter (Figure 3.2) indicates that all six samples from Sections D and E, for which Folk Statistics could be calculated, have properties similar to sediments deposited by turbidity currents (tills and mudflows) as opposed to tractive current deposits. The plot of Skewness vs Standard Deviation (Figure 3.3) suggests that just one sample from Section D has characteristics similar to tills from Illinois, Indiana, Iowa and N.E. Ohio, but not Ontario, Iceland or New Brunswick. The other 5 samples are similar to Fossil Mudflow and Alluvial Fan deposits in California. The plot of Standard Deviation vs Mean Diameter (Figure 3.4) negates any suggestion that these are of till origin.

In addition to statistical analysis, all of the clasts from every sample in Ram River area were studied for evidence of striations and other glacial markings. None were found.

Based on these two studies and the nature of other aspects of Ram Canyon, there is no evidence for the presence of competent glacier ice within the canyons. It is, therefore, most probable that Sections D and E are slump or mudflow deposits.

Section F is at one of the conical slump mounds (Plate 3.7) near the back of Western Bowl at an elevation of 490 m. The upper half of the 20 m high slumpface has no extensive slope wash detritus covering bedding structures. Two portions were studied in detail. The lower example shows

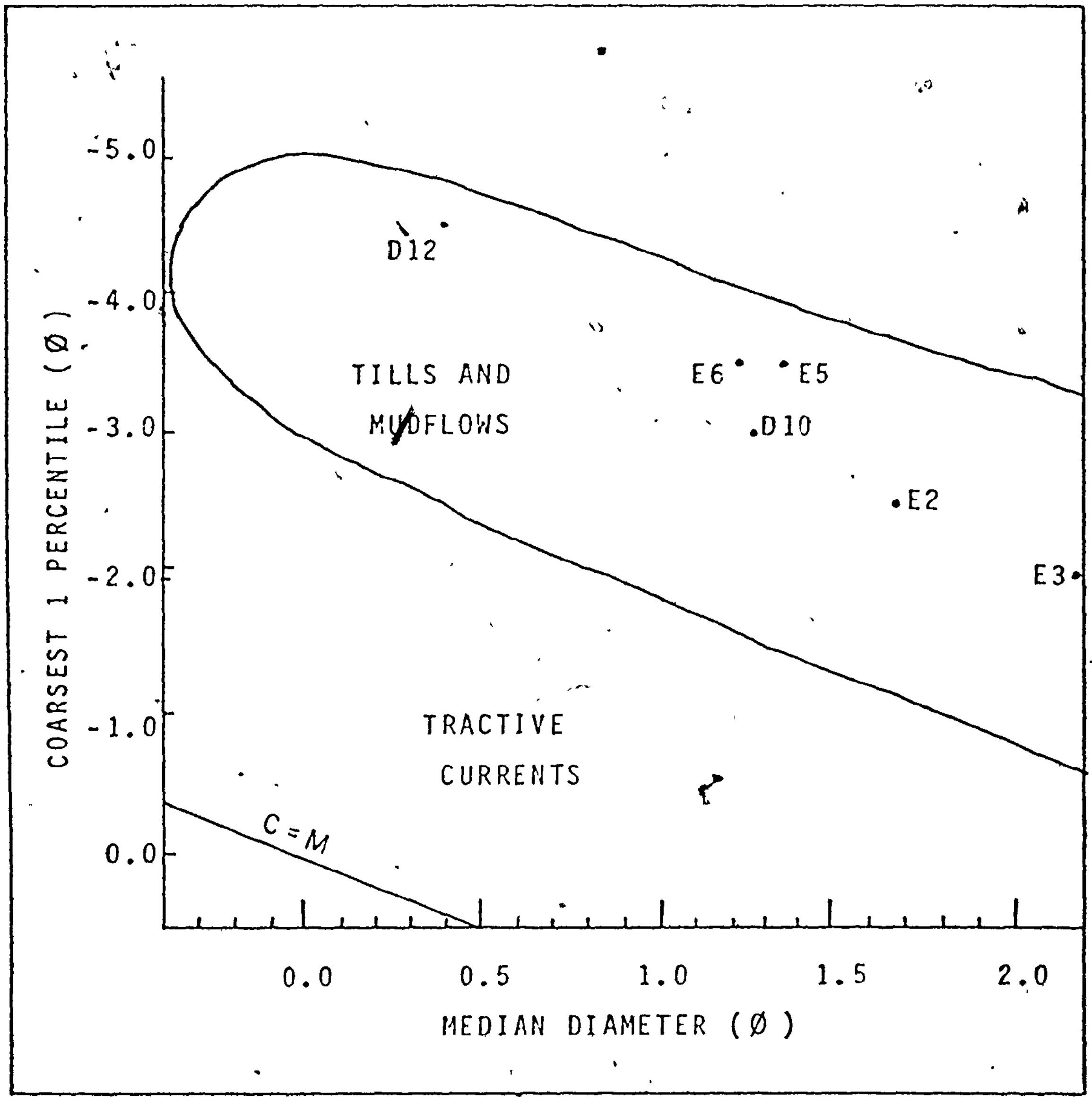


FIGURE 3.2 PLOT OF COARSEST 1 PERCENTILE vs MEDIAN DIAMETER FOR SECTIONS D AND E (FOLK STATISTICS)

(after LANDIM AND FRAKES, 1968)

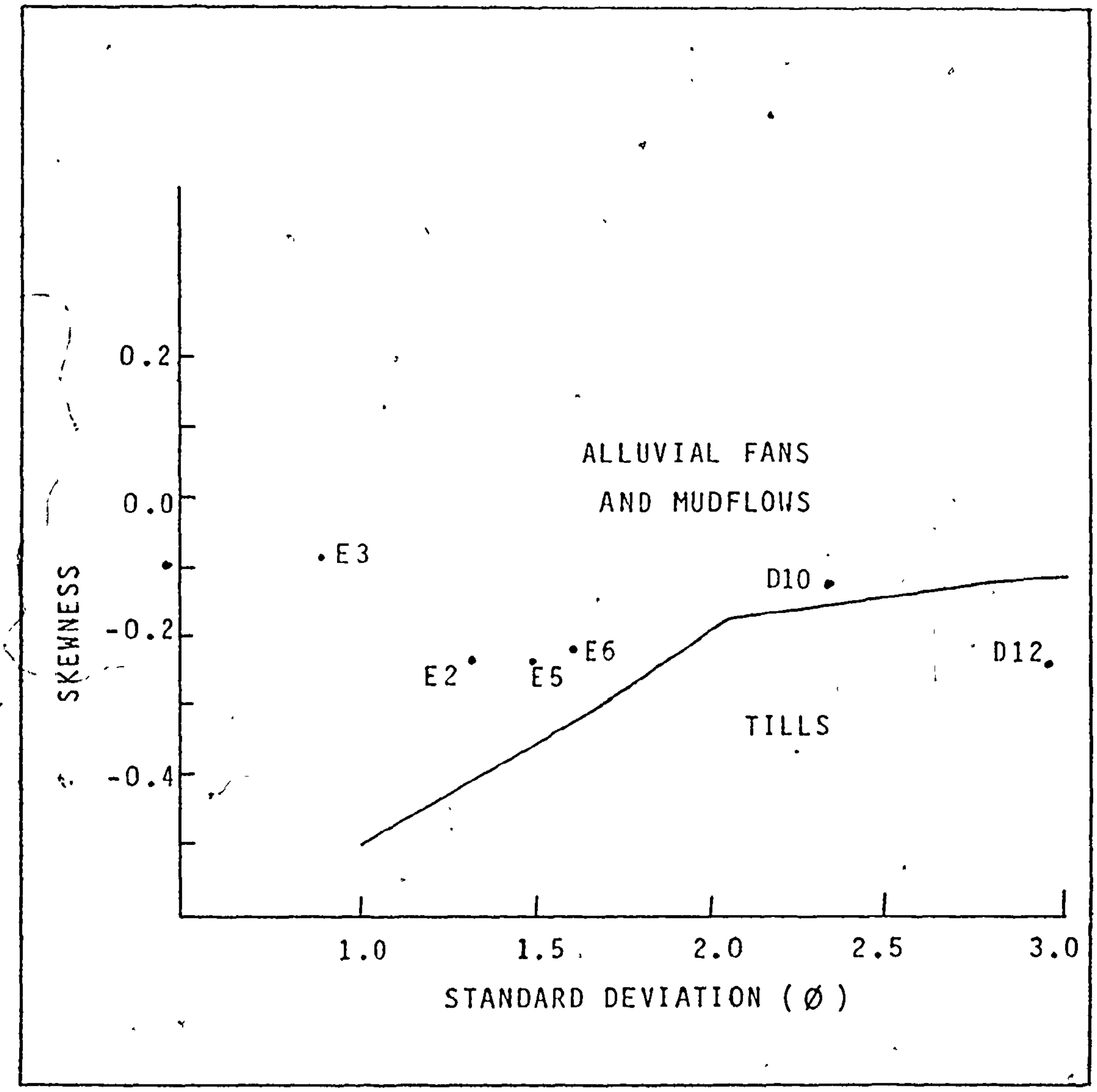


FIGURE 3.3 PLOT OF SKEWNESS vs STANDARD DEVIATION FOR SECTIONS D AND E (FOLK STATISTICS)

(after LANDIM AND FRAKES, 1960)

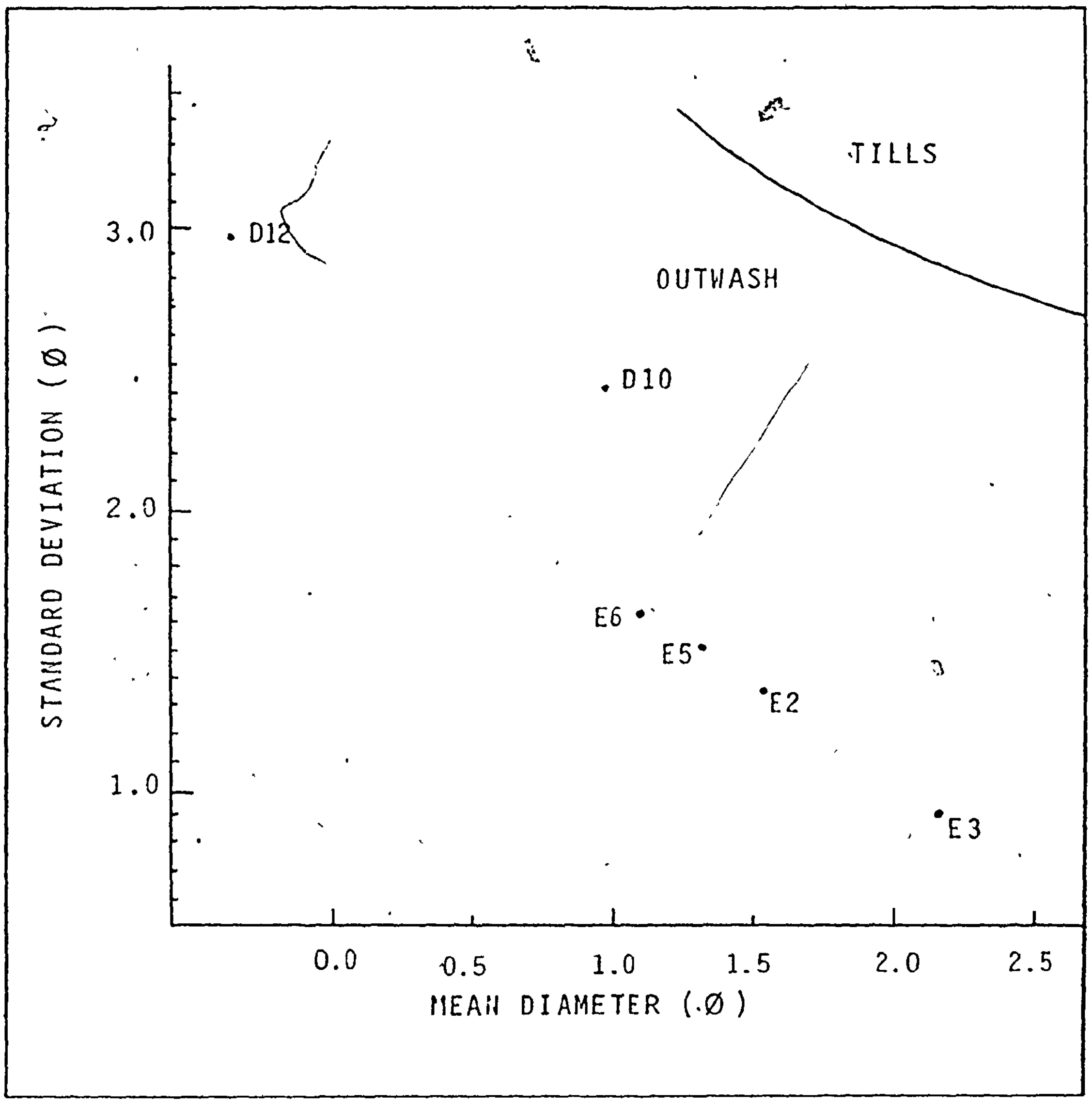
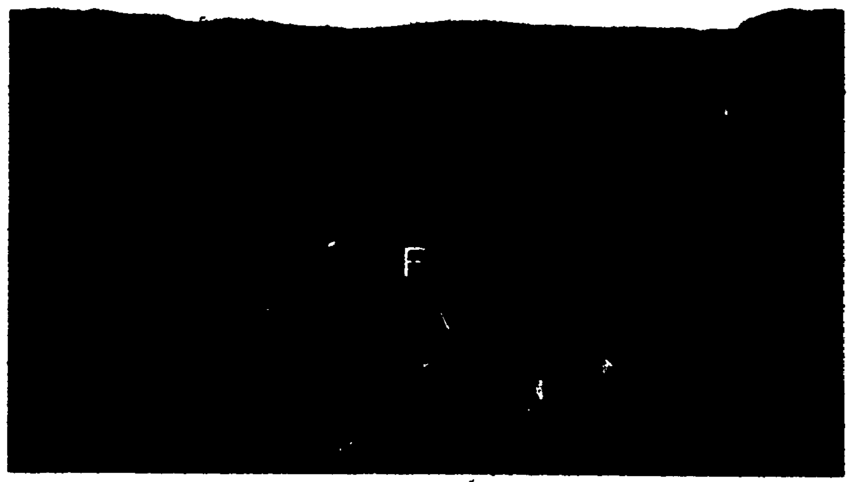


FIGURE 3.4 PLOT OF STANDARD DEVIATION vs MEAN DIAMETER FOR SECTIONS D AND E (FOLK STATISTICS)

(after LANDIM AND FRAKES, 1968)



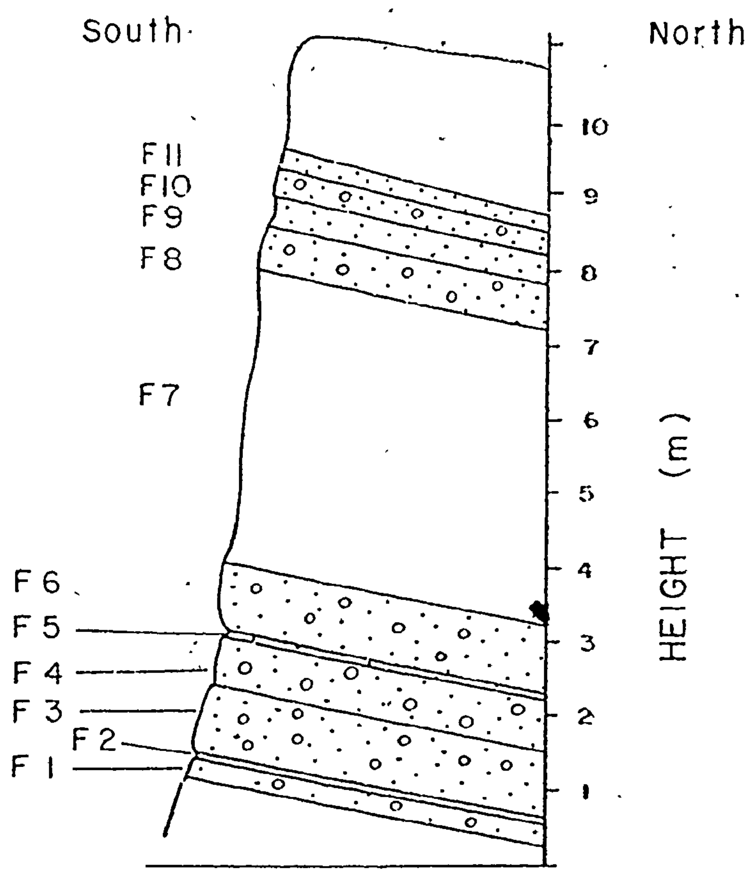


Plate 3.7: Section F

no pattern in its bedding structure, whereas the upper one exhibits a fining upwards sequence very clearly.

At the base of the lower section is a bed (F1) of medium-fine gravels having a matrix of coarse sands, followed by F2, a narrow bed of fine sands containing a minor proportion of fine and very fine gravels. Coarse sands and gravels make up Bed F3 and slightly coarser sands and gravels with cross-bedding are found in F4. A narrow bed of coarse sands (F5) preceeds F6, a bed of coarse sand and very fine gravels which also shows cross-bedding. The dip of the contacts between beds is at an angle of 30° W and with a strike of 224°.

Approximately 4 m above this another example was studied. A bed of coarse gravels (F8) lies below a bed of fine gravels (F9), followed by a bed of very coarse sands (F10) and then a bed of coarse sands (F11). As the mean grain size and bed thickness decrease upwards the moment measure values for sorting increase. According to Reineck and Singh (1973) this is very characteristic of channel fill deposits. Although the beds in the lower section do not have a fining upward sequence, they too are similar to channel deposits. The narrow beds of fine-grained sands are sediments of shallow water overbank flow and the thicker, coarser beds are main channel deposits as the channel shifted laterally. Trough cross-bedding in beds F4 and F6 is certainly indicative of a fluvial environment.

Clast fabric analysis shows that a significant number of clast planes have a preferred dip west with a strike of 226° ± 58°, which is almost the same direction as the strike of the beds (224°). Because the beds dip so steeply towards the head of the bowl and because the north side of the conical mound with an azimuth of 295°, plunging 27°, has a steep slope, it is very likely that Section F has been affected by rotational slumping. In order to account for this the pole to the plane for each clast was replotted. The effect of slumping was removed by a 30° rotation of each pole to the plane around the 225° strike line. The results show that before slumping the clasts had a preferred dip to the east, striking at 37° ± 40°. The Chi-square value of 60.3 indicates that this is significant at >99.5% with 2 D.F. Because clasts dip preferentially upstream in a fluvial environment (Simons *et al.*, 1965; Rust, 1975) the radical suggestion is that Ram River must have flowed to the west when it was depositing these materials at an altitude of 490 m.

The N-S cross section of Western Bowl (Figure 3.5) shows that an expansive plain extends away from the base of the conical mounds and dips at a low angle towards Ram River. Close to the river (where sections D and E are situated) is another series of slump faces where the slope is much greater. The explanation of this may be similar to the situation in Sundog Basin (Chapter 3.2.4) where it is apparent that clay deposits below beds of sand and gravel could no longer support the weight of the beds above and gave way under the stress. It is reasonable to propose that this has occurred on a much grander scale in Western Bowl where the height of slump fronts is potentially much greater. This form of slumping is also common in similar deposits along South Nahanni River, 60 km to the south (Ford, 1974). If this is the case, then Section F is part of a fluvially-bedded sand and gravel sequence, preserved intact though rotated, above fine-grained, possibly lake, sediments. Sections D and E are situated at the toe of the slump where minor amounts of coarse material are found incorporated in a matrix of fine-grained silts and clays.

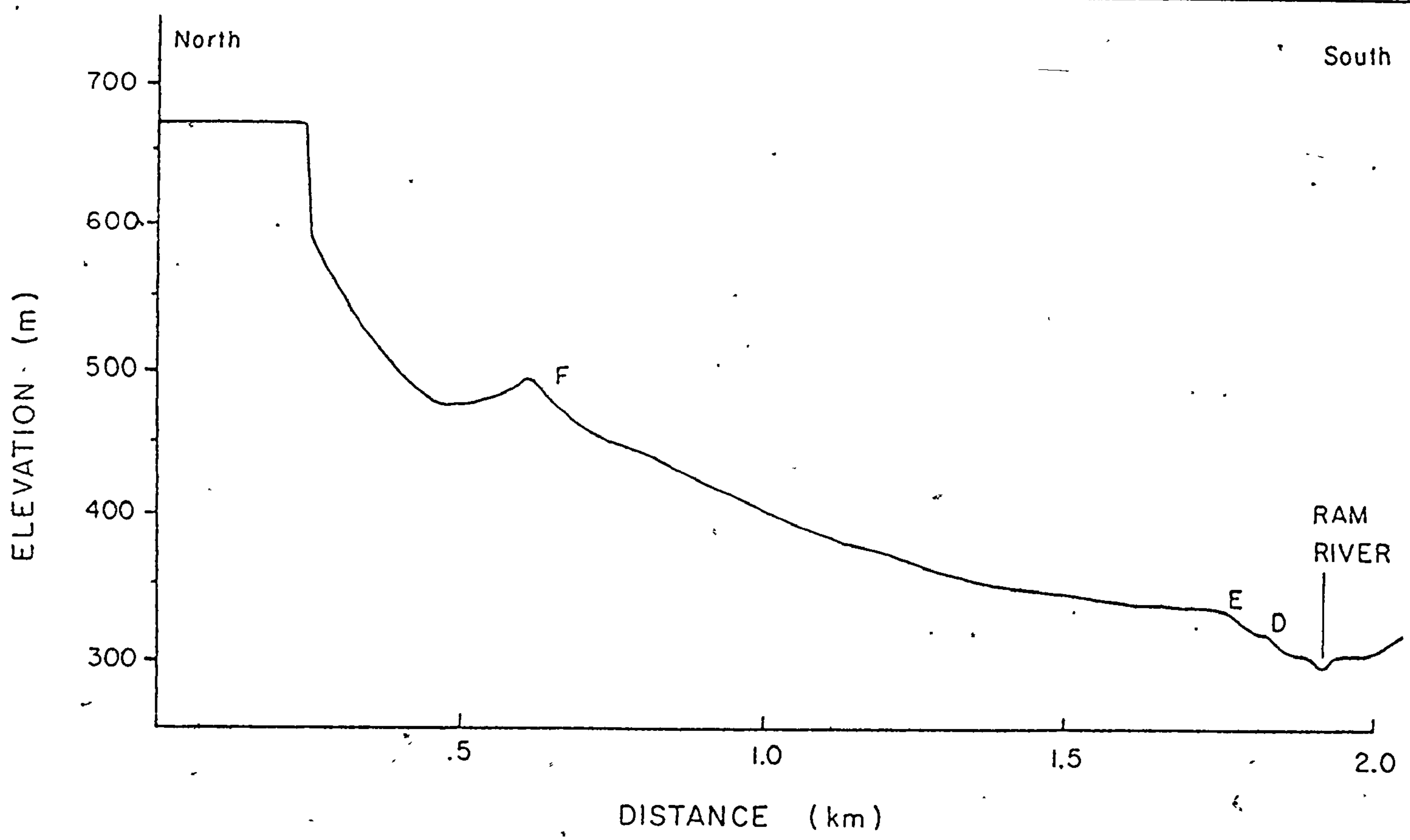


FIGURE 3.5 CROSS SECTION OF WESTERN BOWL

Immediately west of Western Bowl is Angel Bowl, a smaller meander scar in bedrock. It has been infilled with unconsolidated deposits which are now partially dissected. Large slump faces are common. To the east on the north bank of Ram River are extensive cross-bedded sands and gravels (Section G, Plate 3.8) at an elevation of 300 m (980 ft).

Bed G1 is comprised of subrounded coarse gravels with a matrix of fine gravels and very fine sands. There are very large rectangular limestone boulders at the base of this bed. Rounded to subrounded, medium to very fine gravels are found in G2, and G3 has very coarse gravels supported by a matrix of fine and very fine gravels with a small proportion of coarse sands. The sandy bed G4 has a mean grain size of 1.5ϕ and a symmetrical, unimodal distribution. G5 is of fine gravels and coarse to medium sands. G6 has coarser gravels and sands, and G7 is finer-grained. The contacts between beds G1-G7 all strike 84° and dip 16°S. There is a sharp erosional contact between this set of beds and G8 which has an apparent rake with an azimuth of 345° and a plunge of 12°, as do G9 and G10. G8 is comprised of very coarse, rounded and subrounded gravels with a matrix of medium gravels. A bed of fine gravels and coarse sands (G9) and then G10, very coarse gravels supported by a matrix of coarse sands, complete the section.

Clast Fabric analysis of the rounded coarse gravels and sands below G1 indicates that the planes of the clasts samples have a Vector Mean of 260° $\pm$ 65° and a Chi-square value of 24.3, significant at >99.5% with 2 D.F. The large-scale cross-bedding is characteristic of a fluvial environment (Walker *et al.*, 1975). Because clasts dip upstream it follows that the river depositing these sands and gravels must have flowed to the east, as it does presently. The modern Ram River is excavating alluvium

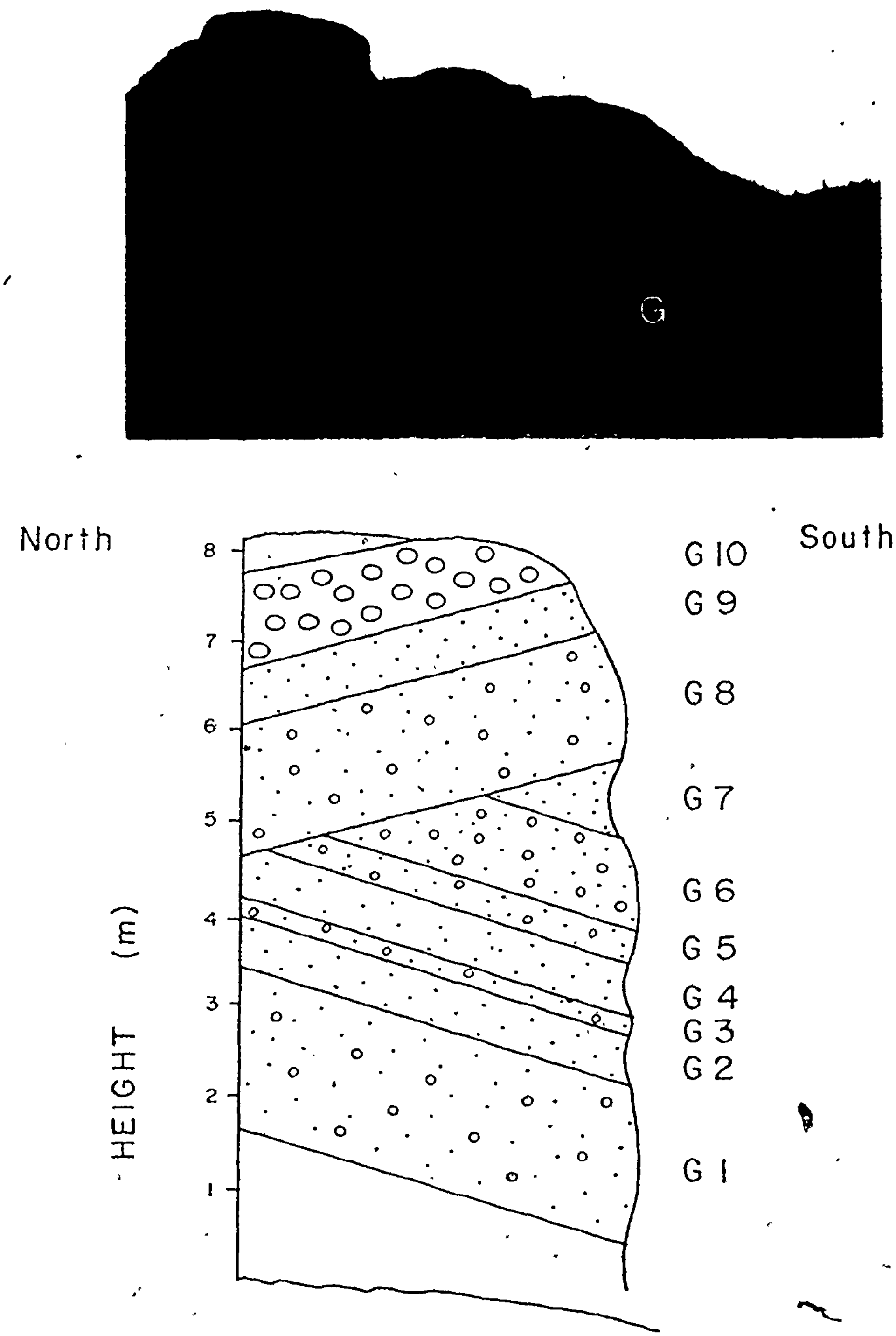


Plate 3.8: Section G

belonging to an earlier depositional phase.

The lag of an ancient till is found almost everywhere on Ram Plateau. The till was studied in detail at H and I (Plate 3.9) and found to contain highly weathered granitic cobbles and boulders derived from the Canadian Shield. Their surfaces are not fresh: they are well-rounded, rough, slightly friable and have no striae. Within all of the sediments studied in the canyons, small proportions of weathered granitic clasts were found, implying that much of the till has been winnowed and redeposited in the canyons and basins over an extended period of time.

Camp and Subject Canyons are oriented N-S and their streams drain north to Ram River. These tributary canyons are not antecedent in origin as is Ram Canyon. They were incised along joints in the bedrock as the plateau domed, as were most of the tributary canyons.

In Camp Canyon there is a ridge of unconsolidated sediment extending northward for approximately 1.5 km from the junction of Camp and Fault Creeks (Figure 3.6). The depression between the ridge and the western scree slope is shallower and narrower than the valley to the east of the ridge, presently drained by Camp Creek. It is possible that the smaller valley was the original channel for Fault Creek before a rock glacier extending eastward from the western canyon wall diverted the water over an 8 m high shale ledge and into Camp Creek.

Camp Creek has eroded the eastern side of the ridge, causing active slumping along most of its length. Section J (Plate 3.10), at a slump face near the top of the ridge at 365 m (1,200 ft) has a matrix of poorly sorted fine gravels, sands and silts with a minor percentage of clays. There is no evidence of bedding structures. Subangular, blocky and pyramidal-shaped

Plate 3.9: Section I

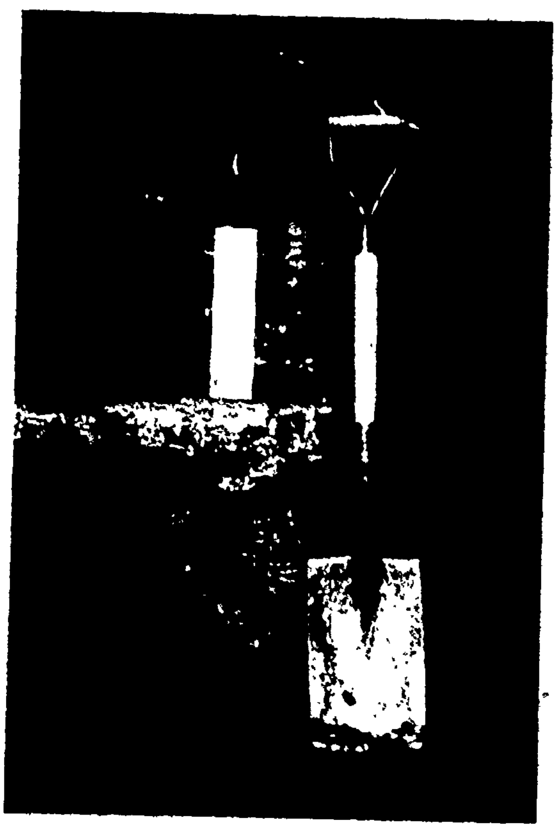


Plate 3.10: Section J

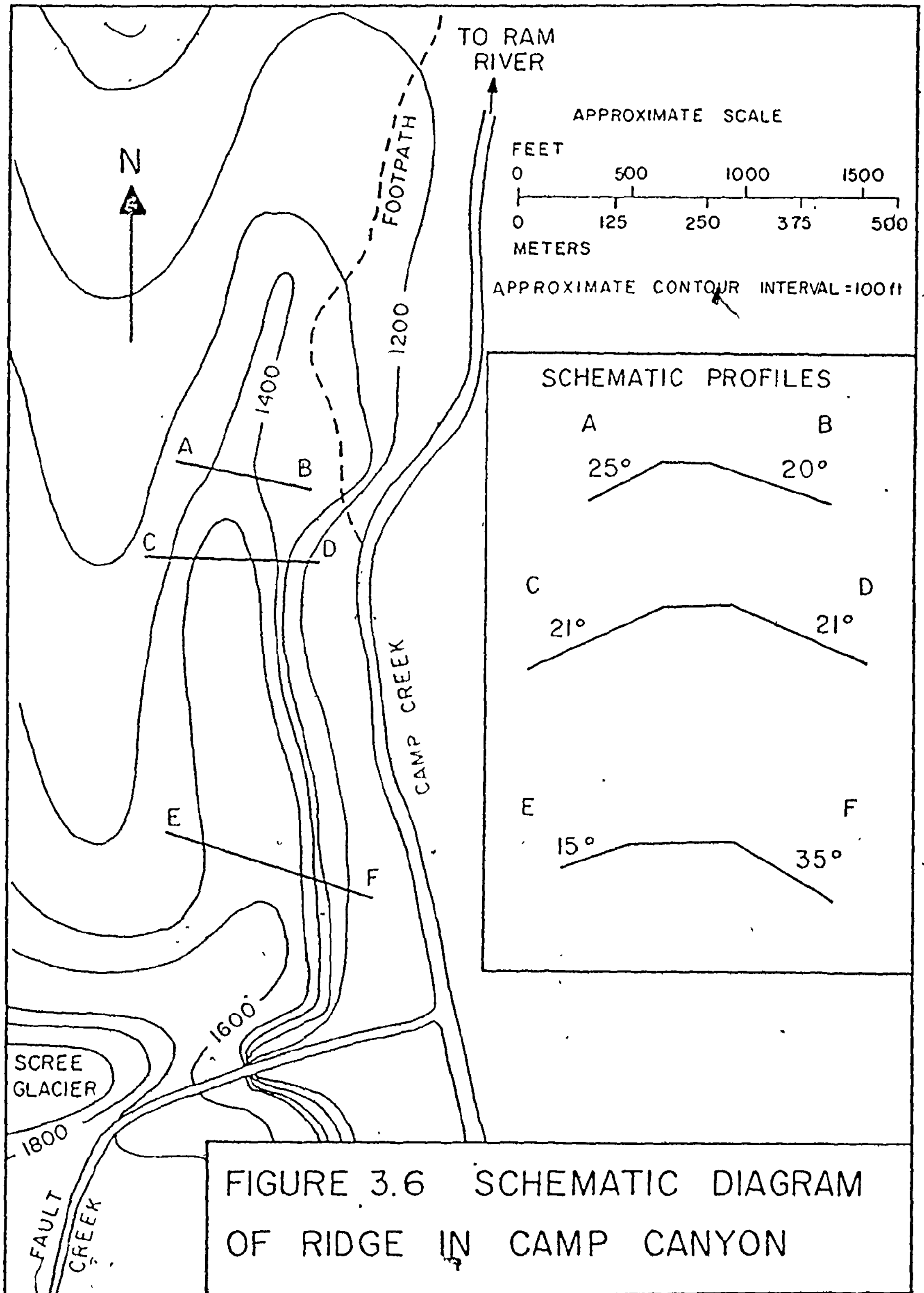


FIGURE 3.6 SCHEMATIC DIAGRAM OF RIDGE IN CAMP CANYON

clasts ranging in size up to 24 x 15 x 11 cm were found throughout. They looked very similar to scree material which was studied in detail by the author in 1976.

Clast fabric analysis shows that the planes of most clasts dip NE to SW (i.e. downslope) with a strike of between 290° and 110°. The angle of dip ranges from 7° to 85°.

The results of grain size and clast fabric analysis suggest that this is part of a slump deposit of fine-grained material failing to the east and incorporating scree clasts within it. The absence of bedding structures makes it impossible to determine the precise origin of the fines, however, their grain size permits the possibility that this slump material was derived from lake sediments.

Extending out from the base of the east wall of the Camp Canyon scree slope between Sections K and M there is a relatively continuous, terrace-like deposit with an irregular surface at an elevation of 550-580 m (1,800-1,900 ft). The Camp Creek meteorological station is situated on this terrace at location K (Plate 3.11), and beside it a hole was dug to a depth of 35 cm. Beneath the 7 cm organic mat were fine silt and clay deposits containing subangular to subrounded and blocky- and pryamidal-shaped limestone clasts, similar to the scree material. The clasts ranged in size from 2.5 x 1.5 x 1.0 cm to 17.5 x 15.5 x 7.0 cm. The matrix was too wet (due to melting of the active layer) to decipher any structures. It is possible that these too are fine-grained lake sediments with incorporated scree clasts. Alternatively the deposit may be scree with the interstices filled with fines, but packing of clasts did not appear to be as compact as in the modern scree slopes.

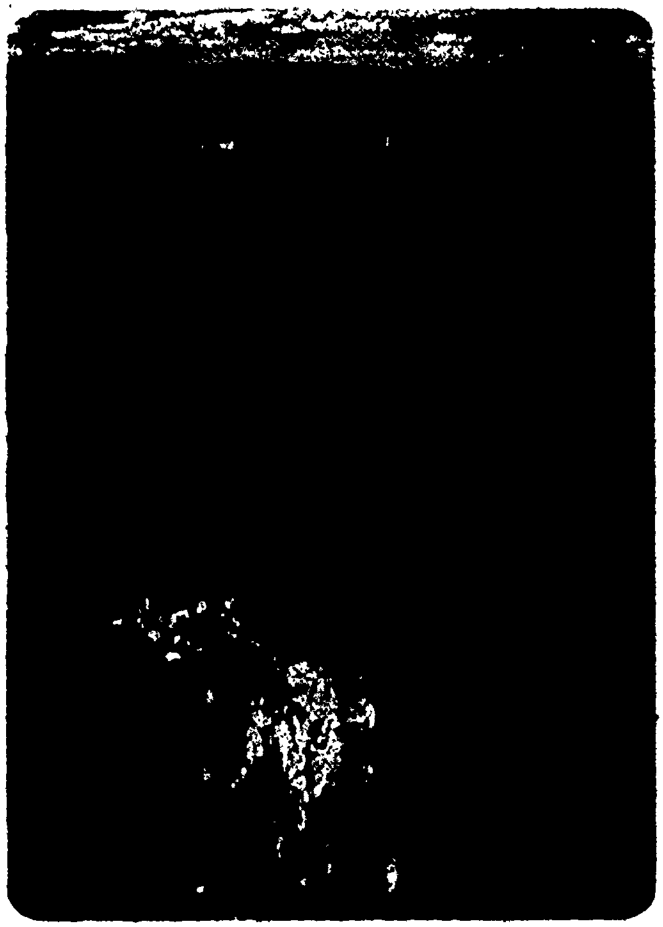


Plate 3.11: Northern extent of the 550-580 m terrace-like deposit in Camp Creek showing location of Section K

At the base of the southern end of the terrace (Plate 3.12) is Section L (Plate 3.13) at 550 m. The section is found on the south side of a gully entrenched at right angles to Camp Creek. The most characteristic feature of the deposit is the sequence of alternating coarse/fine, parallel-bedded sands and gravels. Bed L1 is a 4 m, massively bedded, gravel unit with a matrix of coarse sands. L2 contains alternating coarsely bedded sands and gravels. L3 is a 3 m gravel bed. L4 contains moderately well-sorted and nearly symmetrically distributed sands with L5, a narrow band of gravels, above it. A unit of alternating layers of fine sands with coarse sands and fine gravels is 65 cm in width (Beds L6-L10). Beds L6, L8, and L10 are fine sands, moderately to poorly sorted and symmetrically distributed. The intervening beds (L7 and L9) are coarse sands, poorly to very poorly sorted and negatively skewed. Bed L11 contains coarse gravels in a matrix of coarse sands and above it is another unit of narrow, alternating coarse/fine layers (L12-L21). The fine beds are all unimodal and nearly symmetrically distributed, medium-sized sands. The coarser beds are very negatively skewed due to polymodal distributions. Above this unit is L22, a bed of coarse gravels with a matrix of coarse sands and very fine gravels.

The thick beds of massively bedded coarse sands and gravels indicate rapid deposition in a high energy environment alternating with deposition in much slower waters, a sequence that is often associated with fluvial environments. The coarse beds may either represent annual, high velocity, spring flows or several high flow periods during one season, with intervening low flow periods. The units of narrow coarse/fine beds (L6-L10 and L12-L21) could have been deposited during a time of

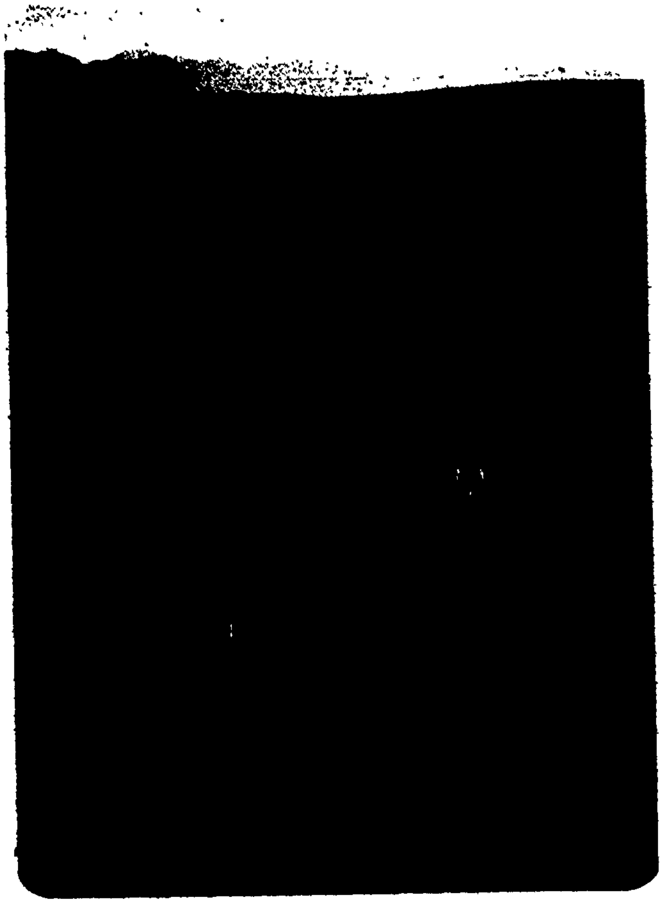


Plate 3.12: Southern part of the 550-580 m terrace-like deposit in Camp Creek showing the locations of Sections L and M

Plate 3.13: Section L

strong diurnal fluctuations.

The beds strike 20° and dip 20°E, suggesting an improbable flow of water into the canyon wall. Any feasible source river must have flowed down-canyon, therefore, the beds must have been affected by rotational slumping as a unit because no faults or contortions are apparent. Whether these are fluvial or deltaic deposits cannot be determined on the evidence contained in Section L.

One kilometer further upstream, near the top of the terrace at 580 m is Section M exposed in a gully 7 m deep (Plate 3.14). A 2.5 meter section was cleared near the top of the exposure, displaying the parallel-bedded layers of fine-grained sand and clayey silt deposits.

At the base, M1 is a bed of sandy silts with a series of three varve-like beds above (M2, M3 and M4), each of which has fine sands grading upwards into clayey silts. Unit M5 contains narrow layers of silty clays approximately 2-3 cm thick, interbedded with slightly thicker layers of fine and very fine sands. The bedding here shows some contortions which may be the result of post-depositional settling, perhaps as the active layer melted. The 30 cm of material above this show signs of being affected by recent slumping.

The beds have a generally horizontal rake. Three-dimensional analysis shows that they strike 250° and dip 10°N.

Section M exhibits fine-grained, parallel-bedded, gently dipping and well-sorted deposits with a varve-like sequence indicative of a low energy environment. This is characteristic of deposition in a local pond or a lake. The depth of the fines is at least 6 m which is not characteristic of the former. It is more likely that these are lake deposits.

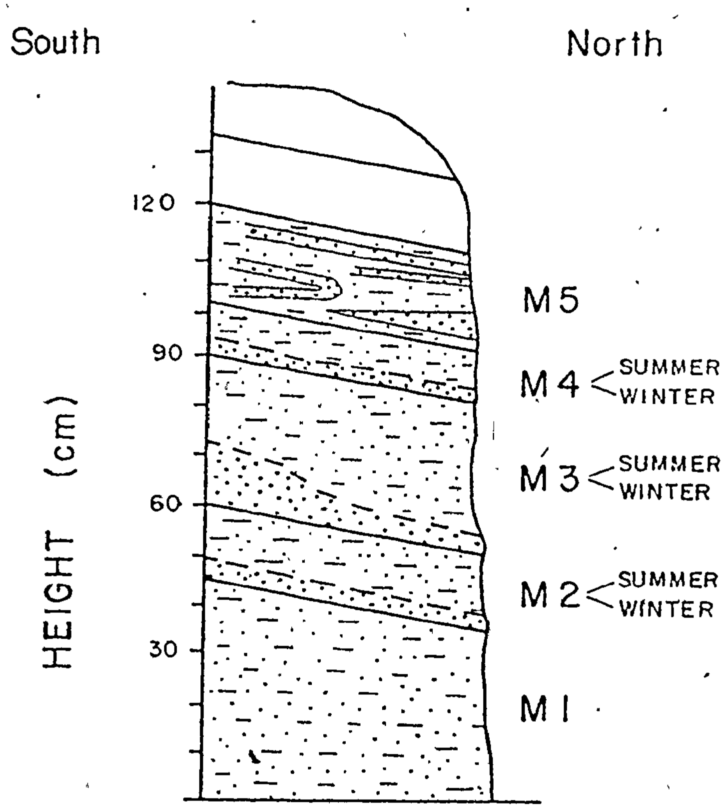


Plate 3.14: Section M

Presence of lake clays at a site upstream of and at an elevation greater than fluvial sediments (Section L) is problematical. The best explanation is to postulate two separate depositional events (Figure 3.7). Near the head of Camp Creek are coarse sands and gravels and boulders at 730 m (2,400 ft) (Section N, Plate 3.15) which may be river deposits from water flowing into a lake with a surface at between 610-730 m (2,000-2,400 ft). The fines found in Section M are the lake deposits belonging to this event.

The lowering of the lake level to approximately 535-550 m (1,750-1,800 ft) or subsequent inundation to this elevation could conceivably be responsible for the fluvial or deltaic deposits of Section L at 550 m without the complete erosion of the lake and river sediments upstream. Downstream from Section L there are the copious amounts of fine-grained sediment which has slumped and which incorporates scree clasts.

Mid-way up Subject Canyon at 535 m there is a collapsed deposit (Section O) of very well-rounded, coarse gravels (Plate 3.16). Even though no bedding structures remain, it is evident from the size and roundness of the clasts that a high-energy fluviatile environment is responsible for their deposition. The 535 m elevation corresponds well with that of Section L and because Camp and Subject Canyons have other deposits of a generally similar nature, it is postulated that Section O is part of the same depositional phase as Section L: i.e. either fluvial or deltaic deposits dating from a 535-550 m lake phase. Unconsolidated terrace-like deposits extend up to 730 m in both Subject and Camp Canyons, implying inundation to this elevation at one time.

When the sedimentary sequences of the Central Canyon area both

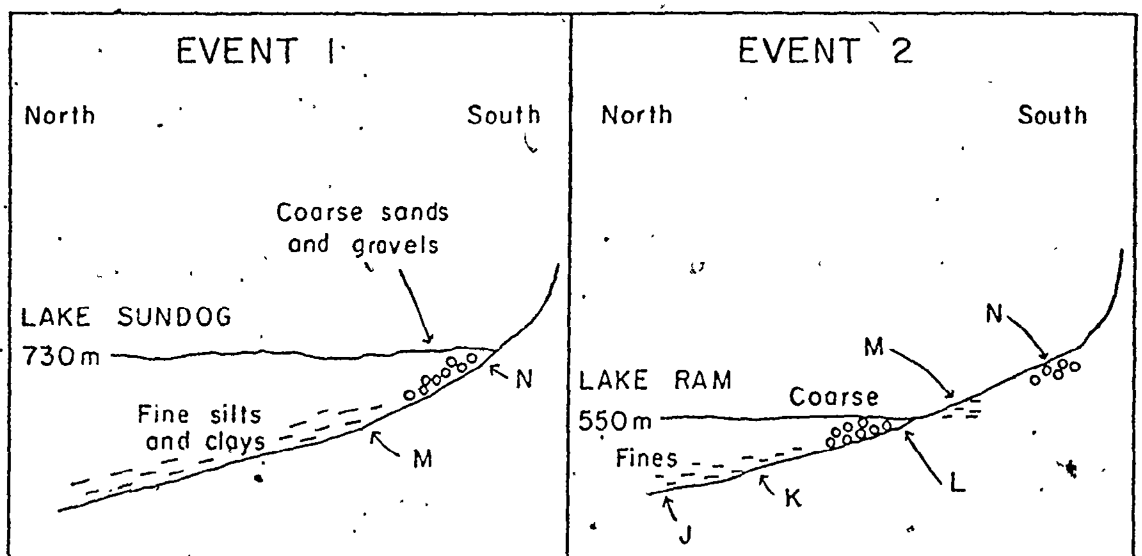


FIGURE 3.7 SCHEMATIC DIAGRAM TO SHOW TWO DEPOSITIONAL EVENTS IN CAMP CANYON

Plate 3.15: Section N

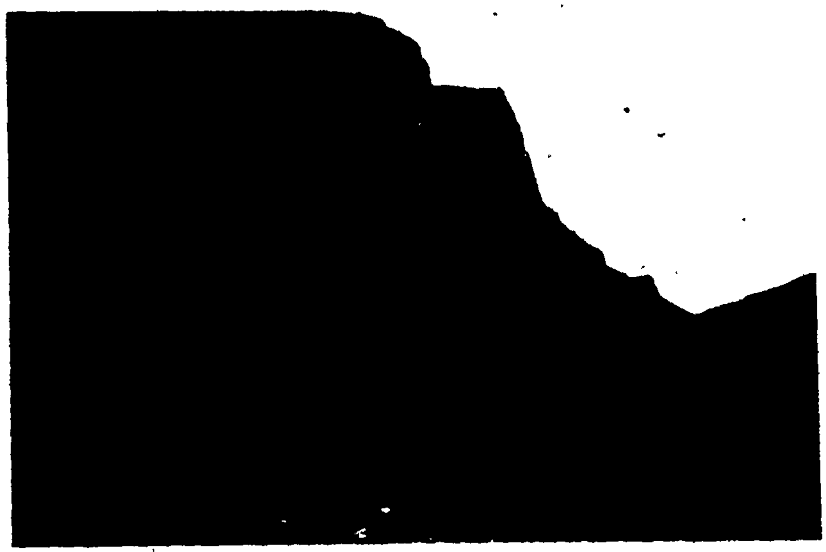


Plate 3.16: Section O

Plate 3.17: Section S at the mouth of Footloose Canyon

north and south of Ram River are combined, it becomes evident that the two are closely linked, as is expected. The infilling to 550 m is represented within both, although much of that in Western Bowl has slumped down to 490 m. Evidence of filling to 730 m, however, is found only in the tributary canyons of Ram River.

3.2.3 Western Canyon Area

The western side of Ram Plateau could be studied only during a four-day period when a fly camp was set up at the junction of Footloose Creek and Ram River. Inclement weather conditions made hiking dangerous. Three sections (P, Q and R) were studied in Golden Bowl (an alluviated ancient meander scar), and two sections (U and V) were studied in Footloose Canyon. In Chapter 2 it was suggested that Butler, Footloose, and Leckie Canyons were the original channels draining Sundog Basin prior to their alluviation and the excavation of Scimitar Canyon. For this reason it was hoped to study all three. Due to difficult access and lack of time, this was not possible. The mouths of Footloose (Section S, Plate 3.17) and Leckie Creeks (Section T) have a ridge of unconsolidated material blocking their original outlets to an altitude to 400 m (1,300 ft), indicating alluviation to at least this elevation. The creeks draining the alluviated valleys did not re-excavate their original outlets and have instead entrenched narrow gorges across bedrock spurs. A similar feature along Ram River at Golden Gate (Plate 3.18) resulted when the river shortened its course to cut a narrow gorge across a bedrock spur instead of re-excavating Golden Bowl.

Golden Bowl is a relict meander scar eroded into bedrock by Ram

Plate 3.18: Golden Gate

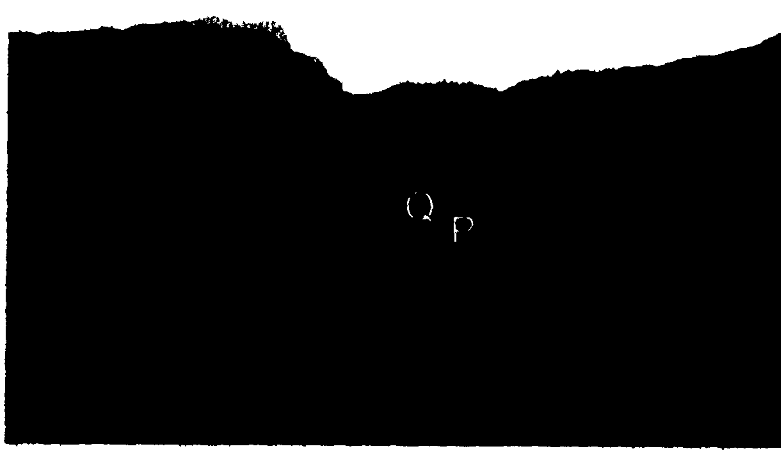


Plate 3.19: Dissected alluvium in Golden Bowl, showing locations of P and Q

River on its south side, between Footloose and Butler Canyons. The bowl was subsequently infilled with unconsolidated sediments up to 550 m (1,800 ft). The sediment has since been eroded by small creeks, leaving two major ridge systems with conical mounds at several places along their lengths (Plate 3.19).

Section P (Plate 3.20) is situated 15 m from the top of the eastern ridge at an elevation of 380 m (1,250 ft). The beds generally dip at an angle of 62° to the east with a strike of 350°. The lowermost deposit studied (P1) is of clayey silts, and the uppermost (P4) is comprised of many 10 cm bands of clay and fine sand laminae alternating with 15 cm beds of fine sands. Along the interface, oblong nodules (P2), 15 cm in width and 35 cm in length, of fine-grained bedded sands are individually encased in a 2 cm thick zone of clays (P3). The sand of P2 dip at the same angle as those of P4 and the clays of P3 are similar to those of P1. This type of formation can be readily compared with a loading phenomenon known as "ball and pillow" structures or "pseudonodules" that are commonly found in fine sediments deposited from suspension without adequate packing. As the weight of the coarser sands being deposited above increases, the clay fails and units of sand sink down into the fines (Blatt, Middleton and Murray, 1972). Because deposition at such a steep angle is unlikely, it is postulated that this section has been affected by post-depositional tilting.

At the top of the eastern ridge and almost directly above Section P, Section Q (Plate 3.21) has an elevation of 400 m. The basal bed exposed (Q1) consists of moderately well-sorted sands with a nearly symmetrical distribution. The contact between Q1 and Q2 shows evidence

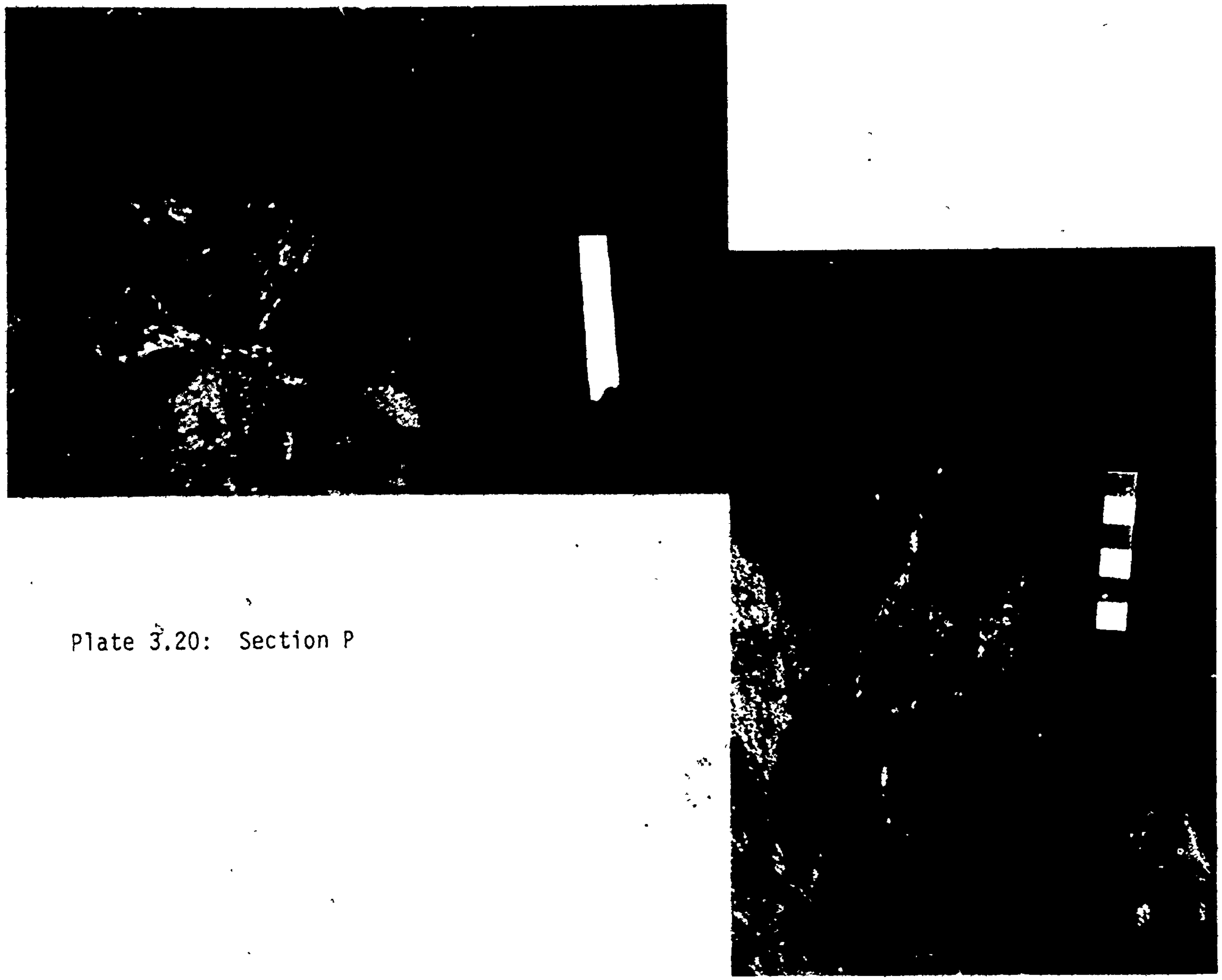


Plate 3.20: Section P

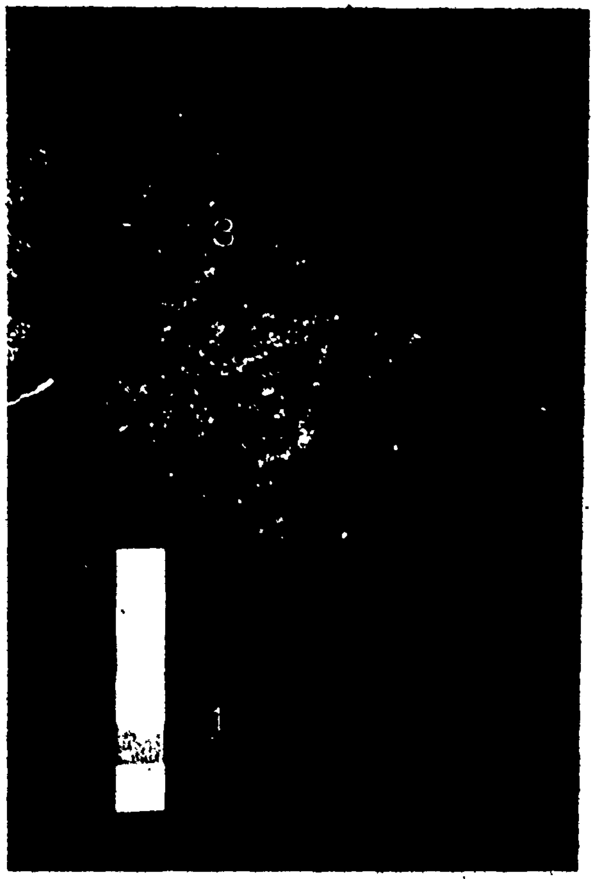
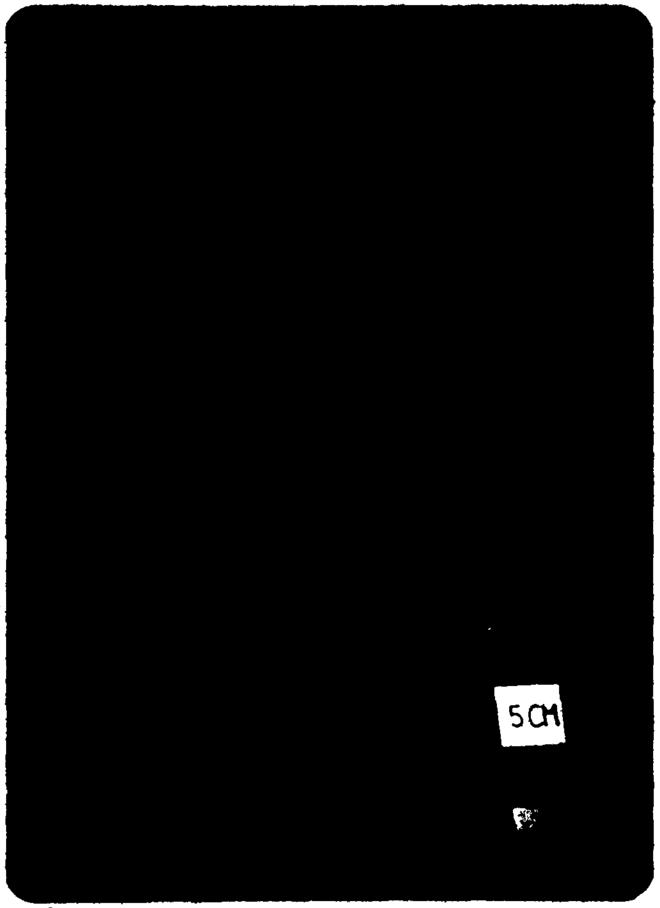


Plate 3.21: Section Q

or either scour and fill, or post-depositional faulting. The 1 m thick Q2 unit has parallel beds striking 351° and dipping 37°E, with fore-sets having an azimuth of 81° and a plunge of 55°. The steep dip of the beds provides further evidence of post-depositional alteration. A sample (Q3) removed from one of the fore-sets in Q2 exhibits a poorly sorted, positively skewed, unimodal distribution of coarse sands. The bed above Q2 is 4.5 m thick and composed of moderately well-sorted coarse sands having a positive skewness. A large proportion of the sand in Q5 is derived from granitic rocks and although a sample was not statistically analysed, it appeared to be composed of very well-sorted, coarse sand. No bedding was detected in the field. This may have been because the sand was very wet when inspected. Throughout Q5, there are silty mud balls armoured with the same sand. They are highly suggestive of a fluviatile environment. Such mud balls are being created and deposited in modern fluvial environments within Ram Canyon, as was noted by the author and studied by Arsenault (1976).

Section R (Plate 3.22) is on the western ridge at an elevation of 460 m (1,500 ft). There are alternating coarse and fine layers which generally strike 232° and dip 26°NW. The basal layer (R1) has medium- to coarse-sized gravels dispersed throughout a matrix of fine sands and silts. This grades upwards into R2, a 4 cm bed of silty clays. Above this are five pairs (R3-R7) of varve-like layers, each consisting of fine sands grading upwards into fine-grained, silty clays. Layers R3 and R4 each have a thickness of 4 cm and R5, R6 and R7 each have a thickness of 1.5 cm. Above these, R8 is a bed of moderately well sorted sands which have a nearly symmetrical distribution. A few well-rounded coarse granules



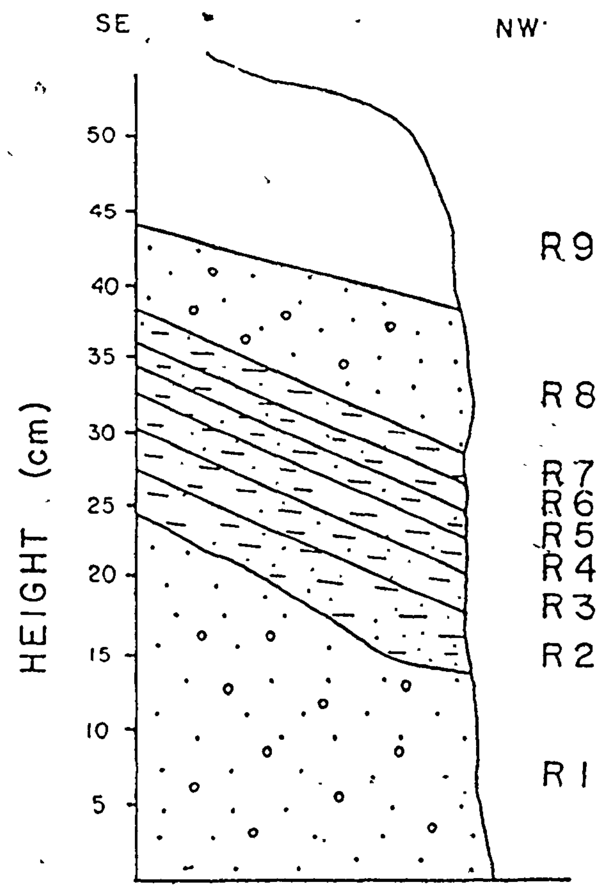


Plate 3.22: Section R

of granite were dispersed throughout. At the top of the section there is a subsequent deposit (R9) of what appears to have been another varve-like sequence of fine sands grading upwards into silts and clays. This showed signs of recent slumping and mixing..

Interpretation of the sedimentary sequence in Golden Bowl is tentative. The fine-grained, parallel bedded silty clays of Q1 indicate quiet water deposition up to approximately 380 m, above which are the deposits of a slightly more active environment. These two may reflect differences in sediment transport between a late summer or winter low flow period and a high discharge period the following spring and early summer. If this hypothesis is correct then one would expect to find alternating units of coarse/fine sediments; however, due to the limited extent of the exposure this could not be determined.

The base of Q, 20 m above P is also well sorted sands. The contact between Q1 and Q2 appears to be erosional, suggesting that a fluvial environment succeeded the lake environment. The fore-set beds of Q2 and the mud balls contained within Q5 provide further evidence of a high energy, fluvial environment. The steep dip of the beds to the north-east indicate either tilting as a unit or deposition in a deltaic environment.

Section R indicates that a fluvial environment, with localized deposition in ponded water existed at an elevation of 460 m. The angle of bedding implies deposition in water flowing to the northwest, and not the northeast as evidenced by the bedding in section Q. It is suggested that the upper deposits at R represent an earlier flow, out through Scimitar Canyon, in the opposite direction to present river flow. The lower deposits at Q were deposited during a subsequent downcutting phase when the ice, blocking the eastern outlet, retreated and Ram River flowed in the same direction as it does presently.

Mid-way up Footloose Canyon (Plate 3.23) there are two north bank exposures approximately 0.5 km apart. The two are similar in that the slump faces are half circles parallel to the creek, and lack similar sediments on the south side where scree extends to creek level. Blanketing the surfaces of both mounds are distinctive beds of yellow silts and fine sands having aggregate thicknesses of 1.5 m. In the blanket deposits, the fine beds, which have an average thickness of 4.0 cm, alternate with slightly coarser beds having general thicknesses of more than 20 cm. Grain size analysis indicates that sample U4, which was removed from a coarser bed is 50% sand and 50% silt and clay.

Sediments below the blanketing deposits for the two exposures are very different. Section U (Plate 3.24), at 410 m (1,350 ft) has beds of sands and fine, subrounded gravels alternating with beds of sand and coarse, well-rounded gravels, totalling a thickness of at least 9 m. The contacts between beds have a uniform rake plunging 12°E down canyon, with an azimuth of 80°. A sample taken from a coarse, sandy bed (U1) is well-sorted and nearly symmetrical about the mean. The bed above, U2 has a mean grain size in the coarse gravel range, is poorly sorted, and positively skewed. Above the unit of alternating coarse/fine sands and gravels are much finer-grained, grey sediments up to the blanketing layer of yellow silts. Massive slumping of these grey muds (U3) during such wet conditions rendered any attempt to study an *in situ* deposit infeasible. The photographs show that they have parallel, horizontal bedding. It is important that U3

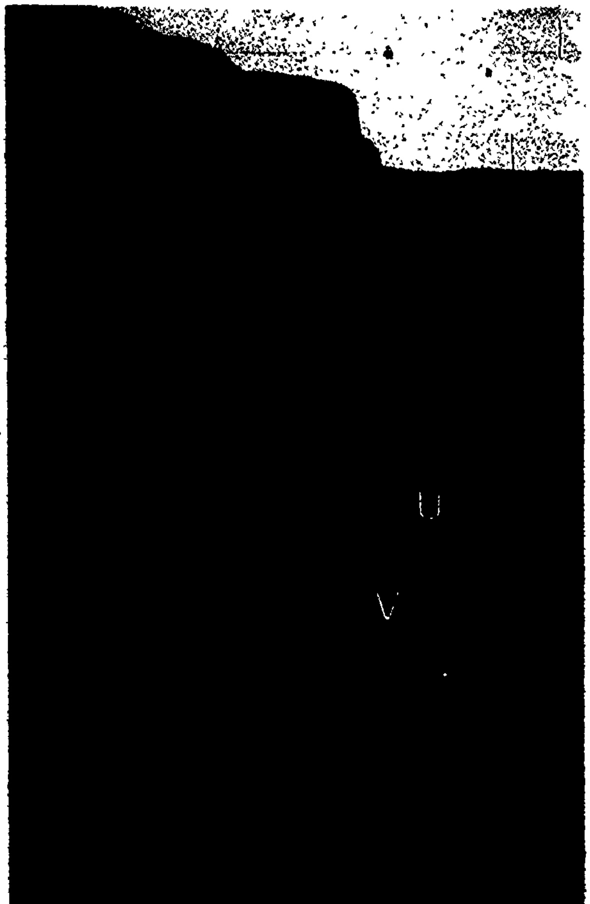


Plate 3.23: Footloose Canyon looking east, showing the locations of Sections U and V

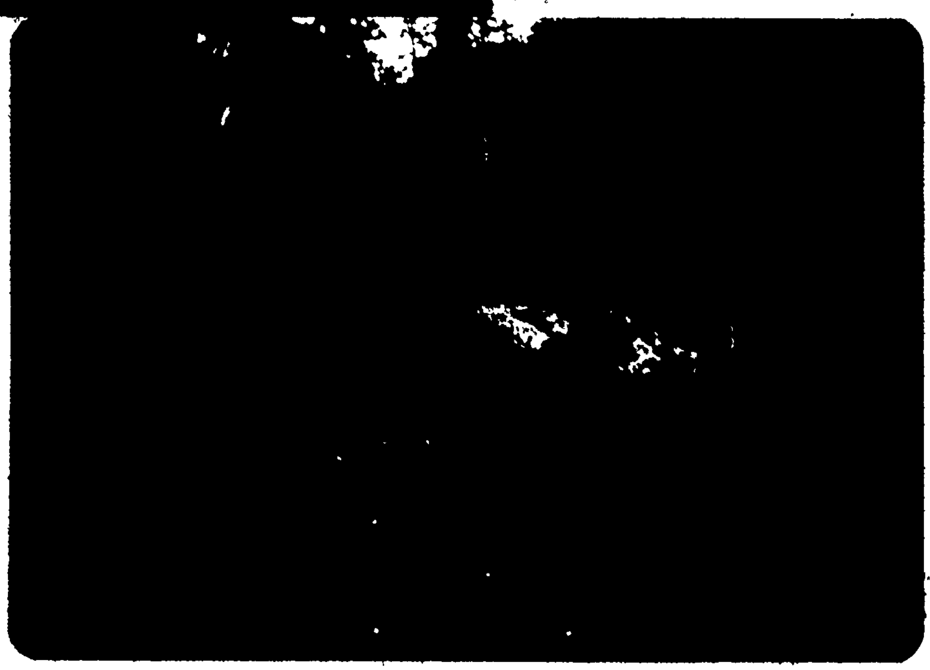


Plate 3.24: Section U

is grey because it precludes the chance that it is slope wash derived from the blanket of yellow silts (U4) at the top.

The face of Section V (Plate 3.25) at 425 m (1,400 ft) and farther upstream is completely covered by layers of yellow, sandy silts dipping at 67°S, striking 90°. Fine-grained layers range 15-20 cm in thickness and alternate with coarser layers, approximately 2 cm thick. The layers are parallel to the face, and dip at such a steep angle that they are readily recognized as rhythmically stratified slope waste deposits that are common in periglacial environments (Dylik, 1960). Their yellow colour suggests that they are primarily derived from the yellow sandy silt layers above. These deposits conceal the original bedding structures within the mound.

The sequence of events which best describes the deposits in Footloose Canyon is as follows. A fluvial regime with a river flowing to the east was responsible for the alternating coarse/fine deposits (e.g. U1 and U2). This gradually changed into a lake environment so that fine-grained, grey clays with horizontal, parallel bedding overlie the fluvial sediments. After a phase of downcutting and dissection, a later infilling to at least 425 m led to the deposition of blanketing layers of yellow fines in a quiet lake environment. Present downcutting has exposed the sediments from these two periods and slopewash of the yellow fines has covered the face of Section V completely.

3.2.4 Sundog Basin

Due to limited helicopter time only a few hours were spent at a slump face (Section W) on the southern side of a prominent hill of unconsolidated sediments in central Sundog Basin. The slump is 90 m

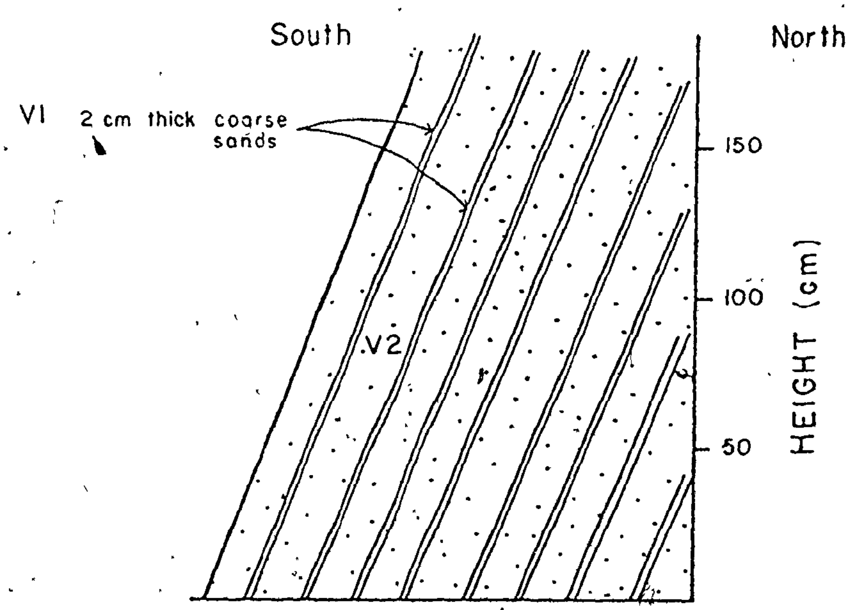


Plate 3.25: Section V

high, 150 m wide near the base, and is situated on the northeastern side of a meander bed of Sundog Creek, at 610 m (2,000 ft). Slumping appears to have been recent because there is no new scrub growth on either the face or the toe. Tall coniferous trees are angled in all directions on the toe and only the very tips of some conifers show signs of turning upwards (Plate 3.26).

The profile of the face is not symmetrical, being higher to the west. At the top of the western third of it there are beds of coarse gravels and cobbles with a matrix of sand (X1). Covering the slump face below are similar sediments, and recent gullying has exposed sections (all of them similar to that of X2, shown in Plate 3.27) which have no bedding structures, but their pebbles and cobbles appear to be imbricated downslope.

The crest of the central portion is lower than that to the west. Sediments here are finer than those in X1 and X2. For example, Y1 has narrow, parallel beds of medium to fine sands and silts which dip north at 55° and strike 287° (Plate 3.28). Section Y2, slightly east, has thin beds of coarse to fine sands which dip south at 76° and strike 89° (Plate 3.29). Contortions and minor faults are common. The eastern portion, where the crest of the slump face is the lowest, has very fine grey muds covering the surface (Z1).

The most obvious characteristic of these sediments is the fining eastward sequence as the height of the clump face decreases. Based on this, a model (shown in Figure 3.8) is presented in order to explain this feature.

Because fines are found at only low elevations, it appears that

Plate 3.26: Slumped sediments at the base of Section W in Sundog Basin

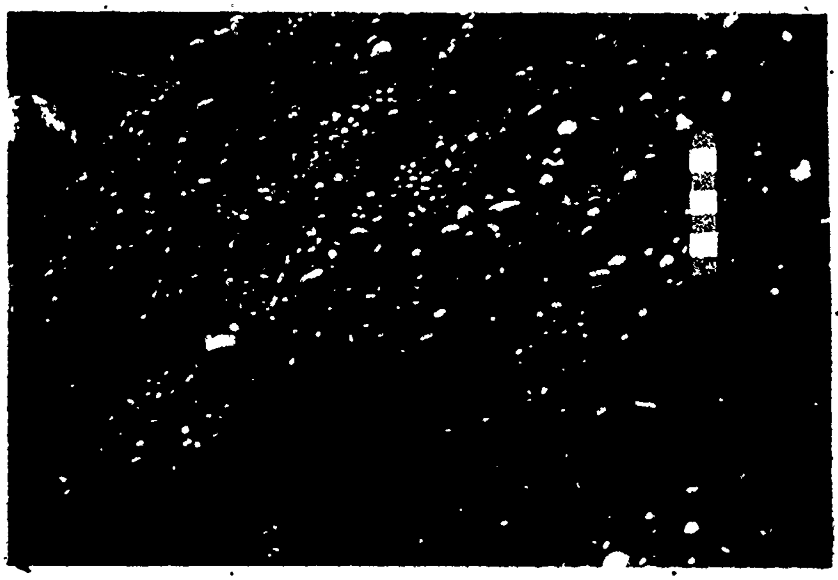


Plate 3.27: Section X2

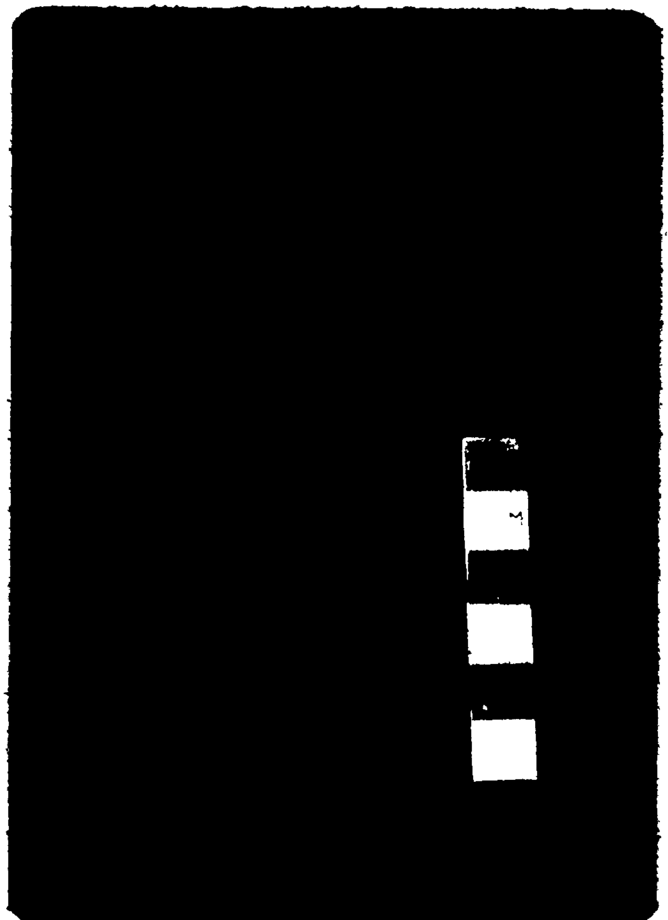


Plate 3.28:

Section Y1
Beds dipping north

Plate 3.29:

Section Y2
Beds dipping south

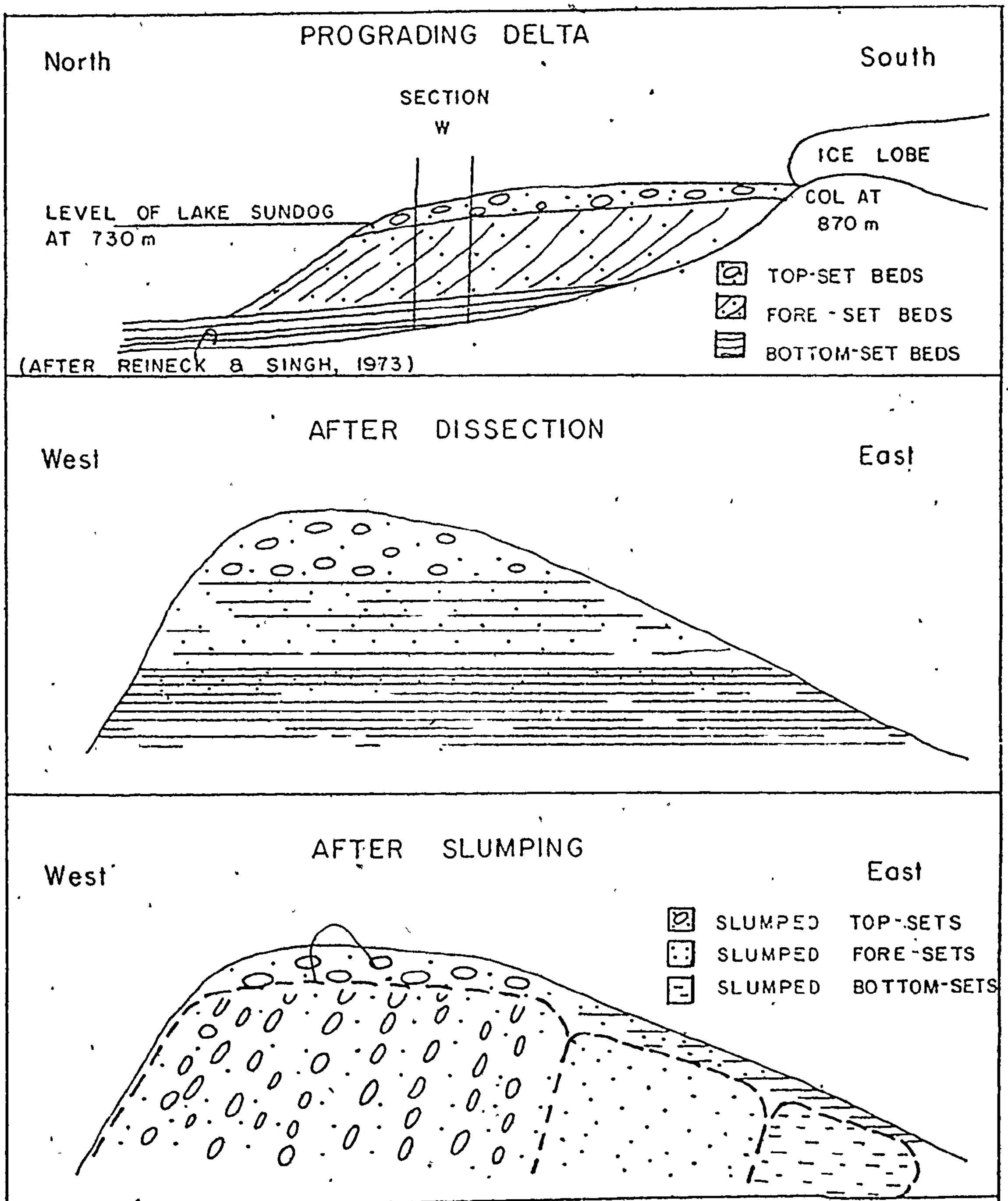


FIGURE 3.8 SCHEMATIC DIAGRAM TO EXPLAIN DEPOSITIONAL SEQUENCE IN SUNDOG BASIN AT "W"

the floor of Sundog Basin was covered with silts and clays above which sands and then gravels and cobbles with a sand matrix were deposited. During the lengthy period of dissection which followed many ridges, hills and mounds of unconsolidated material were left, dominating the landscape. In the case of Section W it is likely that Sundog Creek undermined the southern slope of one of the most prominent hills. Slumping was initiated when the clays near the base failed beneath the overlying coarser deposits.

During and after slumping, material from the top moved down the exposed face; thus materials on the face are derived from the crest area. They are not *in situ* deposits. Because deposits at the crest line presently vary with its height, this has resulted in what appears to be a fining eastwards sequence, when in fact the sediment was originally deposited in a coarsening upwards sequence, characteristic of deltas (Broussard, 1975).

At X2 the gravel deposits near the freshly exposed surface slid downslope until they stabilized, so that the clasts became imbricated downslope without establishing bedforms. At Y2 beds dip parallel to the slump face and may be interpreted as slopewash, because the dip is so steep and there are contortions.

The north-dipping sand layers of Y1 are difficult to explain. Either these beds have been subjected to localized rotational slumping, or they are remnants of the original deposit from water flowing to the north.

3.3 Interpretation of Field Results

In light of findings in Chapter 2 the deposits described here may be interpreted as follows.

3.3.1 First Glacial Event

The presence of Shield erratics on top of the plateau surfaces indicates that Laurentide ice covered the plateau on at least one occasion. The highly weathered lag of this granite-rich till implies that such an event occurred comparatively early in the Pleistocene, because weathering in a periglacial environment is a slow process.

The lack of glacial features found within the canyons themselves also suggests an early glaciation followed by a period of fluvial and periglacial erosion of such length that the effects of glacial scour and deposition are almost obliterated. Only the lag till remains on the plateau surfaces and weathered granitic clasts are found in small proportions in the sediments of the canyons and basins.

3.3.2 Glacial Advance and First Infilling Event

Section W, in Sundog Basin gives evidence for an infilling event when a subsequent ice sheet blocked eastern drainage routes. Water drained northwards from a source at the Nahanni-Ram Plateaux col, building an extensive delta deposit with a coarsening-upwards sequence into a lake occupying Sundog Basin and Ram Canyon. In the most economical interpretation of the sequence this event is also responsible for the sands and gravels in Footloose Creek at U1, which were deposited by water flowing out of Sundog Basin and into Ram Canyon during the initial stages of infilling and because the eastern outlet was blocked, the water accumulated. As the depth increased fine-grained sediments (U2) were deposited on top of the sands and gravels. Lake sediments deposited during this event are also found at M in Camp Creek, and at P1 and P2 in Golden Bowl. The level of the lake was 730 m (2,400 ft) as evidenced by the presence of alluvium to this elevation in the tributary canyons and Sundog Basin. As noted in Chapter 2, the lake drained north via the Scimitar and Sundog Canyons routes. When the ice mass retreated the lake drained eastwards and fluvial sediments dipping east were deposited over the lake sediments at Q.

3.3.3 First Re-excavation

The well-dissected nature of the deposits in Sundog Basin implies that they are remnants of an early infilling. The erosional contact between U2 and U3 in Footloose Creek, and the difference in the colour of the clays is evidence of a second lake phase after an extended period of erosion, during which much of the sediment in the canyons, especially Ram Canyon, was flushed out. Much of that in Sundog Basin remained because drainage was rerouted via Scimitar Canyon, where a bedrock sill held the local base level at a comparatively high elevation. The heads of Butler, Footloose and Leckie Canyons remained alluviated due to the incompetence of their streams.

3.3.4 Glacial Advance and Second Infilling Event

Evidence for the second infilling event is much more abundant. Water poured into Ram Canyon from the east and great thicknesses of cross-bedded sands and gravels with beds dipping west were deposited at A and B. The sediment choking the heads of Leckie, Footloose and Butler Canyons blocked drainage into Sundog Basin so the level of water rose until it overtopped the bedrock gorge at Scimitar Canyon. In the backwater area of Footloose Canyon, yellowish lake clays (at U and V) blanketed the earlier dissected deposits. In Camp Canyon there are fluvial deposits at L at an elevation of 550 m (1,800 ft) that could be part of a delta building out into a lake at this elevation. Well-rounded gravels at O in Subject Creek were probably deposited at the same time and by similar processes. Downstream in Camp Canyon at Section J are the slumped, fine-grained lake sediments with scree clasts incorporated in them. The 550 m terrace in Camp Creek (K) also contains fine-grained sediments with a large proportion of scree clasts.

Eventually Ram Canyon and its tributaries were filled with unconsolidated sediments up to 550 m. Braided channel deposits of sands and gravels dipping west are found at 490 m (1,600 ft) in Western Bowl and 460 m (1,500 ft) in Golden Bowl. This is evidence that the 550 m lake was initially drained by a river flowing to the west, perhaps when Scimitar channel was eroded down to an altitude of 460 m. Fluvial sediments were deposited laterally as the river cut down through the lake sediments. When the eastern outlet was re-opened the direction of flow was reversed and the rivers began entrenching into the unconsolidated infill.

3.3.5 Second Re-excavation

This period of downcutting is still continuing. Large-scale slumping of sediments has altered many of the original bedding structures, giving rise to the complicated nature of the deposits studied. The bedded sands and gravels at L in Camp Creek and F in Western Bowl have been rotationally slumped. The resulting mixture of scree, lake and fluvial deposits in Western Bowl was studied at D and E. In Sundog Basin, slumping is common also, with the most prominent example being at W.

The sediments close to the Ram River (at A, B, D, and G) are presently being excavated as the river follows its original channel configuration. There are several instances where the rivers have cut narrow gorges across bedrock spurs instead of following the previous channel which had been infilled, for example at Golden Gate and at the mouths of Leckie and Footloose Canyons.

CHAPTER FOUR

SUMMARY

The outline of events formulated in Chapter 2 proposes that after the paleodrainage system had evolved, water impounded by ice resulted in alluviation of: 1) Sundog Basin and canyons of Ram Plateau to 730 m (2,400 ft); 2) canyons of Ram Plateau to 550 m (1,800 ft) with a lowering or later infilling to 460 m; and 3) Tetcela Basin to 380 m (1,250 ft) with a lowering to 210-275 m (700-900 ft).

The field results discussed in Chapter 3 indicate that the plateau surfaces were glaciated at least once prior to any infilling events. Impoundment by ice during succeeding glaciations resulted in: 1) alluviation of Sundog Basin and canyons of Ram Plateau to 730 m; and 2) alluviation of canyons of Ram Plateau to 550 m followed by a lowering to 460 m when the lake was drained initially via Scimitar Canyon and then to the east.

The findings of the two chapters are thus in good agreement. Their correlation is outlined below and in Table 4.1.

4.1 Outline of Events Responsible for Deposition

4.1.1 Pre-Glacial Period

Prior to the known first glaciation, Ram River and its four tributaries Karst, Ridge, Sundog and Tundra Creeks drained the eastern

TABLE 4.1 SEQUENCE OF EVENTS RECOGNIZED FOR RAM PLATEAU STUDY AREA

NAME OF EVENT	COMMENTS
Post-glacial Period	- further excavation and dissection - slumping of unconsolidated sediments common - vertical cliff recession and extensive scree development continues
Tetcela Glaciation	- Lake Tetcela impounded in Tetcela Basin to 210-275m - drains north via Carlson Creek route
Third Interglacial	- re-excavation of infill, but not completely down to bedrock - much sediment remains in relict meander scars
Ram Glaciation	- Lake Ram impounded in Ram Canyon to 550m - lake drains north via Scimitar route
Second Interglacial	- initiation of Scimitar diversion route - excavation of infill, but not down to original bedrock floor
Sundog Glaciation	- Lake Sundog impounded in Ram Canyon and Sundog Basin to 730m - lake drains north via Sundog and Scimitar routes
First Interglacial	- antecedent Ram Canyon and subsequent tributary canyons are deeply incised into bedrock - vertical cliff recession and scree development resumes
Nahanni Glaciation	- Laurentide ice sheet covered entire study area - deposits till with granitic erratics
Preglacial Period	- paleodrainage pattern established - Ram Plateau upwarped - Ram River begins to cut antecedent canyon

slope of Tundra Ridge, and flowed eastward across a plain of little relief. Ram Plateau was upwarped and Sundog and Tetcela Basins were depressed. Ram River cut the antecedent Ram Canyon into the rising mass and its major head streams cut Butler, Footloose and Leckie Canyons. Minor tributaries initiated at this time began to incise S-N subsequent canyons along major joints or faults.

4.1.2 Nahanni Glaciation

The lag of a till containing Shield erratics found on the surface of Ram Plateau indicates that a Laurentide ice sheet covered the plateau and may have spread west across Sundog Basin. None of the erratics are fresh and they no longer have striations. According to Ford (pers. comm.) the till on the flanks of Nahanni Plateau and Tundra Ridge to 1,400-1,615 m (4,600-5,300 ft) is identical to that on Ram Plateau. It can, therefore be inferred that this ice sheet extended as far west as Tundra Ridge, and covered Sundog Basin.

The ice advance must have occurred before the canyons were well developed because the vertical limestone cliffs and extensive scree slopes show no signs of having been glaciated.

4.1.3 First Interglacial

After the withdrawal of this massive ice sheet, there was a lengthy period of fluvial erosion. Canyon development resumed and Ram River continued to entrench a deep meandering canyon into bedrock along a course very similar to that of today, except that drainage into the canyon was via Leckie, Footloose and Butler Canyons. The tributary canyons were incised into bedrock below their present level, (due to subsequent alluviation the bedrock floor has not yet been exposed except in a few places) even though they were probably not as wide as they are today.

Vertical cliff recession of Nahanni Limestones and extensive scree development have not been interrupted since this time, so the effects of glacial scour have been obliterated. Much of the till has been redeposited in the canyons over the extended period of time following the Nahanni Glaciation, so that the till on the plateau surface appears winnowed and small proportions of granitic clasts which are presently well-rounded and have no striations are found within all of the sediments studied in Ram Canyon, its tributary canyons and Sundog Basin.

4.1.4 Sundog Glaciation

The strongest evidence for a second ice advance is the presence of unconsolidated sediments up to an elevation of 730 m (2,400 ft) in Ram Canyon and its tributaries, and filling the extensive Sundog Basin. As in the cases of many other eastwardly draining basins of the Mackenzie Mountains where alluvial sediments have been found at similar elevations (e.g. North Redstone River Valley, (Prest *et al.*, 1967)) the only feasible explanation suggested to account for infilling to such high altitudes is the blocking of the lower eastern outlets by Laurentide ice. Evidence of extensive ice-dammed proglacial lakes at the periphery of the Laurentide ice sheet is ubiquitous.

Laurentide ice passed through the breaches in the Nahanni Range at Camsell Bend, Cli Lake, Little Doctor Lake and South Nahanni River and came to rest along the eastern flanks of Nahanni and Ram Plateaux, blocking the easterly drainage routes. That the ice sheet did not pass over the Nahanni Range is evidenced by the steep east-facing cuesta which shows no signs of glacier scour, and the lack of glacial features in the valleys of the western slope. Ice in the Tetcela Basin did not spread over the Ram Plateau, but lobes of ice fingering into the eastward draining canyons to various elevations blocked their drainage. Accumulation of meltwater and sediment resulted in alluviation of Tucker, Latham and Tetcela Canyons up to altitudes of 850 m (2,850 ft), 1,000 m (3,300 ft) and 945 m (3,100 ft) respectively.

Meltwater issuing from a larger ice lobe that occupied the 870 m (2,850 m) col between Nahanni and Ram Plateaux to an elevation of at least 945 m poured into Sundog Basin and into Ram Canyon via Butler and Footloose Canyons. Bedded sands and gravels dipping to the west, which were studied at Section U in Footloose Canyon and at Section G in Ram Canyon, were deposited at this time. With the eastern outlet of Ram River blocked by ice to an elevation of at least 730 m, the depth of the water increased and as shown at U, fine-grained lake sediments were deposited on top of the fluvial beds. What may be alternating beds of fine- and coarse-grained lake sediments are also found in Golden Bowl at Section P.

With Lake Sundog at an elevation of 730 m occuping Ram Canyon and Sundog Basin, lake sediments were deposited within the canyons and a delta began building northward into Sundog Basin (studied at W) alluviating the basin and the upper reaches of Butler, Foothoose and Leckie Canyons. Evidence of an outwash plain extending out from the ice lobe occupying the col between Nahanni and Ram Plateaux down to the 730 m lake level is still found at three locations at the southern end of Sundog Basin:

1. The terraces on the southwestern flank of Ram Plateau have a strong gradient to the north and an elevation of from 945 m to 760 m (2,500 ft).

2. An alluviated terrace over limestone to the west of the terraces has an elevation of 915 m (3,000 ft), and

3. The flat valley floors of Hiller and Texas Canyons are alluviated to 850 m (2,800 ft).

The tributaries of Ram Canyon all have alluviated deposits up to a consistent elevation of 730 m. The coarse sand and gravels at the head of Camp Creek (Section N) may be the fore-set deposits of a delta building out into the lake, and the fine-grained silts and clays at Section M may be either the distant deltaic deposits or lake bottom sediments.

Due to ice blocking outlets to the east, flow was diverted to the north over the ridge of shales extending across the northern end of Sundog Basin and over limestone bedrock above what is now Scimitar Canyon. Although these outlets are presently at much lower elevations, it is possible that they were as high as 730 m at that time. North of Scimitar Canyon, Jackson and Pratt Canyons have been alluviated to 670 m (2,200 ft) and the former directions of flow have been diverted to the west. Just south of these two canyons, yet north of Scimitar are terraces which slope to the north from 640 m to 550 m (2,100-1,800 ft) indicating the direction of flow.

4.1.5 Second Interglacial

After the Sundog Basin and Butler, Footloose and Leckie Canyons were alluviated to 730 m (2,400 ft) and the ice had withdrawn, the Ram River in Sundog Basin maintained a course similar to that initiated during the second glaciation, flowing northward across the partially buried ridge of shales. The river may have either continued flowing to the north or reversed the proglacial drainage direction to enter Ram Canyon via the Scimitar route. The latter is more plausible because if the river had drained into the North Nahanni River, the basin would show signs of having been more intensively excavated. The base level for erosion, therefore, must have been limited by bedrock at Scimitar as it is today.

The newly initiated streams draining the alluviated Butler, Footloose and Leckie Canyons were not competent enough to clear the heads of these canyons so the original drainage pattern was not resumed. Mounds of the fluvial beds grading upwards into lake deposits were left along the northern canyon wall of Footloose Creek and the downstream sections of Leckie and Butler Canyons were probably not completely excavated either. The other tributaries of Ram River were not competent enough to clear their canyons completely so evidence of the 730 m infilling is still present at their heads.

Ram River gradually cut down through the lake sediments as it flowed to the east through Ram Canyon, following its original channel and excavating almost all of the sediment. No evidence of infill at an elevation of 730 m has been retained in Ram Canyon because the competence of the Ram was much greater than that of the tributary streams and because no limit to the gradient had been imposed downstream. It is unlikely that the river reached its original bedrock-channel floor because fluvial deposits from this previous infilling event are only recently being incised at Section G. The depth of sediment still below river level is unknown because the river has cut down to bedrock at only two locations. The depth of sediment in portions of the tributary canyons remaining from this infilling event is also unknown for the same reason.

During the second interglacial the canyons slowly widened over the years as the limestone cliffs retreated and as the scree slopes extended outward over the infill along the sides of the canyons.

4.1.6 Ram Glaciation

The major evidence for a second infilling event is the presence of an obvious erosional contact between two distinctly different sediment types found everywhere in Footloose Canyon. Many features in the other canyons support this hypothesis.

Several lobes of a second Laurentide ice mass advanced through the breaches in Nahanni Range and coalesced in Tetcela Basin reaching an elevation of approximately 580 m (1,900 ft) along the eastern flank of Ram Plateau. Water pouring off of the ice sheet into Lake Canyon resulted in alluviation of this canyon to 560 m (1,850 ft). These deposits level out as a terrace at 550 m (1,800 ft) on which the only lake in Ram Canyon is situated.

Ice blocked the eastern outlet of Ram River and as meltwater flowed into Ram Canyon from the east, the crossbedded sands and gravels (studied at Sections A and B) which dip to the west were deposited. Because the heads of Leckie, Footloose and Butler Canyons were still alluviated to 730 m (2,400 ft), the fluvial environment changed to a lake environment (Lake Ram). The depth of the water increased until the northwestern outlet via Scimitar at an altitude of 550 m was overtopped. Sundog Basin was not affected by this infilling event because the 730 m elevation of infill at the heads of Butler, Footloose and Leckie Canyons prevented the water in Ram Canyon from draining into the basin. Also, the ice did not advance as far as it did during the second glaciation when it occupied the 870 m (2,850 ft) col between Ram and Nahanni Plateaux, to discharge large quantities of water into Sundog Basin.

Evidence of this infilling event remains in Ram Canyon at a consistent elevation of 550 m in Eastern Bowl, Western Bowl and Golden Bowl. In the tributary canyons there are terraces and/or delta-like deposits at this elevation also. Sections studied include beds of sand and gravel in Camp Creek at Section L, gravels in Subject Creek at Section O, and a large terrace of fine-grained deposits incorporating scree clasts at Section K in Camp Creek. Smaller terraces are found at this elevation in Raynor, Subject and Mike Canyons.

In the lower reaches of the canyons there is an abundance of fine-grained alluvium. For example, at Section J in Camp Creek there are sandy silt deposits with scree incorporated within them. In what would have been a backwater area in Footloose Creek, yellow silt and clay lake sediments blanket the previously eroded deposits of the earlier infilling event such that bedding is parallel to the surface configurations.

Bedded sand and gravel deposits found at an elevation of 490 m (1,600 ft) (Section F) in Western Bowl and at 460 m (1,500 ft) (Section R) in Golden Bowl indicate that after the canyons had been alluviated to approximately 550 m the lacustrine environment was altered to a fluvial environment in which a river flowed to the west. The Scimitar channel must have been eroded down from an elevation of 550 m to an elevation of 460 m in order to initiate such a sudden change in environment. The lip of the gorge still has an elevation of 460 m, possibly due to recession of the nickpoint as opposed to lowering. The 580 m elevation of alluvium in the valley north of Scimitar is problematical. Perhaps the valley was alluviated to this elevation after the lake drained through it at 460 m.

There is also evidence on the topographic maps and air photos for an outlet at 460 m between the eastern flank of Ram Plateau and shale outliers north of Ram River. In view of the results of sediment analysis of deposits within the canyons, it is proposed that this was used when the ice sheet retreated to a stationary front at 460 m. What appears to be a recessional of terminal moraine on the air photos between two of the shale outliers may have been deposited at this time. The middle section of Karpuk Canyon has been alluviated to 460 m in much the same way as was Lake Canyon during the second glaciation and the upstream part of the creek has been diverted to the south. The mouth of Tucker Canyon shows alluviation to 460 m also and the stream has eroded into its original canyon wall and now flows to the east, leaving alluvium choking the southeasterly channel. At the southwestern end of Tetcela Basin along the southeastern flank of Ram Plateau there is an expansive terrace at an elevation of 425-460 m (1,400-1,500 ft) that may have been created when the ice in the basin retreated far enough to pond water here but not far enough to expose the lower regions of the basin or the South Nahanni River. It may also be possible that the Tetcela Basin was filled with till at a higher elevation and that the till has subsequently been eroded.

4.1.7 Third Interglacial

The third interglacial was again a period of extensive excavation of the sediment infilling Ram Canyon and less intensive dissection of that in the tributary canyons and Sundog Basin. Ram River draining Sundog Basin resumed its course south via Scimitar over the bedrock lip at 460 m (1,500 ft) incising a 120 m deep and narrow gorge: Scimitar Canyon. That the river did not flow north to North Nahanni River is evidenced by the limited depth of excavation in Sundog Basin, restricted by bedrock at Scimitar, and present alluviation of Glew Spillway to 580 m (1,900 ft).

There have been no subsequent infillings of Ram Canyon so many of the erosional processes initiated at this time are still continuing. As Ram River cut into the alluvium, lateral deposition of sands and gravels covered most of the lake sediments which are exposed in only a few places. Many of the sand and gravel beds have been either massively or rotationally slumped; either due to undercutting by streams and rivers or because the lake clays underlying them have given way. Instances of the latter process are Section W in central Sundog Basin and possibly the massive slump deposits found in Western Bowl. The sand and gravel beds at Section L in Camp Creek also appear to have been rotationally slumped, however the reasons and mechanisms are unknown. Massive slumping of fine-grained sediments and scree clasts is characteristic in the lower reaches of Camp Creek, at Section J.

Except in a few places within the plateau area, Ram River and its tributaries have followed the original channels cut into bedrock prior to alluviation. At the mouths of Footloose and Leckie Canyons (Sections S and T) the original channels have remained infilled while the streams have cut narrow gorges in bedrock spurs a short distance away. Instead of flowing around through Golden Bowl, Ram River has shortened its course by downcutting into a bedrock spur at Golden Gate. The sediment still occupying the ancient meander bowls has yet to be eroded before the Ram follows its original course completely.

4.1.8 Tetcela Glaciation

There is evidence for another glaciation east of Ram Plateau but not in Sundog Basin or the Canyons of Ram Plateau. Because fluted ground moraine is found east of Nahanni Range but not to the west, it appears that Laurentide ice advanced only as far as the mountains.

Tetcela Basin was alluviated to 210-275 m (700-900 ft) by Lake Tetcela impounded to an elevation of 275 m which drained northward via North Nahanni and Carlson Rivers over a low col with a present altitude of 260 m (850 ft). Another lake impounded in the South Nahanni River basin by ice at the mouth initially drained northward into Tetcela Basin over a 380 m (1,250 ft) breach between Ram Plateau and Mattson Mountain, and then through the Fishtrap Creek channel at an elevation of 250 m (800 ft) between Mattson Mountain and Silent Hills as the ice retreated. Meltwater also poured into the basin through breaches at Cli Lake and Little Doctor Lake, where remnants of an alluvial fan still exist, and through the breach at Grainger Creek, where it deposited material to an elevation of 560 m (1,850 ft) at the head of Grasper, Grainger and Bluefish Creeks.

4.1.9 Post-Glacial Period

Tetcela Basin has not been as extensively dissected as Sundog Basin or Ram Canyon due to its much more recent alluviation. At the mouth of Ram Canyon there is a series of terraces at elevations ranging from 245-275 m (800-900 ft) that were carved by the migrating channel as

Ram River cut down into the lake sediments.

The profusely meandering Tetcela River, Fishtrap Creek and Bluefish Creek have incised narrow floodplains slightly below the level of alluvium. Because the basin is so flat the marshy headwaters of the southerly draining Fishtrap and Bluefish Creeks are at almost the same level as the north-flowing Tetcela River drainage system. The abundance of marshland may indicate the presence of impervious lake clays within the central area of the basin.

4.2 Correlation With Other Studies

In the Ram River Area of the Mackenzie Mountains evidence has been found for four major Laurentide ice advances and three proglacial lake phases. These can be tentatively correlated with results of studies in other areas of the Mackenzie Mountains. The correlation with events in Nahanni Plateau proposed by Brook (1976), Ford (1976) and Harmon *et al.* (1977) is outlined in Table 4.2.

It has been suggested that during the first glaciation ice covered the entire field area and extended as far west as Tundra Ridge. In the South Nahanni River area, Ford (1976) and Brook (1976) have determined that the granitic erratics there were emplaced more than 350,000-400,000 years B.P., during the greatest incursion of Laurentide ice into the Mackenzie Mountains. The lag deposits are so similar on Ram Plateau (Ford, pers. comm.) that they may be assigned to the event recognized by Ford and Brook: the "Nahanni Glaciation".

During Sundog Glaciation a lake was impounded at an elevation of 730 m (2,400 ft) in Sundog Basin and Ram Canyon, resulting in infilling

TABLE 4.2 TENTATIVE GLACIAL CHRONOLOGY AND CORRELATIONS FOR THE SOUTHEASTERN MACKENZIE MOUNTAINS

DATE (years B.P. $\times 10^3$)	EVENTS IN RAM PLATEAU	EVENTS IN NAHANNI PLATEAU	
Harmon et al. (1977)	CROSBIE (1978)	FORD (1976)	BROOK (1976)
POST GLACIAL			
WISCONSINAN	TETCELA GLACIATION (Lake Tetcela, 210-275m)	JACKFISH GLACIATION (Lake Jackfish 280m) (Lake Tetcela, 400m)	JACKFISH GLACIATION (Lake Tetcela, 400m) CLAUSEN GLACIATION (Lake Nahanni, 640m)
SANGAMON INTERGLACIAL			
ILLINOIAN 150-180	RAM GLACIATION (Lake Ram, 550m)	CLAUSEN GLACIATION (Lake Nahanni, 580-650m)	SUNDOG GLACIATION (Lake Sundog II, 670m)
YARMOUTH INTERGLACIAL			GROTTE VALERIE INTERGLACIAL II
KANSAN 235-275	SUNDOG GLACIATION (Lake Sundog, 730m)	cold phase	DEATH CANYON GLACIATION (Lake Sundog I, 790-850m)
AFTONIAN INTERGLACIAL			GROTTE VALERIE INTERGLACIAL I
NEBRASKAN 7400	NAHANNI GLACIATION	FIRST CANYON GLACIATION	FIRST CANYON GLACIATION

to this level plus alluvial fan deposition at the southern end of Sundog Basin that descends from 945 m (3,100 ft) down to the 730 m lake level. To explain the two levels of alluviation, Brook (1976) unnecessarily proposed two infilling events: Lake Sundog I (790-850 m (2,600-2,800 ft)), and Lake Sundog II (730-760 m (2,400-2,500 ft)). Because the only evidence for deposition above 730 m is found at the southern end of Sundog Basin it is more likely that they were deposited by water descending to a lake at 730 m from the surface of an ice lobe occupying the col between Nahanni and Ram Plateaux. Brook's hypothesis is less likely because for Laurentide ice to have blocked all outlets less than 850 m at the northern end of Sundog Basin, Ram Canyon would have also been filled with ice and evidence shows that this was not the case.

During Ram Canyon Glaciation, a third ice mass abutted against the eastern flank of Ram Plateau and impounded a 550 m (1,800 ft) lake within Ram Canyon. Alluviation of Lake Canyon to 560 m (1,850 ft) and erosion of its eastern canyon wall is evidence that Lake Nahanni (580-650 m (1,900-2,350 ft)) which was impounded by Clausen ice (Ford, 1976) drained northward between the edge of the ice mass and the flank of Ram Plateau and into the lake in Ram Canyon via Lake Canyon. The clays along both South Nahanni River and Footloose Canyon which date from this event are buff-coloured (Weirich, in litt.). This is another indication that the two drainage systems were linked. There is insufficient evidence from this study to determine whether the Ram Canyon (or Clausen) glaciation should be ascribed to the Illinoian (Ford, 1976) or Early Wisconsinan (Brook, 1976).

A lake in Tetcela Basin at 245-275 m (800-900 ft) impounded during the Tetcela Glaciation correlates with Lake Tetcela which was impounded by Jackfish Ice during the "Classical Wisconsinan" to an elevation of 400 m (1,320 ft) along South Nahanni River (Ford, 1976; Brook, 1976). This lake drained into Tetcela Basin over a col at an altitude of 380 m (1,250 ft) between Ram Plateau and Mattson Mountain. When the ice front at the mouth of South Nahanni River retreated farther east, the lake level lowered to 245 m and drained into the lake occupying Tetcela Basin, cutting a prominent channel at 245 m between Mattson Mountain and Silent Hills.

Absolute dates of glacials and interglacials cannot be calculated for the Ram Plateau area due to the lack of datable material. It is considered that the results of ^{230}Th - ^{234}U dating of $CaCO_3$ speleothem from caves in Nahanni Plateau (Ford, 1976) are relevant to the interpretation of the glacial history. In Nahanni Plateau the times of speleothem growth during warm climatic periods (often interglacials) have been dated and the ages of the hiatuses during cold climatic periods (often due to glacierization) have been inferred (Harmon *et al.*, 1977). There is evidence for widespread glaciation >400 ka B.P. (Nahanni Glaciation). This was followed by a very lengthy interglacial which Harmon *et al.*, suggest may be the "Great Interglacial" older than 200 ka B.P., which was initially proclaimed by Penck and Bruckner (1909) and supported by other research in northern Europe during succeeding decades before being recently criticized. The Sundog and Ram Glaciations may be correlated with the second and third periods of glaciation dated at 235-275 ka B.P. and 150-180 ka B.P. The final glacial event, Tetcela Glaciation, during the Wisconsinan is dated at 15-90 ka B.P.

North of the study area evidence for at least one (possibly two) Laurentide ice incursions up to elevations of between 1,070-1,525 m

(3,500-5,000 ft) has been found by:

1. Craig (1965) in the eastern Mackenzie Mountain area,
2. Rutter and Boydell (1973) in the Upper Mackenzie River area,
3. Hughes (1969) along the east flank of Richardson Mountains and north flank of Mackenzie Mountains,
4. Gabrielse *et al.* (1973) in the Flat River, Glacier Lake and Wrigley Lake map areas, and
5. Rutter (1974) for the northern and southwestern District of Mackenzie.

A second ice advance reaching an elevation of 670 m (2,200 ft) is recognized by Rutter and Boydell (1973) and there is a general concensus among all authors that the most recent "Classical" Wisconsinan ice sheet left most of the Mackenzie Mountains unglaciated. However, the elevations cited vary. Even though no direct correlations can be made based on the data published, it is obvious that the Mackenzie Mountains contain evidence for at least three glacial advances from the east during the Pleistocene, terminating at successively lower altitudes.

Correlation with impounded lake phases for other regions of the Mackenzie Mountains is also difficult. Evidence has been cited for proglacial lakes in the North Redstone River Valley up to an elevation of 760 m (Prest *et al.*, 1967), Bonnet Plume, Bell, Old Crow and Bluefish Basins (Hughes, 1969) and in the Bulmer Lake and Wrigley Lake map-areas up to an elevation of 396 m (1,300 ft) (Rutter and Boydell, 1973). All of these lakes, like those in the Ram River region, drained to the north, and infill along the northward diversion courses of the major W-E flowing rivers (e.g. Carcajou, North Redstone and North Nahanni Rivers) indicates this.

4.3 Concluding Remarks

Evidence suggests that there have been at least two to three Laurentide ice incursions into or as far as the eastern Mackenzie Mountains, and four in the Nahanni-Ram region which has been studied in more detail than the other sites. The number of glacial advances is difficult to correlate due to the different localities studied, and the possibility that later ice advances removed traces of earlier events locally.

From all reports it is clear that Cordilleran ice did not penetrate east of the western margins of the Canyon Ranges and local cirque glaciers occupied only the highest or most sheltered spots. The ice-free, inter-range valleys and straths functioned as lake basins and spillways, collecting the Cordilleran and Laurentide meltwaters and channelling them northward through a series of troughs. During each interglacial the troughs were abandoned and the east-flowing cordilleran drainage patterns were resumed. The stratified, proglacial sediments were dissected along courses normal to trough orientations.

The morphological complexity of the region coupled with the certainty that these events were repeated several times (with the Laurentide ice sheets terminating at significantly different elevations for each recognized glaciation) have created a record which is difficult to interpret. The present findings are in accordance with those of other authors whose work pertains to the Mackenzie Mountains. The contribution of this study is to have offered a comparatively detailed explanation of the events for a particularly critical area of Laurentide ice incursion.

APPENDIX A

Pretreatments

Pretreatments were necessary for several samples before analysis. Carbonate-cemented sands were placed in a beaker of 1N NaOAc (pH 5) and heated at 80°C for 30 minutes and filtered under suction on a Buchner funnel and then washed twice with distilled water on a Buchner funnel. This method, suggested by Bunting and Campbell (1976) was preferred to that by Folk (1974) in which dilute HCl is used so that the fine-grained carbonates would be dissociated and not dissolved. Minor amounts of organic material in some samples were removed by "Loss on Ignition". The sample was heated in an oven at 500°C for 20 minutes as suggested by Bunting (pers. comm.).

Granulometric Analysis

Sieving analysis was carried out according to the method outlined by Folk (1974). Each sample was dried at 105°C for 24 hours and allowed to cool for at least five hours. Any aggregates were separated by pounding small fractions of the sample at a time in a porcelain mortar with a rubber cork. The weight of sample to be sieved varied from 50-100 gms for sandy samples and 100-450 gms for samples containing fine gravels. Coarse fractions were sieved by hand at ½ phi (ϕ) intervals down to -3.0ϕ and fine fractions were mechanically sieved at ½ϕ intervals on Endicott Screens, 20.3 cm (8 inches) in diameter for 15 minutes. The fractions retained on each sieve were weighted to 0.01 grams on a chemical balance (Mettler P1200). The raw weight data was converted to percentage values and cumulative percentage values. Plots of cumulative percentage against ϕ diameter (where $\phi = -\log_2$ (diam. in mm) were drawn in order to determine the 5, 16, 25, 50, 75, 84 and 95th percentiles required to calculate Folk Statistics using the FORTRAN programme SEDS which was used by Klovan at the University of Winnipeg and modified by Lakhan at the University of Toronto. Moment measure statistics were calculated by the FORTRAN programme SEDANL which was written for Wood Hole Oceanographic Institute and subsequently modified by Ingram in 1968 and Stewart (1976) at McMaster University. This programme also plotted an histogram and an interpolated cumulative percentage curve for each sample.

Calculating Folk Statistics (Folk and Ward, 1957)

$-\phi = \log_2$ diam (mm)

Md — Median

$$Md = \phi 50$$

Mz — Graphic Mean

$$Mz = \frac{\phi 16 + \phi 50 + \phi 84}{3} \ \phi$$

σ_I — Inclusive Graphic Standard Deviation

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6} \ \phi$$

SK_I — Inclusive Graphic Skewness

$$SK_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

K_G — Inclusive Graphic Kurtosis

$$K_G = \frac{\phi 95 - \phi 5}{2.44 \times (\phi 75 - \phi 25)}$$

Descriptive Meaning of Statistical Values (Folk, 1974)

Sorting

σ	>.35	very well sorted
	.35-.50	well sorted
	.50-1.0	moderately sorted
	1.0-2.0	poorly sorted
	2.0-4.0	very poorly sorted
	>4.0	extremely poorly sorted

Kurtosis

<.67	very platykurtic
.67-.90	platykurtic
.9 -1.11	mesokurtic
1.11-1.50	leptokurtic
1.50-3.00	very leptokurtic
>3.00	extremely leptokurtic

Skewness

-1.0 to -.30	very negative skew
-.30 to -.10	negative skew
-.10 to +.10	nearly symmetrical
+.10 to +.30	positive skew
+.30 to +1.0	very positive skew

Calculating Moment Measure Statistics (Griffiths, 1967, p.88)

- for grouped data

First Moment
Mean

$$Mg = \frac{1}{\Sigma f_i} \sum_{i=1}^{k} f_i m_i$$

Second Moment
Variance

$$\sigma_g^2 = \frac{1}{\Sigma f_i} \sum_{i=1}^{k} f_i (m_i - m_g)^2$$

Standard Deviation

$$\sigma = \sqrt{\sigma_g^2}$$

Third Moment

$$m_3 = \frac{1}{\Sigma f_i} \sum_{i=1}^{k} f_i(m_i - m_g)^3$$

Skewness

$$sk = \frac{m_3}{2\sigma_g^3}$$

where, f = frequency

m = value of midpoing

Mg = value of mean

APPENDIX B

Fabric analyses were completed for five of the profiles in the Central Canyon area. Using a Brunton Compass, bearing and plunge were measured for the long (A) and intermediate (B) axes for elongate clasts having an A axis of at least 2.5 cm. For each clast, the lengths of the three axes (measured at right angles), shape, angularity or roundness and type of rock were also noted. At least 50 clasts were chosen from each profile.

The data for each section were plotted on a Rose Diagram and a Lambert Equal Area Polar Net. For a Rose Diagram, the number of clasts having a dip orientation within each 20° class interval is recorded by placing a dot at the midpoint of the appropriate class interval. Each circle away from the centre (zero clasts) represents one additional clast.

A Lambert Equal Area Net can be used only when the bearing and plunge for the A and B axes are known. The great circle in the lower hemisphere through which these two lines pass defines the strike and dip angle of the plane. The pole normal to this plane can then be plotted as a unique point.

Fabric studies are useful because they reveal the preferred orientation or imbrication of bladed or platy clasts. The planes of clasts are commonly oriented so that they dip upcurrent in a fluvial environment (Blatt *et al.*, 1976) and downslope in a mudflow deposit

(Lindsay, 1968). The long axis tends to be oriented parallel to or transverse to direction of ice flow in a till deposit (Glen *et al.*, 1957).

The two dimensional characteristics of the fabric analysis data were statistically analyzed according to the method in Curray (1956). The data are treated as a circular frequency distribution unlike linear statistical methods so that the measures of central tendency and dispersion will not vary with the choice of origin or dividing point. The programme calculates: the vector direction (or measure of central tendency); the vector magnitude as a percentage value (or degree of preferred orientation); and the probability that the preferred orientation is real and not merely due to chance using the x^2 test. The vector magnitude is related to standard deviation using the graph in Curray (1956, p.123). The FORTRAN program used for this analysis was written by Martini and modified by Walker at McMaster University.

APPENDIX C

Sample	Median Diameter	Mean Diameter	Standard Deviation	Skewness	Kurtosis
A2 coarse	.70	-.40	2.34	-.57	1.17
A2 fine	2.40	2.37	.96	-.03	.97
D7 (mm)	1.68	1.43	1.65	-.40	-.19
D8 (mm)	2.21	1.81	1.96	-1.10	1.23
D9 (mm)	-1.34	-1.09	2.48	.54	-.95
D10	1.27	.99	2.39	-.14	.82
D11	.40	-.33	2.95	-.24	.65
E2	1.68	1.51	1.33	-.24	.97
E3	2.18	2.17	.90	-.09	1.38
E4 (mm)	-.26	-.68	2.55	-.26	-1.16
E5	1.35	1.31	1.50	-.24	2.01
E6	1.24	1.10	1.62	-.23	1.88
F1	-.14	-.29	1.99	-.05	1.15
F2	2.35	2.22	1.16	-.20	1.46
F5	.44	.74	1.64	.29	1.61
F6	.58	.77	1.40	.23	1.14
F8 (mm)	-1.58	-1.51	1.91	.64	-.12
F9	-.90	-.74	1.72	.20	1.06
F10	-.10	-.10	1.52	.07	1.16
F11	.97	1.20	1.62	.16	1.40
G1 (mm)	-1.47	-1.45	1.90	.50	.14
G2	-1.80	-1.63	1.70	.25	1.03
G4	1.40	1.48	1.25	.07	1.51
G5	-.50	-.43	1.65	.10	1.00
G8 (mm)	-4.38	-3.60	2.19	1.75	2.32
J (mm)	2.58	1.68	2.31	-.70	-.70
L3 (mm)	-2.32	-1.91	2.03	.64	-.89
L4	1.45	1.47	.83	.09	1.13
L5 (mm)	.09	-1.05	2.66	-.09	-1.60
L6	2.05	2.08	.96	.07	1.14
L7	1.35	.72	2.00	-.43	1.03
L8	1.77	1.77	1.10	-.03	1.14
L9	.66	.38	1.62	-.27	1.06
L10	1.85	1.78	1.31	-.07	1.19
L11 (mm)	-2.41	-2.00	2.30	.45	-1.19
L12	1.55	1.56	.88	.05	1.24
L13	.93	.56	1.53	-.46	2.02
L14	1.68	1.68	1.06	-.04	1.13
L15	.66	.04	1.78	-.45	.97
L16	1.20	1.20	.94	-.06	1.13
L17	.36	.27	1.25	-.14	1.08
L18	1.26	1.02	1.21	-.31	1.09
L20	1.02	1.03	.81	-.04	1.09
L21	1.50	1.50	.92	.03	1.03
L22 (mm)	-2.84	-2.30	2.05	.61	-.84
M1	1.93	2.05	1.05	.18	1.06
M3	1.75	1.92	.88	.36	1.58
M5	2.23	2.38	.85	.26	1.00
Q1	1.00	1.00	.80	.10	1.23
Q3	-.20	.00	1.19	.33	1.15
Q4	1.68	1.79	1.05	.25	1.48
Q5	.50	.53	.96	.13	1.20
R1 (mm)	2.75	1.57	2.66	-.84	-.52
R8	1.50	1.47	.74	-.03	1.09
U1	.20	.20	.77	.07	1.15
U2	-2.65	-2.65	1.70	.21	1.20
U4 (mm)	3.98	2.86	1.20	-.52	-1.04
V1 (mm)	-.72	-.59	1.65	.49	-.38
X2	-2.40	-2.05	1.18	.43	.82

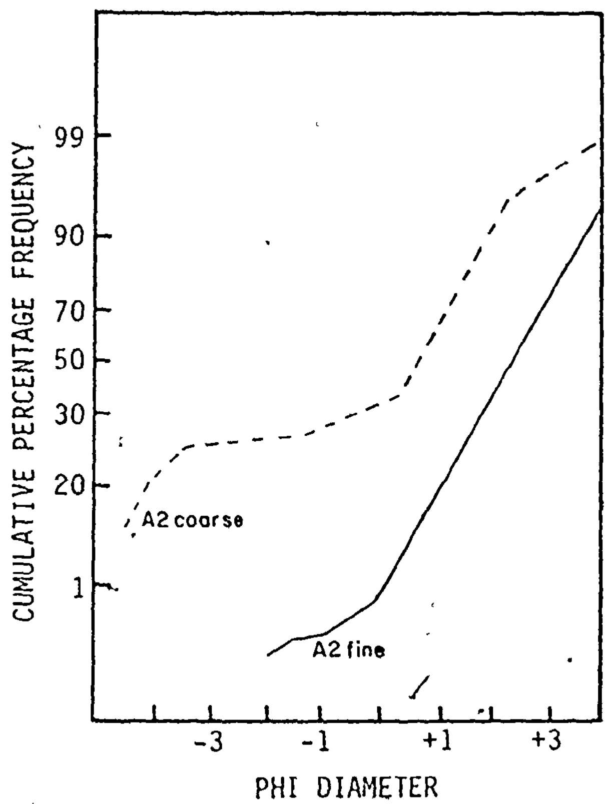
Data calculated using Folk Statistics except where (mm) denotes Moment Measure Statistics.

GRAIN SIZE SCALE

PHI SCALE -phi = $\log_2$ diam (mm)	SIEVE DIAMETER (mm)	WENTWORTH-LANE CLASS LIMITS	
-9.0	512.		
-8.5	362.		BOULDERS
-8.0	256.		
-7.5	181.	large	COBBLES
-7.0	128.		
-6.5	90.50	small	COBBLES
-6.0	64.00		
-5.5	45.25	v. coarse	GRAVEL
-5.0	32.00		
-4.5	22.63	coarse	GRAVEL
-4.0	16.00		
-3.5	11.31	medium	GRAVEL
-3.0	8.00		
-2.5	5.66	fine	GRAVEL
-2.0	4.00		
-1.5	2.83	v. fine	GRAVEL
-1.0	2.00		
-0.5	1.414	v. coarse	SAND
0.0	1.000		
0.5	.707	coarse	SAND
1.0	.500		
1.5	.354	medium	SAND
2.0	.250		
2.5	.1768	fine	SAND
3.0	.1250		
3.5	.0884	v. fine	SAND
4.0	.0625		
4.5	.0442	coarse	SILT
5.0	.0313		
5.5	.0221	medium	SILT
6.0	.0156		
6.5	.01105	fine	SILT
7.0	.00781		
7.5	.00552	v. fine	SILT
8.0	.00391		
8.5	.00276	coarse	CLAY
9.0	.00195		
9.5	.00138	medium	CLAY
10.0	.00098		
		fine	CLAY

(Folk, 1974)

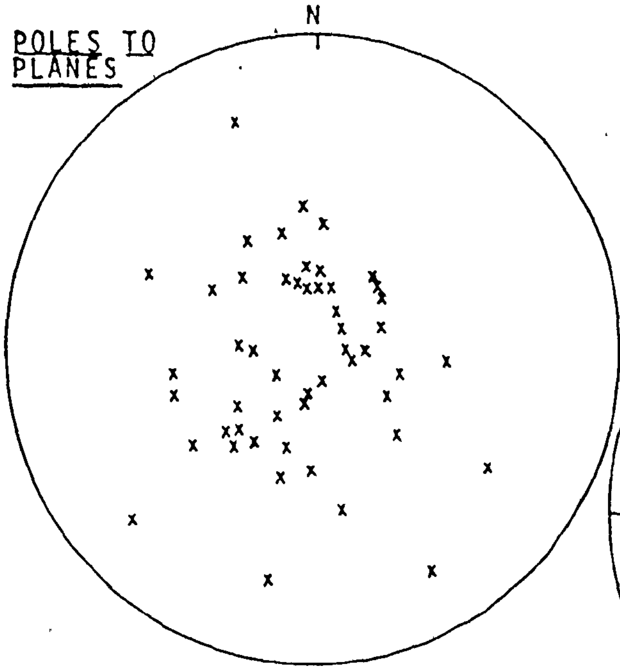
SECTION A



CUMULATIVE PERCENTAGE FREQUENCY
99
90
70
50
30
20
1
A2 coarse
A2 fine
-3
-1
+1
+3
PHI DIAMETER

SECTION D

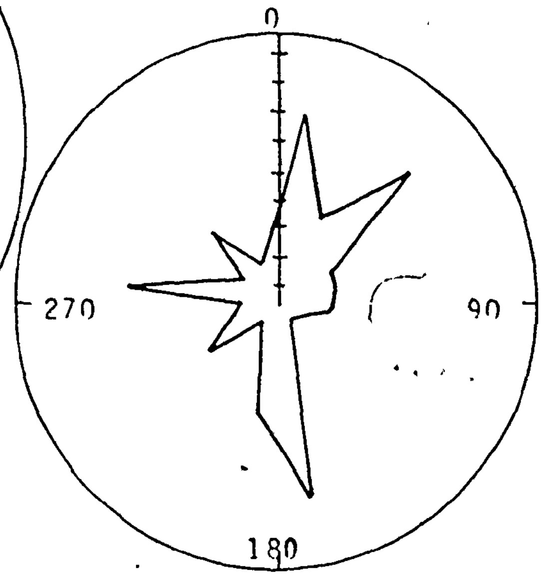
POLES TO PLANES



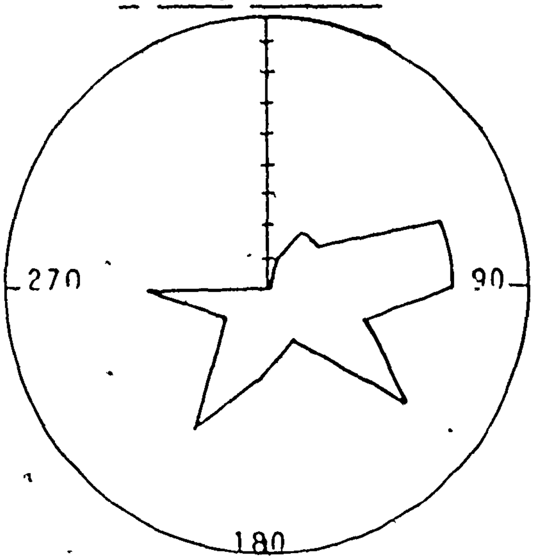
NUMBER OF CLASTS = 50

DIP AZIMUTH FOR PLANES OF CLASTS

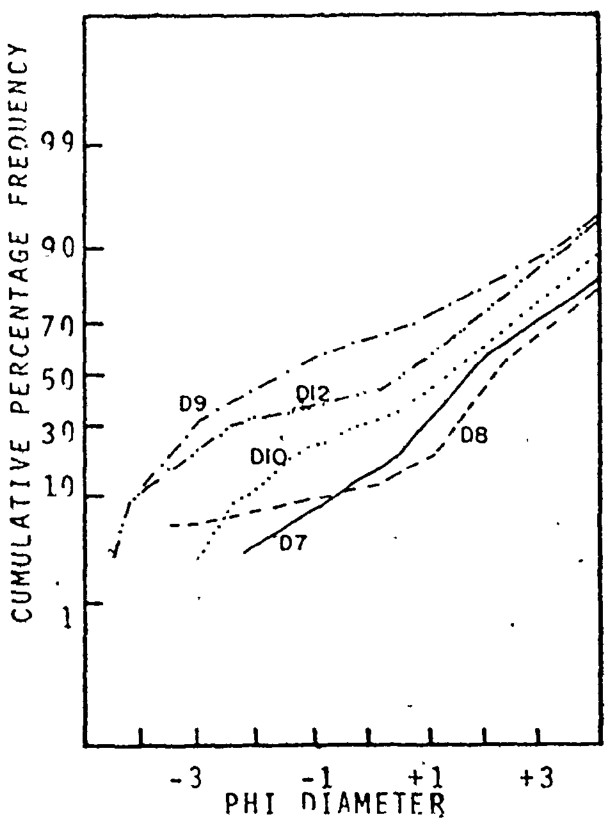
θ = 68.0° χ^2 = 0.4 at
VL = 5.7%   <25%
σ = 100°



A AXIS AZIMUTH

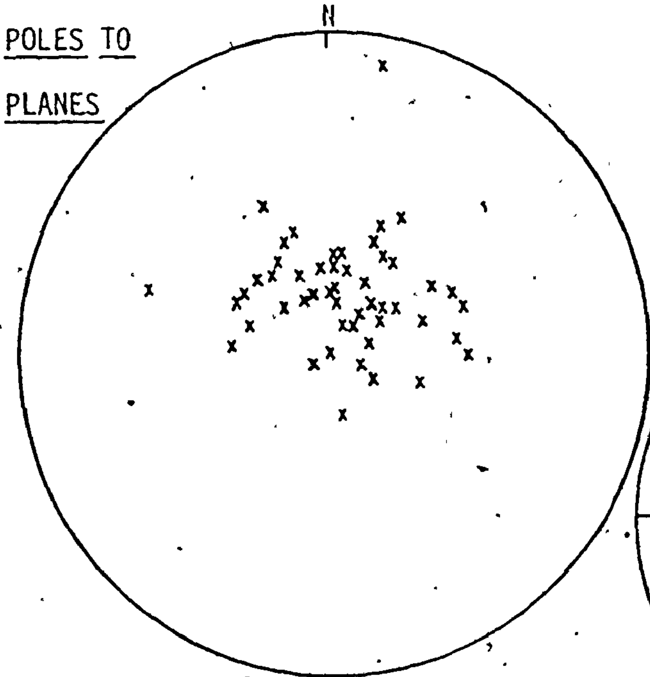


θ = 127.5° χ^2 = 6.9 at
VL = 26.3%   >95%
σ = 86°



SECTION E

POLES TO PLANES

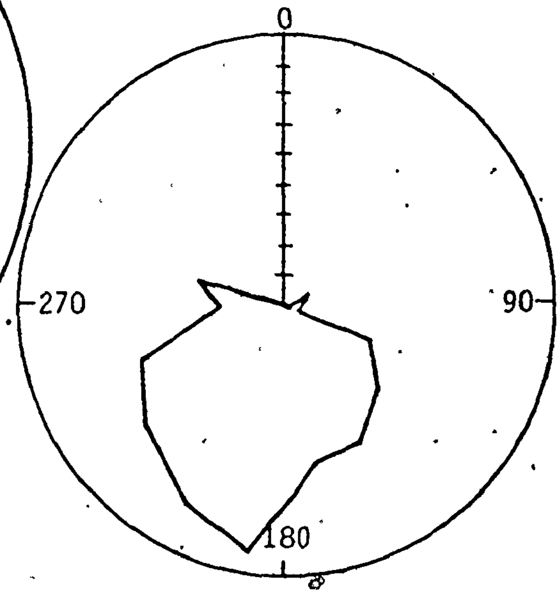


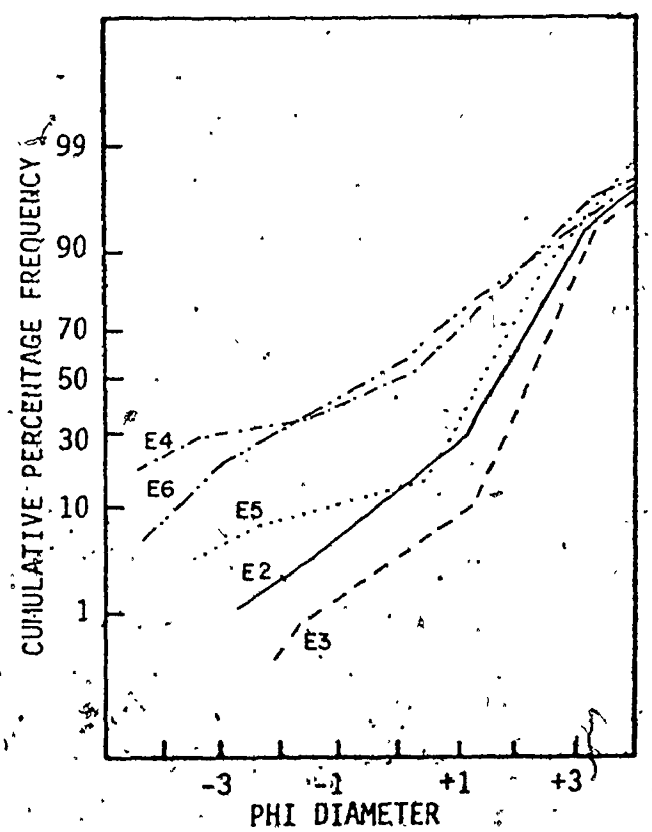
NUMBER OF CLASTS = 50

DIP AZIMUTH FOR PLANES OF CLASTS

θ = 194.8°
VL = 64%
σ = 54°

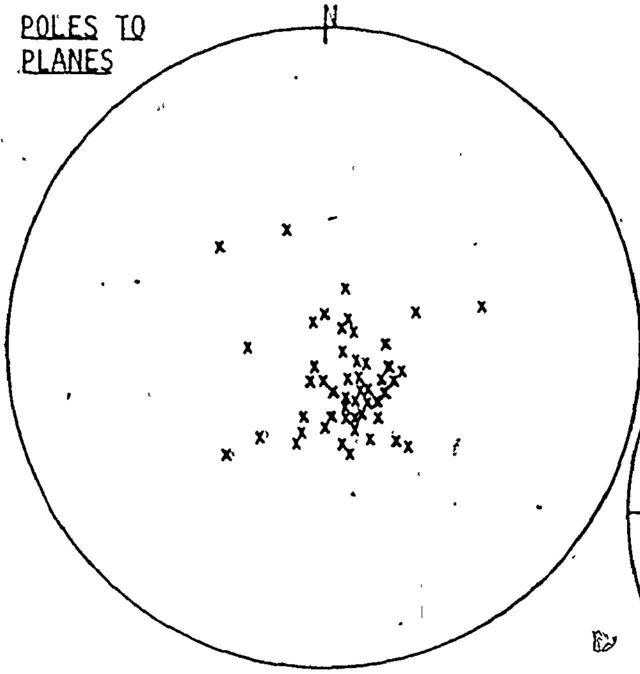
χ^2 = 35.8 at >99.5%





SECTION F

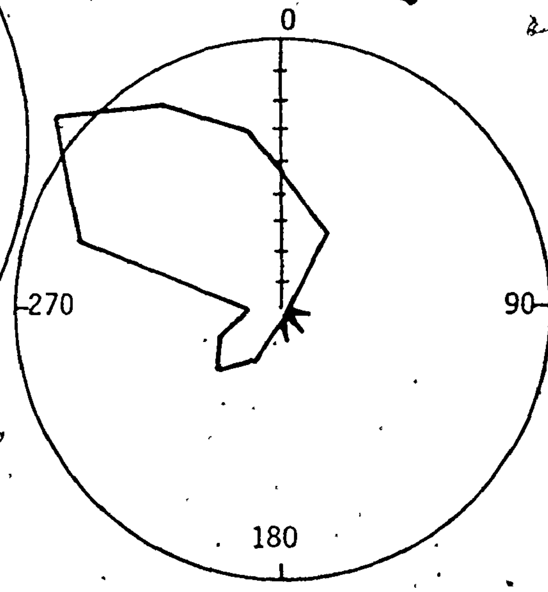
POLES TO PLANES



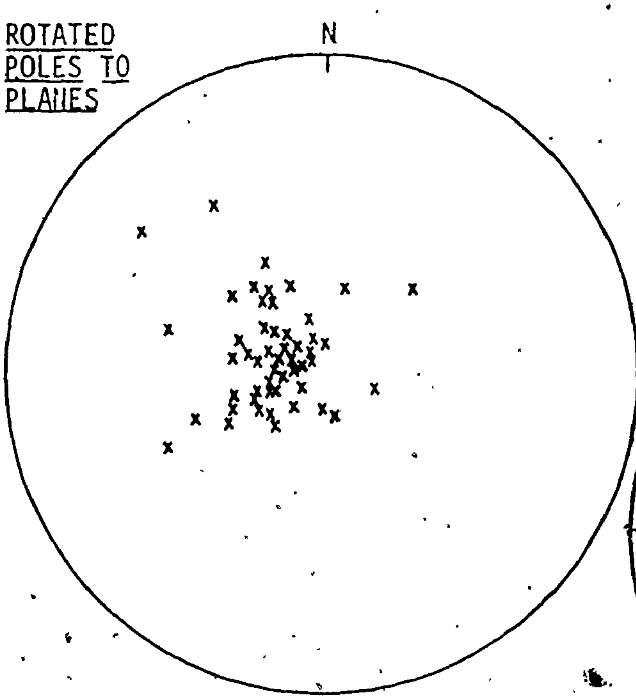
NUMBER OF CLASTS = 50

DIP AZIMUTH FOR PLANES OF CLASTS

θ = 316.4° χ^2 = 36.3 at >99.5%
VL = 58.9%
σ = 58°



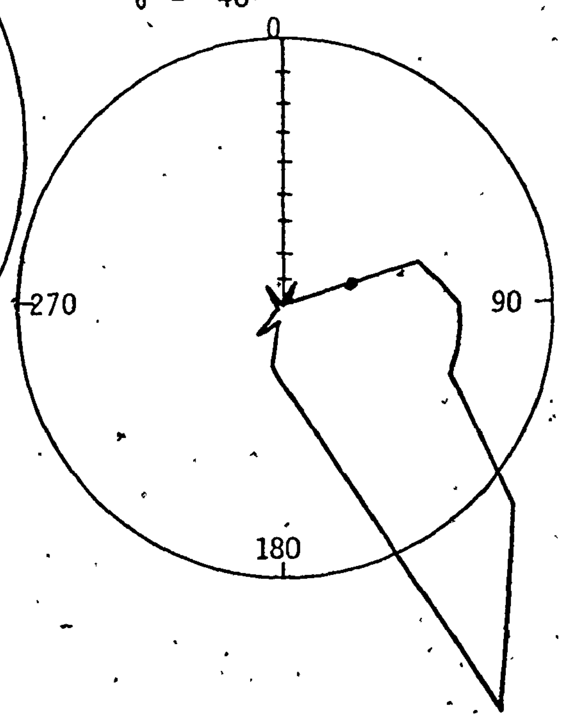
ROTATED POLES TO PLANES



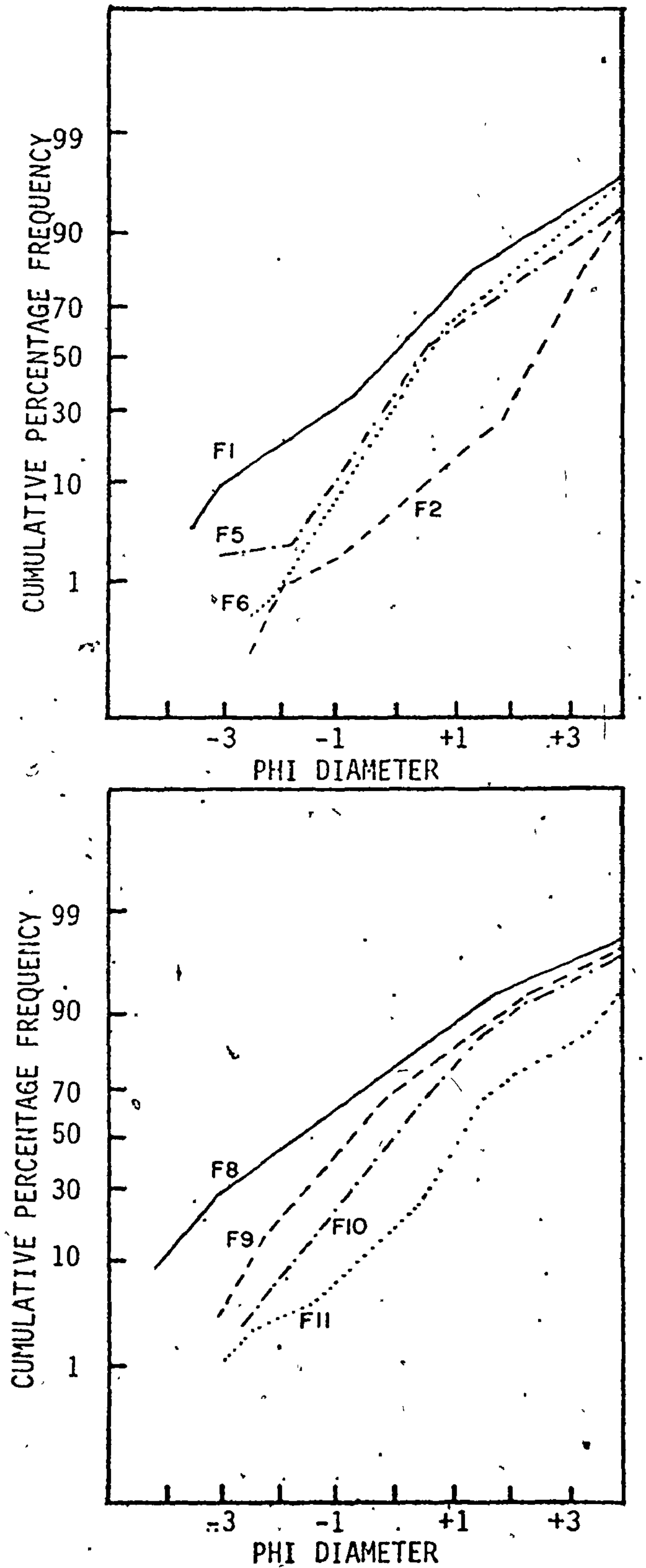
NUMBER OF CLASTS = 50

DIP AZIMUTH FOR PLANES OF CLASTS AFTER ROTATION OF 30°NW AROUND A STRIKE LINE OF 45°

θ = 127.0° χ^2 = 60.3 at >99.5%
VL = 79.3%
σ = 40°

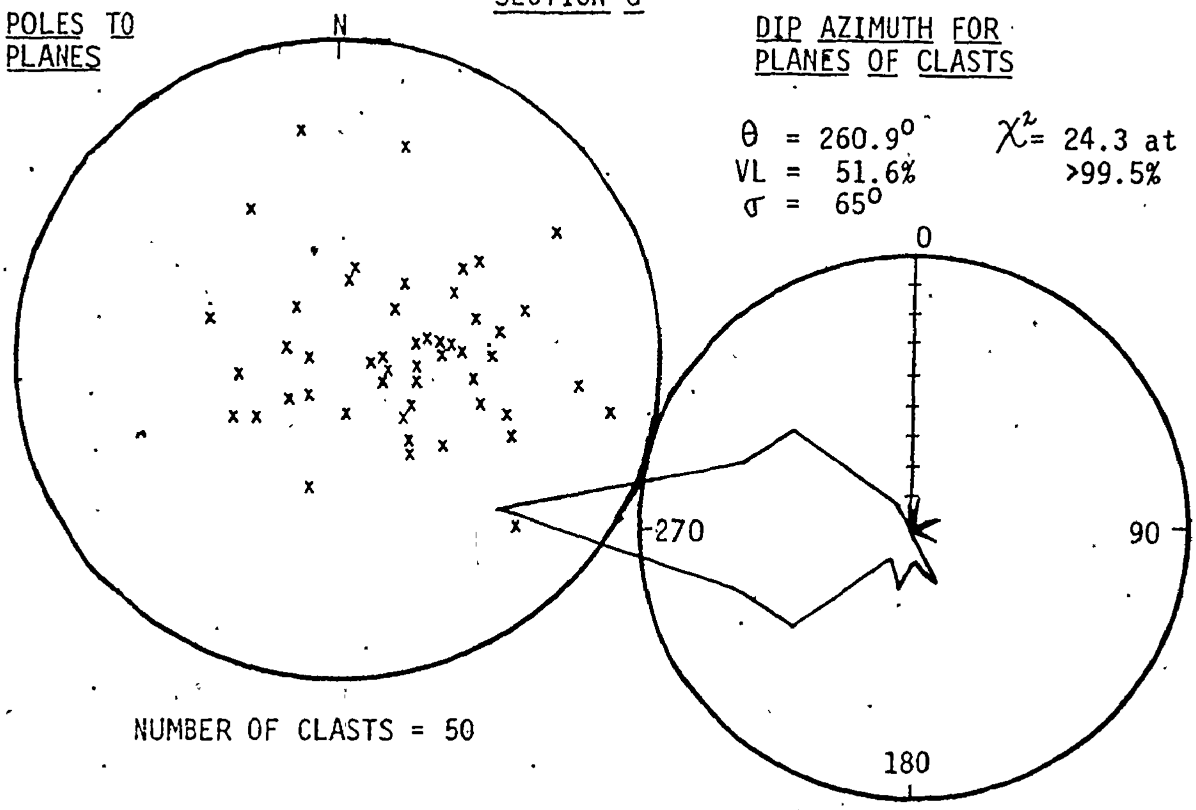


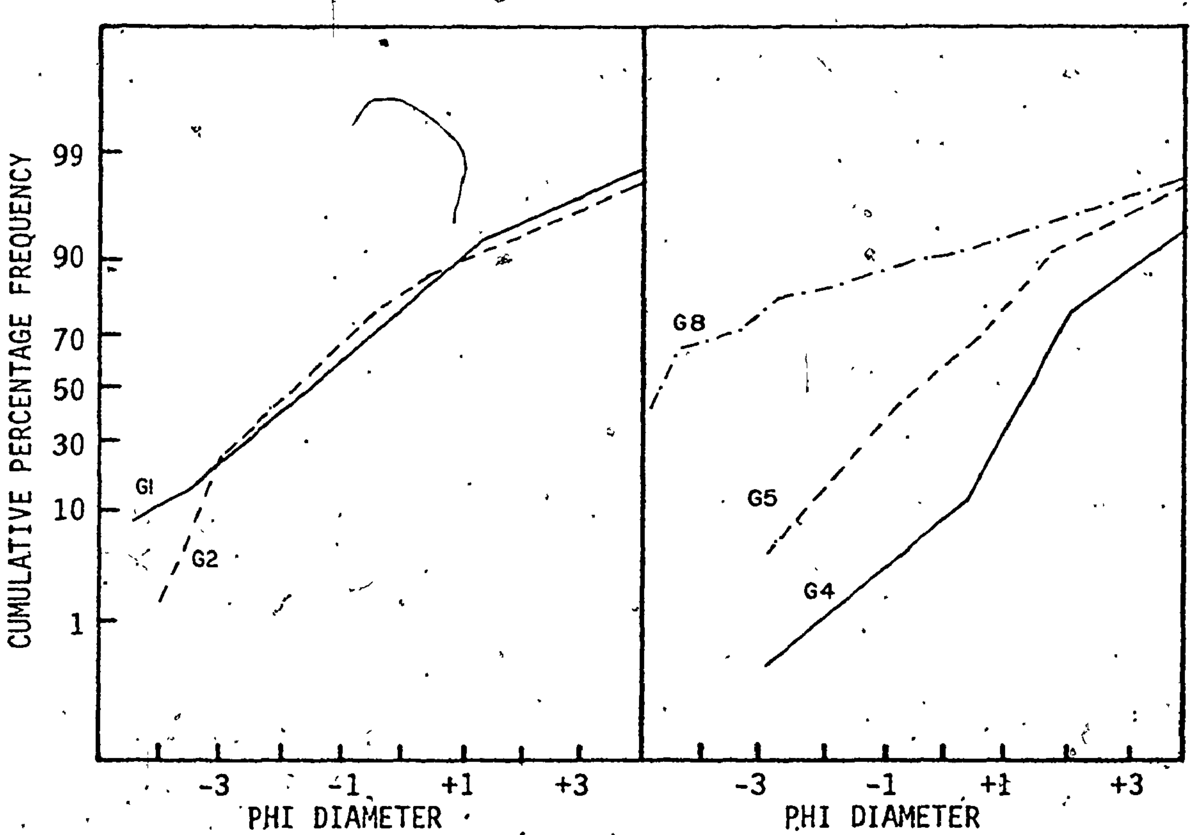
SECTION F



CUMULATIVE PERCENTAGE FREQUENCY
99
90
70
50
30
10
1
F1
F5
F6
F2
-3
-1
+1
+3
PHI DIAMETER
CUMULATIVE PERCENTAGE FREQUENCY
99
90
70
50
30
10
1
F8
F9
F10
F11
-3
-1
+1
+3
PHI DIAMETER

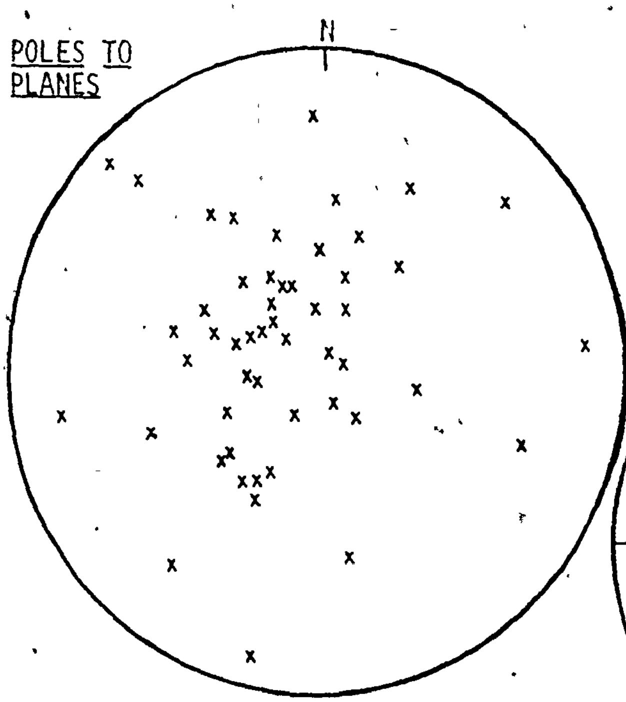
SECTION G


POLES TO PLANES
N
DIP AZIMUTH FOR PLANES OF CLASTS
θ = 260.9°
VL = 51.6%
σ = 65°
χ² = 24.3 at >99.5%
0
90
180
270
NUMBER OF CLASTS = 50


CUMULATIVE PERCENTAGE FREQUENCY
99
90
70
50
30
10
1
G1
G2
G8
G5
G4
-3
-1
+1
+3
PHI DIAMETER
-3
-1
+1
+3
PHI DIAMETER

SECTION J

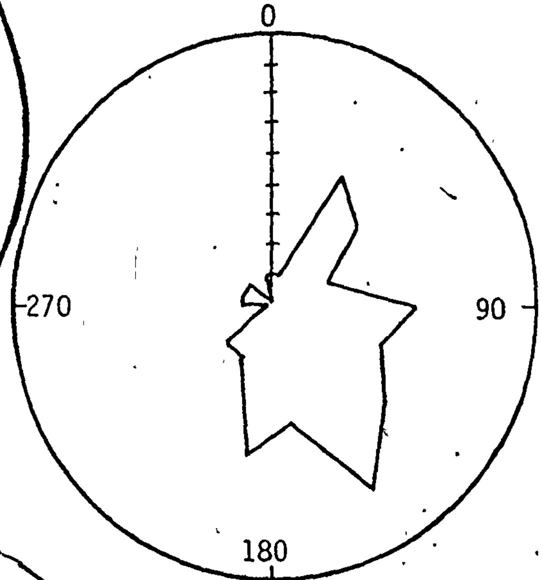
POLES TO PLANES

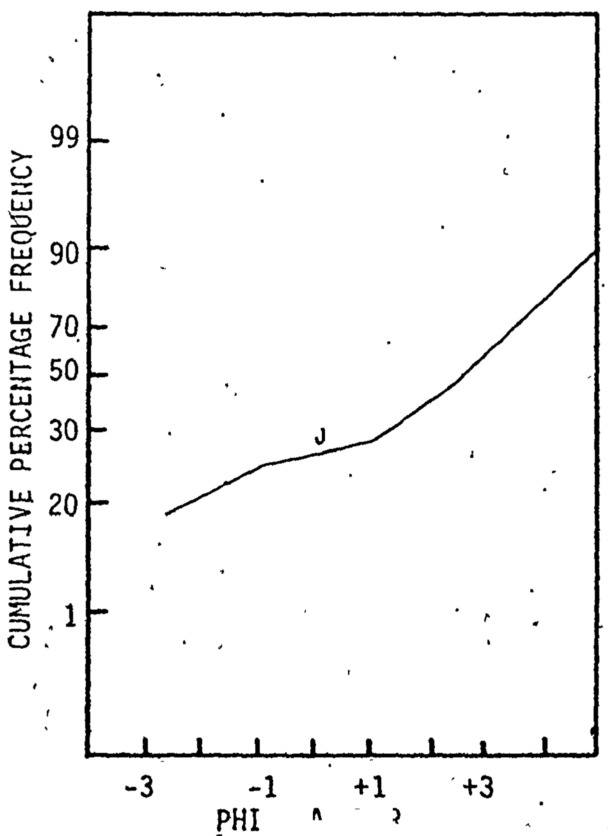


NUMBER OF CLASTS = 50

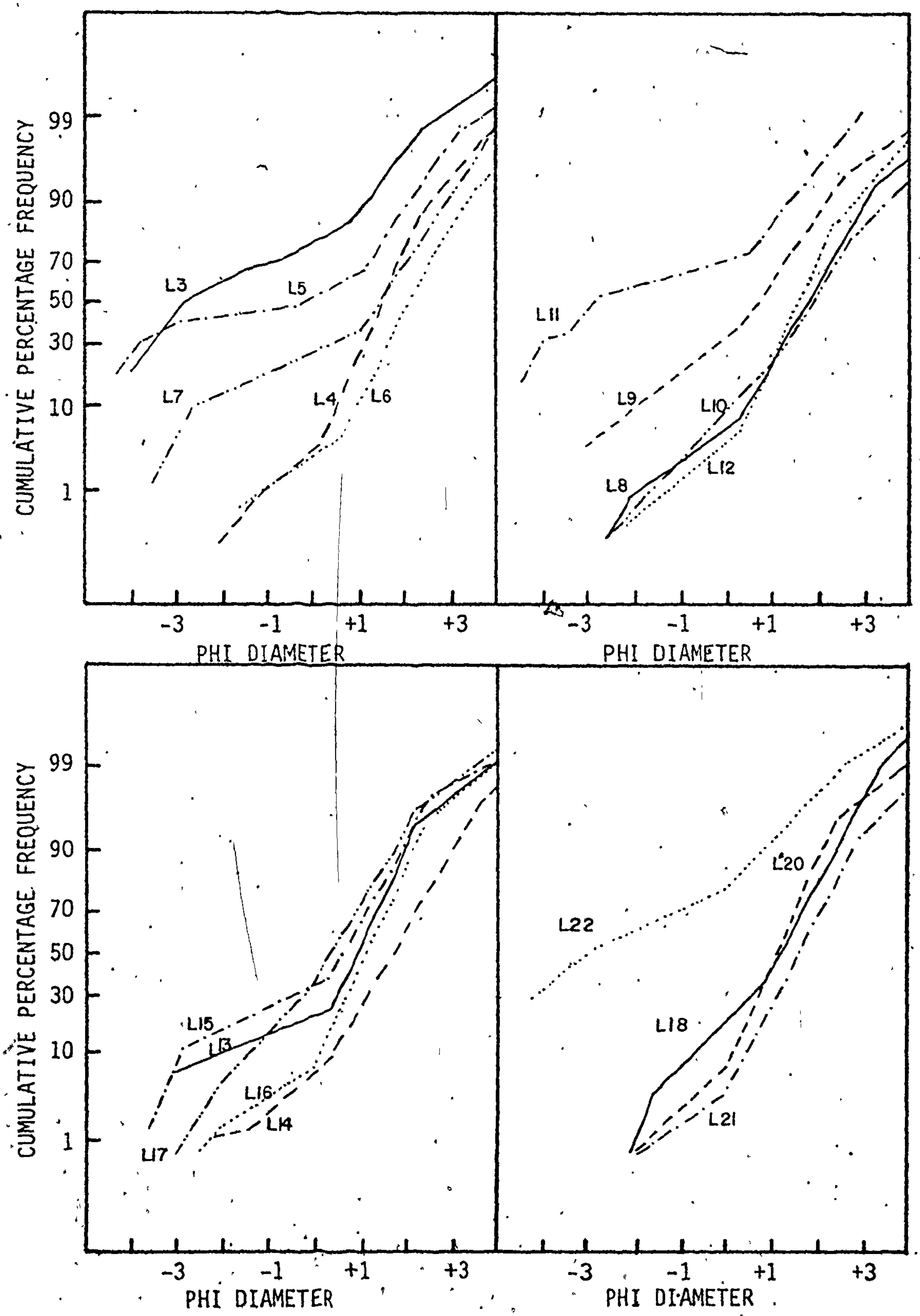
DIP AZIMUTH FOR PLANES OF CLASTS

θ = 124.5° χ^2 = 19.4 at
VL = 43.9% >99.5%
σ = 70°

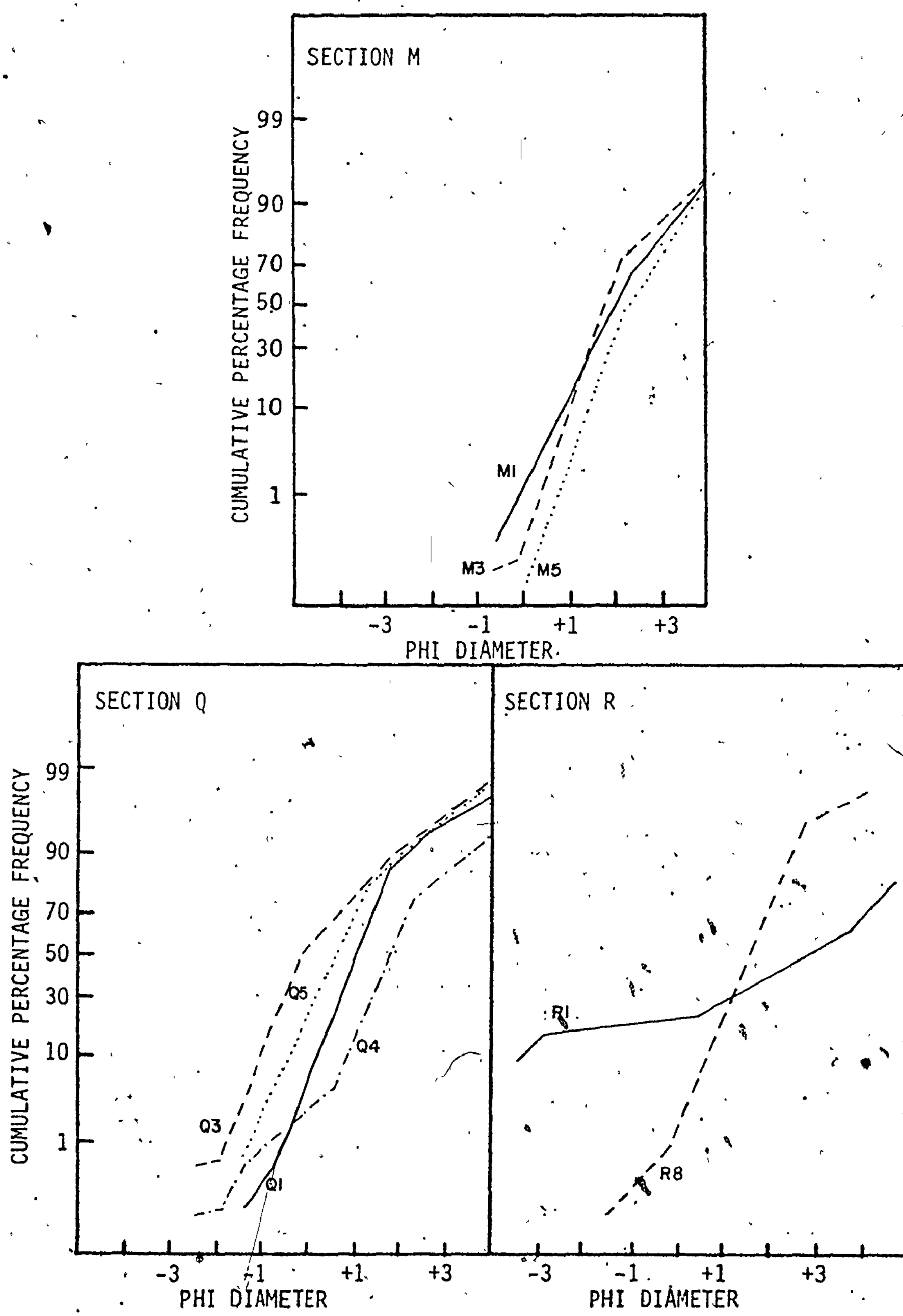




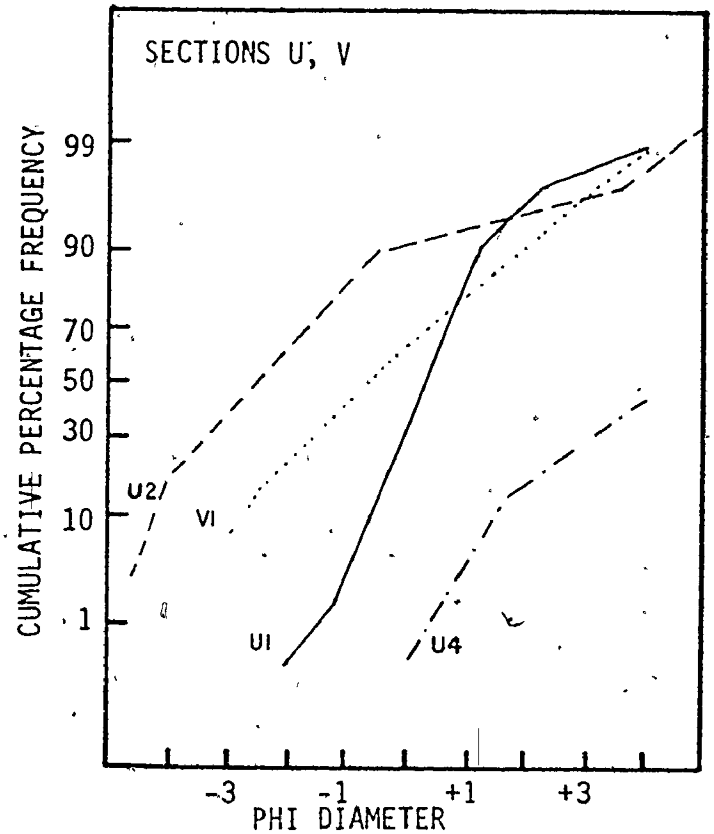
SECTION L

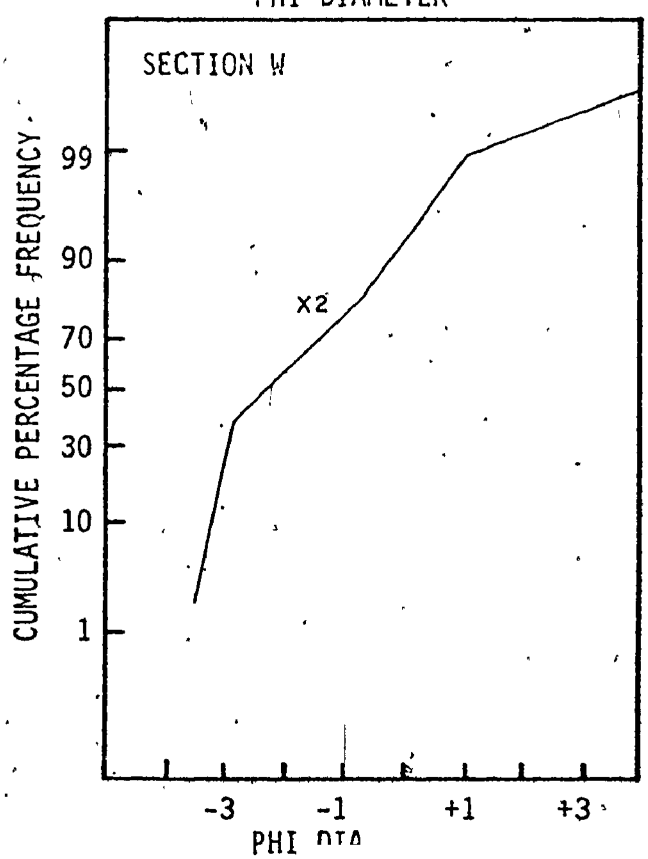

CUMULATIVE PERCENTAGE FREQUENCY
99
90
70
50
30
10
1
L3
L5
L7
L4
L6
L11
L9
L10
L8
L12
-3
-1
+1
+3
PHI DIAMETER
PHI DIAMETER
CUMULATIVE PERCENTAGE FREQUENCY
L15
L13
L16
L14
L17
L22
L20
L18
L21
PHI DIAMETER
PHI DIAMETER

SECTIONS M, Q, R



SECTIONS U, V, W





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