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LOWER CAMBRIAN ARCHEOCYATHID BUILDUPS, PELLY MOUNTAINS YUKON

B.C. READ

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LOWER CAMBRIAN ARCHEOCYATHID BUILDUPS, PELLY MOUNTAINS, YUKON

Abstract

The Lower Cambrian succession in the Ketza River area, central Yukon, includes carbonate and terrigenous clastic rocks of predominantly shallow marine lithofacies. They were deposited as part of the middle carbonate facies belt on the continental shelf at the west edge of the North American craton. The succession ranges in age from early Early to late Early Cambrian and is 700 m thick.

Detailed field and laboratory studies allow recognition of five lithostratigraphic subdivisions. In ascending order, these divisions and the depositional environments represented by them are: (a) intermittently agitated to quiet-water, fine grained terrigenous clastics; (b) restricted marine fine grained carbonates; (c) quiet-water, restricted to normal marine fine grained terrigenous clastics and minor carbonates; (d) quiet-water to intermittently agitated, subtidal carbonates and minor fine grained terrigenous clastics; (e) intermittently agitated, subtidal, fine grained, terrigenous clastics and carbonates.

Carbonate buildups, largely of organic origin, occur in the two upper subdivisions of these Lower Cambrian rocks. Those of (d), constructed by archaeocyathids and an encrusting algal-like organism, possibly ***Renalcis****, are "potential reefs" because they had a rigid organic framework capable of withstanding limited intermittent turbulence. The reefs grew in quiet water below the surf zone and probably below normal wave base, but were periodically subjected to agitation during storms. The dominant reef archaeocyathids include* ***Pycnoidocyathus****,* ***Protopharetra*** *and* ***Coscinocyathus****.* ***Altaicyathus?****, also found locally in the reefs, is remarkably like Stromatoporoidea, suggesting that representatives of this order occurred in carbonate buildups as old as the Early Cambrian.*

The buildups of subdivision (e) are archaeocyathid mud "banks" with similar fauna as the reefs. ***Renalcis****? is present but did not bind the archaeocyathids and these buildups lack a rigid, organic framework. The banks grew in an intermittently agitated environment that may have inhibited binding by* ***Renalcis****?.*

Résumé

La succession du Cambrien inférieur de la région de la rivière Ketza, dans le Yukon central, comprend des roches carbonatées et des roches clastiques terrigènes, qui appartiennent surtout à un lithofaciès marin peu profond. Ces sédiments font partie intégrante de la zone des faciès carbonatés intermédiaires du plateau continental, sur le rebord ouest du craton nord-américain. L'âge de la succession se situe entre le début du Cambrien inférieur et la fin du Cambrien inférieur; sa puissance est de 700 m.

Des études détaillées effectuées sur le terrain et au laboratoire permettent de la subdiviser en cinq unités lithostratigraphiques. On énumère, de bas en haut, les subdivisions et le milieu de sédimentation qu'elles représentent. On a donc: (a) des roches clastiques terrigènes de granulométrie fine, formées dans des eaux agitées de fa on intermittente; (b) des carbonates de granulométrie fine, formés dans un milieu marin confiné; (c) des roches clastiques et volumes mineurs de carbonates, de granulométrie fine, formés dans des eaux calmes, en milieu marin confiné à normal; (d) des carbonates et quantités mineures de roches clastiques terrigènes, de caractère subtidal et de granulométrie fine, formés dans une eau calme ou agitée de fa on intermittente; (e) des carbonates et roches clastiques terrigènes de granulométrie fine, de caractère subtidal, formés dans une eau agitée de fa on intermittente.

Les structures carbonatées, qui ont surtout une origine organique, se sont formées dans les deux subdivisions supérieures du Cambrien inférieur. Dans le cas (d), ces roches, qui ont été construites par des archaéocyathidés et un organisme semblable à une algue et sécrétant du calcaire, probablement ***Rénalcis****, sont des "récifs en puissance" parce qu'elles possèdent une charpente organique rigide, capable de résister à des périodes de turbulence modérée. Ces récifs se sont formés dans des eaux tranquilles au-dessous de la zone de déferlement, et probablement au-dessous du niveau de base normal des vagues, mais ils ont été périodiquement battus par les vagues pendant des tempêtes. Les principaux archaéocyathidés constructeures de récifs sont* ***Pycnoïdocyathus****,* ***Protopharétra*** *et* ***Coscinocyathus****.* ***Altaïcyathus?****, que l'on rencontre aussi localement dans les récifs, ressemble fortement à un stromatoporoïdé, et l'on pourrait penser que des représentants de cet ordre ont contribué à édifier des structures calcaires dès le Cambrien inférieur.*

Les structures de la subdivision (e) sont des "bancs" de boue à archaéocyathidés contenant une faune comparable à celle des récifs. ***Rénalcis?*** *y est présent mais ne lie pas entre eux les archaéocyathidés, et les structures édifiées ne sont pas caractérisées par une charpente organique rigide. Les bancs se sont développés dans un milieu agité de fa on intermittente, où* ***Rénalcis?*** *n'a pu cimenter les structures édifiées.*

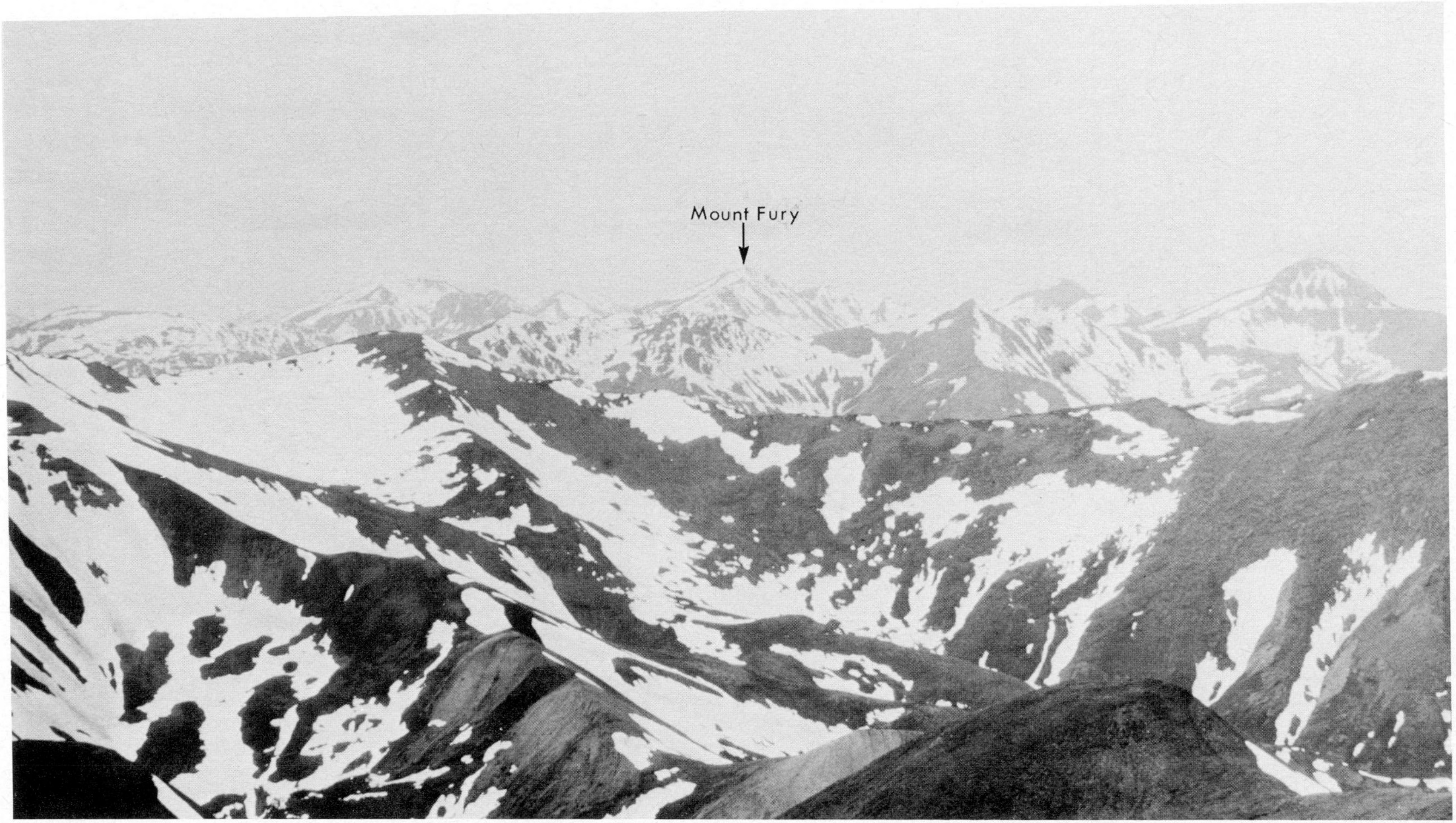


PLATE 1

View looking westward across the Ketza River at the study-area, which constitutes the mountains along the skyline. Mount Fury is near the centre of the study-area. GSC 203328

LOWER CAMBRIAN ARCHEOCYATHID BUILDUPS, PELLY MOUNTAINS, YUKON

INTRODUCTION

The Lower Cambrian of the Ketza River area, Yukon Territory, is of particular interest because it contains excellent exposures of archaeocyathid carbonate buildups. These structures occur in a 700 m thick, miogeoclinal succession which includes carbonate and terrigenous clastic strata of predominantly shallow marine lithofacies.

This report describes the Lower Cambrian succession and interprets its depositional environment. Special emphasis is placed on evaluating the growth conditions of the carbonate buildups. Although formed in calm water it is shown that some of these structures exhibit evidence of potential wave resistance and therefore may be termed "reefs" (sensu Heckel, 1974). They were formed by the problematic sponge-like archaeocyathids and an encrusting organism, possibly the algal-like **Renalcis**?. The study of the buildups constructed by these organisms provides insight into a type of reefal environment at least 550 million years old – the first in which skeletal animals, archaeocyathids, played an important role.

The study area is within the St. Cyr Range of the Pelly Mountains in central Yukon Territory (Fig. 1). The range is in northeastern Quiet Lake map area (Wheeler et al., 1960). The region investigated covers about 80 km² at the headwaters of Ketza River, about 19 km southwest of the Tintina Trench. Ross River, the closest settlement, is approximately 50 km north of the Ketza River area.

The St. Cyr Range is rugged with the highest peak about 2130 m (Pl. 1). Helicopters, which can be chartered at Ross River, provide the fastest and easiest access to the area. An abandoned mine access road that branches off Campbell Highway (Fig. 1), terminates about 2 km east of the study area, but is passable only during the fall.

Previous Work

The Pelly River, flowing through the northeast corner of Quiet Lake map area, provided early investigators of the region with a convenient transportation route (Tempelman-Kluit, 1972). It was first travelled in 1843, by Robert Campbell, an explorer for the Hudson's Bay Company. He was followed by G.M. Dawson in 1887, and in 1935 by J.R. Johnston (Dawson, 1888; Johnston, 1936), both officers of the Geological Survey of Canada.

In 1956, 1958, 1959 and 1960 the Geological Survey of Canada systematically mapped Quiet Lake map area during "Operation Pelly". A preliminary geological map and brief description of the area was published in 1960 (Wheeler et al., 1960).

The Ketza River area and its vicinity have been prospected since 1843 when Campbell discovered the Pelly River. In the early 1950s scientifically minded prospectors, impressed by the abundant, well preserved, archaeocyathids in the Ketza River area, collected numerous specimens and donated them to V.J. Okulitch at the University of British Columbia. These collections, which were described and assigned an Early Cambrian age by Kawase and Okulitch

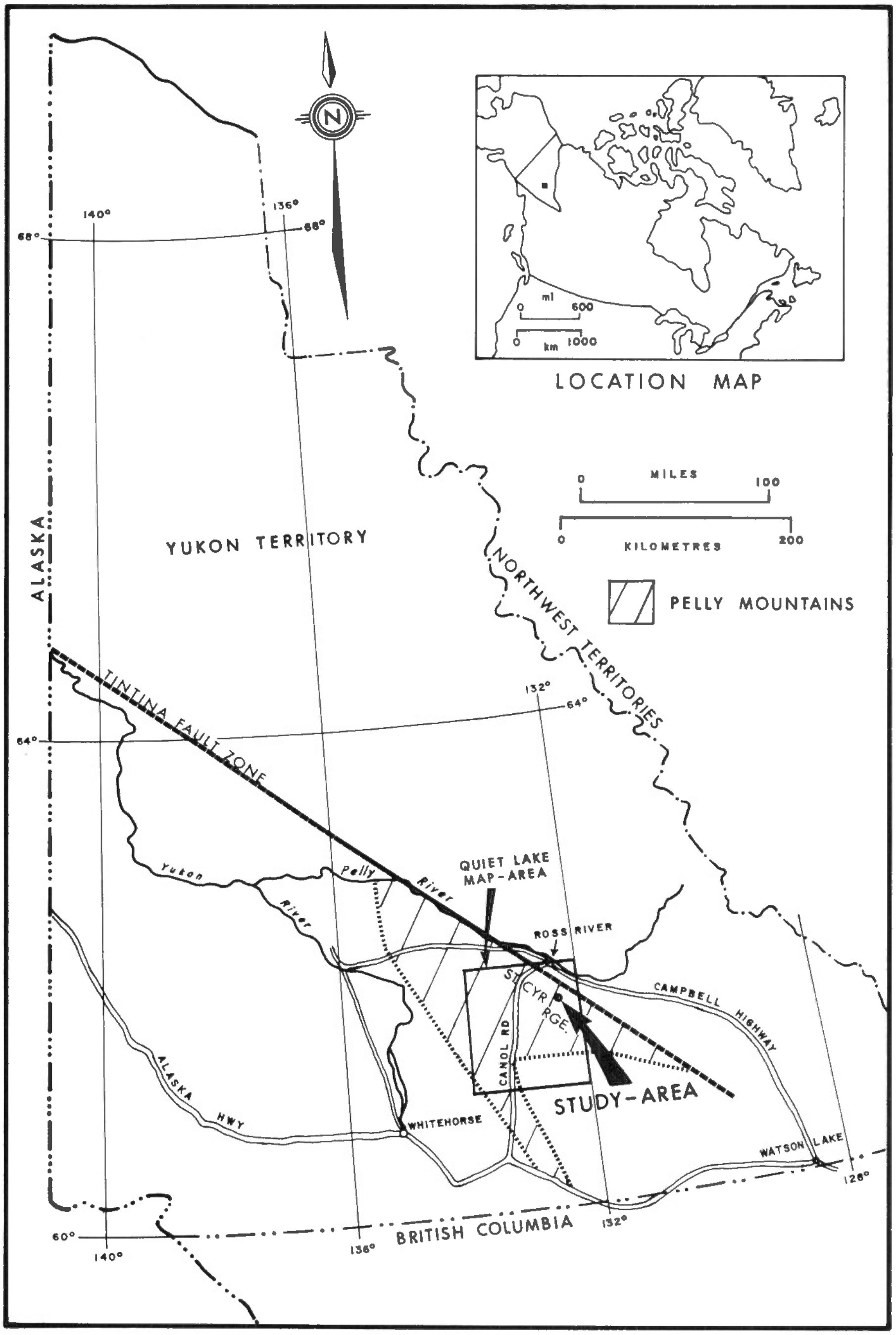
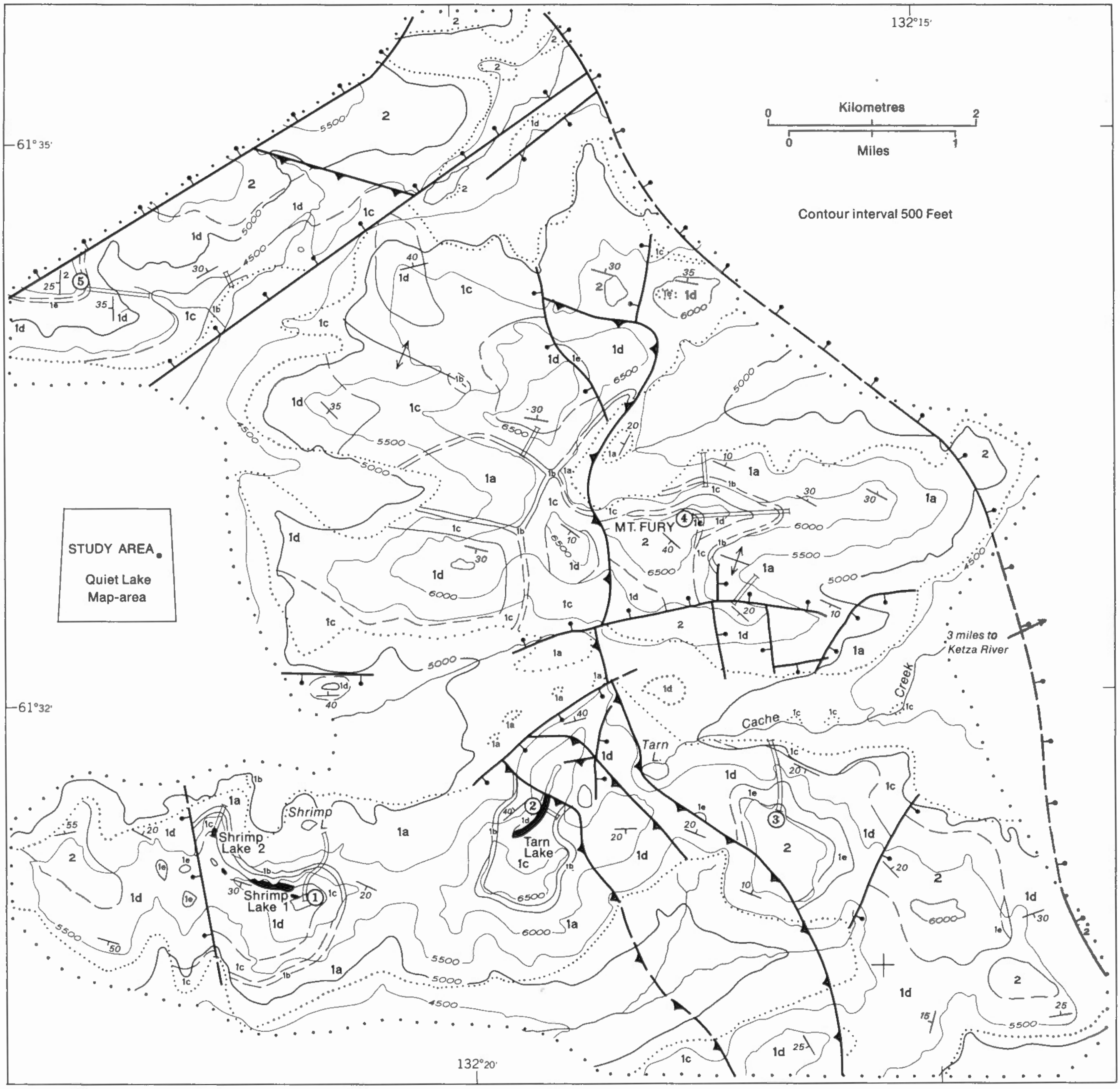


Figure 1. Location map.



2	Argill., limest., calc. argill.
1e	Argill., minor lenses of limest. dolo. limest.
1d	Limest., minor dolo. limest. argill. limest., calc. argill.
1c	Calc. argill., argill., minor limest.
1b	Limest.
1a	Argill., locally qtzite.

(See Table 1 for detailed lith).

Geological boundary (defined, approximate, assumed)

Bedding (horizontal, inclined)

Fault (defined, inferred, solid circle indicates downthrow side)

Thrust fault (defined, inferred, teeth indicate upthrust side)

Anticline

Measured section

Buildup

Limit of geologic mapping

MEASURED SECTIONS: 1. Shrimp Lake 2. Tarn Lake 3. Cache Creek 4. Mount Fury 5. Cloutier Creek

Figure 2. Geological map of the Ketza River study area.

(1957), have been used to make correlations between the Ketza River succession and other Lower Cambrian rocks in the Cordillera (Okulitch and Greggs, 1958; Handfield, 1971).

In 1967 and 1968 D.J. Tempelman-Kluit, of the Geological Survey, conducted a study of the Faro, Vangorda, and Swim concordant zinc-lead deposits 80 km northwest of the study-area (Tempelman-Kluit, 1972).

Present Work

A re-examination of Quiet Lake map area, in the light of new geological data, was begun in 1973 (Tempelman-Kluit et al., 1974, 1975, 1976). During the summers of 1973, 1974 and 1975, the writer was a field assistant on this project. Field work for this report was carried out for 11 days in 1973, 2 months in 1974 and 5 days in 1975.

The 80 km^2 study area was geologically mapped at a scale of 1:50 000 using the Cloutier Creek topographic map (N.T.S. 105 F/9) as base (Fig. 2). Field data were plotted on aerial photographs and later transferred to the map. Detailed Lower Cambrian stratigraphic investigations included measuring five control sections and extensive sampling of three exceptionally well-exposed carbonate buildups. For convenience, the sections and buildups are named as follows (Fig. 2): (1) Shrimp Lake, (2) Tarn Lake, (3) Cache Creek, (4) Mount Fury and (5) Cloutier Creek. The buildups are: Shrimp Lake 1, Shrimp Lake 2, and Tarn Lake.

Samples from all facies in the succession were slabbed, polished, and examined under the binocular microscope. Large specimens, some up to 25 cm in diameter, were collected from the carbonate buildups and polished slabs were made from them. These provide a more accurate means of evaluating component abundance and interrelationships than thin sections. Component abundance of the slabs was determined by point counting photographs overlaid by a transparent grid.

More than 200 thin sections, from samples of all facies, were studied under the polarizing microscope. The mineral composition of most carbonate thin sections and slabs was determined by staining (Friedman, 1959). Four thin sections of quartzite were stained to determine their K-feldspar content (Bailey and Stevens, 1960). The mineral constituents of these quartzites were counted using a mechanical stage and polarizing microscope.

Acknowledgments

This report is based on a graduate thesis submitted to the department of geology at the University of Calgary. To S.J. Nelson, my thesis supervisor, goes my sincere gratitude for his advice and guidance. J.E. Klovan and D. Perry constructively criticized the manuscript. Discussions with Dr. Klovan helped shape several of the interpretations presented.

Fieldwork was done under the auspices of the Geological Survey of Canada. D.J. Tempelman-Kluit, suggested the study and his advice in the field was valued. D. Van Appelen provided competent assistance and companionship during fieldwork.

R. Gangloff, of Merritt College, California, A.Y. Rosanov, of the Academy of Science, Moscow, and C.C.K. Fong, of the Newfoundland Department of Mines and Energy, provided assistance with identification of archaeocyathids. W.H. Fritz of the Geological Survey of Canada identified the trilobites and aided in interpreting biochronology and regional correlations.

The Technical Staff at the University of Calgary helped to prepare thin sections and photographs. In particular, I thank D. Harvey, R. Larush, A. Graham, and K. Wilson. U. Visher, of Dome Petroleum Canada Ltd., helped draft some of the original diagrams.

GENERAL GEOLOGY

The argillite, quartzite and carbonate in the Ketza River area are part of a miogeoclinal succession deposited under shallow marine conditions on the stable shelf adjacent to the North American craton (Tempelman-Kluit et al., 1976). Stelck and Hedinger (1975) suggested that the craton lay to the east and that deeper water environments were west of the study area. Several writers have postulated that throughout most of Cambrian time sedimentation took place in three main belts of facies that fringed western North America (Aitken, 1966; Fritz, 1975; Gabrielse et al., 1973; Palmer, 1960; Robison, 1960). These belts, named in Nevada by Palmer (1960) and Robison (1960), are: a landward "inner detrital" belt, of sandstone, siltstone and shale; a "middle carbonate" belt, composed of carbonate rocks and an "outer detrital" belt, dominated by shale and argillaceous limestone. Northern extensions of the belts have been recognized in the Rocky Mountains (Aitken, 1966), Cariboo Mountains (Fritz, 1975), and Mackenzie and Selwyn mountains (Fritz, 1975; Gabrielse et al., 1973). Distribution of Lower Cambrian facies in the northern Cordillera, as illustrated by Gabrielse et al. (1973, p. 25), suggests that in this region the inner detrital and middle carbonate belts are each 50 to 80 km wide. The outer detrital belt is little studied and its width is unknown.

On the basis of its dominant lithologies and interpreted depositional environments, discussed in succeeding chapters, the Ketza River succession is considered representative of the outer middle carbonate belt (Fig. 3). Its present position is reconciled with the distribution of the three facies belts by restoring 400 km of movement on the Tintina Fault (Fig. 3). Right lateral displacement of 350 to 450 km (Roddick, 1967; Tempelman-Kluit, 1970; Tempelman-Kluit et al., 1976) occurred on the Tintina Fault after the mid-Cretaceous. Such palinspastic restoration indicates that the Ketza River succession accumulated closer to the craton than its present geographic position implies. Deposition probably occurred in the southern extension of the middle carbonate belt in the Selwyn and Mackenzie mountains (Gabrielse et al., 1973).

Aitken (1966) demonstrated that repeated lateral shifts in the position of the three facies belts has resulted in overlap of the facies onto the adjacent belts. He suggested that these lateral shifts were cyclic and defined the basic sedimentary package, or "Grand Cycle" as ". . . depositional cycles. . ., each comprising two or more fossil zones. . . Each. . . commences at an abrupt basal contact, and consists of a lower shaly half-cycle gradationally overlain by a carbonate half-cycle". (Aitken, 1966, p. 405.) In general, the shaly half-cycle reflects a rapid transgression resulting from increased water depth and terrigenous influx; the carbonate half-cycle results from gradual shoaling and clearing of the water (op. cit., p. 437). Aitken recognized eight grand cycles in Middle Cambrian through Lower Ordovician strata of the southern Rocky Mountains.

Fritz (1975) combined the concepts of Aitken, Palmer and Robison with his own trilobite zonation (Fritz, 1972) to formulate a model for the distribution of Lower Cambrian rocks in the Cordillera (Fig. 4). He proposed three grand cycles, with boundaries corresponding roughly to those of the trilobite zones. Fritz suggested that the Ketza River succession was deposited in the outer part of the middle carbonate belt and that it spans the first grand cycle and the lowest part of the second (Fig. 4).

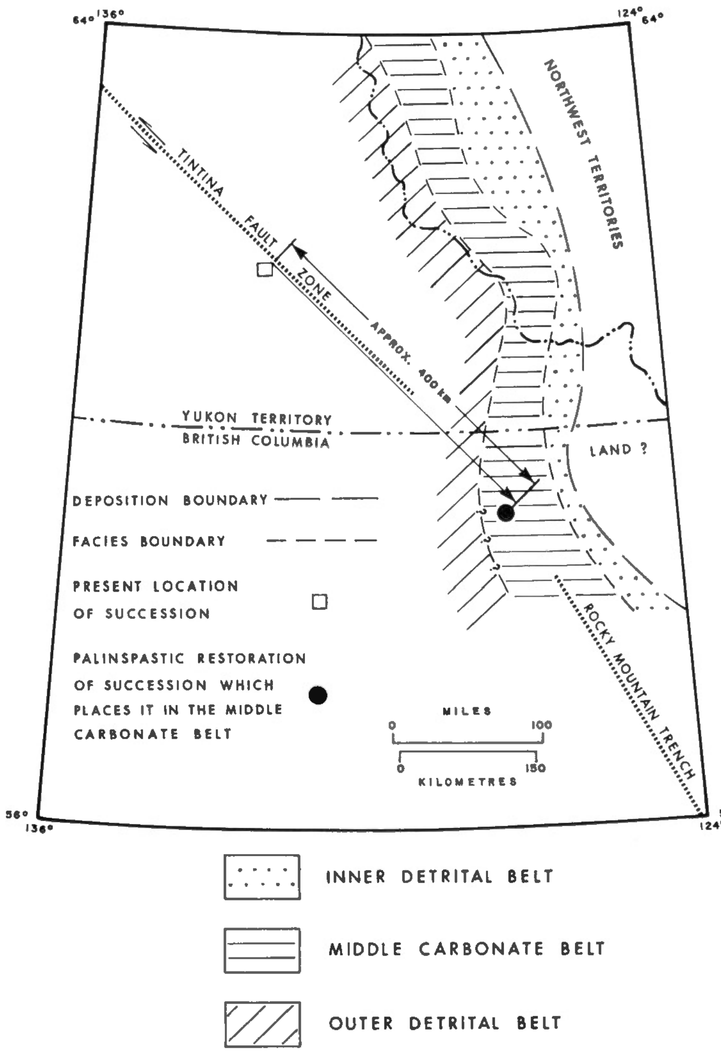


Figure 3. Lower Cambrian sedimentary belts in part of the Northern Cordillera (modified from Gabrielse et al., 1973).

Stratigraphic Succession

Reconnaissance work divided the Paleozoic rocks of Quiet Lake map area into 8 units (Wheeler et al., 1960). The Lower Cambrian succession, 700 m thick and designated unit 1, is informally divided into three parts; a lower quartzite, medial shale, and upper carbonate. Although useful in regional mapping, these divisions are too general for detailed stratigraphic investigation. In this study, unit 1 is separated into five lithostratigraphic divisions termed subunits 1a, 1b, 1c, 1d and 1e (see Fig. 5, Table 1). The subunits are lithologically distinctive and contacts are generally sharp and unequivocal. The contact between calcareous argillite (1c) and carbonate (1d) is gradational and its position is arbitrary. The base of subunit 1d is therefore drawn where carbonate makes up more than half of the rock. Subunits 1d and 1e are of particular interest because they contain spectacular archaeocyathid carbonate buildups.

Subunits 1a-1e are a conformable succession without known stratigraphic hiatuses. The base of subunit 1a is not exposed in the study area. Subunit 1e, youngest in the succession, is unconformably overlain by unit 2, which is late Cambrian and younger. Unit 2 consists of phyllite, calcareous argillite, and thin bedded argillaceous limestone.

Table 1

Summary of physical characteristics of subunits

AGE		SUBUNIT	THICKNESS (FEET)	THICKNESS (METRES)	DESCRIPTION	LOWER CONTACT
EARLY CAMBRIAN	LATE	1e	125-300	40-90	noncalcareous, grey or green weathering, thin bedded to laminated argillite; lenses and tabular beds of ooid grainstone/packstone, oncoid rudstone/floatstone, and skeletal packstone/rudstone; local archaeocyathid carbonate buildups	sharp
	MIDDLE	1d	400-600	120-180	massive, thin- to medium-bedded mudstone; argillaceous mudstone and calcareous argillite common in lower beds, oncoid and cryptalgal coated grain floatstone and non-argillaceous mudstone common in upper beds; local archaeocyathid carbonate buildups	gradational
		1c	350	105	brown weathering, laminated calcareous argillite and argillite; thin beds of mudstone, wackestone, and rare packstone occur in upper part of subunit	sharp
	?	1b	150-200	45-60	dark grey weathering, laminated silty mudstone	sharp
	EARLY	1a	> 700	> 215	noncalcareous, rusty weathering green argillite, thin bedded to laminated, minor thin beds of grey weathering very fine grained quartzite; locally thin- to medium-bedded very fine grained quartzite is abundant	not exposed

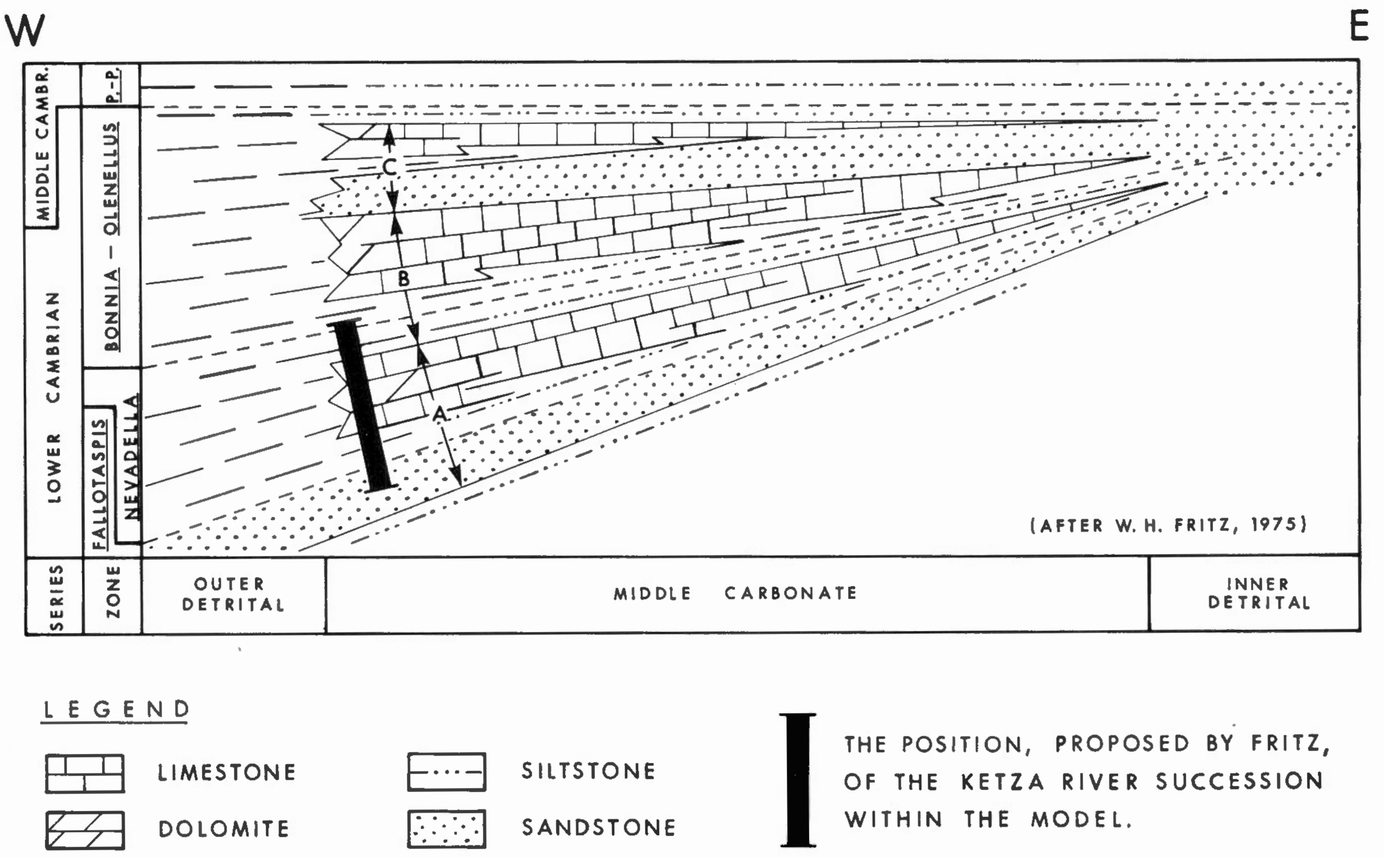


Figure 4. Theoretical model showing distribution of Lower Cambrian strata. Grand cycles are marked A, B, and C.

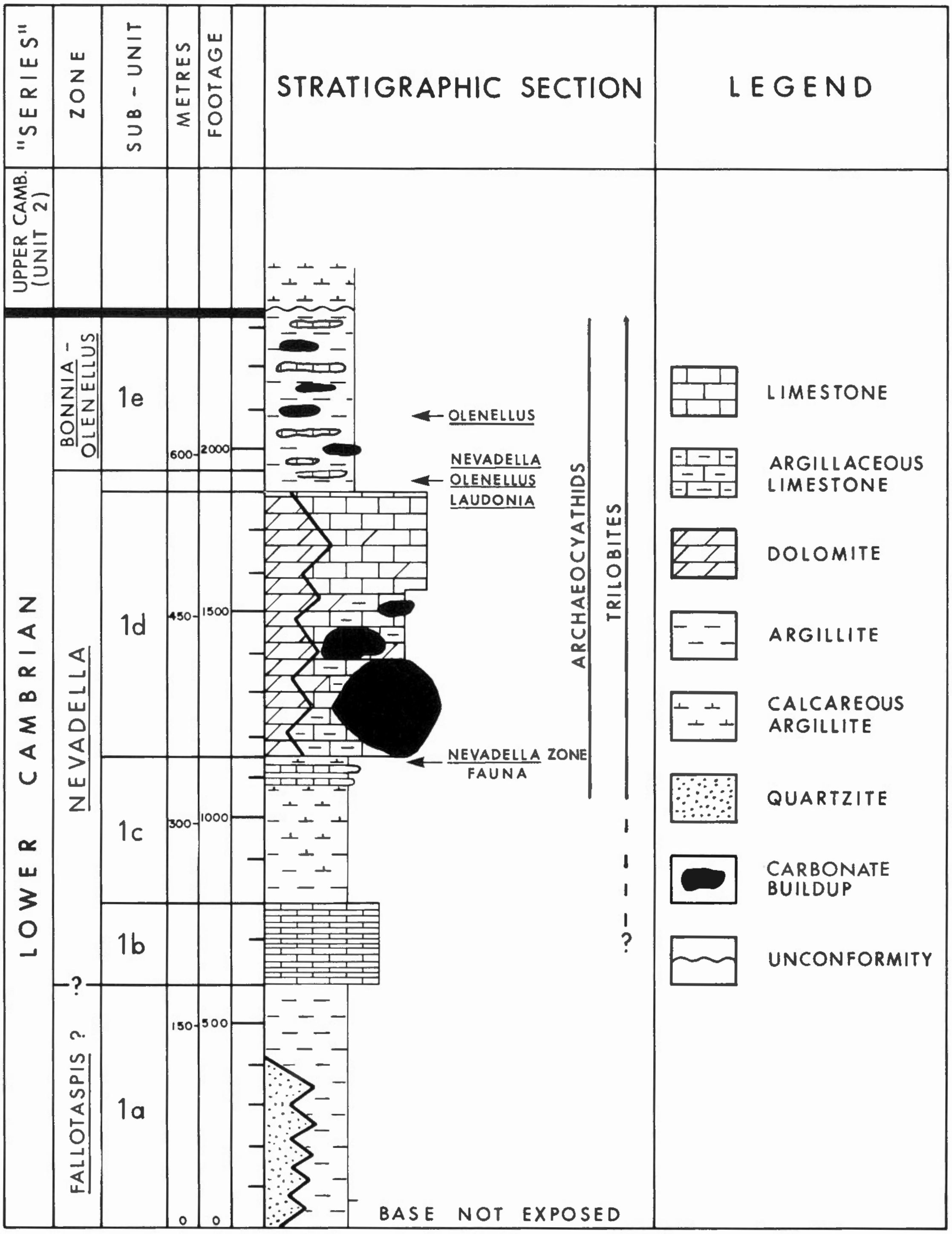


Figure 5. Generalized composite columnar section of the Ketza River area, Pelly Mountains.

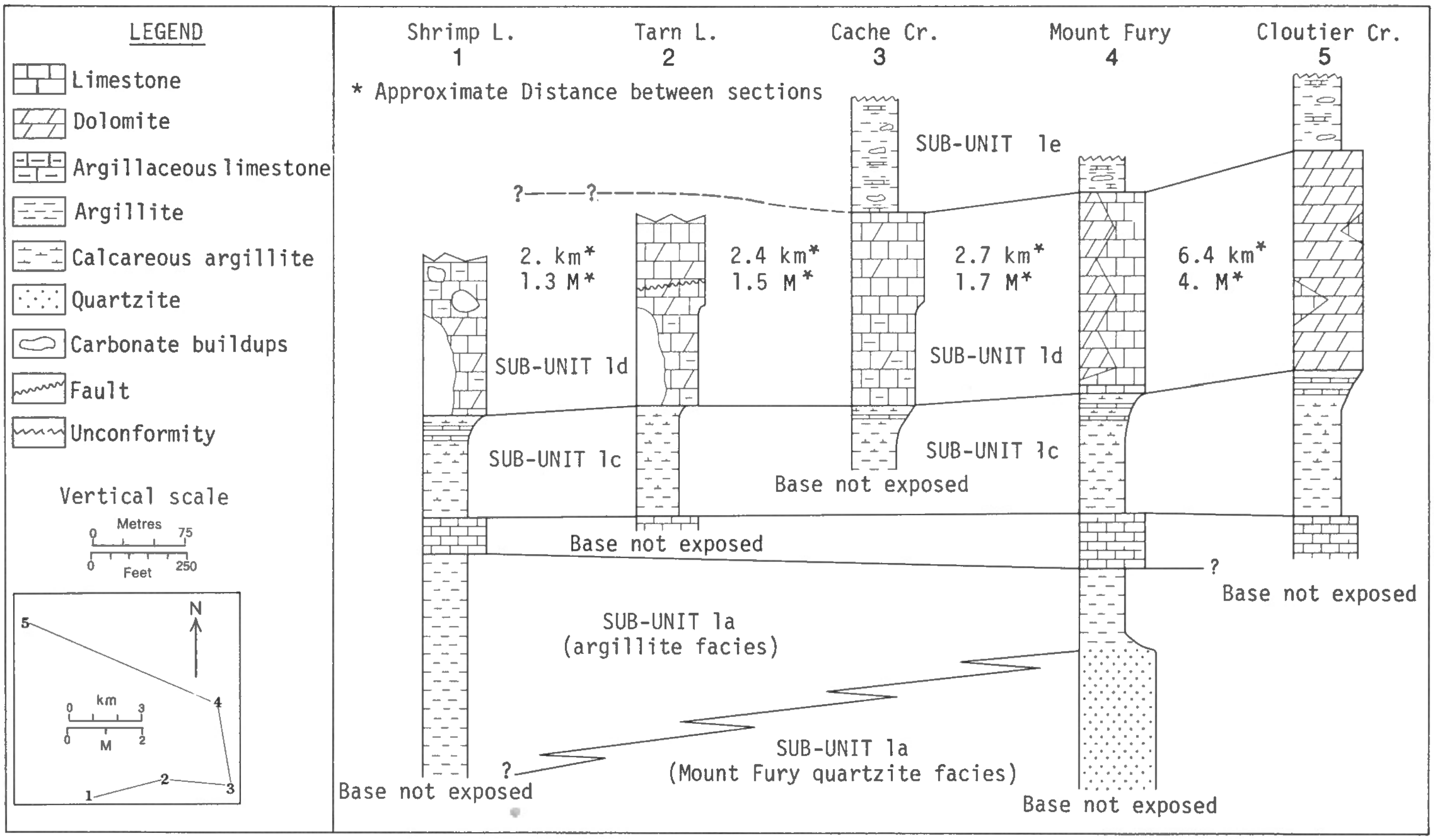


Figure 6. Stratigraphic cross-section of Lower Cambrian succession in the Ketza River area, Pelly Mountains.

The general facies relations of subunits 1a to 1e (Fig. 6) illustrate several broad trends. Quartzite of subunit 1a grades southwestward into argillite. Argillite of subunit 1c and interbedded carbonate and argillite of subunit 1e are relatively uniform throughout the study area. Also of constant lithofacies are carbonates of subunit 1d, except in the southwest where large carbonate buildups occur. To the north, subunit 1d is progressively more dolomitized.

Age and Correlation

Early Cambrian archaeocyathids and/or trilobites occur in all subunits save 1a (Fig. 5) which is devoid of shelly fossils and is of uncertain age. Fritz (1972) proposed 3 trilobite zones for Lower Cambrian strata in the Cordillera; the **Fallotaspis**, **Nevadella** and **Bonnia-Olenellus** zones (Fig. 4). Trilobites collected in the study area were studied by W.H. Fritz of the Geological Survey of Canada who considers them characteristic of the **Nevadella** and **Bonnia-Olenellus** zones (Fig. 5). Identifiable **Nevadella** Zone fossils first occur at the base of subunit 1d. **Nevadella, Olenellus** and **Laudonia**?, an early **Bonnia-Olenellus** Zone genus, were collected from the basal 15 m of subunit 1e. Hence subunit 1d, and the lowest part of subunit 1e, are assigned to the **Nevadella** Zone and the remainder of subunit 1e to the **Bonnia-Olenellus** Zone. Fritz (1975) projected the **Nevadella-Fallotaspis** zones boundary into the Ketza River succession from nearby homotaxial equivalents. He placed this boundary near the upper contact of subunit 1a. This suggests that the rare and poorly preserved trilobites of subunits 1b and 1c belong to the **Nevadella** Zone and that subunit 1a is, at least in part, within the **Fallotaspis** Zone.

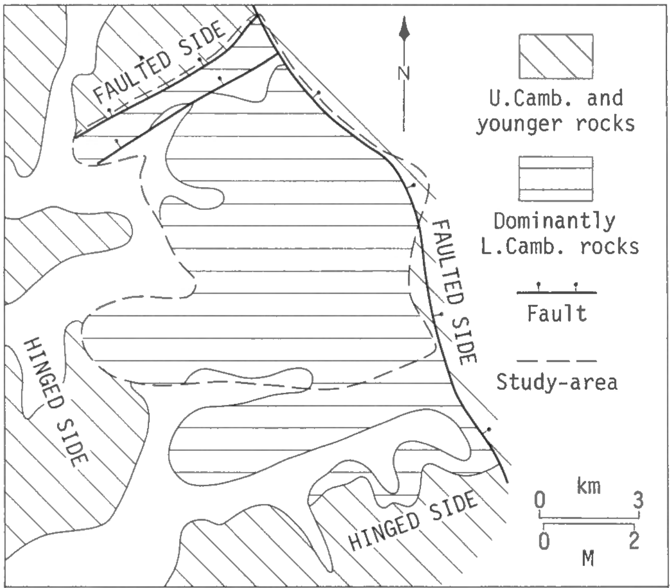
Ages assigned on the basis of archaeocyathid assemblages agree with those determined from trilobites (see Kawase and Okulitch, 1957; Handfield, 1971). The Ketza River archaeocyathids are tentatively correlated with the Lena stage in Siberia (Rozanov and Debrenne, 1974).

On the basis of trilobite and archaeocyathid assemblages, regional correlations have been made between the Ketza River succession and other Lower Cambrian rocks in the Cordillera. Sequences which are of similar age include: the Sekwi Formation in the Mackenzie and Selwyn mountains in the Northwest Territories and Yukon Territory (Fritz, 1975; Handfield, 1971) and, in British Columbia, the Atan Group in the Cassiar Mountains (Okulitch and Greggs, 1958), the Yanks Peak, Midas and Mural formations in the Cariboo Mountains (Fritz, 1975), and the Donald Formation in the Dogtooth Mountains (Okulitch and Greggs, 1958).

Structure and Metamorphism

Strata in the Ketza River area are exposed in a broad irregular dome or culmination, roughly 12 km across (Fig. 7). This culmination is superimposed on older small and large scale structures which are similar to those found in other parts of eastern Quiet Lake map area (Wheeler et al., 1960; Tempelman-Kluit et al., 1974, 1975, 1976).

Large scale structures are dominated by faults, folds being of minor importance in the study area. Two types of faults are recognized (Fig. 2). The oldest are northeasterly directed, mid-Triassic or younger (Tempelman-Kluit et al., 1976) thrust faults with stratigraphic throws up to 150 m. These thrusts are disrupted by a younger set of steep dipping, mid-Cretaceous (Tempelman-Kluit et al., 1975) faults which trend northeast and northwest and have stratigraphic throws



At the northern and eastern sides of the study-area steeply dipping faults juxtapose Lower Cambrian rocks against Upper Cambrian and younger strata. At the southern and western sides, strata are "hinged", resulting in Lower Cambrian rocks dipping away from the centre of the study-area and underneath younger strata. Combination of this "hinging" and faulting has resulted in Lower Cambrian rocks being exposed in a broad irregular dome or culmination.

Figure 7. Structural setting of Lower Cambrian rocks in Ketza River area.

of 100 m or so. Two of these steep dipping faults are the northern and eastern boundaries of the study-area. They have greater lateral continuity and stratigraphic displacement than many of the steep faults and juxtapose Lower Cambrian against Upper Cambrian rocks (Fig. 2 and 7).

Small-scale structures are locally developed in the argillaceous rocks. They include a slip cleavage or crenulation foliation, crinkle and fold axes lineations, and minor folds. The crenulation foliation generally trends northwest. It transposes bedding and approximately parallels the axial planes of small-scale folds. Spacing and displacement associated with foliation planes is usually a few millimetres or less. On the microscopic scale these planes are defined by parallel-oriented white micas. Locally, extensive crystallization of these micas results in some rocks splitting along the foliation in preference to bedding. Two lineations, both with the same trend and plunge, are noted. The most common is a crinkle lineation formed at the bedding-foliation intersection. It plunges northwest or southeast at angles which rarely exceed 20°. The second lineation comprises the axes of small folds that deform bedding and which have amplitudes of 2 cm or less.

The rocks are weakly metamorphosed to greenschist facies as indicated by the mineral assemblage quartz-muscovite-dolomite in pelitic rocks.

PALEONTOLOGY

The main fossils found in rocks of the Ketza River succession include, archaeocyathids, the stromatoporoid-like **Altaicyathus?**, trilobites, echinoderms, hyolithids, brachiopods, oncoids, cryptalgal coated grains, and a problematic encrusting algal-like organism, possibly **Renalcis?**. This chapter describes these fossils and considers their environmental implications.

Archaeocyatha

Archaeocyathids are a group of sessile, rooted, benthonic organisms that had a world-wide distribution in Early Cambrian shallow marine environments and which became extinct during the Middle Cambrian (Hill, 1972). They have affinities to sponges and corals and are particularly interesting because they were the first major calcium carbonate secreting animals to construct carbonate buildups.

The general form of archaeocyathids is an inverted cone or cup (Fig. 8). Skeletons are usually 1 or 2 cm in diameter and 8-15 cm high. Most archaeocyathids are solitary and were attached to the ocean bottom by means of holdfasts (Hill, 1972).

Archaeocyathid skeletons consist of a porous outer wall separated from a porous inner wall by a volume termed the intervallum. The intervallum may contain a variety of skeletal elements (Fig. 8) including radial, straight, longitudinal, porous septa, radial, wavy longitudinal taeniae, horizontal or arched, porous tabulae, and thin, bubble-like, non-porous dissepiments. Taeniae and septa may be joined by small cylindrical rods called synapticulae. The central cavity lies inside the inner wall; it contains few skeletal elements. Exothecal growths are additional skeletal components of varying shape and size which may occur attached to the outer wall or rarely, in the central cavity. These skeletal components have been interpreted as outgrowths of attachment; outgrowths, without specific purpose; parasitic organisms; and independent, encrusting archaeocyathids (Handfield, 1971). Balsam (1973) considered that exothecal growths in archaeocyathid reefs of Labrador helped bind skeletons into a rigid framework.

Archaeocyathids occur in subunits 1e, 1d and the upper part of 1c. The following is a composite faunal list of genera from the Ketza River area which were identified by V.J. Okulitch (Tempelman-Kluit 1973; Kawase and Okulitch, 1958);

?**Rhizocyathus** sp.

?**Protopharetra** sp.

Archaeocyathus cf. **loculiformia** Billings

Archaeocyathus sp.

?**Ethemocoscinus** sp.

Coscinocyathus inequivallus Kawase and Okulitch

C. serratus Kawase and Okulitch

C. dentocanis Okulitch

C. sp.

Pycnoidocyathus columbianus Okulitch

P. cf. **dissepimentalis** Okulitch

Metacoscinus sp.

Claruscyathus ketzaensis Kawase and Okulitch

Ajacicyathus nevadensis Okulitch

A. purcellensis Okulitch

A. cf. **purcellensis** Okulitch

A. yukonenesis Kawase and Okulitch

A. sp.

Unfortunately, the stratigraphic positions of these specimens, which are late Early Cambrian (Okulitch and Greggs, 1958), were not recorded.

Exhaustive systematic classification of archaeocyathids was not attempted in this study and only the dominant taxa of the carbonate buildups are identified to the generic level. Archaeocyathids are classified using Hill's scheme (1972) in which there are two classes, Irregularia and Regularia. Taxa from the carbonate buildups are dominated by irregular genera of the suborder Archaeocyathina and one regular genus, **Coscinocyathus?**. Species of the genera **Pycnoidocyathus** and **Protopharetra** account for most irregular archaeocyathids. Less abundant taxa include the regular **Ajacicyathus** and **Cordilleracyathus?**, the irregular **Bicyathus?**, and the problematic, stromatoporoid-like **Altaicyathus?**.

There are two common species of **Pycnoidocyathus**. One is similar to **P. sekwiensis**, a large, solitary, cylindro-conical form up to 20 cm high and 4 cm in diameter. The intervallum is wide and complex, with relatively straight taeniae connected by numerous synapticulae (Pl. 2a). The other species of **Pycnoidocyathus** is narrow and cylindrical with diameters usually less than 0.5 cm and heights ranging up to 8 cm (Pl. 2b). C. Fong (pers. comm., August 20, 1976) suggested this stick-like form might be close to **P. uniserialis** and is the same genus found abundantly in archaeocyathid "patch reefs" of Labrador. Intervalla are moderately wide and filled with thick wavy taeniae linked by synapticulae.

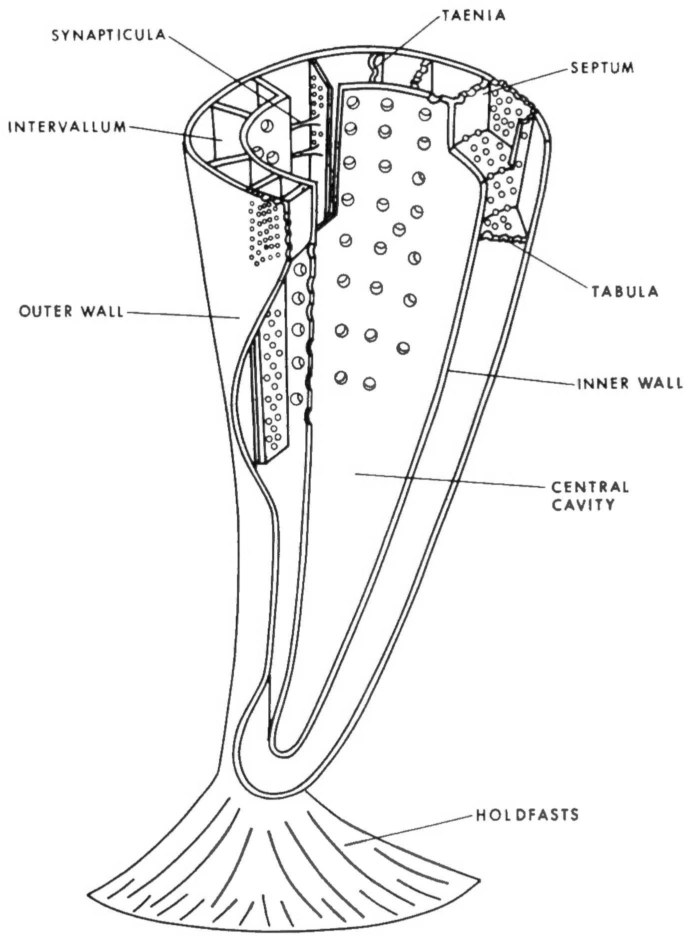
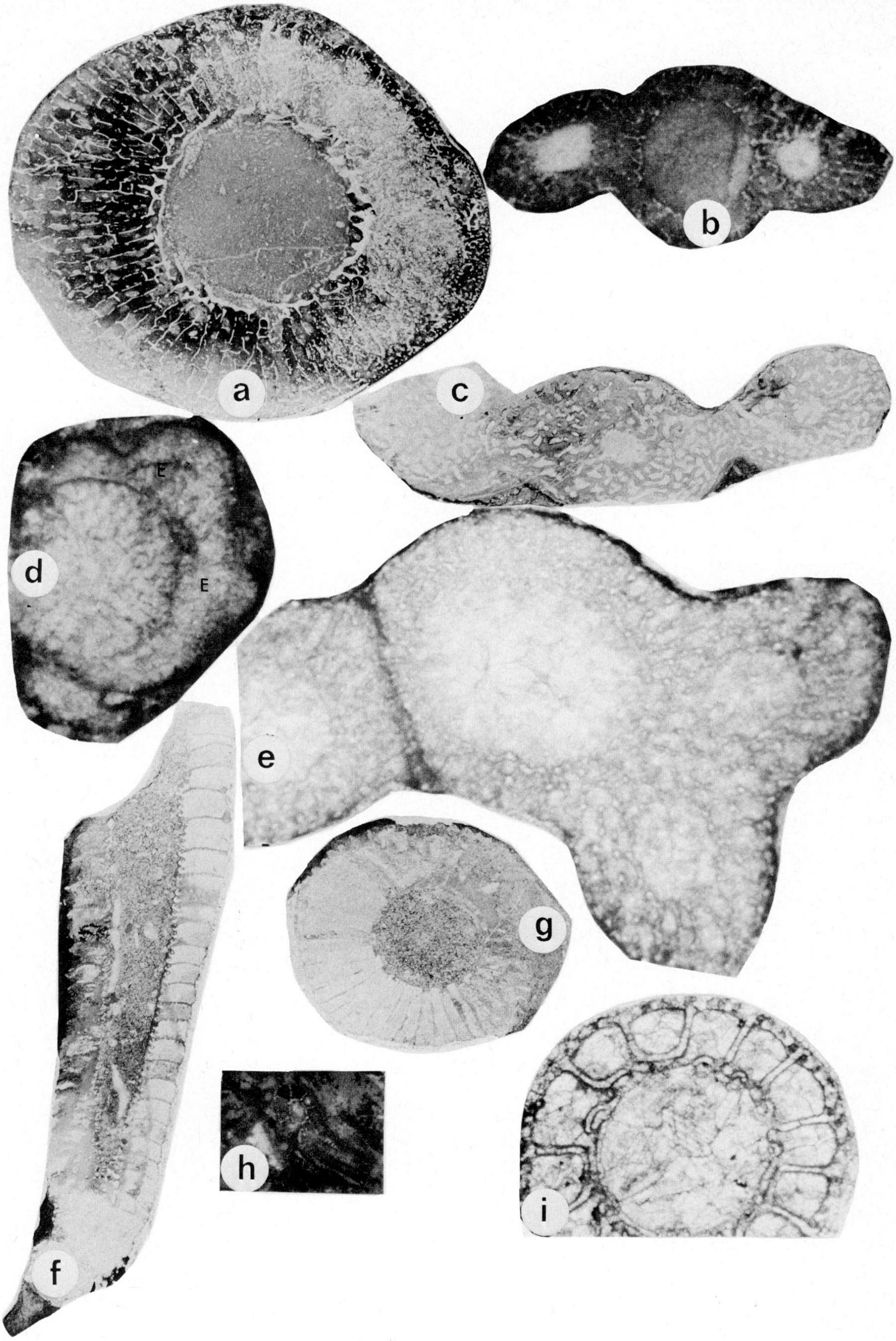


Figure 8. A generalized reconstruction of an archeocyathid skeleton (from Debrenne, 1964).


a
b
c
d
E
E
e
f
g
h
i

Protopharetra is a large, cylindrical, robust archaeocyathid with a diameter up to 1.5 cm and height to 8 cm. Skeletal elements are thick, and taeniae and synapticulae form a complex mesh-like pattern within a wide intervallum (Pl. 2c). Exothecal growths are attached to the outer walls of some specimens (Pl. 2d).

In carbonate buildups, **Pycnoidocyathus uniserialis?** and **Protopharetra** locally occur in thicket-like clusters in which a colonial habit is weakly developed (Pl. 3b, 3c). Either taxon may be fused into catenulate colonies. These consist of two or more cups of the same genus arranged in a row and the outer wall is not developed between neighbours (Pl. 2c, 2e). In addition **Protopharetra** also forms dendroid colonies of branch-like cups isolated from others except at their point of origin (Pl. 3a). Clusters of archaeocyathids with some individuals joined together were found only in carbonate buildups. This suggests that clustering may represent an adaptation to the buildup environment.

Coscinocyathus is a large, solitary, cylindrical archaeocyathid. This genus has a wide intervallum filled with upward arching tabulae (Pl. 2f) and numerous straight septa (Pl. 2g).

Subordinate archaeocyathids in the carbonate buildups include **Ajacicyathus** (Pl. 2h), **Cordilleracyathus**? (Pl. 2i) and **Bicyathus**?. In general these are small, fragile forms compared to the dominant reef genera.

Although not abundant, **Altaicyathus**? is one of the most interesting buildup organisms because it resembles a stromatoporoid. Specimens are commonly bulbous with diameters reaching 6 cm (Pl. 4a, 4b, 4c and 4d). They may occur in clusters (Pl. 4h). Columnar-shaped varieties, some up to 8 cm high (Pl. 4f, 4g) and tabular forms are also present (Pl. 4e). Some specimens have digitate extensions (Pl. 4e).

Internally, **Altaicyathus**? consists of porous laminae 0.5 mm apart with radial pillars that do not extend across interlaminae (Pl. 4i). Most specimens have randomly oriented "tube-like" structures which lack walls (Pl. 4a, 4b, 4c and 4d). The "tubes" are 1 to 2 mm in diameter and filled with spar, or less commonly, mud. Their lack of walls and random orientation suggest that the "tubes" may be borings made by an unknown organism. Alternatively, they may represent an integral part of the **Altaicyathus?** skeletal structure.

As Zhuravleva (1970) has indicated, the affinities of **Altaicyathus** are uncertain. Many workers have postulated that it is an ancient stromatoporoid (Vlasov, 1967; Khalfina and Yavorskey, 1967); others an aberrant archaeocyathid (Nestor, 1966).

PLATE 2 (opposite)

Common Archaeocyathids found in buildups

a. **Pycnoidocyathus sekwiensis** (x2)

b. **P. uniserialis**? (x7)

c. **Protopharetra sp.** (x3)

d. Exothecal growth (E) on outer wall of **Protopharetra sp.** (x4)

e. Catenulate **Pycnoidocyathus** uniserialis? colony (x15)

f. Longitudinal section of **Coscinocyathus sp.** showing tabulae (x4)

g. Transverse section of **Coscinocyathus sp.** showing numerous septa (x4)

h. **Ajacicyathus sp.** (x2.5) (see also Pl. 5g)

i. **Cordilleracyathus**? (x18)

GSC 203328-A

The shape and internal structure of **Altaicyathus?** from the Ketza River area suggest to the writer that it is related to the stromatoporoids. Gangloff (fide.) Rasanov (pers. comm., May 12, 1976) also thinks that specimens sent to him are stromatoporoids. If this is so these organisms, which are generally considered to appear first in the Middle Ordovician, were present in carbonate buildups as old as the Early Cambrian. That **Altaicyathus**? exhibits possible borings is also significant because such biological destruction is generally thought to be absent in most early Paleozoic buildups (Copper, 1974; Scoffin, 1971).

Paleoecology and Affinities of Archaeocyathids

Archaeocyathids probably preferred warm, normal-marine, shallow water (Hill, 1972, p. E27) and their presence in rocks of the Cordillera indicates an environment of shelf deposition (Stelck and Hedinger, 1975). Studies of the Siberian Platform suggest that water depths from 20-50 m were most favourable to archaeocyathid growth and it is within this range that archaeocyathids constructed their buildups (Hill, 1972, p. E28). Sediments interpreted to have been deposited below 100 m lack archaeocyathids. These depth restrictions are based on ". . . the association with the blue-green algae **Renalcis**, the fragmentation of many skeletons, and the dimensions of the bioherms which with the algae, they (archaeocyathids) were able to construct." (op. cit., p. E28). The extent to which these depth ranges apply to Cordilleran archaeocyathids is not known. Furthermore, if **Renalcis** is a foraminifer rather than an algae, as some writers have postulated (Riding and Brazier, 1975), the validity of proposed optimal depths for bioherm construction may need revision.

Based on Lower Cambrian carbonates of Labrador, Copper (1974) made several observations pertinent to archaeocyathid ecology. He suggested that skeletal adaptations to higher energy biohermal environments include (a) discoid shape, (b) dissepiments and exothecal growths which served a strengthening role, (c) dense walls and septa, and (d) squat, colonial structure, low dendroid forms. Adaptations to quieter water biostromal conditions are thin, cylindrical, organ-pipe colonies and deeply conical forms. Archaeocyathid skeletons from carbonate buildups in the Ketza River area exhibit characteristics of both these biohermal and biostromal adaptations.

Archaeocyathids were low to intermediate level (0-20 cm) suspension feeders which probably filtered nutrients from currents that flowed through their porous skeletons (Balsam and Vogel, 1973). Most writers consider that the intervallum was the site of principal life processes (Hill, 1972; Balsam, 1973). Possible food sources may have been bacteria, dissolved or suspended organic matter, and plankton (Balsam, 1973).

The affinities of archaeocyathids, which have generally been regarded as ancient sponges or corals, are controversial (Okulitch, 1943). Okulitch and de Laubenfels (1953) considered them to be sufficiently different from other organisms to erect a new phylum, Archaeocyatha (see also Hill, 1964, 1972). Hill (1972) postulated that archaeocyathids were simple multicellular animals with a level of differentiation lying between that of Protozoa and Porifera. However, some writers suggest that archaeocyathids are an extinct class of sponge and, therefore, should not be elevated to phylum status (Zeigler and Rietschel, 1970; Balsam, 1973). Galloway (1957) and Copper (1974) even considered that archaeocyathids may be related to the calcareous stromatoporoids, now classified by some as fossil representatives of Recent sclerosponges (Hartman and Goreau, 1970).

PLATE 3

a. Hand specimen of dendroid **Protopharetra sp.** colonies.

b. Hand specimen of clustered **Protopharetra sp.** cups.

c. Hand specimen of cluster of mainly **Pycnoidocyathus uniserialis?** cups.

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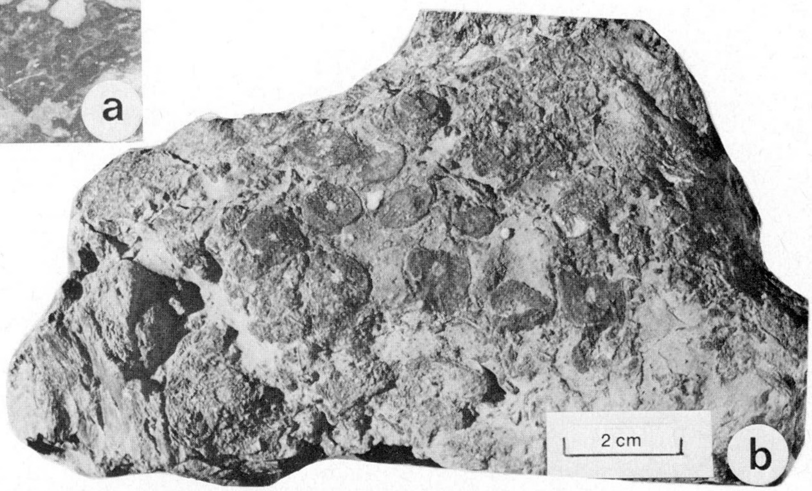
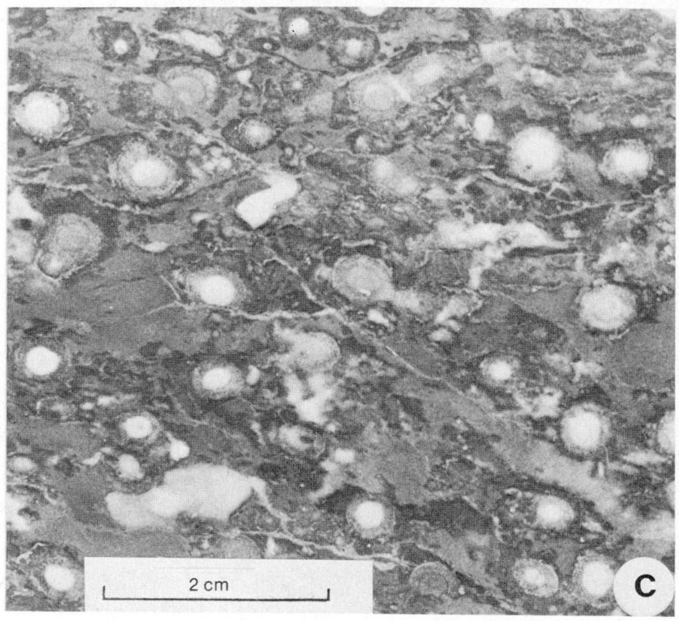




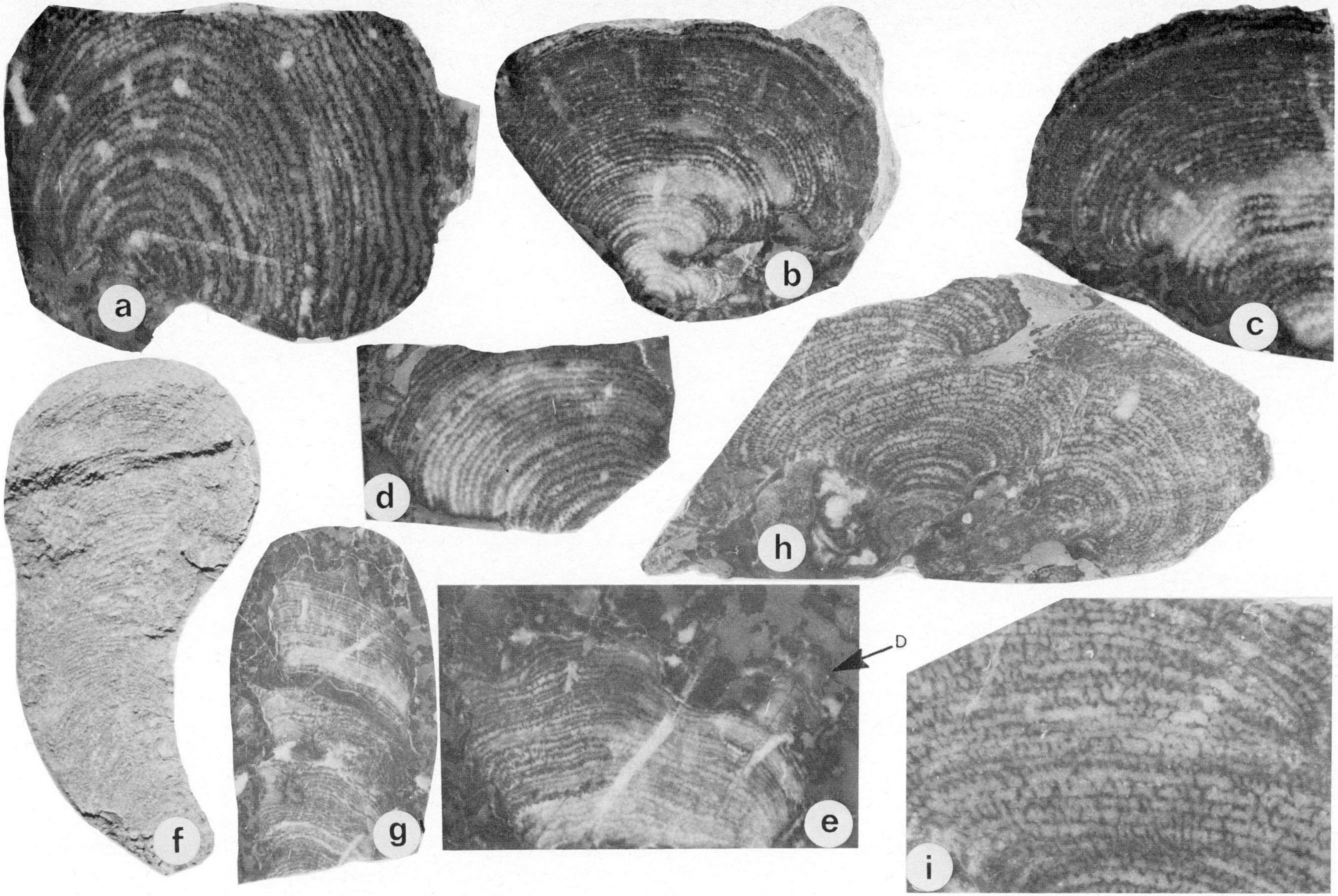


PLATE 4

a. Bulbous **Altaicyathus**? (x2)

b. Bulbous **A.**? (x1.2)

c. Bulbous **A.**? (x1.7)

d. Bulbous **A.**? (x1.5)

e. Tabular **A.**?, note digitate extension at D (x1)

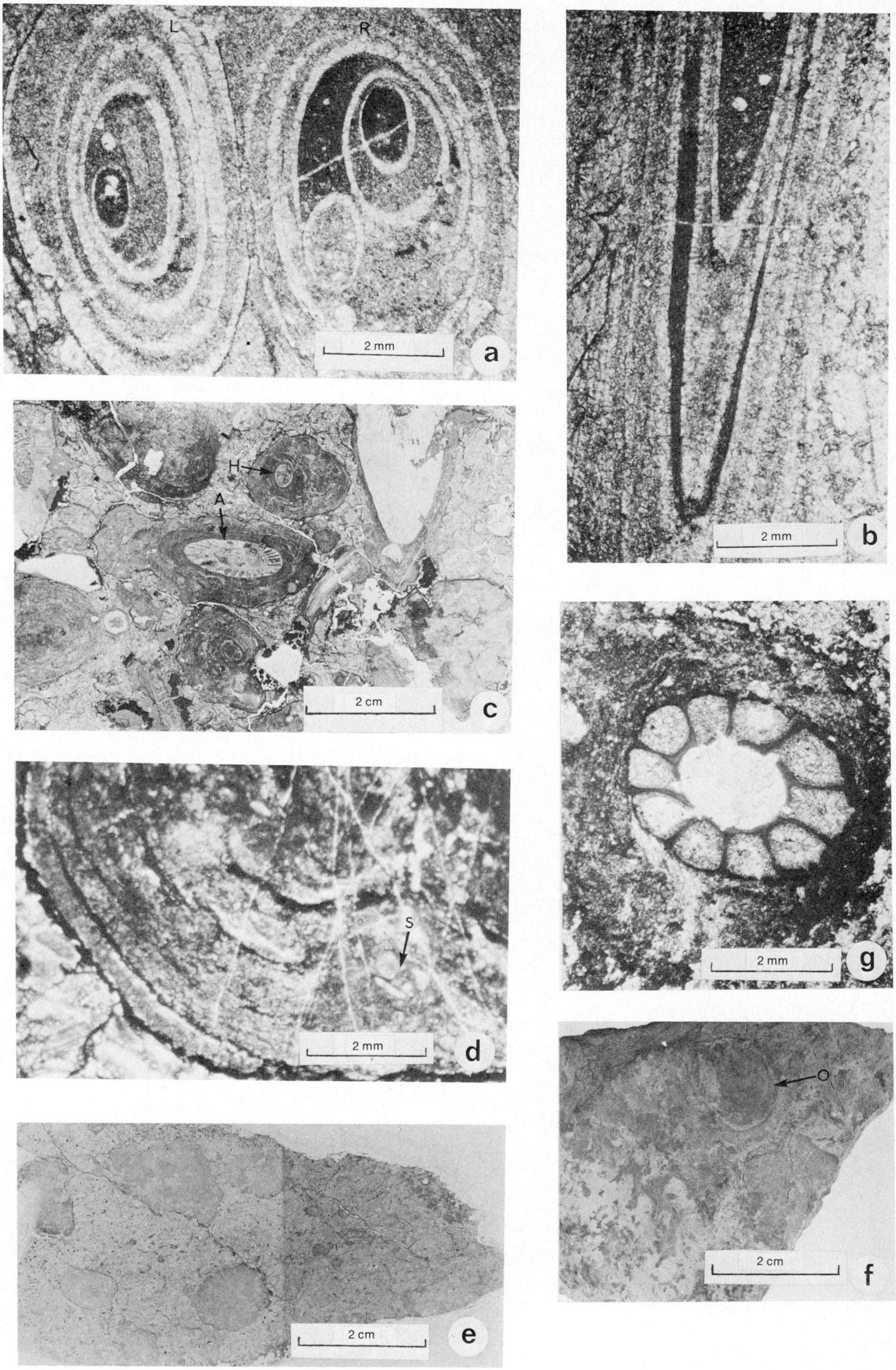
f. Columnar **A.**? (x1)

g. Columnar **A.**? (x7)

h. Cluster of bulbous **A.** (x1.2)

i. Laminae and pillar internal structure of **A.**? (x3.5)

GSC 203328-C


L
R
2 mm
a
2 mm
b
H
A
2 cm
c
S
2 mm
d
2 mm
g
O
2 cm
f
2 cm
e

Trilobites

Trilobite fragments occur sporadically in subunits 1b to 1e and are locally abundant in some packstone and rudstone beds. Intact specimens are rare. However, the following genera have been identified by W.H. Fritz (pers. comm., November 4, 1974), **Nevadella**?, **Olenellus**, and **Laudonia**?.

Echinoderms

Echinoderm fragments are sparsely distributed in rocks of subunits 1c to 1e. Although conspicuous because of their complete extinction and porous structure when viewed with petrographic microscope, these fragments are common only in some skeletal-rich carbonates.

Hyolithids

Hyolithids are abundant in some skeletal rudstone lenses of subunit 1e but they are also sparsely distributed in subunit 1d. These fossils are bilaterally symmetrical, conical, and circular to subtriangular in cross section (Pl. 5a). Large tests average 2 mm in diameter and are up to 1.5 cm long. Hyolithids are commonly stacked irregularly one inside the other, their cones filled with fine detritus (Pl. 5b). Large, solitary skeletons, irregular stacking, and lack of axial openings or skeletal elements joining cones implies that stacking does not represent successive growth stages. Hockley (1973) speculated that stacking is the result of reworking by bidirectional wave or current action. Hyolithids are considered members of an extinct molluscan class, the Hyolitha (Yochelson, 1961; Merek and Yochelson, 1964) that ranges from Lower Cambrian to Permian.

Brachiopods

Brachiopods are rare and occur only in subunits 1d and 1e. Molds, casts, and complete tests, normally with lengths less than 1.5 cm, show growth lines. Some appear similar to the inarticulate **Obollela** (Pl. 5f) whereas others may be lingulids. Sparsely distributed shell fragments are found in some skeletal packstones.

Algae

Oncoids

Oncoids occur locally in subunits 1d and 1e and are of two types; "simple" and "spongy" (sensu Aitken, 1967). The simple variety has concentric mode "C" envelopes, (Logan et al., 1964) consisting of thin, irregular laminae that completely enclose the preceding one (Pl. 5c, 5d). Small skeletal fragments are sometimes incorporated into these laminated coatings (Pl. 5d). Spongy oncoids, as defined by Aitken (1967), are composed of discontinuous successive laminations with the discontinuities spread radially (Pl. 5e). Nuclei for both types are usually fossil fragments. Algal filaments or fibres have not been observed in oncoids from the study area. Oncoids range in size from 0.5 to 4 cm and their shape depends on the amount of coating and nucleus shape. In general, larger oncoids and those with thicker coatings tend to be oblong or spherical.

Recent mode "C" oncoids develop in subaqueous environments and in water sufficiently agitated to keep the grains in continuous motion (Logan et al., 1964). Considering this, Aitken (1967) has suggested that most oncoids originated in submergent, shallow, moderately turbulent environments.

Cryptalgal Coated Grains

Cryptalgal (sensu Aitken, 1967) coated grains occur locally in subunits 1c to 1e. They consist of skeletal fragments coated with dense, dark carbonate (Pl. 5g) which may exhibit vague, irregular laminations. Grains range in size from 1 mm to 2 cm; like oncoids, their shape is strongly influenced by coat thickness and nucleus form. Coatings are presumably of algal origin and cryptalgal grains probably have a history of formation similar to that of oncoids. The difference between the two grain types is that cryptalgal coated grains lack the well-defined laminae that characterize oncoids.

Renalcis?

Dark encrustations of structureless or "clotted" micro-crystalline calcite (Pl. 6; see also Pl. 21, 22) commonly occur between, and as coatings on, archaeocyathids in the carbonate buildups. Locally they are shaped like small "algal heads". Encrustations are interpreted as organic because "algal heads" are oriented upwards and laterally from archaeocyathids and because the encrustations are also present on the underside of cups. It seems inconceivable that inorganic processes, such as settling of carbonate mud on skeletons, produced these features.

Although remains of this encrusting organism are poorly and rarely preserved in rocks from the buildups, some samples provide clues to its identity. In these specimens clusters of small, bulbous, hollow chambers encrust archaeocyathids and are surrounded by the mud matrix (Pl. 7a, 7b, 7c and 7d). Chambers, which are normally 1 mm or less in diameter, have thin, structureless walls composed of dark, microcrystalline calcite. These chambers are similar to **Renalcis** Vologdin, a problematic encrusting organism found in archaeocyathid carbonate buildups throughout the world (Copper, 1974; Balsam, 1973; James and Fong, 1976; Heckel, 1974; Hill, 1972). The abundant dark encrustations and heads discussed earlier are therefore thought to represent **Renalcis?** which has undergone extensive recrystallization.

Since preservation is generally poor, the possibility that some of these encrustations may be the recrystallized remains of an unidentified organism, such as a calcareous algae or algal consortium, cannot be ruled out. In archaeocyathid reefs of Labrador, Balsam (1973, p. 35) noted that in most cases **Renalcis**, and **Epiphyton**, a calcareous algae (Hill, 1972), ". . .are so intimately intergrown that identification of either genus is impossible. These algae form either nondescript masses or, less commonly, heads". **Epiphyton** and binding stromatolitic algae were not found in rocks from the Ketza River buildups.

PLATE 5 (opposite)

a. Thin section showing transverse sections of hyolithids. Tests are stacked concentrically at L and irregularly at R.

b. Thin section showing longitudinal section of stacked hyolithids.

c. Thin section of "simple" oncoids. Both archaeocyathids (A) and hyolithids (H) occur as nuclei.

d. Thin section showing irregular laminae of "simple" oncoids. Note skeletal fragments at S.

e. Thin section of "spongy" oncoids.

f. Hand specimen showing a brachiopod (O), possibly **Obolella**.

g. Thin section of cryptalgal coated grain. The nucleus is an archaeocyathid, **Ajacicyathus.**

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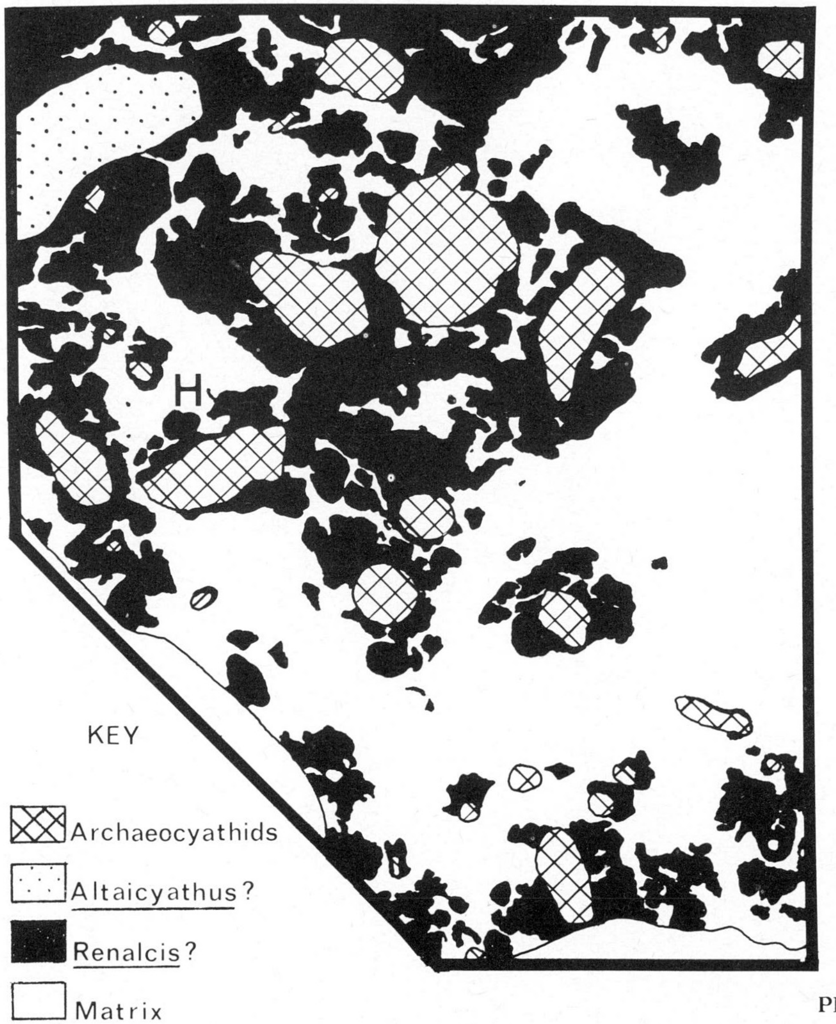


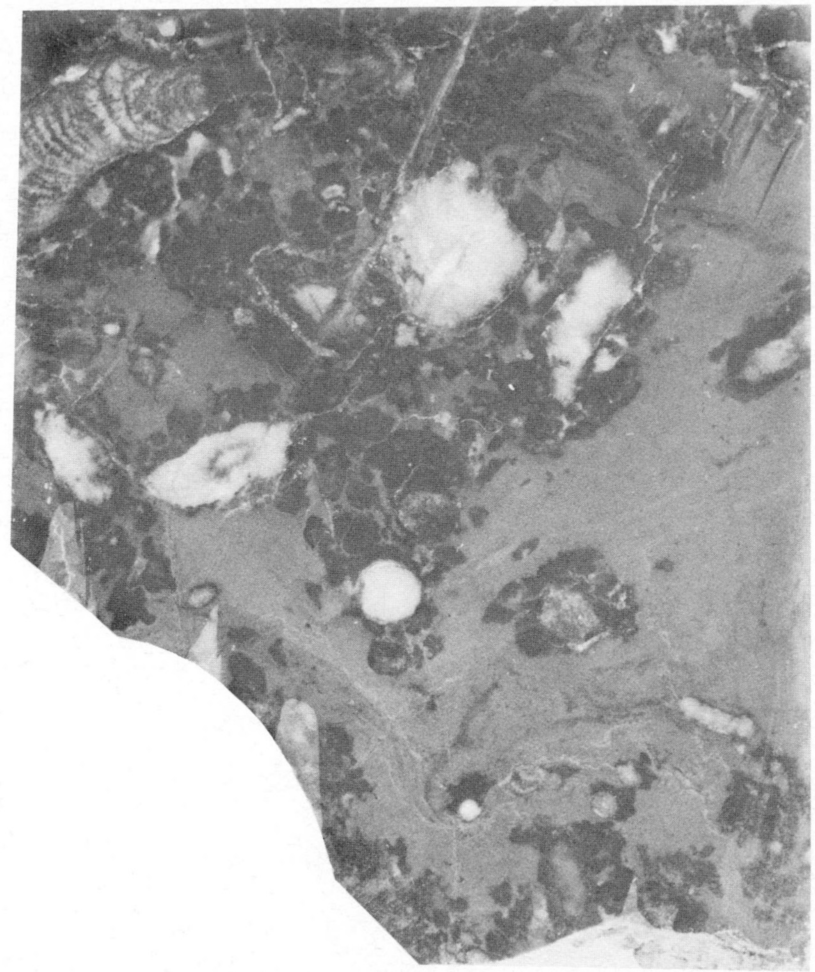
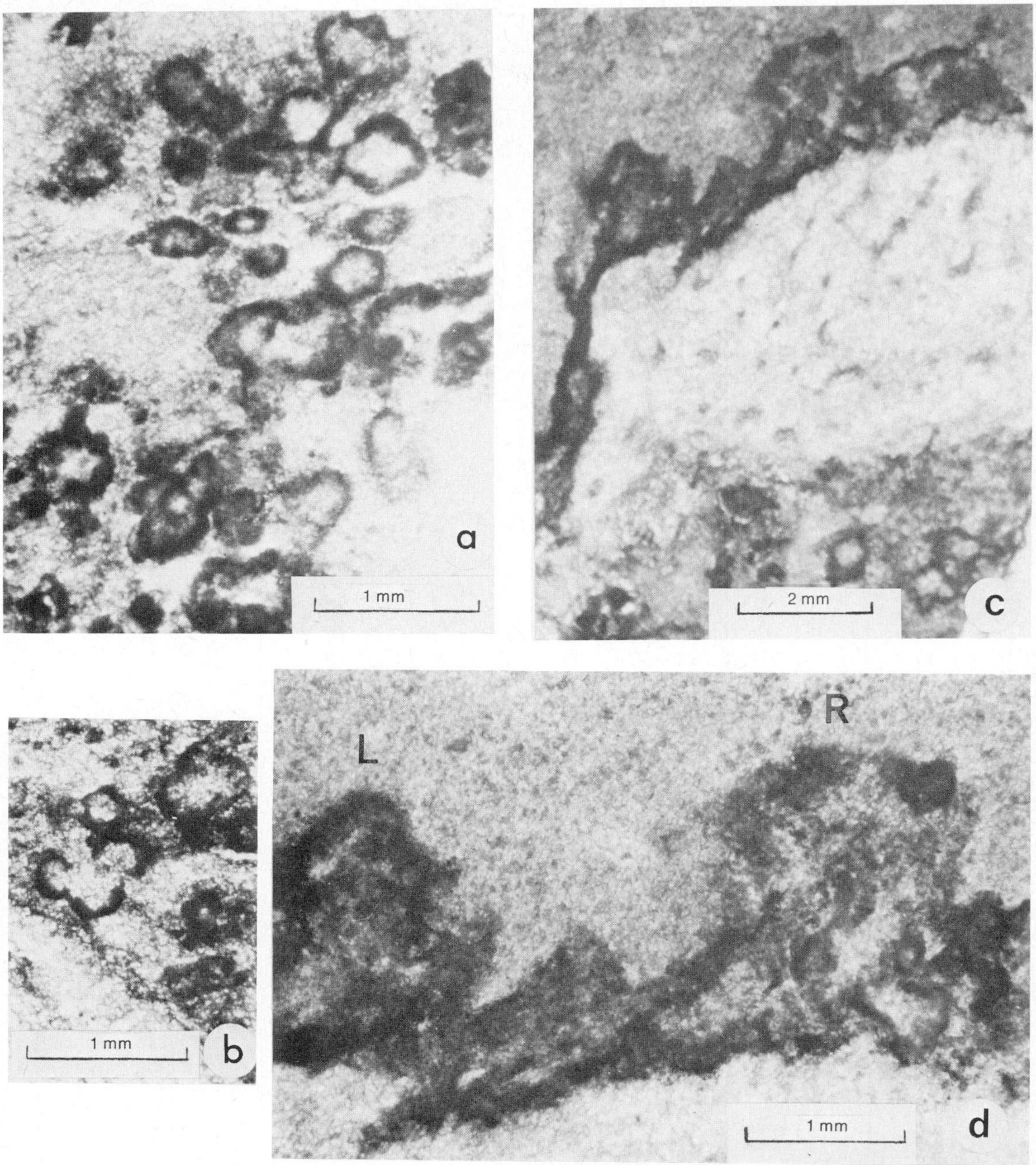


PLATE 6

Polished slab and drawing showing spatial relationship between archaeocyathids, **Altaicyathus**?, mudstone matrix, and dark microcrystalline coatings, possibly the recrystallized remains of **Renalcis** (see also Pl. 21, 22). Note "algal head"-like structures at H. Slab is 6 cm across. GSC 203328-E



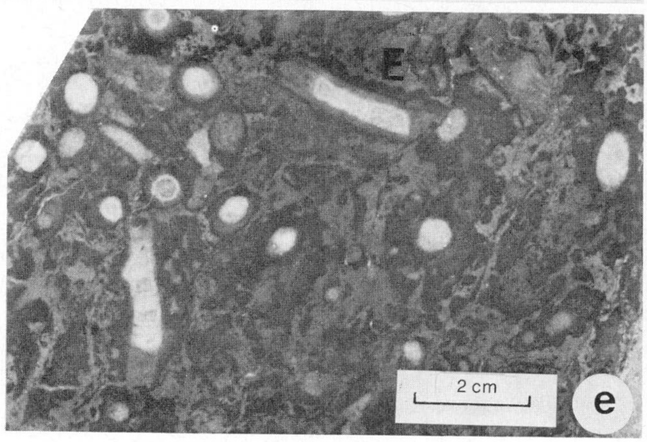


PLATE 7

a. Thin section showing bulbous, hollow chambers of **Renalcis**?.

b. Thin section showing bulbous, hollow chambers of **Renalcis?**. Note the thin structureless walls composed of dark, microcrystalline calcite.

c. Thin section of **Renalcis**? encrustation on an archaeocyathid cup.

d. Higher magnification of **Renalcis**? encrustation illustrated in Plate 7c. Note that this encrustation is dark and structureless at L but exhibits poorly preserved **Renalcis**? chambers at R.

e. Hand specimen of "typical" **Renalcis**? encrustations found in most rocks from the carbonate buildups (see also Pl. 6, 21, 22). Note similarity between dark, structureless encrustation on archaeocyathid at E in Pl. 7e and at L in Pl. 7d.

GSC 203328-F

The affinities of **Renalcis** are controversial, but many workers consider it a blue-green calcareous algae (Balsam, 1973; Hill, 1972; Hofmann, 1975; Johnson, 1966). Because of its size, shape, and wall microstructure, some writers suggest renalcids were foraminifers (Jamieson, 1971; Klovan, 1964; Riding and Brazier, 1975). **Renalcis** was probably adapted to shallow marine, warm, biohermal carbonate environments (Riding and Brazier, 1975). Klovan (1964) suggested that such organisms found in certain parts of the Devonian, Redwater Reef Complex may have preferred quiet water conditions. Because of its ability to bind skeletons together, **Renalcis** played a key role in the construction of framework in archaeocyathid carbonate buildups (Balsam, 1973; James and Fong, 1976; Heckel, 1974).

STRATIGRAPHY

Carbonate Rock Classification and Buildup Terminology

The carbonate classification of Embry and Klovan (1971), essentially an expanded version of Dunham's (1962), is used in this study (Fig. 9). Because it was devised to describe the rocks of carboante buildups it is well suited to the Ketza River carbonates which contain such structures. The general term "skeletal sand", is used herein for packstones and coarser grained rocks commonly found in the buildups. They normally contain abundant carbonate grains, some larger than 2 mm, derived from archaeocyathids, trilobites and echinoderms.

The carbonate rock classification of Embry and Klovan (1971) and most other classifications (Dunham, 1962; Folk, 1959) are in part, based on the proportion of carbonate mud in a rock. Mud is characteristic of calm water where it is able to settle and remain at the bottom. Therefore, mud abundance in a sediment is a good measure of agitation in the depositional environment. Modern carbonate mud is usually less than 0.004 mm (Bathurst, 1971). However, in ancient limestones aggradational neomorphism (Folk, 1965) of mud results in increased crystal size. For example, writers have observed "coarser" mud with the following grain sizes: up to 0.012 mm (Aitken, 1968), up to 0.070 mm (Balsam, 1973) and 0.002 to 0.015 mm (Beales, 1956). Folk (1962) suggested that the mud component of limestones consists of particles less than 0.062 mm. The 0.004 mm upper size limit of Recent lime mud is especially impractical for fine grained carbonates in the study area because the rocks have undergone low grade metamorphism. In this report "carbonate mud" refers to grains less than 0.062 mm in diameter which do not exhibit the fabric criterion of cement (Bathurst, 1971). This "mud" is similar in grain size to "microspar" and "pseudospar" (Folk, 1965) and is interpreted as recrystallized, depositional mud.

Dolomitization is common and of variable degree. The modifiers, "dolomitic" for carbonates with 10 to 50 per cent dolomite, and "dolomite" for carbonates with more than 50 per cent dolomite, precede the appropriate textural term from the classification. Where the original depositional texture is obscured by dolomite the carbonate is referred to as "sucrosic dolomite".

The term "mudstone" is used herein to describe fine grained carbonate rocks. The word "argillite" is used to denote fine grained terrigenous clastics regardless of their degree of metamorphism. Locally the "argillite" grades into phyllite.

To prevent confusion regarding unbedded or poorly bedded carbonate rocks the terminology of Heckel (1974) is used (Fig. 10). Heckel's uses of the terms "carbonate buildup" and "reef" are briefly reviewed. A carbonate buildup is a "...circumscribed body of carbonate rock which displays topographic relief above equivalent sediment and differs from typically thinner equivalent deposits and surrounding and overlying rocks" (op. cit., p. 90). According to Heckel, recognition of positive topographic relief is primarily based upon flank beds that dip away from a buildup or which pinch out against it and strata that thin over a buildup. Carbonate buildups commonly differ in composition and internal fabric from equivalent deposits. Heckel defined reefs as "carbonate buildups which display evidence or potential for maintaining growth in the zone of waves" (op. cit., p. 90). The principal cause of wave resistance may be a rigid organic or inorganic framework. This definition is more inclusive than Lowenstam's (1950) which proposed that reefs are built by organisms and, therefore, have organic frameworks only. Evidence for maintaining growth in the zone of waves includes contemporaneous, buildup-derived, wave-washed talus and abraded calcarenites along the buildup margin (Heckel, 1974). A buildup lacking such evidence is termed a "potential reef" if it exhibits potential for wave resistance. An example is a deep or calm water buildup with a preserved rigid framework and hence, potential for withstanding waves.

Subunit 1a

Description

Subunit 1a, a sequence of fine grained clastics, are the oldest strata exposed in the study area. Argillite predominates, except at Mount Fury where sandy facies occur in lower beds. The greatest measured thickness is 215 m, but in other regions within Quiet Lake map area correlative argillite is about 1000 m thick.

Argillites are thin bedded to laminated, normally recessive, and weather a distinctive greenish grey. They are composed of fine white mica, quartz and some chlorite (Pl. 8a). Euhedral pyrite is a common accessory mineral. More resistant argillites are silty.

Light grey weathering, even bedded quartzite up to 0.3 m thick is locally interbedded with the argillite. This quartzite is texturally and mineralogically similar to the quartzite at Mount Fury which was very fine grained feldspathic sandstone (sensu Pettijohn, 1957) before low grade metamorphism.

Recognition of organic activity in argillite is difficult because of deformation. However, both deformative and formative bioturbation (Schafer, 1972) is present in quartzite interbeds. Trace fossils are mainly simple horizontal burrows, but some are lined and penetrate bedding at right angles and then parallel it (Pl. 8b). Although both types are probably feeding burrows, the latter may also have been excavated for protection.

<table>
<tr><td colspan="6">ALLOCHTHONOUS LIMESTONES
Original components not organically bound during deposition</td><td colspan="3">AUTOCHTHONOUS LIMESTONES
Original components organically bound during deposition</td></tr>
<tr><td colspan="4">Less than 10% >2mm components</td><td colspan="2">Greater than 10% >2mm components</td><td rowspan="4">By organisms which act as baffles</td><td rowspan="4">By organisms which encrust and bind</td><td rowspan="4">By organisms which build a rigid framework</td></tr>
<tr><td colspan="3">Contains lime mud (<.03mm)</td><td>No lime mud</td><td rowspan="3">Matrix supported</td><td rowspan="3">>2mm component supported</td></tr>
<tr><td colspan="2">Mud supported</td><td colspan="2" rowspan="2">Grain supported</td></tr>
<tr><td>Less than 10% grains (>.03mm <2mm)</td><td>Greater than 10% grains</td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Floatstone</td><td>Rudstone</td><td>Bafflestone</td><td>Bindstone</td><td>Framestone</td></tr>
</table>

Figure 9. Classification of limestones according to depositional texture (after Embry and Klovan, 1971).

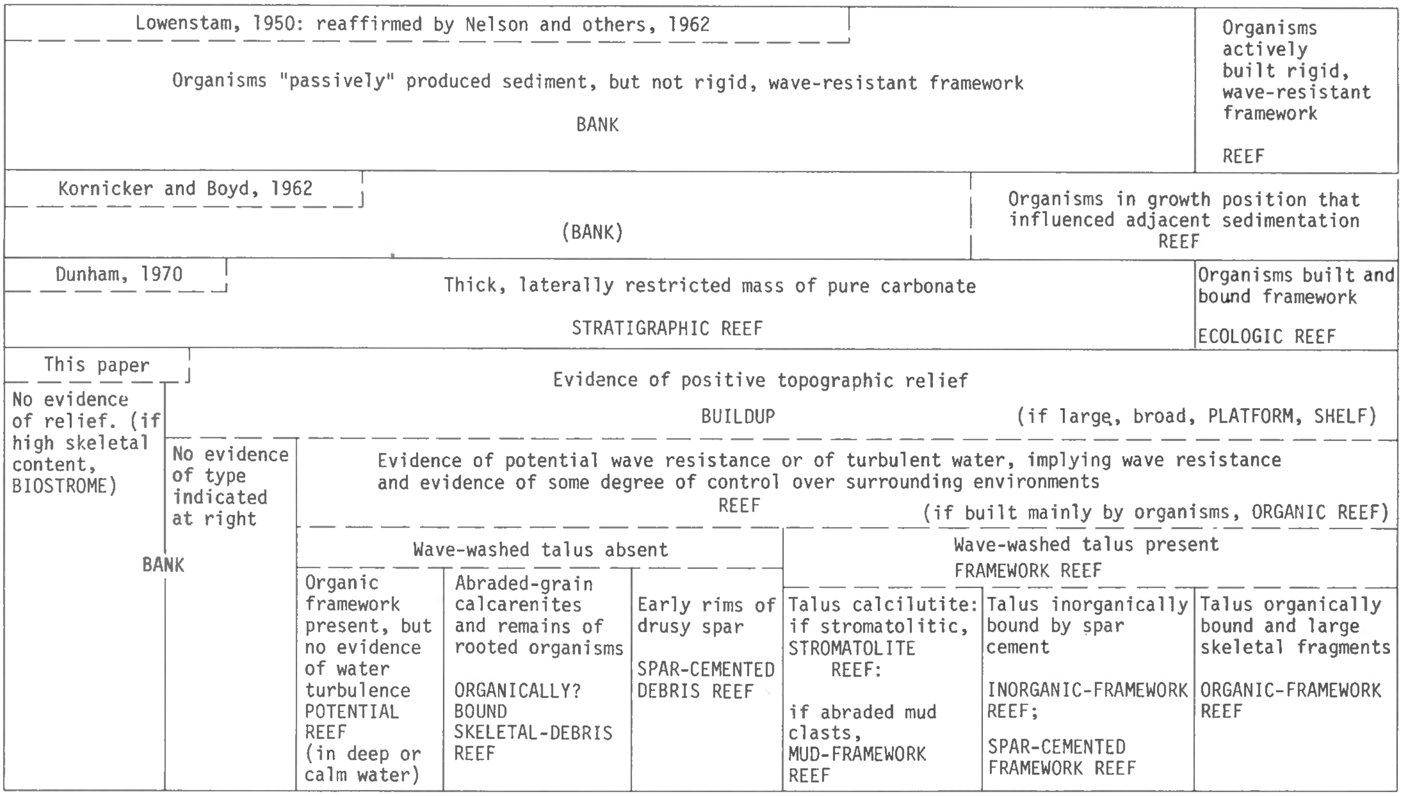


Figure 10. Usage of terms "reef", "bank", "buildup" (and modifiers) in previously proposed and here proposed schemes of definition. Terms are in capital letters; criteria are in small letters. Usage proposed in this paper is largely hierarchical in that more general terms (above dashed lines) include more specific terms (below dashed lines) which allows refinement of terminology as progressively more evidence becomes available (from Heckel 1974).

At Mount Fury the green argillite changes facies; it thins to about 60 m and its lower part is replaced by more than 125 m of resistant quartzite (Fig. 6). This quartzite occurs as beds from 2 cm to 75 cm thick interbedded with lesser argillite (Pl. 8c, 8d). Before low grade metamorphism the quartzite was a very fine grained feldspathic sandstone (sensu Pettijohn, 1957). No medium or coarse grained lithologies are present. The quartzite is composed of 80 to 86 per cent quartz and feldspar in a white mica matrix which rarely exceeds 5 per cent (Pl. 8e). Grains are well sorted and subangular to subrounded. Monocrystalline, inclusion-free, unstrained quartz constitutes 55 to 74 per cent and feldspar contributes up to 26 per cent. The feldspar is mainly plagioclase, some of which shows polysynthetic twinning. K-feldspar grains are rare but the possibility that their small grain size inhibited staining cannot be overlooked. Calcite and silica cements account for up to 18 per cent. Hematite, which coats some quartz grains, and euhedral pyrite are accessory minerals.

Argillite in the Mount Fury quartzite facies is similar to that of the argillite facies. However, silty varieties are more common at Mount Fury (Pl. 8f).

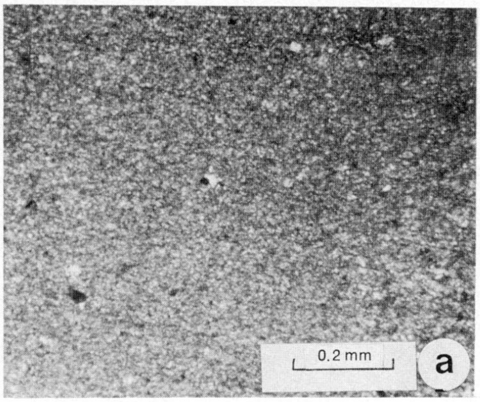
Even parallel and slightly inclined laminae are characteristic of most quartzite beds, particularly thicker ones (Pl. 9a). Large-scale cross stratification, except for a few channel-like deposits, is absent. Minor physical sedimentary structures include small-scale crossbeds (Pl. 9a), cut-and-fill structures (Pl. 9b), ripples, slump structures and lenticular bedding.

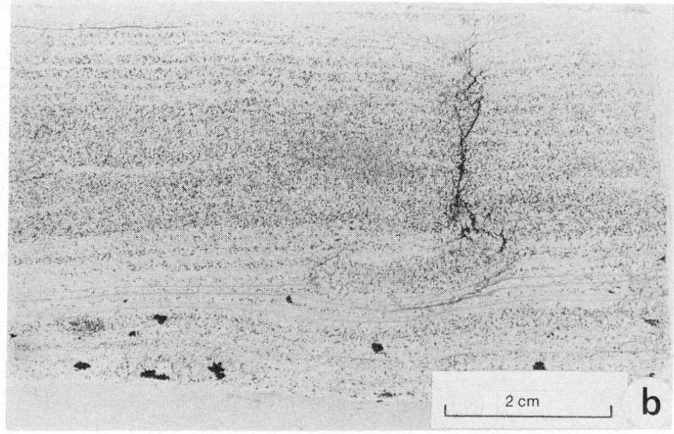
In attempting to determine direction of sediment transport, 34 crossbeds and 2 channels were measured at a single locality, in a stratigraphic interval of approximately 60 m. Crossbeds, which seldom exhibit erosional bases, are tabular and occur as solitary sets. Foresets are usually less than 5 cm high. The two channels measured were about 1 m in lateral extent, not more than 30 cm thick, and composed of quartzite.

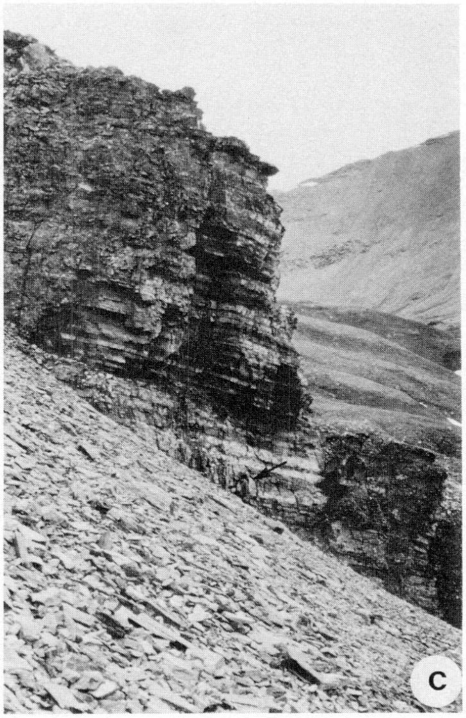
Orientation data are summarized in a rose diagram (Fig. 11). The resultant vector of 327° determined graphically has a consistency ratio of .75 (High and Picard, 1971) which indicates a relatively high unimodal preferred orientation of foresets. The orientation data imply that the paleoslope dipped to the northwest, and that dominant sediment transport was from the southeast. An easterly source for Cambrian terrigenous clastic sediments elsewhere in the Cordillera has been suggested by Aitken (1966), Mountjoy and Aitken (1963), Young (1969) and Gabrielse (1967).

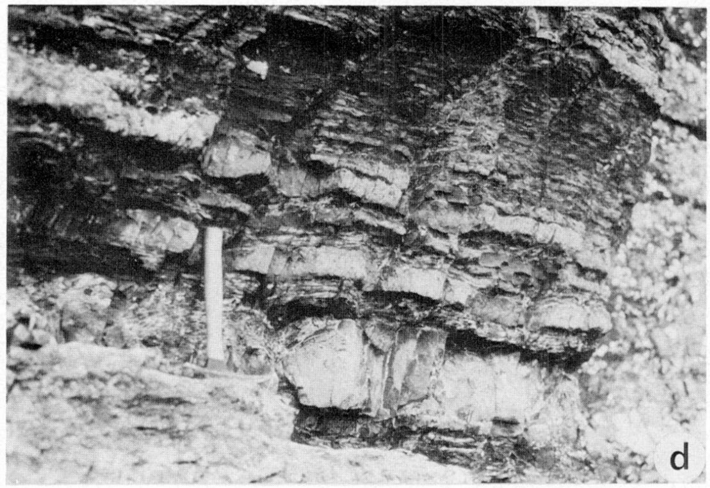
Although the thick quartzite beds lack bioturbation, many intervals of thin bedded quartzite and argillite are moderately to strongly bioturbated (sensu Reineck and Singh, 1973). Both deformative and formative bioturbation (Schafer, 1972) disrupt primary bedding.

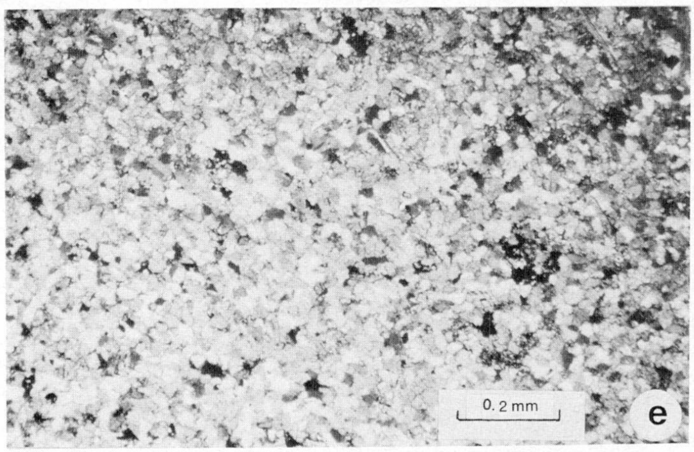
Deformative bioturbation, consisting of blebs, wisps and whorls of fine sand-sized particles (Pl. 9c, 9d), was probably formed by deposit feeders as they passed through the sediment.











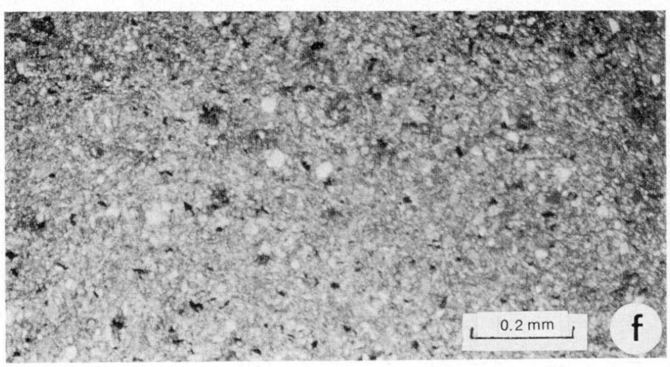


PLATE 8

a. Thin section of typical argillite from the argillite facies (subunit la, Shrimp Lake section).

b. Thin section of thin quartzite interbed found in the argillite facies. Note lined burrow which penetrates bedding then becomes parallel to it. "Speckled" nature of quartzite results from hematitic coatings on quartz grains (subunit la, Shrimp Lake section).

c. Outcrop of Mount Fury quartzite facies. Arrow points to man at the base of the cliff (subunit la, Mount Fury section).

d. Outcrop showing interbedded quartzite and argillite of Mount Fury quartzite facies (subunit la, Mount Fury section).

e. Thin section (crossed nicols) of quartzite from Mount Fury quartzite facies (subunit la, Mount Fury section).

f. Thin section of silty argillite from Mount Fury quartzite facies (subunit la, Mount Fury section).

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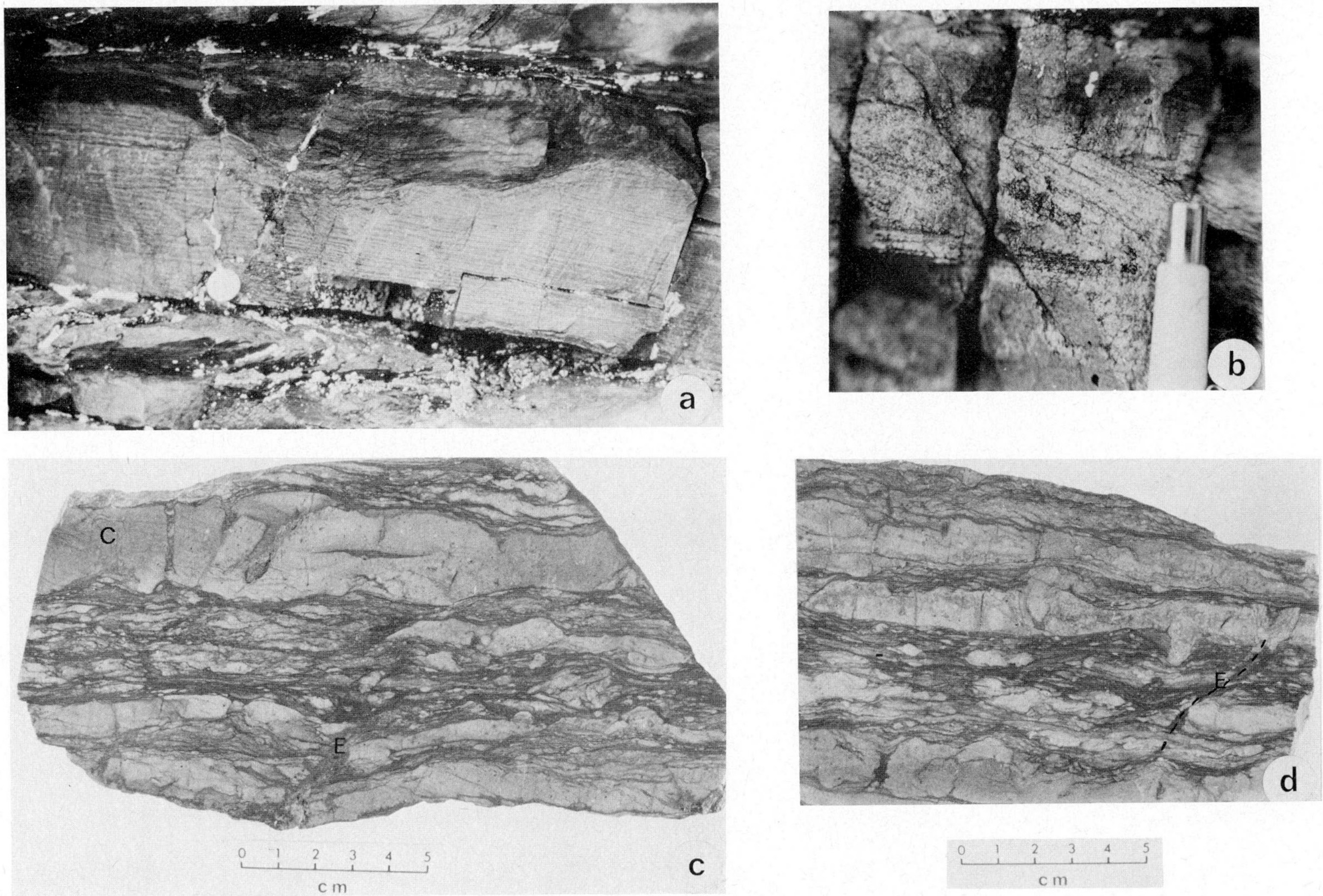

PLATE 9

a. Cut-and-fill structure developed at the top of even parallel laminated quartzite bed. Coin is 2.5 cm across (subunit la, Mount Fury section).

b. Small-scale tabular crossbedding. Scale is top 2.5 cm of a pen (subunit 1a, Mount Fury section).

c. and d. Hand specimens of bioturbated quartzite and argillite. Deformative bioturbation consists of blebs, wisps, and whorls of lighter coloured sand-sized particles. Most vertical traces appear to be "escape structures" (E). Note small-scale crossbed at C in Pl. 9c. (subunit la, Mount Fury section).

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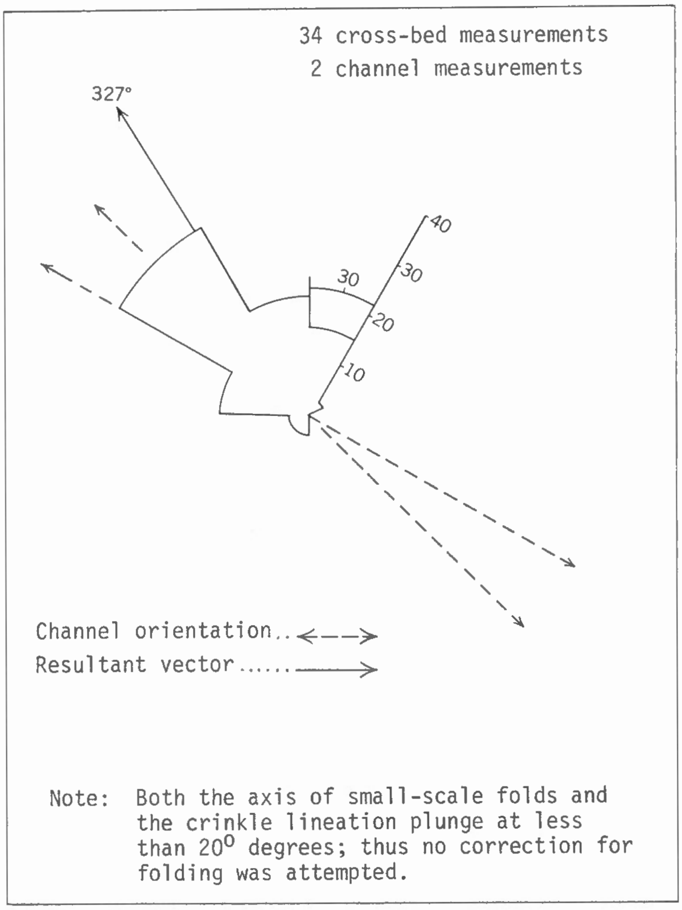

Figure 11. Rose diagram summarizing cross-stratification data from Mount Fury quartzite facies.

Planolites-like burrows are the most prolific formative bioturbation. These arcuate to straight, unbranched burrows occur singly or in swarms on bedding surfaces (Pl. 10a). They are usually horizontal but may transect bedding or be slightly inclined to it. Most have circular cross sections from 0.1 to 0.25 cm in diameter and are up to 7 cm long. **Planolites** is thought to have been formed by a deposit feeding worm-like organism (Alpert, 1975).

Vertical traces are uncommon and most of those present appear to be "escape structures" not dwelling burrows. They have indistinct boundaries and in places pass from an argillaceous layer through a thin quartzite layer to the next overlying argillaceous bed (Pl. 9c, 9d). Such burrows are probably produced by infauna attempting to stay a certain distance below the sediment-water interface of an aggrading substrate (Young and Rahmani, 1974).

Environmental Interpretations

The Mount Fury quartzite facies was deposited in a shallow, normal marine, intermittently agitated environment. The facies was evidently subtidal because it lacks supratidal and intertidal features like flaser bedding, "herringbone" crossbeds, algal mats, and desiccation structures. The moderate to strong bioturbation within argillaceous intervals suggests a dense infaunal population, characteristic of environments where sedimentation is slow, and where nutrient-rich and oxygenated water supports an abundant fauna (Young and Rahmani, 1974).

Changes from quartzite to argillite suggest intermittent agitation and variable sediment supply. Quartzite beds probably result from storms or stronger currents which briefly produced agitation and rapid sedimentation. Cut-and-fill structures, ripples, small-scale crossbeds, and "escape burrows" in sandy beds imply current activity and periodic rapid deposition. Lack of bioturbation in thick quartzite beds suggests intermittent sedimentation rates too rapid for extensive burrowing. Another reason for lack of disturbance in thick quartzite beds may be that deposit feeders, which account for most bioturbation in subunit 1a, preferred nutrient-rich muds rather than arenaceous beds.

The Mount Fury quartzite facies is similar to deposits from the transition zone between agitated coastal bars or beaches and deeper offshore muds on continental shelves. Interbedded very fine sand and silty muds, strong bioturbation, ripples, and small scale crossbeds, characteristic of this zone (Reineck and Singh, 1973, p. 307, 323) are also typical of the Mount Fury quartzite facies.

The argillite facies was probably deposited in a low energy, shallow, normal marine environment. Absence of peritidal features indicates these rocks are entirely subtidal.

Sandy rocks of the Mount Fury quartzite facies, deposited in a shallow, subtidal, intermittently agitated environment, grade southwestward into the lower energy, subtidal deposits of the argillite facies (Fig. 3). This facies change may reflect a westward increase in water depth. The argillite facies probably represents offshore shelf muds deposited in deeper water than the Mount Fury quartzite facies. Toward the northwest the deeper water argillite facies intertongues with and overlies the shallower water Mount Fury quartzite facies (Fig. 6). This indicates a gradual eastward transgression during deposition of subunit 1a.

Subunit 1b

Description

Subunit 1b, informally called the "black platy limestone", is a distinctive marker horizon throughout the study area which helps to delineate facies relationships in overlying archaeocyathid-bearing beds. The unit is generally 35 to 60 m thick and forms resistant, dark grey cliffs (Pl. 16).

Subunit 1b consists of alternating laminae of light grey, silty mudstone and dark grey mudstone (Pl. 10b). Minor components include white mica, rhombohedral dolomite, euhedral pyrite, and authigenic, euhedral albite. Abundant dark inclusions in calcite crystals and disseminated iron sulphides probably impart the dark colour to the mudstones. Continuous, even parallel laminae are characteristic of the subunit (Pl. 10c). Intraformational slumps and folds and small scale crossbeds occur rarely. Subunit 1b is devoid of skeletal fossils except for rare trilobite fragments. Bioturbation is conspicuously absent. Both these features indicate a low density of bottom dwelling organisms.

Environmental Interpretation

Subunit 1b was likely deposited in a low energy, subtidal, restricted-marine environment judging from its composition, thin laminations, and lack of skeletal fossils and bioturbation. Dominance of mudstones and scarcity of traction current structures suggest low energy conditions. Features indicative of intertidal and supratidal carbonates are absent. The continuous, even parallel laminations probably resulted from slight changes in current velocity or sediment supply and lack of burrowing organisms. Poorly circulated anaerobic waters may have caused toxic conditions that excluded these organisms.

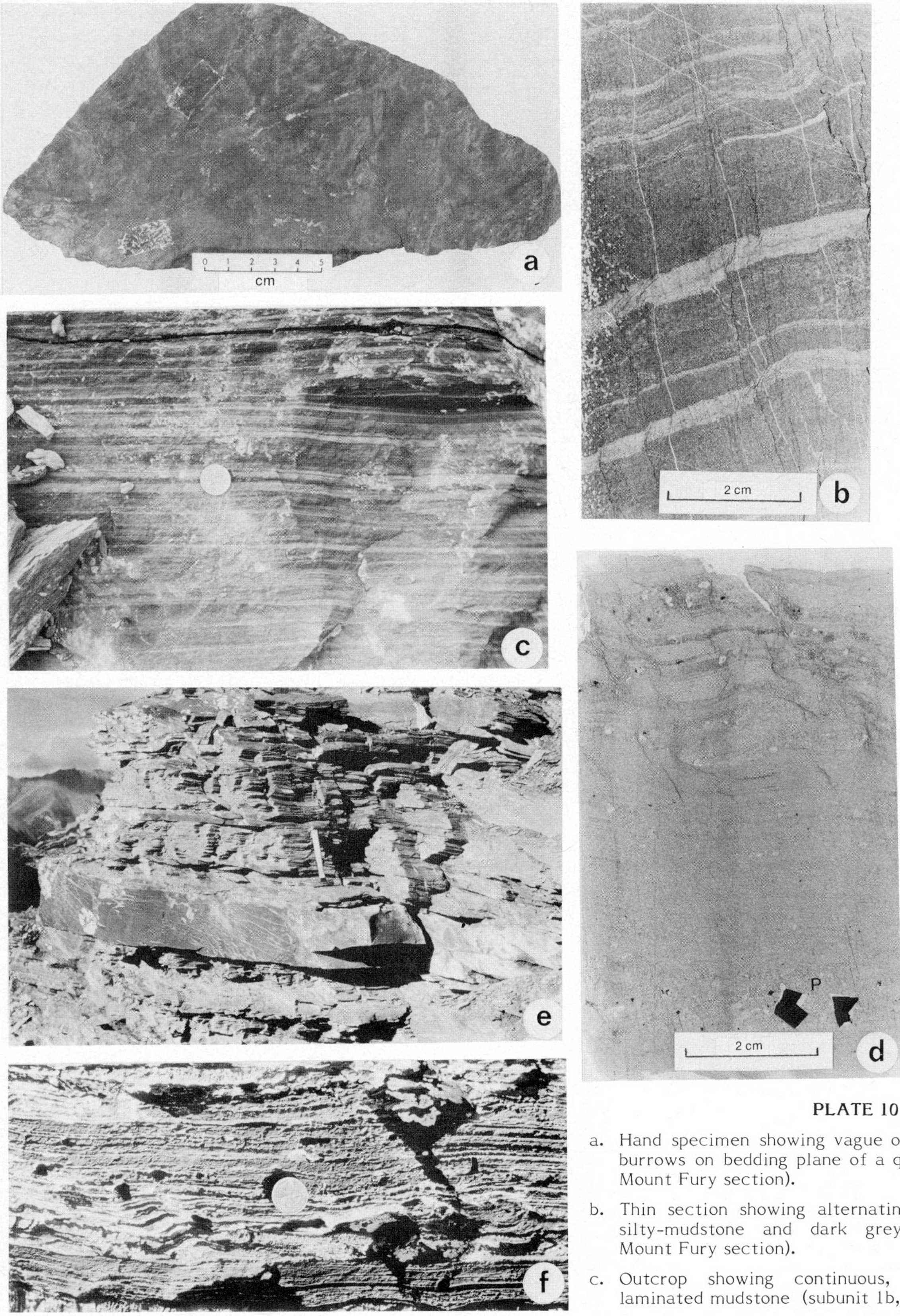

PLATE 10

a. Hand specimen showing vague outline of **Planolites**-like burrows on bedding plane of a quartzite slab (subunit 1a, Mount Fury section).

b. Thin section showing alternating laminae of light grey, silty-mudstone and dark grey mudstone (subunit 1b, Mount Fury section).

c. Outcrop showing continuous, regular, even parallel laminated mudstone (subunit 1b, Shrimp Lake section).

d. Thin section showing disrupted bedding in laminated calcareous argillite. Note euhedral pyrite at P (upper part of subunit 1c, Tarn Lake section).

e. Outcrops of interbedded limestone (more resistant strata) and argillite (upper part of subunit 1c, Tarn Lake section).

f. Outcrop of interlaminated mudstone and argillite (upper part of subunit 1c, Tarn Lake section).

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Subunit 1c

Description

Subunit 1c consists of 75 to 105 m of recessive, brown, calcareous argillite with minor limestone. The subunit is gradationally overlain by argillaceous limestone and in some areas passes upwards into archaeocyathid carbonate buildups.

Throughout the subunit argillite is characteristically thin bedded to laminated. White mica and quartz silt, with varying amounts of carbonate mud, are the major components. Accessory minerals include chlorite, authigenic amorphous inclusion-rich quartz, and pyrite. Rare echinoderm fragments are the only skeletal fossils. Although lower beds lack bioturbation, upper strata locally exhibit disrupted laminations suggestive of organic activity (Pl. 10d).

Minor, brown, fossiliferous limestone interbeds, between 5 mm and 60 cm thick, occur in the upper part of subunit 1c (Pl. 10e). These exhibit indistinct bed boundaries and a chaotic texture suggestive of bioturbation. Traction current structures are absent. The limestone includes argillaceous mudstone, wackestone, and rare rudstone. The mudstone contains minor white mica, quartz, silt, authigenic quartz, pyrite cubes, and isolated dolomite rhombs. Scattered trilobite and echinoderm fragments make up the fauna. Mudstone generally forms the thinner limestone beds which are rhythmically interbedded with argillite (Pl. 10f). The wackestone contains complete, prostrate archaeocyathids, echinoderm fragments, and a few trilobite fragments. Minor components include peloids, white mica, and euhedral pyrite. Peloids are ovate to irregular shaped, 0.3 to 3 mm in diameter, lack internal structure, and are composed of microcrystalline carbonate. A peloid is "an allochem formed of cryptocrystalline or microcrystalline material irrespective of size or origin" (Bathurst, 1971, p. 547). Their formation has been attributed to micritization of grains by algae (Wolf, 1965; Bathurst, 1966), fecal origin (Bathurst, 1971), algal origin (Wolf, 1965), mechanical erosion of semiconsolidated muds producing intraclasts (Logan et al., 1969) and pelletization as a result of diagenetic processes (Folk, 1959). The shape and lack of internal structure of peloids in rocks of subunit 1c and the rest of the succession suggest that these grains are probably fecal pellets or mudstone intraclasts.

Rare rudstone interbeds, less than 5 cm thick, occur toward the top of subunit 1c. Intact, prostrate archaeocyathids and echinoderm and trilobite fragments are the major skeletal grains (Pl. 11a). Peloids, like those in the wackestone, are the main nonskeletal grains and make up 30 per cent of some rudstones. Archaeocyathid and trilobite grains with dark, crudely laminated cryptalgal coatings of microcrystalline calcite are minor constituents of the rudstone (Pl. 11b; 5g). Granular mosaic, syntaxial rim cement and dolomitic mud fill original void spaces. Some grains have a thin layer of granular cement which may have been drusy before neomorphism.

Environmental Interpretation

Dominance of fine grained lithologies and lack of traction current structures and peritidal sedimentary features indicate that subunit 1c was probably deposited in a low-energy, subtidal environment. The general absence of skeletal fossils and bioturbation in lower beds suggests that conditions during that deposition were restricted or semirestricted. In contrast, the presence of archaeocyathids, echinoderms, trilobites, bioturbation and cryptalgal coated grains in limestones of the upper part of subunit 1c imply that conditions had become favourable to normal marine life. These limestones are dominantly mudstone and wackestone which is consistent with the interpreted low-energy environment of the subunit. The rare, thin, rudstone interbeds were probably deposited in quiet water, as shown by indistinct bed boundaries, absence of broken archaeocyathids and other evidence of turbulence. These rudstones are like Heckel's (1972) "whole shell calcarenites" which result from local production of shell material at a faster rate than mud is accumulating in a low energy environment.

Subunit 1d: Mudstone Facies

Subunit 1d, 120 to 180 m thick, consists primarily of mudstone, but the most interesting rocks are the large archaeocyathid carbonate buildups. These structures are surrounded by mudstone and found only in the southwest part of the area. Rocks of the subunit are divided into the mudstone, carbonate buildup, and skeletal sand facies. The following discussion is restricted to the mudstone facies. The carbonate buildup facies and its associated skeletal sands is described in the following chapter.

The mudstone facies is dominated by resistant, cliff-forming, thin to thick bedded, grey weathering mudstone (Pl. 11c, 11d). It includes lesser argillaceous mudstone and calcareous argillite in lower beds, and wackestone, oncoid floatstone/rudstone, and cryptalgal-coated grain floatstone in upper strata. The facies is progressively more dolomitized to the north where sucrosic dolomite is typical.

Mudstone is poorly fossiliferous and contains a sparse archaeocyathid, trilobite, and echinoderm fauna. Bedding is even parallel to wavy. Dolomitic mudstone with tan weathering mottles is common. Mottles have indistinct boundaries and are arranged randomly in some strata; in others they are oriented parallel to bedding (Pl. 11e). The abundance of argillaceous mudstone and calcareous argillite decreases toward the top of the mudstone facies (Pl. 11c). This trend is conspicuous in most stratigraphic sections and probably reflects decreasing influx of terrigenous clastics during deposition.

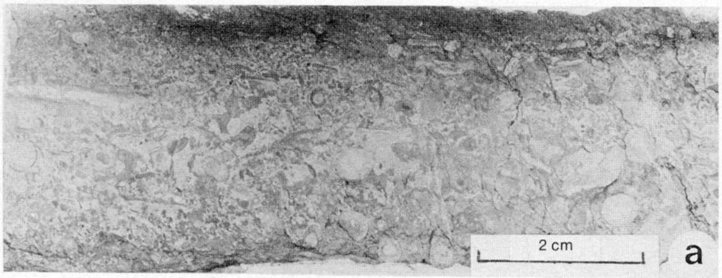
Most wackestones (Pl. 11f) contain less than 20 per cent grains which are trilobite and echinoderm fragments and less commonly, peloids, recrystallized ooids, and angular, rounded or tabular mudstone intraclasts.

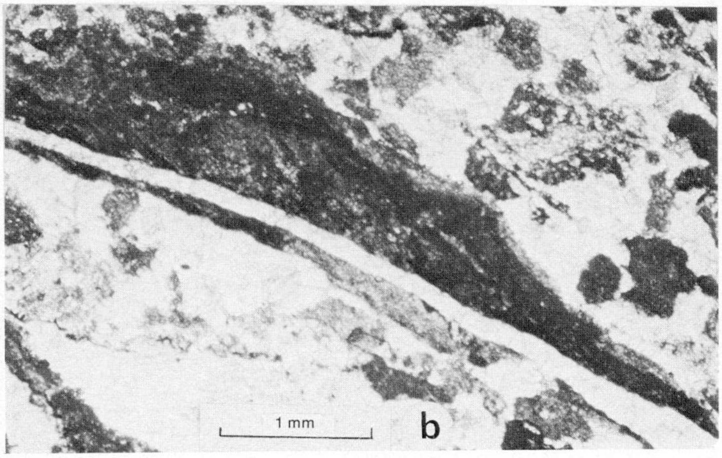
Cryptalgal-coated grains are abundant in some floatstones and are better developed than those in upper limestone beds of subunit 1c (Pl. 12a). Most grains are ovate with diameters to 1.5 cm. They consist of thick, dark, vaguely laminated, microcrystalline calcite coatings around skeletal fragments (Pl. 12b). Some fragments are thinly or incompletely coated. The cryptalgal grain floatstone has a dolomitic, trilobite, echinoderm, peloid, wackestone matrix. Fragments of cryptalgal coatings also occur in this matrix.

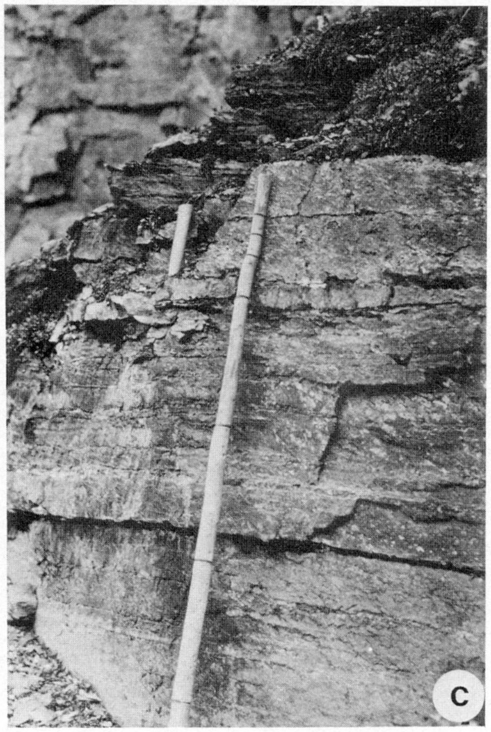
Oncolite floatstones and rudstones contain "simple" oncoids (Aitken, 1967) with concentric mode "C" envelopes (Logan et al., 1964) (Pl. 12c, 12d). Where preservation is good, each thin lamina completely encloses that preceding it. The nucleus, preserved, is usually a trilobite or archaeocyathid fragment. Oncoids are generally set in a dolomitic, skeletal, peloid wackestone groundmass. In the Cloutier Creek section, the matrix is sucrosic dolomite with peloids and tabular, dolomite mudstone intraclasts.

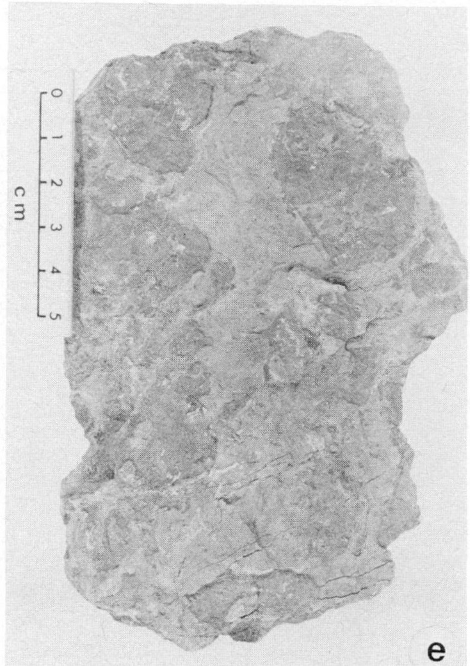
The sucrosic dolomite (Pl. 12e) is probably secondary because facies in dolomite also occur in limestone and because dolomitization does not parallel bedding. However, not all dolomite is diagenetic. During deformation, limestones at some fractures and faults were intensely dolomitized.

Evidence of bioturbation in rocks of the mudstone facies includes disrupted bedding, elongate grains that lack planar orientation, absence of laminations in many beds, and smooth, ovate peloids suggestive of fecal pellets.









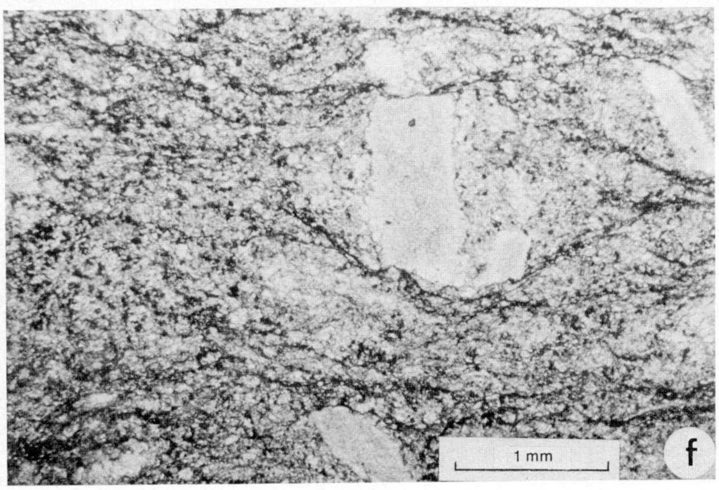


PLATE 11

a. Thin section of archaeocyathid rudstone with a trilobite echinoderm peloid packstone matrix (upper part of subunit 1c, Cache Creek section).

b. Thin section showing dense, dark, vaguely laminated cryptalgal coating on upper convex surface of a trilobite fragment (see also Pl. 5g) (upper part of subunit 1c, Cloutier Creek section).

c. Outcrop of thin bedded mudstone. Large divisions on pole are 30 cm long (subunit 1d, Cache Creek section).

d. Outcrop of resistant, cliff-forming mudstone. Dark recessive interbeds, composed of argillaceous mudstone and minor calcareous argillite, decrease in abundance toward the top of the cliff where relatively "clean" mudstone predominate (subunit 1d, Cache Creek section).

e. Hand specimen of dolomitic, mottled mudstone. Dark grey is lime mudstone whereas light grey is dolomitic mudstone (subunit 1d, Cloutier Creek section).

f. Thin section of echinoderm wackestone (subunit 1d, Cache Creek section).

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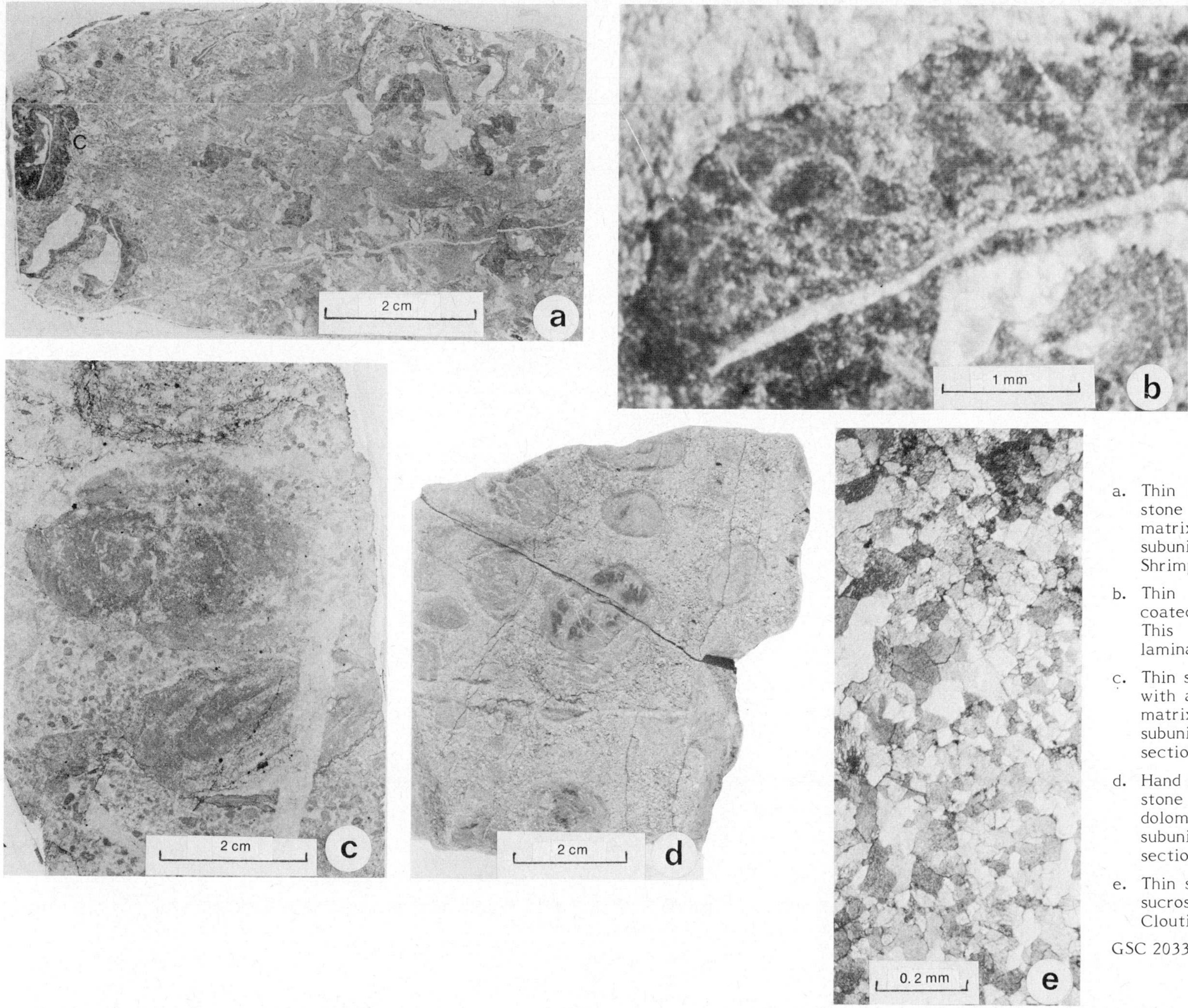

PLATE 12

a. Thin section of oncoid floatstone with a wackestone matrix (upper part of subunit 1d, 1.3 km west of Shrimp Lake section).

b. Thin section of cryptalgal coated grain (C) in Pl. 12a. This grain lacks vague laminations.

c. Thin section of oncoid rudstone with a peloid sucrosic dolomite matrix (upper part of subunit 1d, Cloutier Creek section).

d. Hand specimen of oncoid floatstone with a peloid sucrosic dolomite matrix (upper part of subunit 1d, Cloutier Creek section).

e. Thin section (crossed nicols) of sucrosic dolomite (subunit 1d, Cloutier Creek section).

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Environmental Interpretation

The sediments and sequence in the mudstone facies of subunit 1d indicate they accumulated in shallow, normal marine water which was calm during deposition of lower beds, but intermittently agitated by the end of 1d time. This upward change in energy regime may reflect a gradual shoaling trend. In other Cambrian carbonates of the Cordillera, mudcracks, algal stromatolites (except oncoids), thrombolites, and fenestral textures indicate extremely shallow, subtidal to peritidal environments (Aitken, 1966, 1967; Hockley, 1973; Sargent, 1975). Lack of such features in the mudstone facies suggests an entirely subtidal origin. Ooid grainstone or traction current structures which indicates turbulent wave or current activity are also absent. Indigenous archaeocyathids in these rocks are evidence of shallow marine conditions (Hill 1972; Heckel, 1972).

Predominance of bioturbated, mottled mudstone and minor calcareous argillite in lower beds implies that this part of the facies was deposited in quiet water. Upper beds of the facies are dominated by nonargillaceous, bioturbated, mottled mudstone with some interbeds of oncoid floatstone and rudstone and cryptalgal-coated grain floatstone. Logan et al. (1964) found that recent oncoids indicate submerged, agitated shoal water or areas low in the intertidal zone. Aitken (1967) suggested a weakly agitated, subaqueous origin. The interbeds with oncoids and cryptalgal grains, therefore suggest that the upper part of the mudstone facies accumulated under intermittently agitated conditions high in the subtidal zone. Tabular mudstone intraclasts in upper beds may be evidence of high subtidal conditions. Such intraclasts are thought to develop by desiccation of sediment in peritidal mud flat areas (Aitken, 1966; Logan, 1964). Those present in the mudstone facies may have been transported from nearby supratidal or intertidal environments into shallow, subtidal areas during storms.

The upward decrease in abundance of argillaceous rocks may reflect deposition from gradually shoaling water. Aitken (1966) suggested that similar conditions were responsible for relatively nonargillaceous carbonate at the top of Cambrian shale-carbonate cycles in the Rocky Mountains. He postulated that as a result of shoaling during the carbonate half-cycle, fine grained terrigenous clastics could not be transported effectively from the inner detrital belt to the middle carbonate belt. The carbonate half-cycles are commonly capped by intertidal deposits but these do not occur in upper mudstone facies rocks.

In summary, the mudstone facies of subunit 1d accumulated during shoaling of the shallow marine, subtidal environment. Although intermittently agitated conditions, possibly high in the subtidal zone, prevailed during late 1d time, this shoaling did not culminate in peritidal conditions in the study area.

Subunit 1e

Description

Subunit 1e includes fine grained, terrigenous clastics and a variety of interbedded carbonate rocks. The subunit, from 40 to 90 m thick, forms recessive, grey weathering outcrops (Pl. 13a). Its basal contact is sharp and the member is overlain unconformably by Upper Cambrian mudstone and calcareous argillite. Small archaeocyathid carbonate buildups, which occur locally, are discussed in the following chapter.

More than half of subunit 1e is grey to green weathering, noncalcareous thin bedded to laminated argillite (Pl. 13b) composed of white mica, quartz, chlorite and accessory pyrite. Although not abundant some trilobites, archaeocyathids and brachiopods occur. Complete trilobite skeletons are rare and even intact cephala are uncommon. Most trilobite remains consist of spines and other fragments. A few nearly complete skeletons of **Olenellus, Nevadella**? and fragments of **Laudonia**? were discovered. Archaeocyathids are intact and oriented parallel to bedding. Brachiopod molds, casts, and complete shells show growth lines and are generally less than 1.5 cm long. Some may be lingulids and others are probably the inarticulate **Obolella,** which is commonly found in archaeocyathid-bearing rocks of Labrador (Balsam, 1973).

Wackestone and mudstone are usually dolomitic and are interbedded with argillite or carbonates of subunit 1e. Grain components, which are sparsely distributed, consist of archaeocyathids, echinoderm and trilobite fragments and peloids.

Lenses and tabular beds, 2 cm to 3 m thick, of ooid grainstone and packstone occur sporadically in subunit 1e. They grade laterally into bioclastic or oncolitic sediments. Oolitic rocks locally exhibit small scale, low angle, cross stratification (Pl. 13c). Graded bedding was not seen. Ooid grainstones have spherical ooids in a granular mosaic of calcite cement (Pl. 13d). They lack a mud matrix which suggests winnowing. Subordinate grains include trilobite fragments, rounded echinoderm grain, superficial ooids (Logan et al., 1969) and quartz silt. Ooids are well sorted, about 1 mm in diameter, and closely packed. Most are recrystallized to calcite spar and are replaced by euhedral dolomite. Hematitic impurities define the regular concentric laminae in such recrystallized ooids. Identifiable nuclei include echinoderm and trilobite fragments, or rarely, quartz grains.

In the ooid packstones, ooids are enclosed in a skeletal dolomitic wackestone matrix with a variable spar/mud ratio (Pl. 13e). Packstones with little mud are similar to grainstones. However, in packstones with low spar/mud ratios peloids, skeletal grains, and superficial ooids are relatively common. These ooids may be ovate, crescent form, or irregular depending on the degree of coating and shape of the trilobite or echinoderm nucleus.

The oncoid mudstone and floatstone associated with the oolitic and skeletal-rich carbonates of subunit 1e are separated into two groups; granule-sized oncoid rudstone and pebble-sized oncoid rudstone and floatstone. The granule oncoid mudstones have simple, ovate oncoids in calcite cement with varied amounts of oolitic skeletal packstone matrix (Pl. 13f). Both granular mosaic and drusy cement are present. Oncoids are generally well-sorted and winnowing is implied by the sparse matrix (Pl. 14a). Oncolitic coatings are dark, wavy, concentric laminae (Pl. 14b) and nuclei are trilobite and echinoderm fragments as well as hyolithids, archaeocyathids, and peloid intraclasts. Other large grains are angular, dark, erosional intraclasts up to 1.5 cm across (Pl. 14a) composed of oncoid rudstone with a skeletal packstone matrix.

The pebble-sized oncoid mudstone and floatstone consists of large, simple and spongy-textured oncoids in an archaeocyathid trilobite echinoderm packstone matrix (Pl. 5c; 14c). In this matrix constituent grains are generally fragmented (Pl. 14d) and minor components include ooids, hyolithids and quartz silt. Some rudstone and floatstone has a high spar/mud ratio. Simple oncoids are up to 5 cm in diameter and may be oblong, subspherical, or irregular depending on the degree of coating and form of the nucleus. Coatings are dark and of uniform thickness around even the most irregular-shaped nuclei. Quartz silt and skeletal fragments are incorporated in some laminae. Common nuclei are fragmented or whole archaeocyathids and rarely, hyolithids and trilobites. Spongy oncoids tend to be ovate and some lack distinct, large, skeletal nuclei.

The skeletal rudstones of subunit 1e include archaeocyathid hyolithid-echinoderm trilobite archaeocyathid-, and trilobite-rudstone. They occur as lenses associated with other coarse grained carbonates and locally exhibit small cut-and-fill structures.

Archaeocyathid hyolithid rudstone (Pl. 14g) generally has a recrystallized skeletal wackestone matrix. Hyolithids are normally stacked concentrically or irregularly inside one another (Pl. 5a, 5b) and cones are preferentially oriented suggesting alignment by currents.

Echinoderm trilobite archaeocyathid rudstones (Pl. 14e) have a groundmass of calcite cement and carbonate mud. Both granular mosaic and drusy calcite cement are present. Subordinate grain types include ooids, hyolithids, brachiopods, peloids and intraclasts of mudstone and argillite. Smooth, ovate peloids may be fecal pellets and indirectly suggest bioturbation. Some rudstones consist of a "hash" of trilobite fragments (Pl. 14f).

Environmental Interpretation

Rocks of subunit 1e are indicative of deposition under shallow marine, intermittently agitated, subtidal conditions, with periodic strong wave or current action. Bioturbation, indigenous, benthonic organisms (archaeocyathids) in carbonate buildups and complete brachiopods in argillite, suggest that water circulation was sufficient to provide bottom dwellers with adequate oxygen. Further, archaeocyathids are generally considered to be shallow marine organisms (Hill, 1972; Heckel, 1972). These biotic considerations show that subunit 1e was deposited in a shallow, normal marine environment. Intermittent current or wave activity is postulated because lenses of high energy deposits (skeletal rudstone and oolite grainstone) are interbedded with argillite, presumably a low energy deposit. Ooids, oncoids, some intraclasts, and much of the skeletal debris in these lenses were probably swept into calmer water from turbulent carbonate shoal areas. Sargent (1975) and West et al. (1968) suggested Cambrian rocks resembling those of subunit 1e resulted from deposition of shallow, turbulent water facies in a quiet water environment during storms. Similarly, in recent deposits of the Persian Gulf region, Loreau and Purser (1973) noted that oolitic sediments are scattered far beyond the locale where they were formed.

Skeletal and nonskeletal grains were occasionally reworked following transport to the depositional site in subunit 1e. This is suggested by the presence of current aligned and stacked hyolithids, erosional intraclasts, occasional cut-and-fill structures, winnowed oncoid rudstones, and well-sorted, crossbedded, winnowed ooid grainstones. Hockely (1973) interpreted stacked hyolithids to result from reworking by oscillatory wave or current action. Merek and Yochelson (1976, p. 68) speculated that these hyolithids ". . .may have lived in shallow, relatively narrow shelf regions which from time to time, perhaps during storms, were swept by currents strong enough to move, sort, and imbricate the shells". Intraclasts, made up of argillite or oncoid rudstone, are similar to rocks in subunit 1e and therefore, suggest subaqueous erosion of semilithified sediment during periods of turbulence. Some thicker lenses of oolitic deposits may represent accumulations of ooids on small shoals or submerged bars.

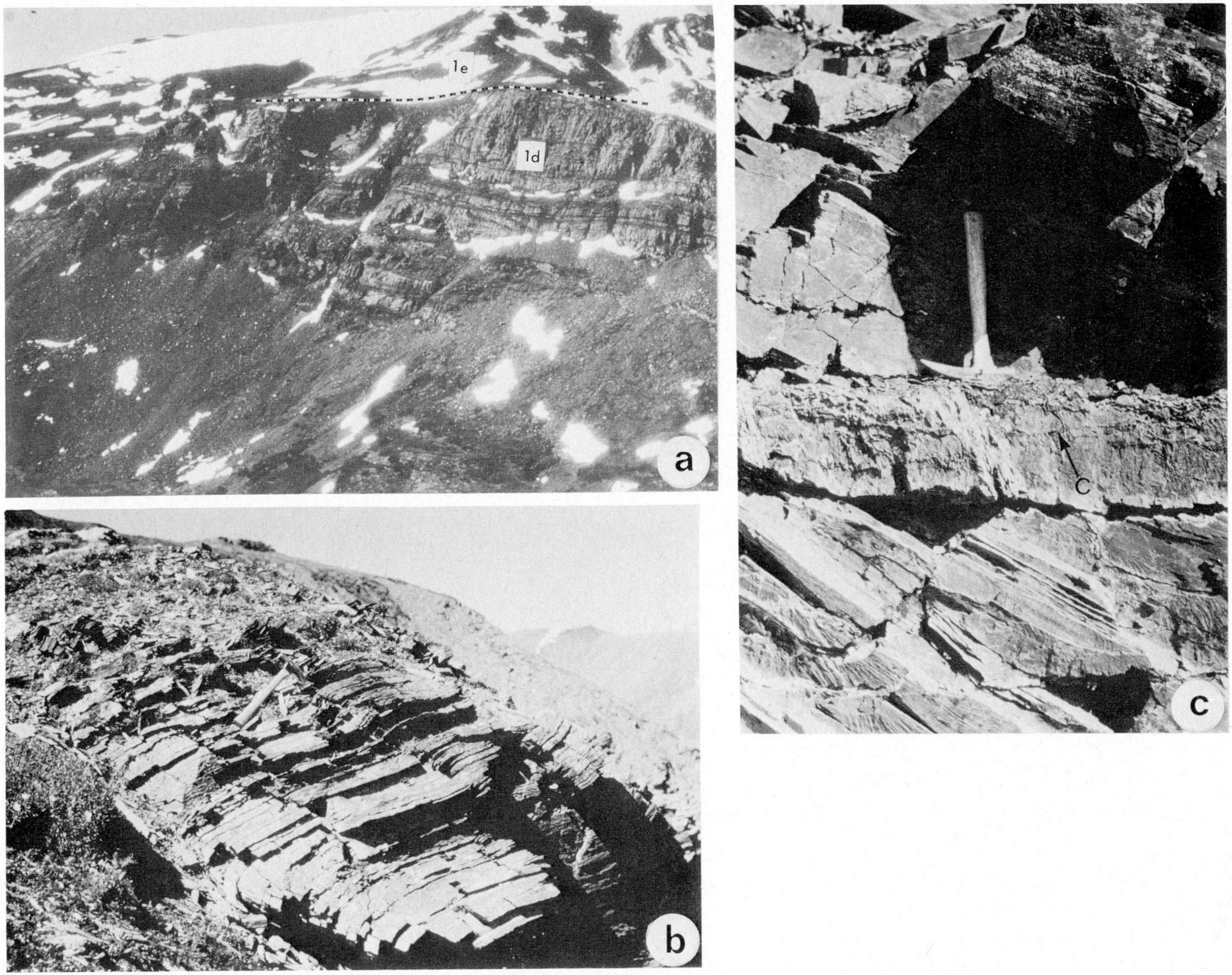
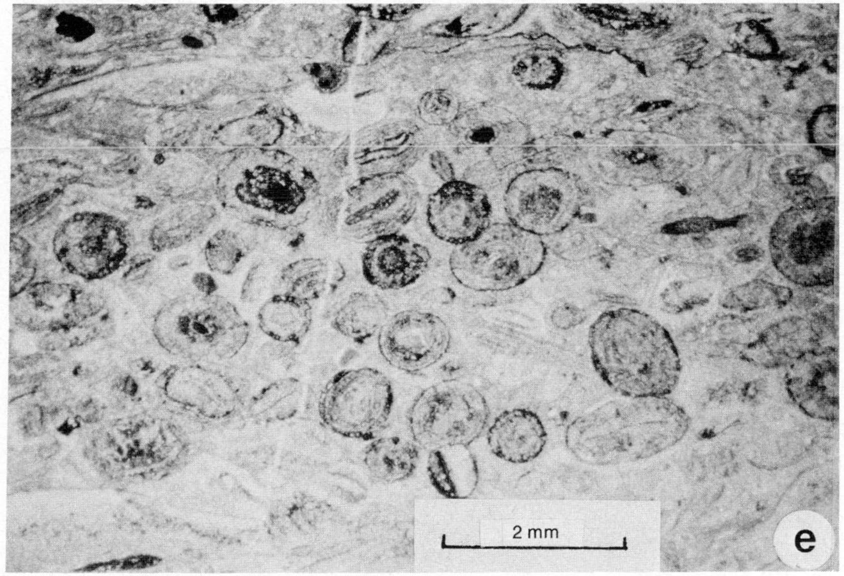


PLATE 13

a. Recessive outcrop of subunit 1e. Note sharp contact between 1e and 1d. (Cache Creek section).

b. Outcrop of non-calcareous argillite. (subunit 1e, Cache Creek section).

c. Outcrop of ooid grainstone bed which exhibits low-angle cross stratification (C). (subunit 1e, Cache Creek section).



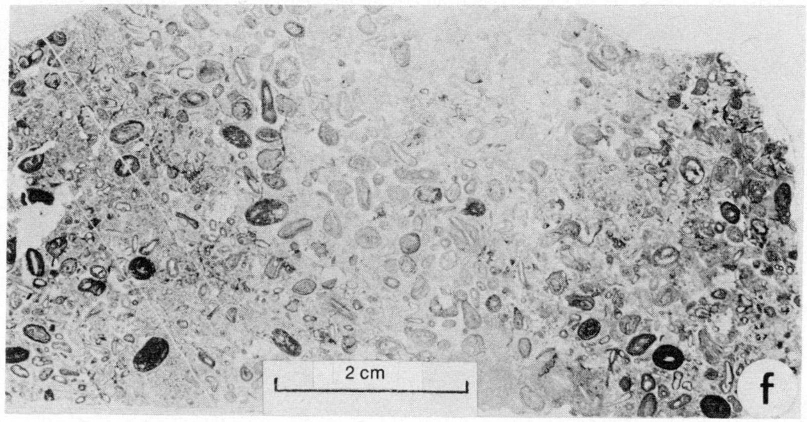


Plate 13 (cont'd)

d. Thin section (crossed nicols) of recrystallized ooid grainstone. Ooids are recrystallized to calcite spar and some contain dolomite rhombs. (subunit 1e, Cloutier Creek section).

e. Thin section of recrystallized ooid packstone. Trilobite and echinoderm fragments occur in the matrix. (subunit 1e, Mount Fury section).

f. Thin section of granule-sized oncoid rudstone with an oolitic skeletal packstone matrix. (subunit 1e, Mount Fury section).

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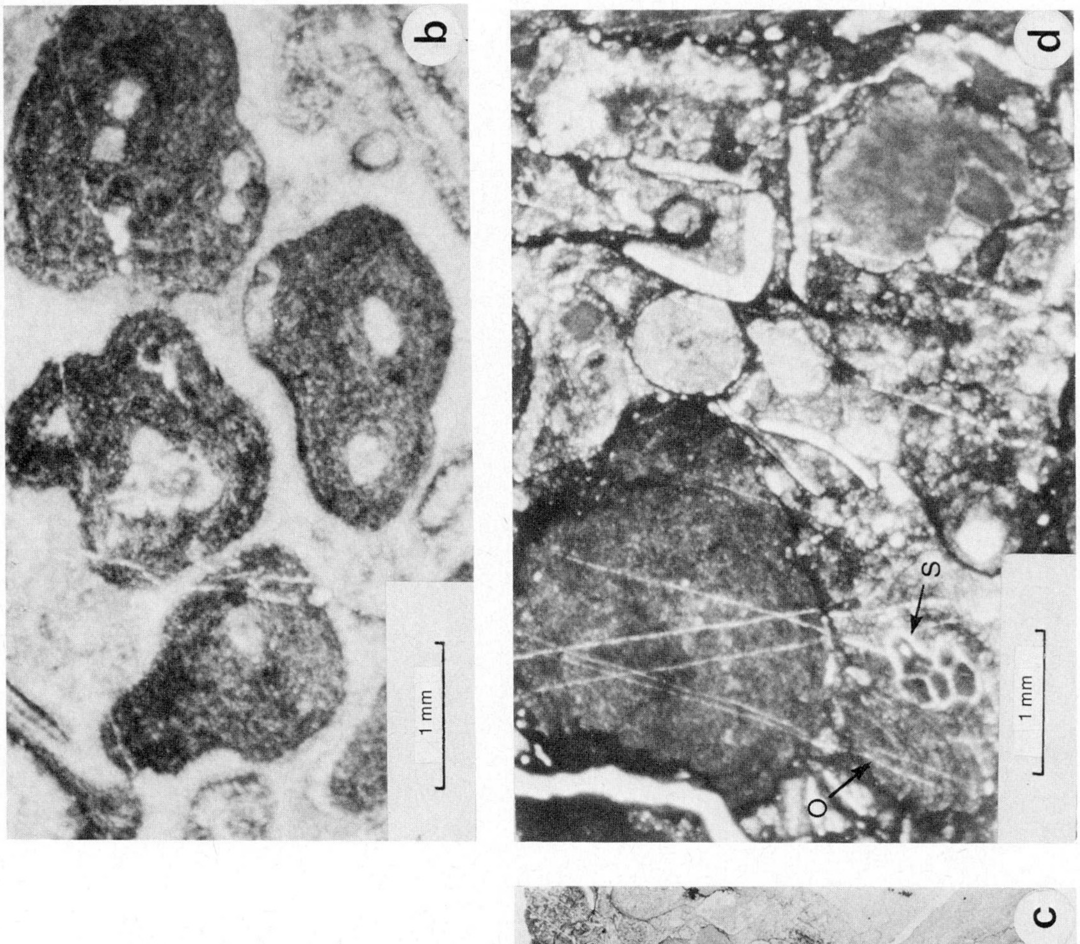
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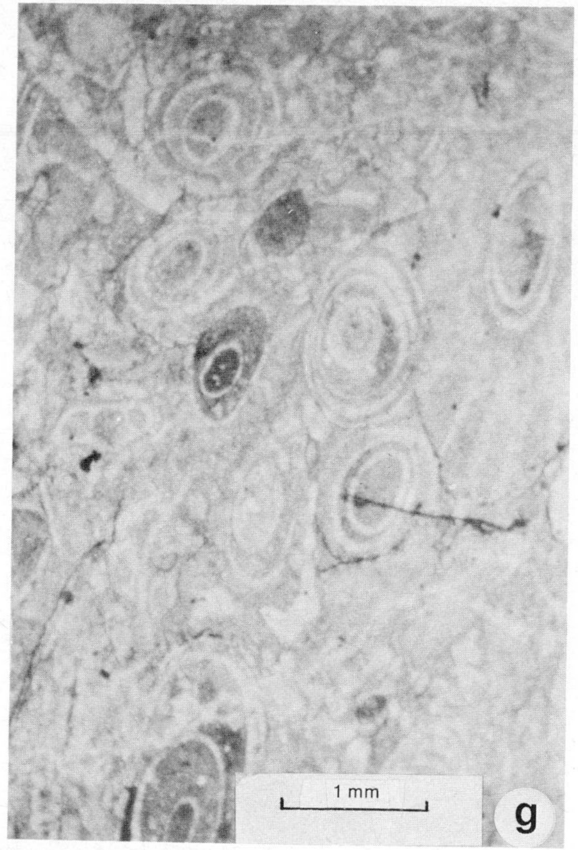

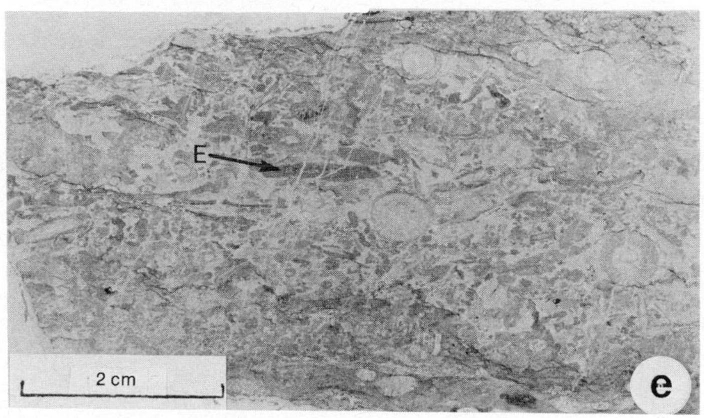

PLATE 14

a. Thin section of granule-sized oncoid rudstone with a high spar/mud ratio. Note dark coloured erosional intraclast consisting of oncoid rudstone with mud-rich matrix (E) (subunit 1e, Mount Fury section).

b. Thin section of granule-sized simple oncoids. Note irregular laminae (subunit 1e, Mount Fury section).

c. Thin section of pebble-sized oncoid rudstone. Oncoids are "simple" and commonly have archaeocyathids as their nuclei (subunit 1e, Mount Fury section).

d. Thin section showing skeletal packstone matrix of oncoid rudstone illustrated in Pl. 14c. Note broken skeletal grain (S) and oncoid fragments (O).

e. Thin section of archaeocyathid rudstone with a skeletal peloid packstone matrix. Note argillite intraclast (E) (subunit 1e, Mount Fury section).

f. Thin section of trilobite rudstone. Note drusy calcite cement around trilobite fragments (subunit 1e, 2.5 km north of Mount Fury section).

g. Thin section of hyolithid rudstone with a recrystallized trilobite packstone matrix. Hyolithids are stacked and tests show a strongly preferred orientation (subunit 1e, 2.5 km north of Mount Fury section).

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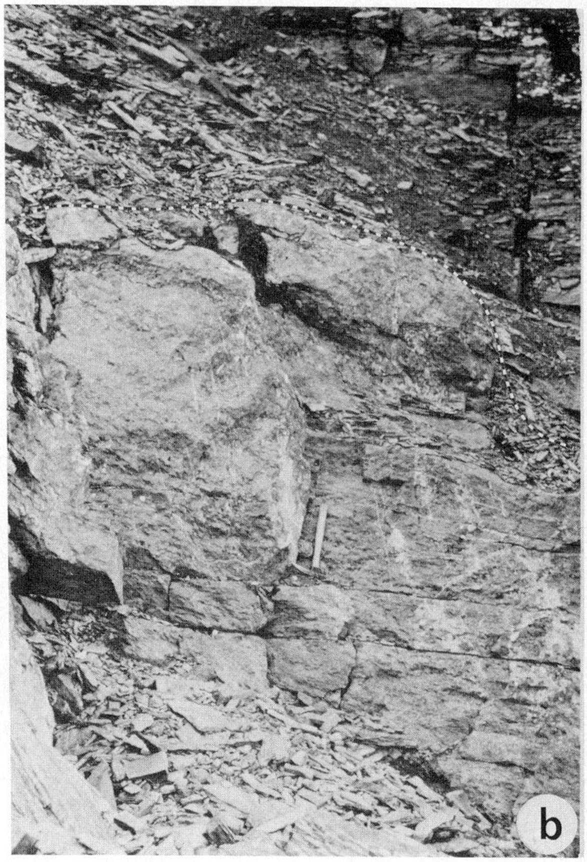
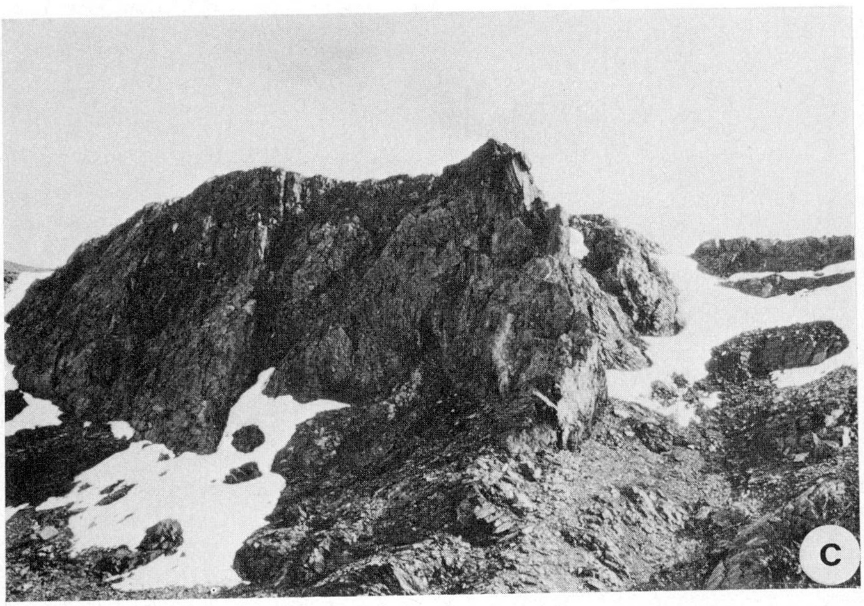
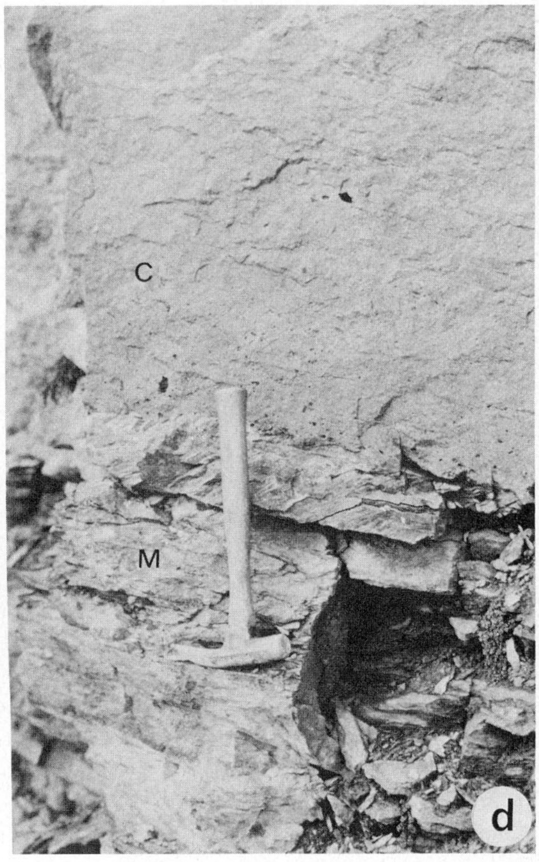
a


b


c


C
M
d

ARCHAEOCYATHID CARBONATE BUILDUPS

Excellent exposures of archaeocyathid buildups, which are rare in most Lower Cambrian sequences of the Cordillera, are found in the Ketza River area. These occur locally in subunits 1d and 1e. Because archaeocyathids are the earliest potential reef builders and because their buildups in the Cordillera have not been studied in detail, this chapter describes the buildups and evaluates their conditions of growth. The buildups of subunit 1d are interpreted as "potential reefs", those of 1e as "banks" (sensu Heckel, 1974).

Carbonate Buildups of Subunit 1d

Distribution, Size, and Shape

Seven large buildups and at least 8 smaller ones are exposed between Tarn and Shrimp lakes in the southwest corner of the area (Fig. 2). The structures are at different horizons in the lower 150 m of subunit 1d. The first buildups do not occur abruptly at one horizon, but at the different stratigraphic levels; none are in the upper part of the subunit.

As a result of topography most buildups are exposed in east-west vertical sections. The largest, Tarn Lake and Shrimp Lake 1, occur at the base of subunit 1d. Shrimp Lake 1 is approximately 610 m wide and as much as 90 m thick (Pl. 16). The original dimensions of the Tarn Lake buildup are unknown because it is faulted at its northeast extremity. This structure was longer than 600 m in northeast direction and as much as 90 m thick (Pl. 18). The smallest carbonate buildups are less than 1 m in diameter and occur as discrete carbonate masses in calcareous argillite or as "mounds" on the tops of some mudstone beds (Pl. 15a, 15b).

In east-west vertical sections, buildups are lensoid with irregular tops and bases (Pl. 15c, 16, and 18). Width/thickness ratios average 6 to 1 or less. Limited evidence from buildups partially exposed in three dimensions suggests they are lens-shaped in all directions. A biohermal geometry (Nelson et al., 1972) is therefore interpreted for the buildups and they probably had an oval or subcircular plan during growth.

In shape and size the buildups of subunit 1d resemble the Recent patch reefs of Bermuda (Garrett et al., 1971; Jordon, 1973) Florida (Bathurst, 1971, p. 157), Yucatan Shelf (Logan et al., 1969) and the Indian Ocean (Stoddart, 1973). Archaeocyathid buildups in Labrador also have the geometry of patch reefs (Copper 1974; James and Fong, 1976).

Buildup Margins

The contact between massive unbedded, orange-weathering buildup rock and the surrounding well stratified, grey-brown weathering strata is commonly sharp (Pl. 15d).

PLATE 15 (opposite)

a. Outcrop of small lensoid archaeocyathid carbonate buildup surrounded by calcareous argillite (subunit 1d, Shrimp Lake section).

b. Outcrop of small archaeocyathid carbonate buildup at the top of a relatively clean mudstone bed (subunit 1d, Shrimp Lake section).

c. Outcrop of unnamed archaeocyathid carbonate buildup. The structure is lens-shaped and approximately 30 m thick in east-west vertical cross-section (subunit 1d, immediately east of Shrimp Lake 1).

d. Outcrop showing sharp contact between massive unbedded rock of carbonate buildup (C) and thin bedded to laminated argillaceous mudstone (M) (subunit 1d, base of Shrimp Lake 1).

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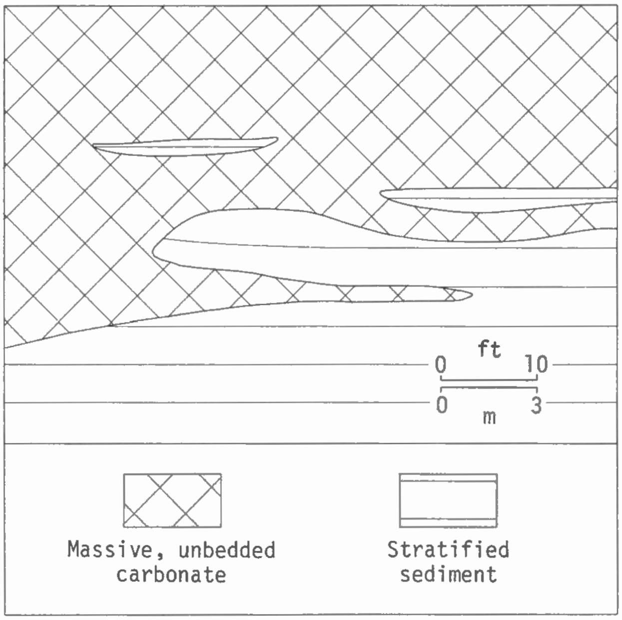


Figure 12. Tongue of massive unbedded carbonate projected into adjacent strata, Tarn Lake Buildup.

The base of the larger buildups is irregular, but the buildup carbonate overlies the argillaceous mudstone conformably. Inclined primary dips of some skeletal sand strata suggest that this irregular outline results from original topographic relief during initial stages of buildup development.

Rocks adjacent to the carbonate buildups are primarily interbedded dolomitic, argillaceous mudstone, calcareous argillite and, rarely, skeletal sand. From a distance the lateral margins of buildups appear smooth, but in detail small "tongues" of unbedded carbonate occasionally project into the adjacent stratified sediments (Fig. 12). These wedges, generally less than 1.5 m thick, pinch out within 5 m of the main buildup mass and are oriented parallel to bedding in surrounding sediment. The tongues were evidently supported by underlying sediment and did not maintain an overhanging position during development. Blocks, composed of unbedded buildup rock, are absent at lateral margins which also implies that tongues did not form over-hangings with cavern-like structures below them. Buildup perimeters probably had low relief and were commonly in contact with adjacent stratified sediment.

Bedding relationships at the lateral margins of Shrimp Lake 1 suggest that this buildup may have attained a height of 8 m above the surrounding seafloor. Positive topographic relief may be demonstrated by "...flank beds that dip away from a buildup...overlying units wedging out against it and thinning above it while displaying no significant transition into it." (Heckel, 1974, p. 19). Such pinchouts and local changes in dip occur in strata adjacent to Shrimp Lake 1 and are discussed below.

Some flanking strata at the upper eastern lateral margin of Shrimp Lake 1 dip southwest, away from the buildup; the same strata 50 m from this margin dip southwest but are concordant with the regional strike and dip (Fig. 13). Some of this change in dip may be caused by compaction of mudstone adjacent to the buildup but most probably results from original relief. If compaction were the only cause, all strata should exhibit local dip changes which they do not.

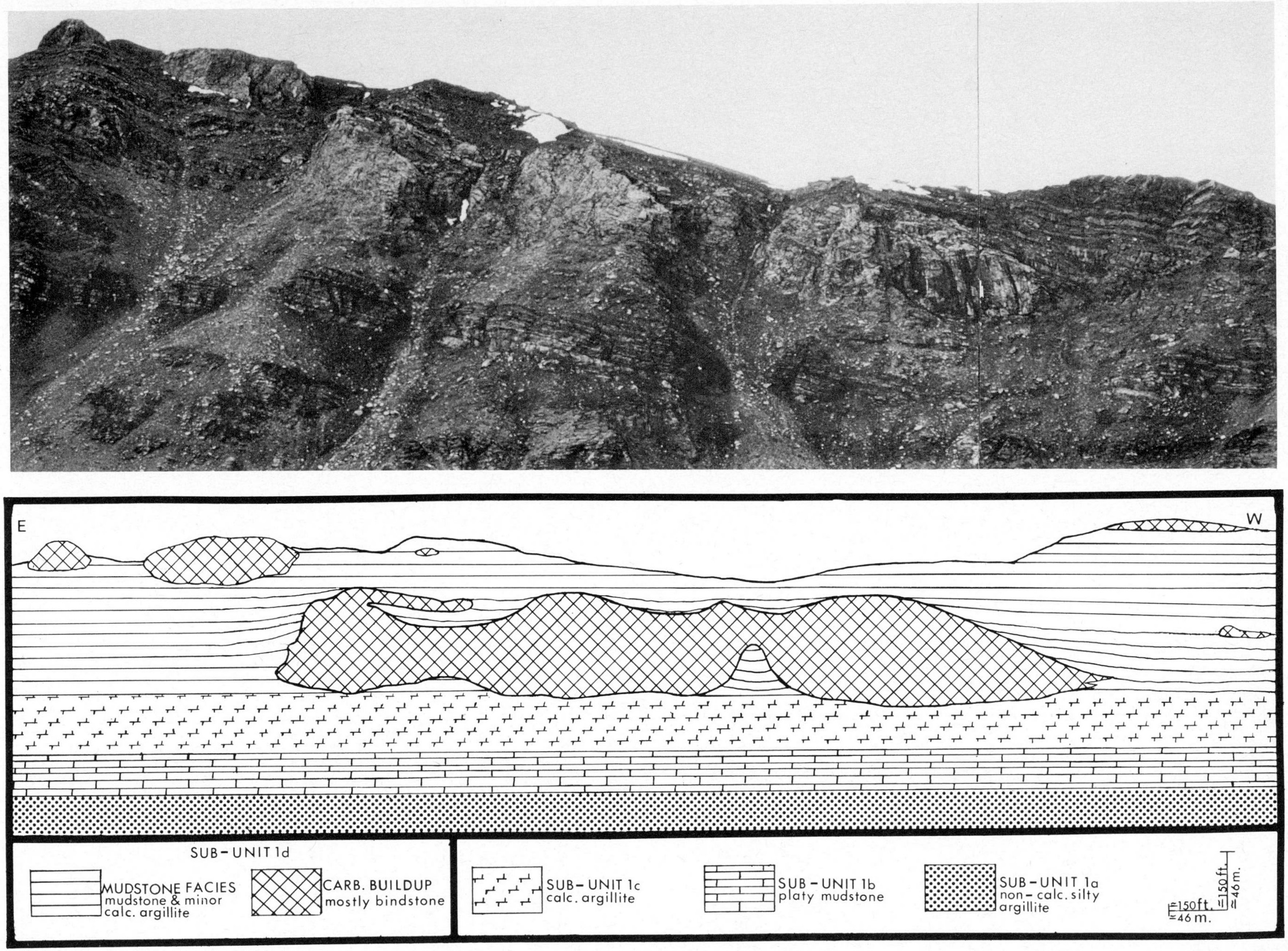
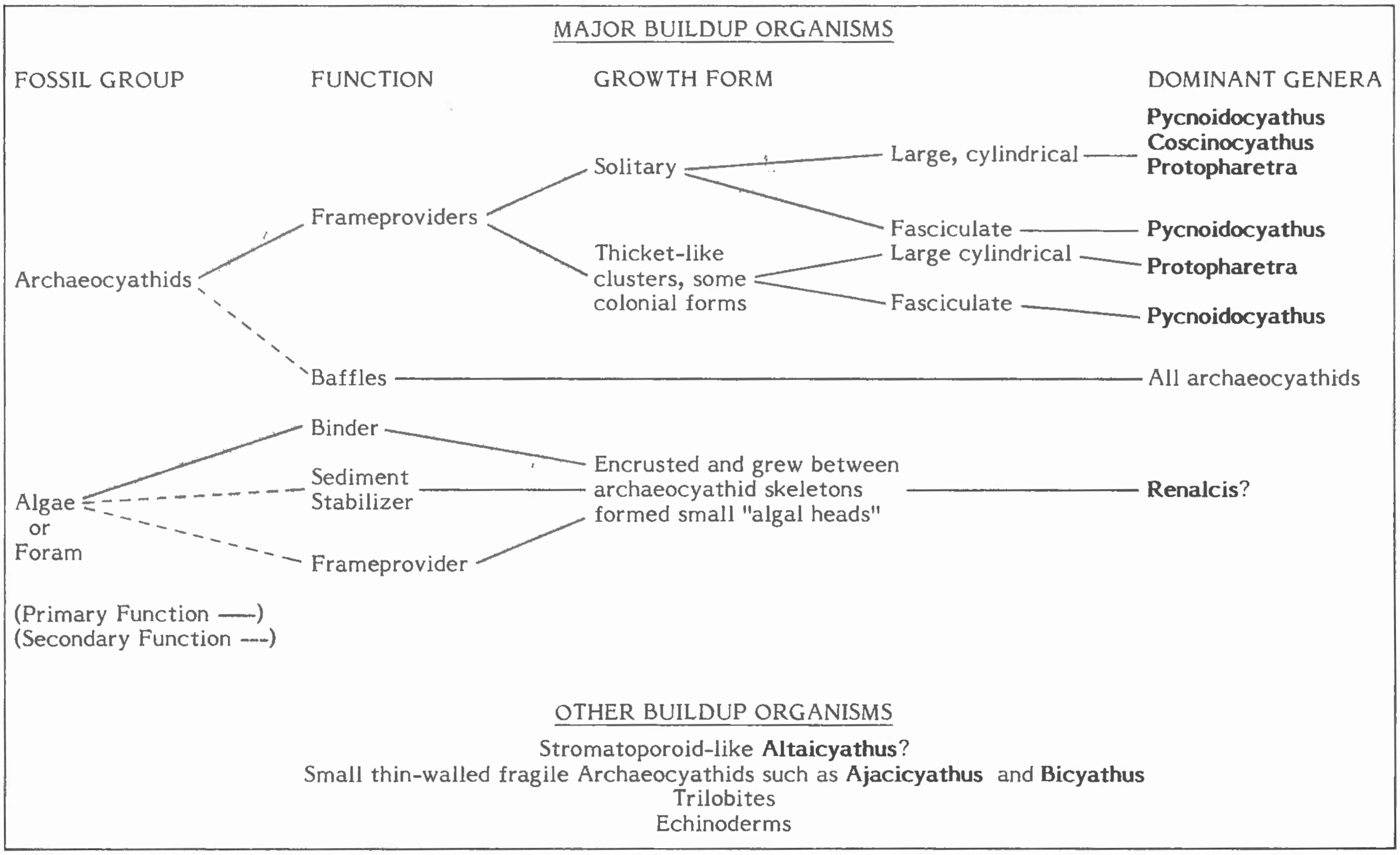


PLATE 16

Photograph and drawing of Shrimp Lake 1, a large archaeocyathid carbonate buildup in the southwest part of the study-area. This buildup was studied in detail. Rocks of subunits 1a, 1b, 1c, 1d, and two other unnamed buildups are also shown. Note primary dips in the upper left of the photograph adjacent to Shrimp Lake 1. View looking south. GSC 203328-O

Table 2

Summary of buildup organisms



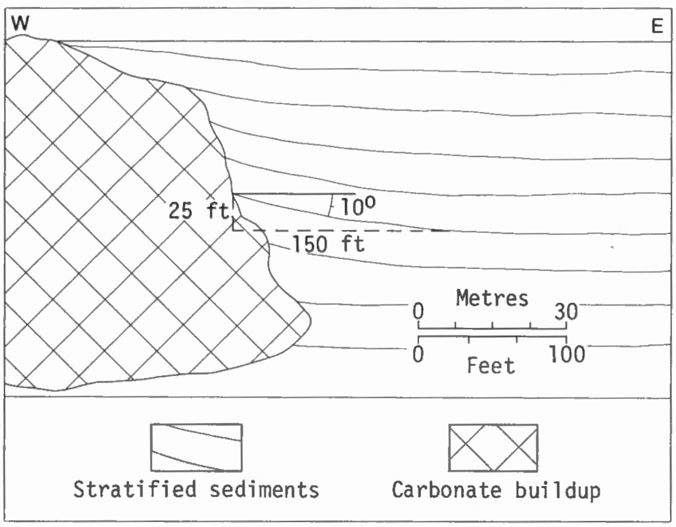


Figure 13. Primary dip of strata adjacent to eastern lateral margin of Shrimp Lake 1.

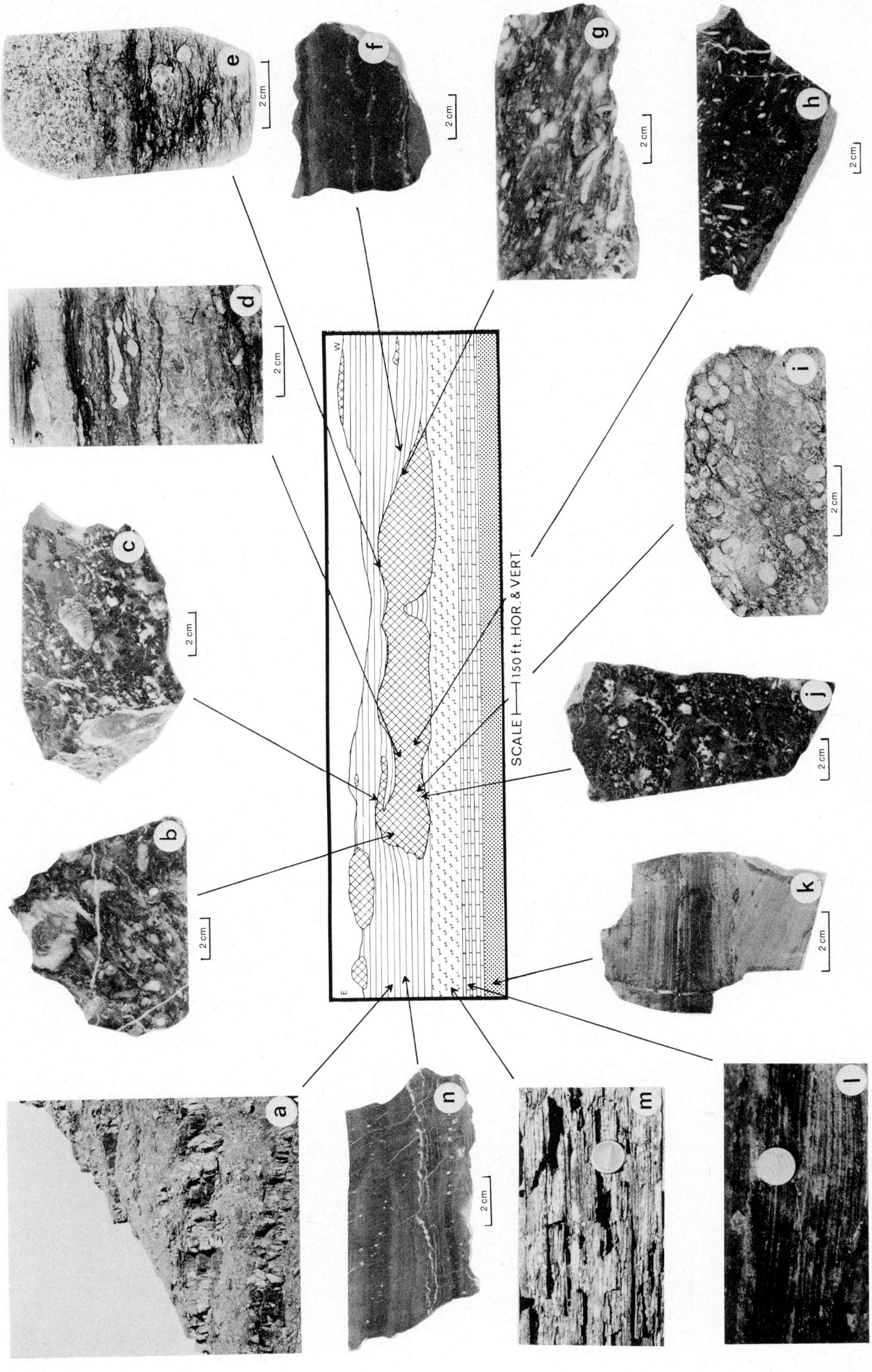
These flanking beds apparently had a primary dip of about 10 degrees and suggest that the upper part of Shrimp Lake 1 attained a minimum height of 8 m above the surrounding seafloor (Fig. 13). Positive relief is also implied by beds that pinch out near the upper eastern margin (Fig. 13). All of the buildups probably had some original relief above the seafloor during growth.

The upper surface of most buildups is broadly convex, but irregular in detail. These surfaces are characterized by small "knolls" less than 1 m high. Locally in the Tarn Lake buildup, large "pinnacle-like" structures are present (Pl. 18). Strata overlying buildups are thin- to medium-bedded dolomitic argillaceous mudstone and minor calcareous argillite. The latter is particularly abundant directly on upper buildup surfaces. Between "knolls" and "pinnacles" skeletal sand predominates.

Inter-"knoll/pinnacle" strata occasionally display saucer-like bedding which, although possibly caused by compaction, may indicate that these prominences had relief during deposition. This type of bedding has also been observed within depression filling strata between the elevated growth surfaces of Silurian reefs in Gotland (Manten, 1971). "Knolls", because of their height, could not have had more than 1 m of relief. Along lateral margins the "pinnacles" were probably in contact with their bordering stratified sediment like the margins of the main mass and their relief during growth was small compared to their present height.

Facies Analysis

Subunit 1d is divided into mudstone, carbonate buildup, and skeletal sand facies. The carbonate buildup facies makes up 90 per cent of the buildups and skeletal sand constitutes the remainder. The buildups are encased by the mudstone facies discussed above. A description and interpretation of the carbonate buildup and skeletal sand facies of Shrimp Lake 1 (Pl. 16, 17) Shrimp Lake 2 and Tarn Lake (Pl. 18, 19) follows.



a
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l
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2 cm
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SCALE 150 ft. HOR. & VERT.

PLATE 17

Common rock types of the Shrimp Lake 1 Buildup
and associated strata

a. Outcrop of mudstone facies adjacent to the eastern margin of Shrimp Lake 1. Recessive intervals are composed of argillaceous mudstone and calcareous argillite whereas more resistant beds consist of "cleaner" mudstone.

b. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix (carbonate buildup facies).

c. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix (carbonate buildup facies).

d. Archaeocyathid floatstone with a dolomitic argillaceous wackestone matrix interbedded with archaeocyathid floatstone with a peloid packstone matrix (intra-buildup deposit of skeletal sand facies).

e. Archaeocyathid floatstone with an argillaceous wackestone matrix overlain by archaeocyathid floatstone with a peloid packstone matrix (skeletal sand facies, upper buildup surface).

f. Interlaminated mudstone and argillaceous mudstone (mudstone facies).

g. Highly recrystallized archaeocyathid bindstone? (carbonate buildup facies).

h. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix (carbonate buildup facies).

i. Archaeocyathid rudstone with an archaeocyathid trilobite peloid packstone matrix (skeletal sand facies at the base of buildup).

j. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix (carbonate buildup facies).

k. Noncalcareous argillite overlain by laminated very fine grained quartzite (subunit 1a).

l. Inter-laminated silty mudstone and mudstone (subunit 1b). Diameter of coin is 2.5 cm.

m. Laminated calcareous argillite (subunit 1c).

n. Interlaminated calcareous argillite and mudstone (mudstone facies).

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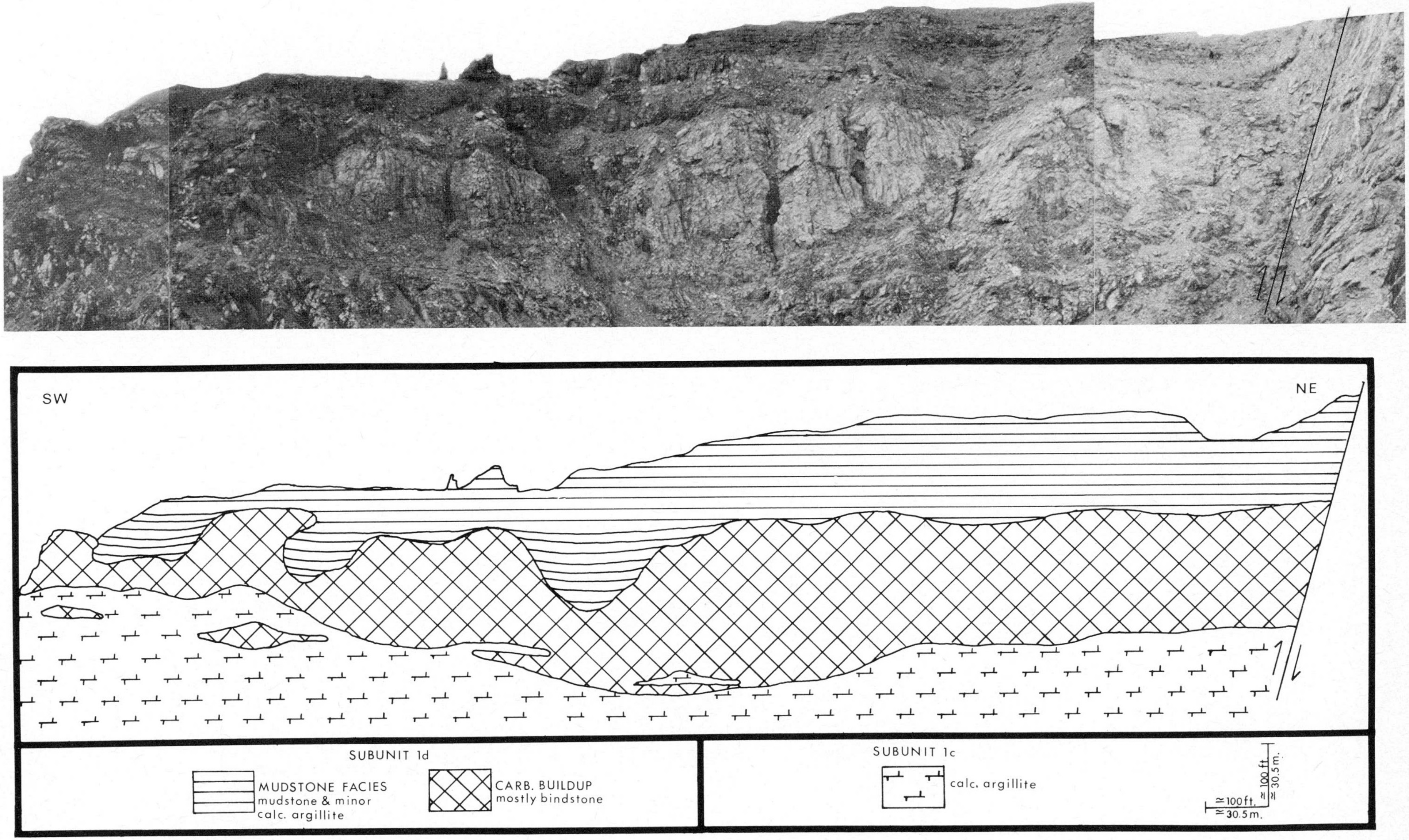

PLATE 18

Photograph and drawing illustrating the Tarn Lake buildup and associated strata. This large buildup is situated in the southwest part of the study-area. Note the "pinnacle-like" structures along the upper surface. View looking northwest. (GSC 203328-Q)

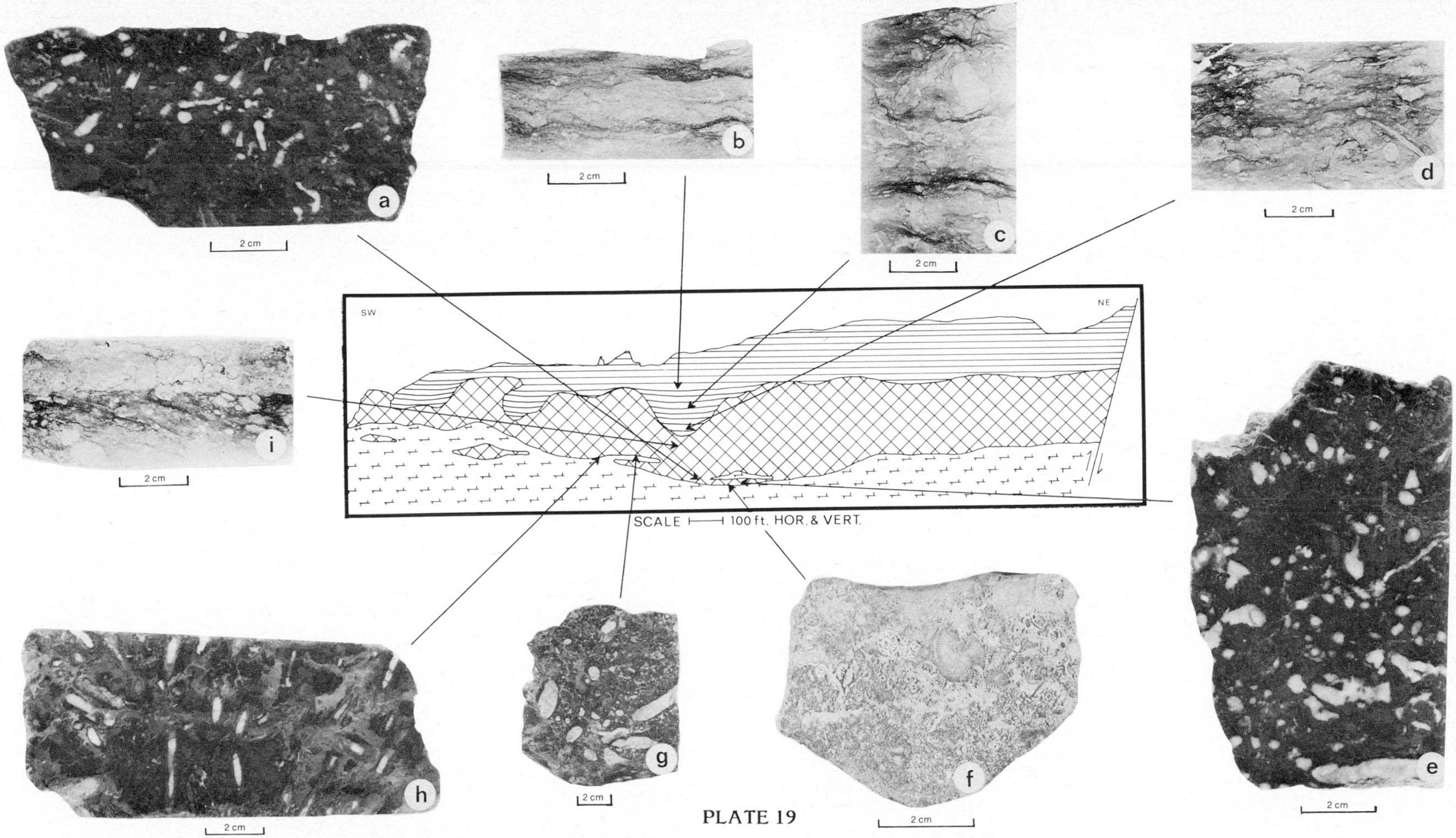

PLATE 19

Common rock types of Tarn Lake Buildup and associated strata

a. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix (carbonate buildup facies). The white spar-filled structures are archaeocyathids.

b. Dolomitic argillaceous wackestone (mudstone facies).

c. Archaeocyathid floatstone with a dolomitic argillaceous wackestone matrix (skeletal sand facies).

d. Archaeocyathid floatstone with an argillaceous dolomitic wackestone matrix (skeletal sand facies).

e. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix (carbonate buildup facies).

f. Archaeocyathid rudstone with a dolomite archaeocyathid peloid packstone matrix. Sample has been etched with HCL so that fossils and mud appear light grey against a dark background of abundant calcite spar (skeletal sand facies).

g. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix. (carbonate buildup facies).

h. Archaeocyathid **Renalcis**? bindstone with a dolomite mudstone matrix (carbonate buildup facies). The sample is from a thicket-like cluster of archaeocyathids some of which are colonial.

i. Archaeocyathid floatstone with a skeletal dolomitic argillaceous wackestone matrix overlain by archaeocyathid floatstone with a skeletal peloid packstone matrix (skeletal facies).

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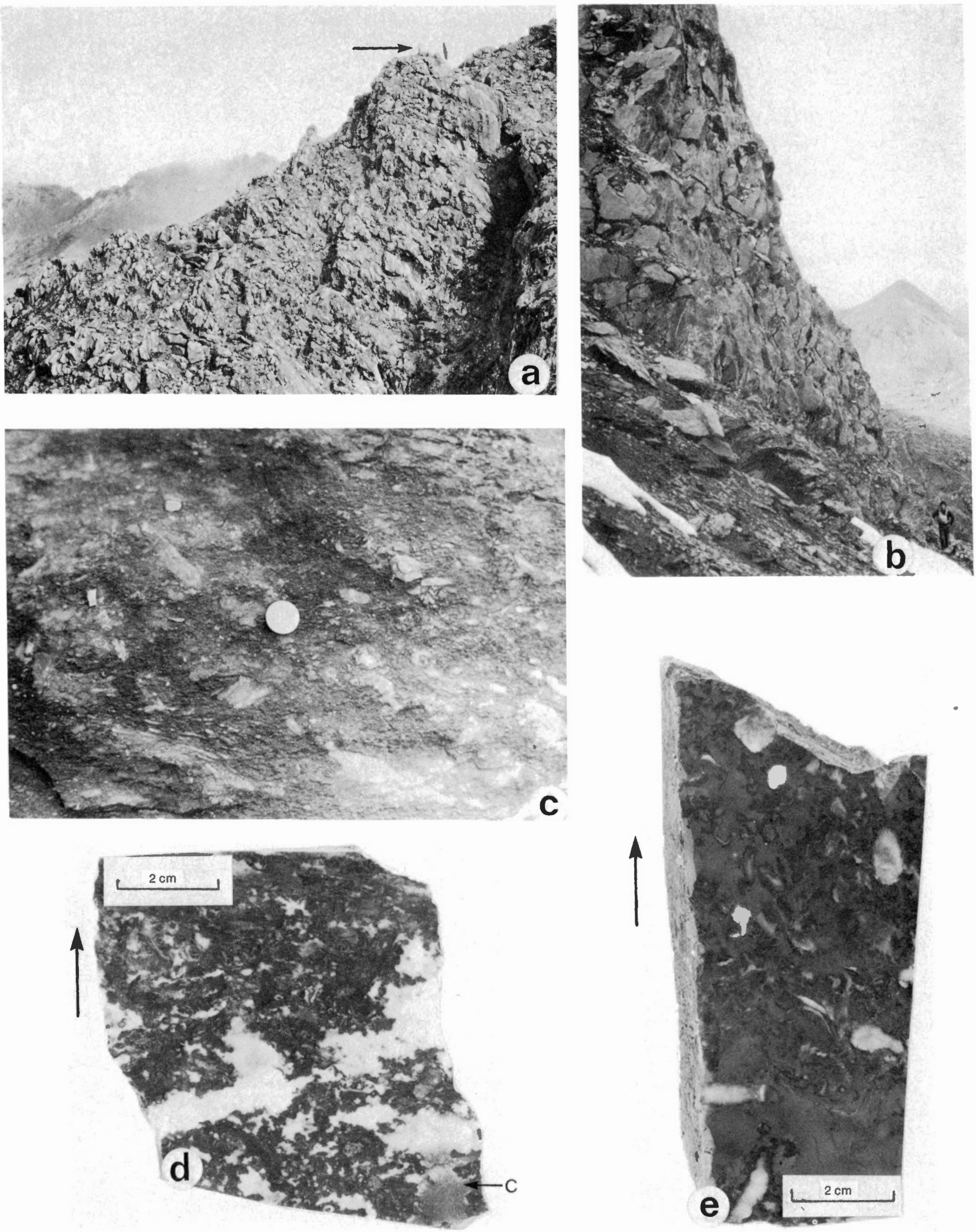
a
b
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2 cm
d
C
2 cm
e

Carbonate Buildup Facies

The buildup facies consists predominantly of resistant, orange-weathering, massive, unbedded archaeocyathid **Renalcis?** bindstone with a dolomite mudstone matrix (Pl. 20a, 20b, 20c). Among 35 representative samples of this bindstone, archaeocyathids average 26 per cent by volume and range from 6 to 51 per cent; **Renalcis?** averages 31 per cent and ranges from 25 to 60 per cent; and mudstone matrix averages 36 per cent and ranges from 31 to 51 per cent. Trilobite and echinoderm fragments, argillaceous mudstone, and granular mosaic calcite cement are less abundant components. Archaeocyathids are overgrown by **Renalcis**? to form a rigid, bound texture (Pl. 6, 21, 22). Primary cavities are uncommon. Those present are irregular, small, and generally filled with calcite; some are partially filled with mudstone (Pl. 20d).

Subordinate in the buildup facies are massive unbedded, **Renalcis**? archaeocyathid floatstone with a dolomite mudstone matrix (Pl. 20e) and calcareous argillite. Floatstone grades into bindstone and the two rock types are difficult to distinguish in the field. In floatstone, **Renalcis**? encrusts archaeocyathids but has not cemented neighbouring cups together. Calcareous argillite occurs as thin, irregular partings generally less than 15 cm thick. Fossils are rare in these partings.

Common archaeocyathids of the buildup facies include the irregular genera **Protopharetra, Pycnoidocyathus,** and the regular **Coscinocyathus?**. The regular **Ajacicyathus** and **Cordillerocyathus**? and the irregular **Bicyathus?** are somewhat less common. **Altaicyathus**? is present locally. Occurrence of several genera within centimetres of one another indicates that the different genera were coextant. Within the buildups archaeocyathids are often erect and although many are oriented at other angles, this indicates that the cups are mainly preserved in growth position. Skeletons, some dolomitized, are complete and commonly solitary. The majority are filled with granular mosaic calcite cement, possibly a result of encrustation by **Renalcis?** before mud filtered into the skeleton. Clusters of erect archaeocyathids with weak colonial habit are seen locally. In these clusters cups are abundant. Copper (1974) and Balsam (1973) have shown that exothecal growths are important binding agents in archaeocyathid reefs of Labrador. Such growths are rare in the carbonate buildup facies and do not contribute significantly to the formation of its common bindstone texture.

PLATE 20 (opposite)

a. Outcrop showing resistant, massive, unbedded nature of the Shrimp Lake 1 buildup. Some bindstone talus blocks are up to 3 m across. Arrow points to man.

b. Outcrop showing resistant, massive, unbedded nature of Shrimp Lake 1. Man is standing near the base of the buildup.

c. Outcrop showing weathered surface of archaeocyathid **Renalcis**? bindstone. Light coloured structures are archaeocyathids in-filled with calcite spar. Diameter of coin is 2.5 cm (carbonate buildup facies, Shrimp Lake 1).

d. Hand speciman showing primary cavities. Most are filled with calcite spar although dark mudstone internal sediment partially fills cavity at (C). Note dark **Renalcis**? growing into cavities suggesting that this organism may have acted as a minor frameprovider (Shrimp Lake 1,)

e. Hand specimen of archaeocyathid **Renalcis**? floatstone with a dolomite mudstone matrix (carbonate buildup facies, Shrimp Lake 2).

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Complete archaeocyathids in growth orientation with an abundant mudstone matrix suggest that, for the most part, low energy conditions prevailed during development of the carbonate buildup facies. Pervasive organic binding implies that the buildups could have endured limited or intermittent turbulence and therefore were potentially wave resistant. The highly fossiliferous nature of bindstones indicates an environment favourable to prolific organic growth. **Renalcis**? grew between maturing archaeocyathids and rapidly encrusted their skeletons after death. In this manner, successive generations of biota produced a rigid framework. The subordinate floatstones which probably formed locally where solitary archaeocyathids and **Renalcis?** grew surrounded by a muddy substrate, demonstrate that the buildups were not rigid throughout.

The functions and growth forms of the fossils found in the carbonate buildup facies, are summarized in Table 2. Archaeocyathids were the primary frame providers and also acted as sediment baffles. Their hard skeletons provided "building blocks" for the framework but most archaeocyathids are solitary and do not exhibit a binding habit. Thus, **Renalcis?** was extremely important in the formation and maintenance of framework. Not only did it bind archaeocyathids, but it also contributed significant volume, and probably acted as a sediment stabilizer and minor frameprovider (Pl. 20d).

Incidental buildup dwellers include trilobites and echinoderms. Although these organisms inhabited the buildups, they did not take an active part in framework construction.

Calcareous argillite partings within bindstone probably reflect the intermittent influx of fine grained terrigenous clastics which settled in local areas on upper buildup surfaces. The poorly fossiliferous nature of these partings suggest that they retarded the growth of framework organisms periodically.

Skeletal Sand Facies

The skeletal sands include thin to medium bedded archaeocyathid rudstone (with a dolomitic, archaeocyathid echinoderm trilobite peloid packstone matrix – Pl. 23a, 23b, 23c) archaeocyathid floatstone (with a dolomitic argillaceous wackestone/packstone matrix – Pl. 23d, 23e) archaeocyathid echinoderm trilobite peloid packstone and interbedded trilobite rudstone – Pl. 24a, wackestone/mudstone, and calcareous argillite.

Peloids found in the facies are normally less than 1 mm in size and are ovate or irregular. The former may be fecal pellets, but the latter are probably intraclasts. Some packstones are made up of peloids in a groundmass of granular mosaic calcite cement (Pl. 24b). Subordinate grain components in the skeletal sand include cryptalgal-coated grains (Pl. 24a); ovate, peloid packstone intraclasts (Pl. 24c); tabular, laminated, calcareous argillite intraclasts (Pl. 24d); archaeocyathid **Renalcis**? bindstone intraclasts (Pl. 24e); and rare ooids. The chaotic texture of some skeletal sands and the presence of possible fecal pellets and rare escape structures suggest that these rocks were bioturbated.

The most common skeletal grains in the facies are intact or broken archaeocyathids, not in growth position. The skeletal sand has the same genera as the carbonate buildup facies, but with small cups. Irregular archaeocyathids predominate over the large regular genera. Other skeletal constituents include trilobites, echinoderms, and rare stacked or solitary hyolithids. Cryptalgal-coated grains with archaeocyathid or trilobite nuclei are present locally.

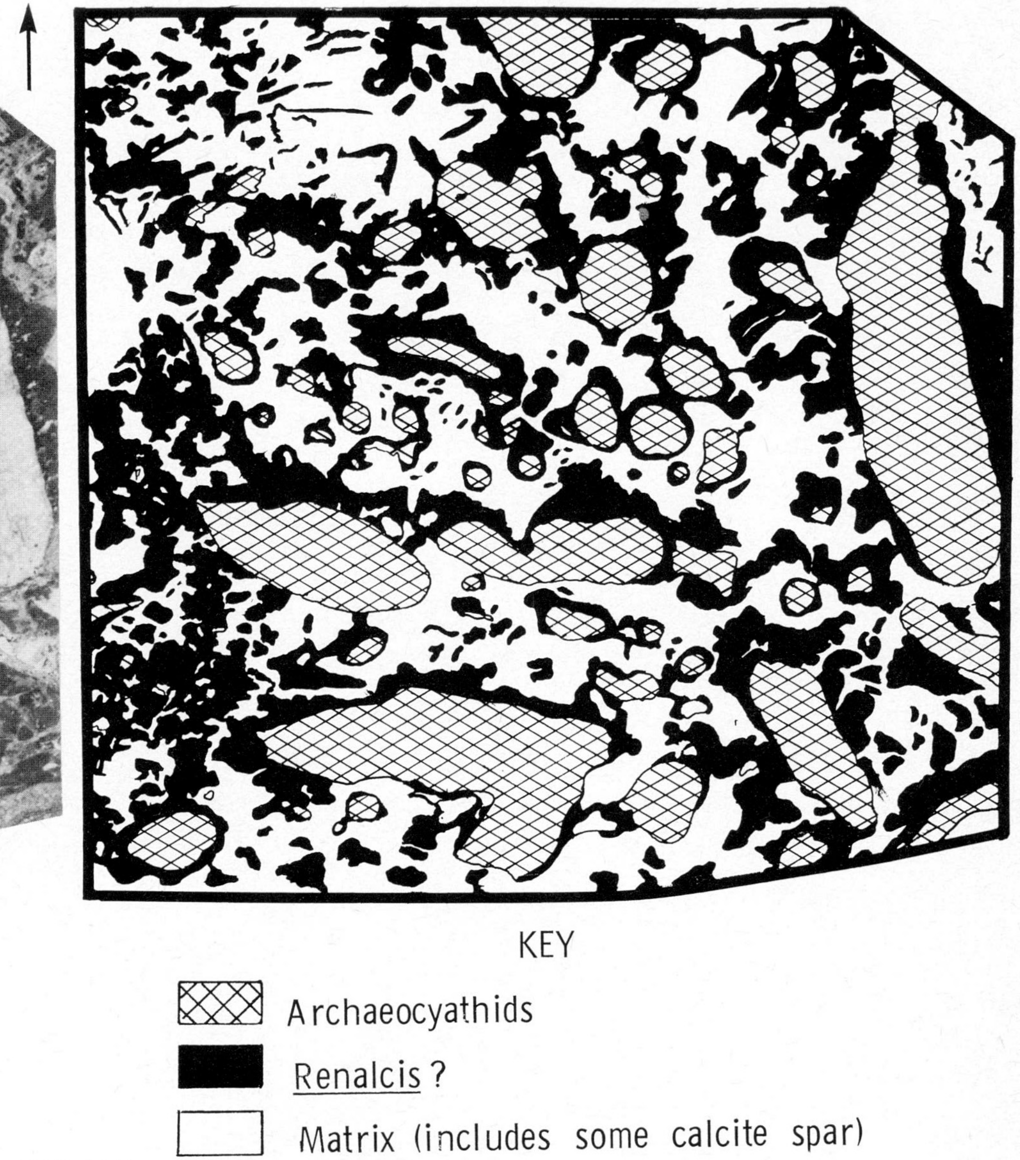


PLATE 21

Polished slab and drawing showing spatial relationship between archaeocyathids, **Renalcis**?, and matrix in bindstone. **Renalcis** encrusted archaeocyathids and grew between them. In this manner, successive generations of biota constructed the rigid, organic framework of the carbonate buildup facies. Note random orientation of cups and encrustations which are thickest on the upper surfaces of some cups. Matrix consists of dolomite mudstone, calcite spar and internal sediment (carbonate buildup facies, Shrimp Lake 1). GSC 203328-T

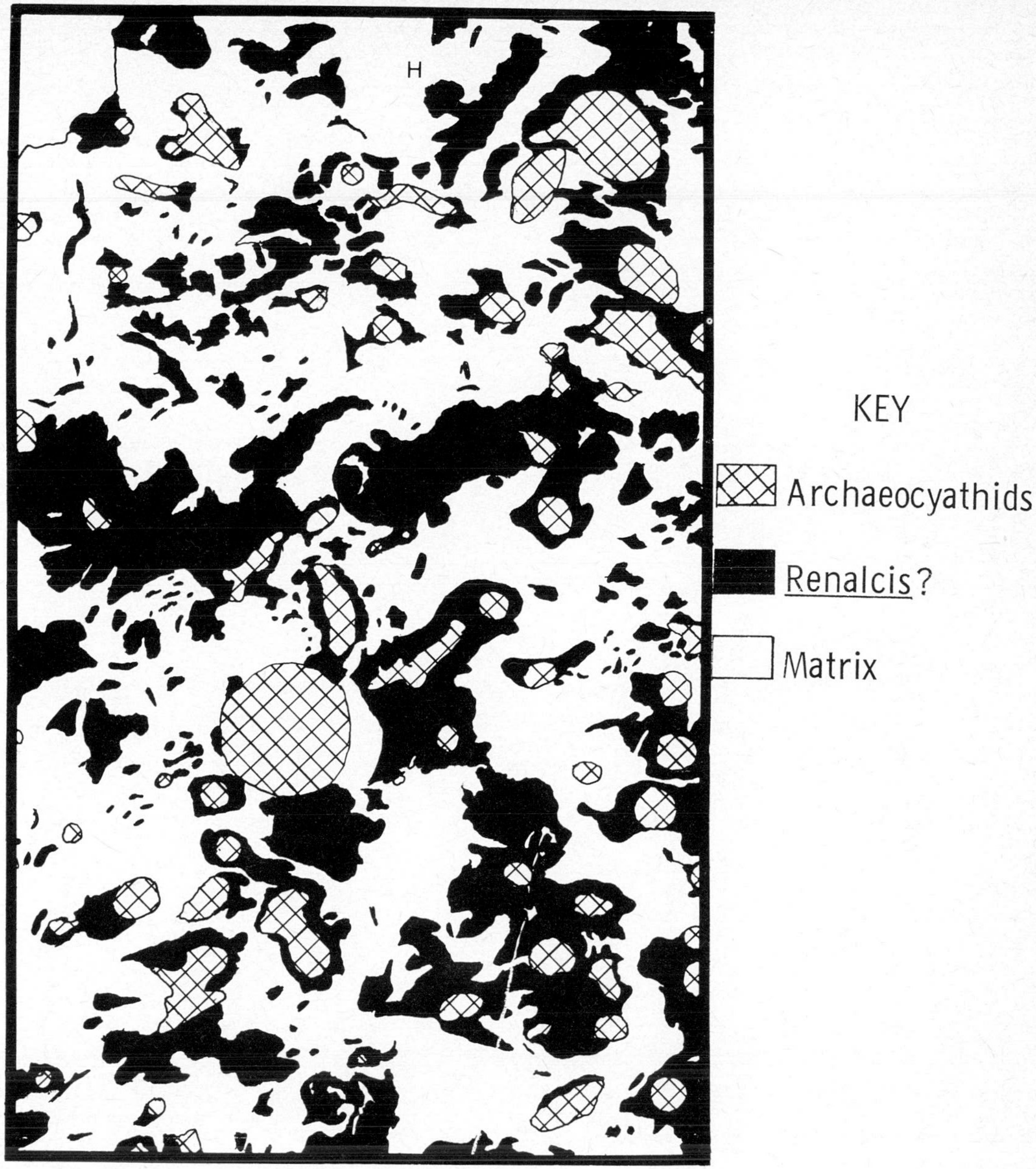
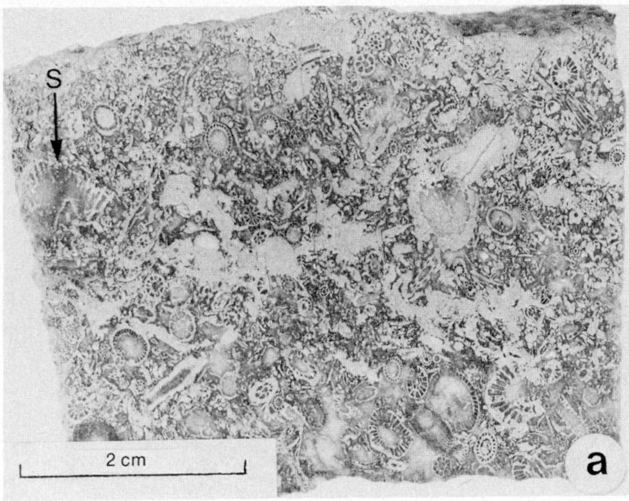
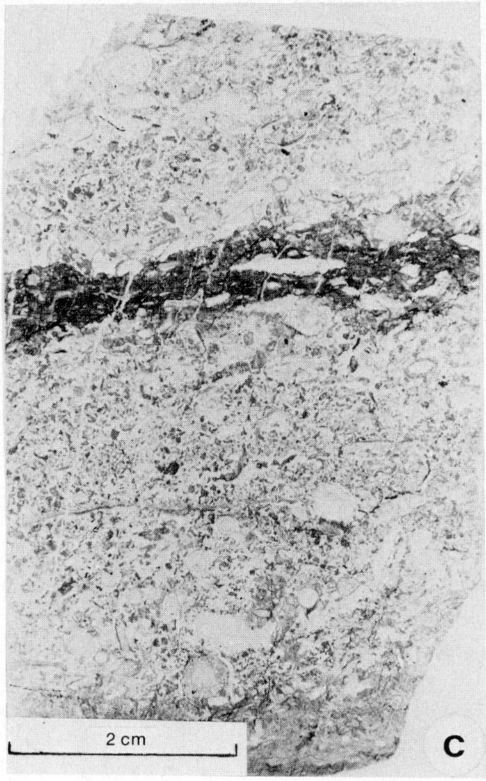
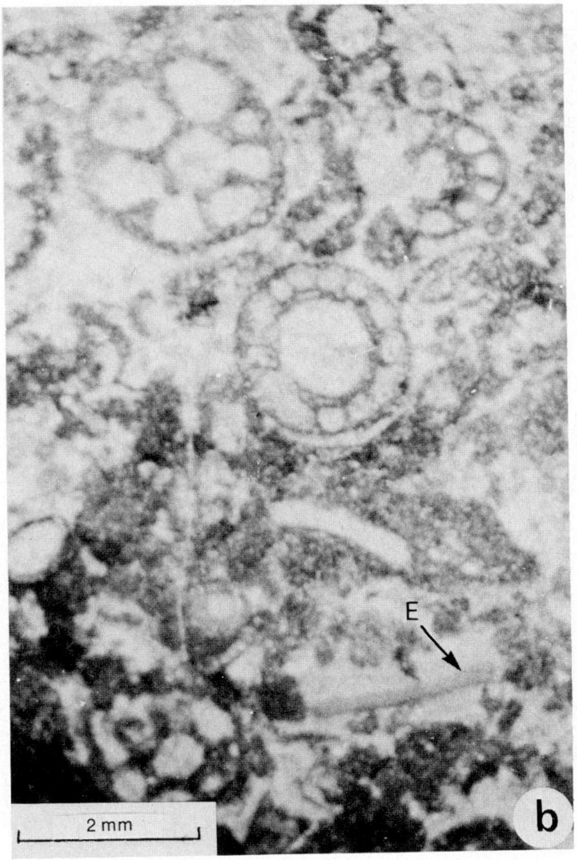


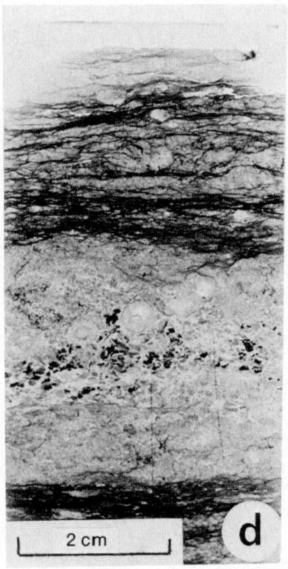
PLATE 22

Polished slab and drawing showing spatial relationship between archaeocyathids, **Renalcis**?, and matrix in bindstone. **Renalcis**? encrusted archaeocyathids and grew between them. In this manner successive generations of biota constructed the rigid organic framework of the carbonate buildup facies. Note the small "algal head"-like structure at H (carbonate buildup facies, Shrimp Lake 1). GSC 203328-U









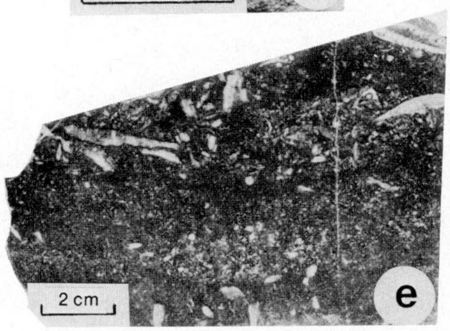


PLATE 23

a. Hand specimen of archaeocyathid rudstone with an archaeocyathid peloid packstone matrix. Sample is etched with hydrochloric acid resulting in light coloured dolomitized skeletal grains and mud and darker calcite cement. Note the large archaeocyathid fragment at (S) (skeletal sand facies, Shrimp Lake 1).

b. Thin section of archaeocyathid peloid packstone matrix of rudstone illustrated in Pl. 23a. Note high spar/mud ratio of this matrix and the echinoderm fragment at (E).

c. Thin section of archaeocyathid floatstone with a skeletal peloid packstone matrix. Note the high spar/mud ratio of this matrix (skeletal sand facies, Shrimp Lake 1).

d. Thin section of archaeocyathid floatstone with a skeletal peloid packstone matrix (skeletal sand facies, Shrimp Lake 1).

e. Hand specimen of archaeocyathid floatstone with a skeletal peloid packstone matrix. Note relatively low spar/mud ratio of this matrix (skeletal sand facies, Shrimp Lake 1).

GSC 203328-V

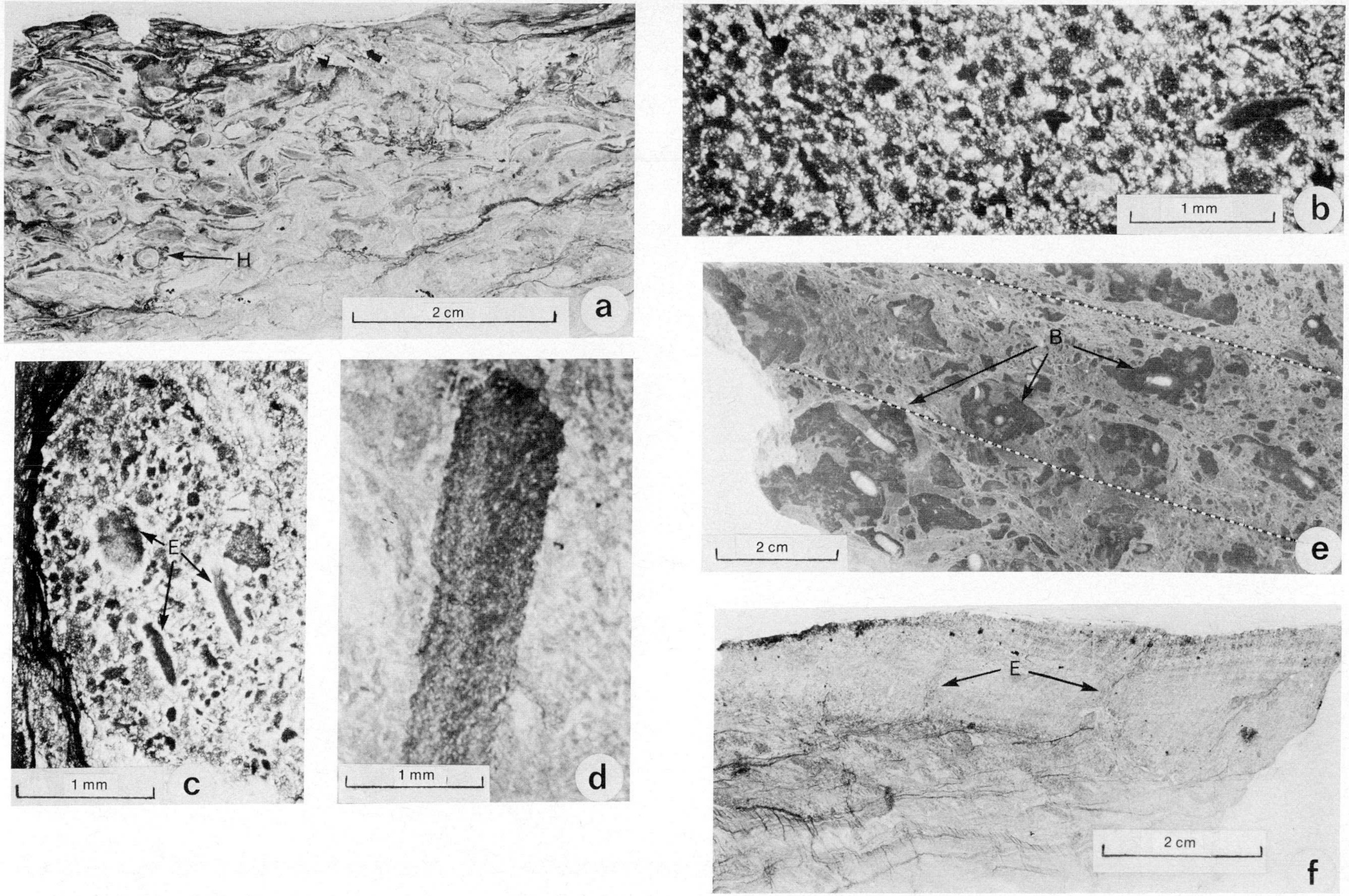


PLATE 24

a. Thin section of trilobite rudstone with an argillaceous peloid packstone matrix. Note the dark cryptalgal coating on many trilobite fragments and the stacked hyolithids at (H) (skeletal sand facies, Shrimp Lake 2).

b. Thin section of peloid packstone from the skeletal sand facies (Shrimp Lake 2).

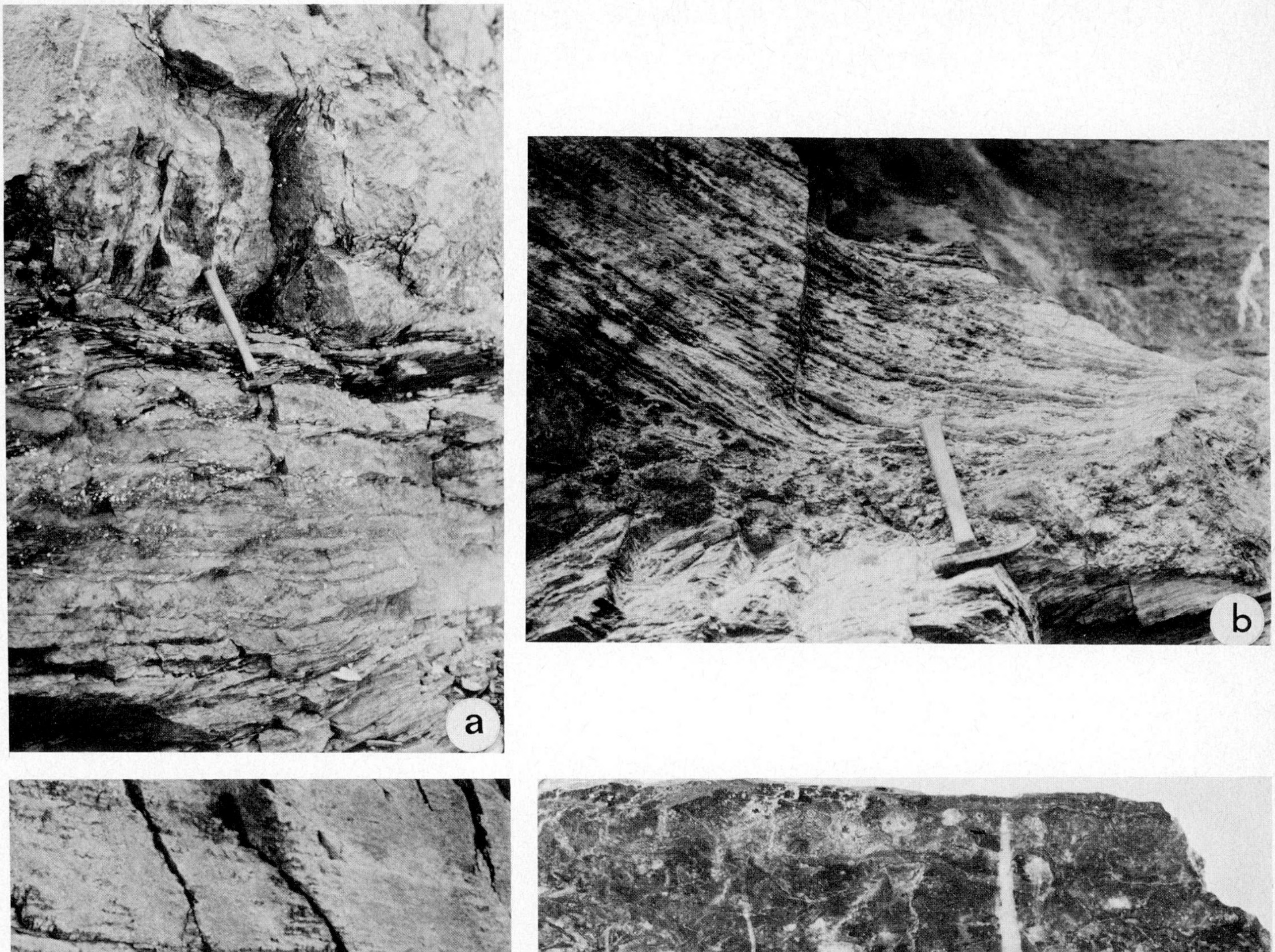
c. Thin section showing a peloid packstone intraclast. Note echinoderm fragments (E) and high spar/mud ratio of this intraclast (skeletal sand facies, Shrimp Lake 2).

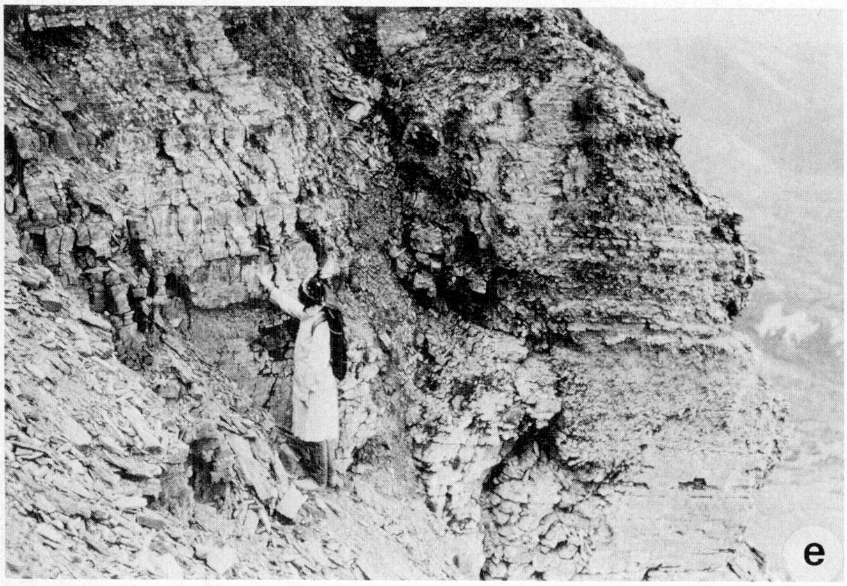
d. Thin section showing laminated, calcareous argillite intraclast (skeletal sand facies, Shrimp Lake 1).

e. Hand specimen showing archaeocyathid bindstone intraclasts (B) set in an argillaceous wackestone matrix. Dashed line indicates bedding (skeletal sand facies, Shrimp Lake 1).

f. Thin section showing escape structures (E) in peloid packstone (skeletal sand facies, Shrimp Lake 2).

GSC 203328-W


a
b
c
2 cm
d



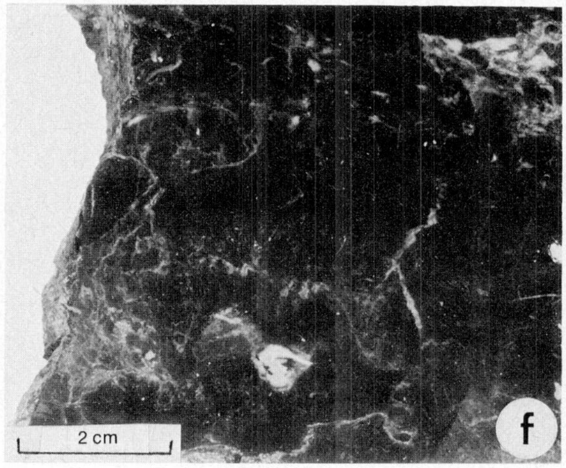


PLATE 25

a. Outcrop of interbedded skeletal sand and mudstone facies at the base of a carbonate buildup. Hammer is at contact with the overlying carbonate buildup facies (base of Shrimp Lake 1).

b. Outcrop of intra-buildup skeletal sand found in "pocket". Note inclined primary dip (skeletal sand facies, Shrimp Lake 1).

c. Outcrop of mudstone facies approximately 45 m from the eastern lateral margin of Shrimp Lake 1. Note the light coloured, thin interbed of the skeletal sand in the lower part of the photograph. Pole is 1.5 m long.

GSC 203328-X

d. Hand specimen of archaeocyathid trilobite peloid packstone of the skeletal sand facies. This packstone occurs interbedded with the mudstone facies approximately 120 m from the eastern lateral margin of Shrimp Lake 1. Note sharp lower contact of the interbed with underlying argillaceous mudstone.

e. Outcrop of thin-bedded dolomitic mudstone and minor calcareous argillite (mudstone facies, approximately 120 m from the eastern lateral margin of Shrimp Lake 1).

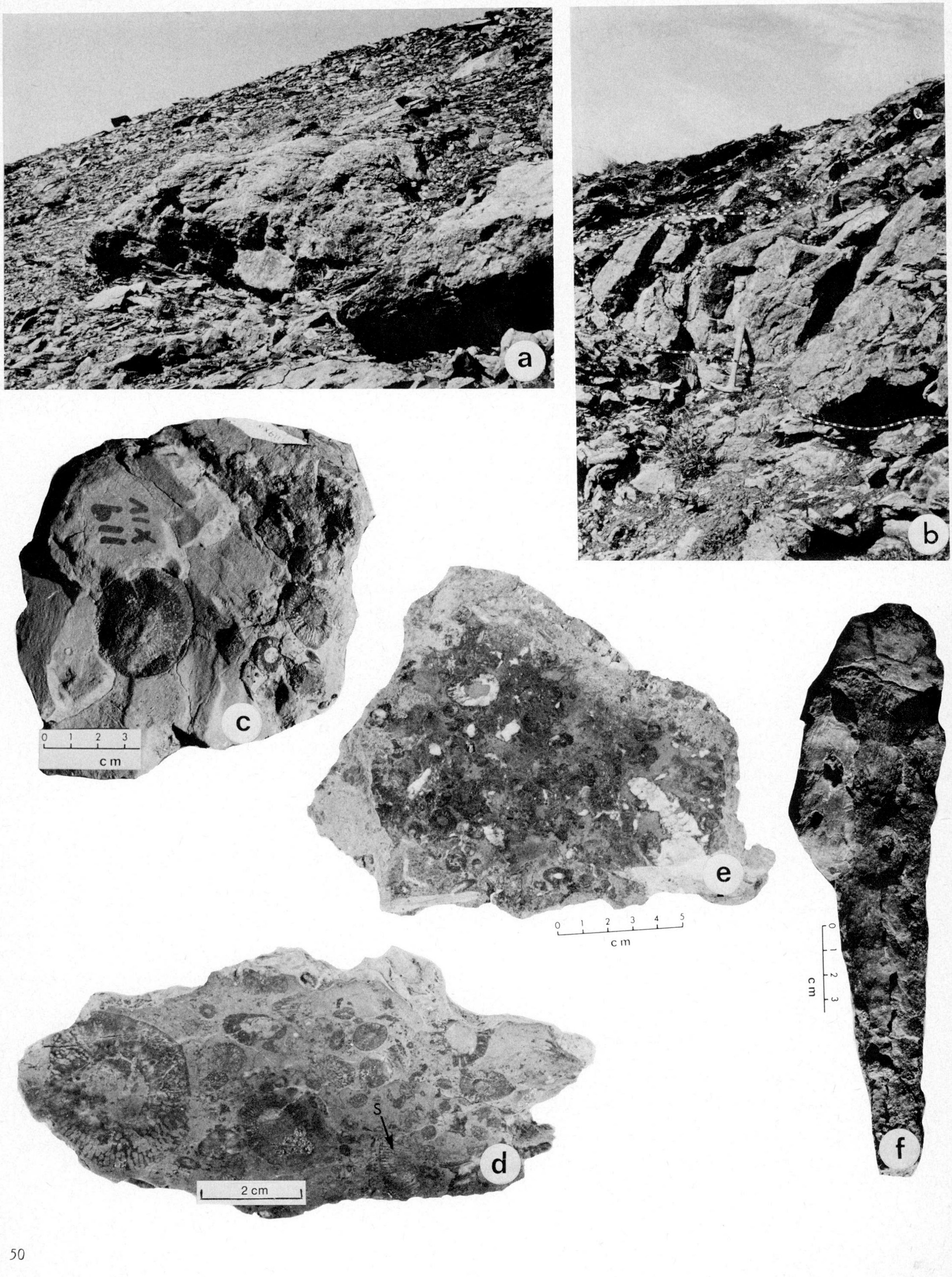
f. Hand specimen of dolomitic mudstone near eastern lateral margin of Shrimp Lake 1.

The skeletal sand facies occurs at the base of carbonate buildups and as pockets within them, on top of them and around them. At the base of buildups it is in discontinuous tabular beds about 30 cm thick that are generally abruptly overlain by the carbonate buildup facies. The "intra-buildup" skeletal sand forms irregular "pockets" and tabular beds completely surrounded by the carbonate buildup facies. Pockets are well stratified and as much as 6 m thick and 9 m wide. Tabular beds are vaguely stratified and generally less than 15 cm thick and 3 m wide. Bedding in the pockets is usually parallel, its attitude similar to that of rocks outside buildups. Locally, saucer-like bedding and inclined primary dips were found (Pl. 25b). The intra-buildup sand grades into the buildup facies or is in sharp contact with it. The skeletal sand that occurs between "pinnacles" and "knolls" on the upper buildup surfaces locally exhibits saucer bedding like that of intra-buildup sand; it grades upwards into the mudstone facies above the buildups. Skeletal sand around the buildups is limited to rare, thin, discontinuous, tabular interbeds (Pl. 25c) less than 15 cm thick which have sharp upper and lower contacts (Pl. 25d).

The skeletal sand facies was deposited under intermittently agitated conditions in depressions on the buildups and locally around them. Their skeletal detritus is clearly derived from the buildups themselves as the mudstone around these structures is poorly fossiliferous (Pl. 25e, 25f). Intermittent agitation, suggested by the presence of broken archaeocyathids, erosional intraclasts, cryptalgal-coated grains, and coarse grained, spar-rich carbonates, probably resulted from storms. Rocks like the intra-buildup skeletal sand occur in Silurian reefs of northern Europe where they are also interpreted as depression fillings (Manten 1971; Scoffin, 1971). A recent analogue of the intra-buildup sand may be skeletal-rich deposits found in hollows between the raised "knobs" of recent patch reefs in Bermuda (Garrett et al., 1973). Shallow depressions overgrown by organic framework resulted in the skeletal sand pockets and tabular beds enclosed by the carbonate buildup facies.

Summary of Carbonate Buildup Development

Based on the above facies analysis, the carbonate buildups of subunit 1d are interpreted as potential reefs (sensu Heckel,1974) which grew in a shallow water environment subject to periodic agitation during storms. Their rigid organic framework suggest that buildups were potentially wave resistent. Shallow water conditions within the photic zone are interpreted from the presence of cryptalgal-coated grains. If **Renalcis**? is a blue-green calcareous algae, its abundance in the carbonate buildup facies also implies relatively shallow water conditions. Even if **Renalcis?** is a foraminifer, it appears that the organism was adapted to "warm, shallow-marine biohermal carbonate environments" (Riding and Brazier, 1975, p. 209). Quiet water below the surf zone and probably normal wave base is suggested because the buildups contain abundant mud matrix and are flanked by low energy deposits which lack thick beds of reef-talus. However, local accumulations of skeletal sand indicate that conditions were not always quiet and limited physical erosion occurred during buildup growth.


a
b
c
0 1 2 3
cm
e
0 1 2 3 4 5
cm
0 1 2 3
cm
f
S
d
2 cm

Carbonate Buildups of Subunit 1e

Carbonate buildups are present at all stratigraphic levels in subunit 1e, but are not volumetrically important. They are biohermal or biostromal shaped (sensu Nelson et al., 1962; Pl. 26a, 26b). The largest, at Mount Fury, is about 20 m wide and 2 m thick, but most are smaller, 6 m by 1 m. These buildups are surrounded by noncalcareous argillite and marginal contacts are sharp. Upper and lower surfaces are smooth and the structures lack "knolls" at their tops. Laterally, buildups pinch without forming "tongues". No skeletal sand facies is associated with them.

Argillite at lateral margins of the buildups does not exhibit local changes of dip or pinchouts and evidence of topographic relief therefore is lacking. However, buildups are surrounded by noncalcareous argillite suggesting that some environmental factor localized carbonate deposition. That factor may have been positive relief. Heckel (1974, p. 91) noted that in a regime of shale deposition, local, elevated structures provide areas where "carbonate can be generated away from the normal paths of currents carrying terrigenous debris".

The buildups in subunit 1e are composed of massive, unbedded, archaeocyathid (25%) floatstone and minor rudstone, both with a dolomite mudstone matrix (Pl. 26c, 26d, 26e). **Renalcis**?, although present, does not bind archaeocyathids into a rigid framework, which gives rise to the floatstone texture.

Archaeocyathid genera found in the buildups of subunit 1d are also present in those of subunit 1e. Large specimens of **Pycnoidocyathus** and **Coscinocyathus**, some with heights up to 20 cm (Pl. 26f) are particularly abundant. Intact or broken cups are generally prostrate and not in growth position. Notable by its absence is the stromatoporoid-like **Altaicyathus**?. **Renalcis**? is not abundant and occurs as encrustations on individual archaeocyathid skeletons or floating in the mudstone matrix. Trilobite and echinoderm fragments are found sparsely in floatstone and rudstone.

Buildups of subunit 1e are interpreted as archaeocyathid mud "banks" (sensu Heckel, 1974), because they are laterally restricted, lack a rigid framework, are made up of archaeocyathids and dolomite mud and may have had slight positive topographic relief. Unlike the reefs of subunit 1d, banks have no potential for wave resistence because they lack a bound texture. Subunit 1e was deposited in a shallow, normal marine, intermittently agitated, subtidal environment periodically subjected to strong current or wave action. Depositional conditions of the banks must have been similar.

Although archaeocyathids are as abundant in banks of subunit 1e as in reefs of subunit 1d, the banks contain less **Renalcis**? than the reefs. This implies that the organic framework of the reefs is generated mainly by **Renalcis**? and that archaeocyathids are incidental in this regard. **Renalcis**? may have been fragile and adapted to relatively low energy conditions (Klovan, 1964). If so, the absence of organic framework in banks possibly results from periodic strong currents that inhibited **Ranalcis**? proliferation.

The source of the carbonate mud in the banks is not clear. These banks are surrounded by noncalcareous argillite and the mud does not originate there. Much of the mud may have been produced on the banks by breakdown of thalli of calcareous algae. Morgan (1975) suggested a similar origin for the mud in Californian archaeocyathid banks which are also encased in fine grained terrigenous clastics. A recent analogue of the subunit 1e banks may be the Florida Bay mud mounds where fine carbonate is produced by breakdown of codiacean algae (Stockman et al., 1967).

PLATE 26

a. Outcrop of small biohermal-shaped carbonate buildup surrounded by recessive non-calcareous argillite. This structure is approximately 1 m thick. (subunit 1e, 2.5 km north of Mount Fury section).

b. Outcrop of biohermal-shaped carbonate buildup surrounded by non-calcareous argillite. Hammer is near the base of this structure. (subunit 1e, Cache Creek section).

c. Hand specimen of archaeocyathid floatstone with a dolomite mudstone matrix. (carbonate buildup, subunit 1e, Mount Fury section).

d. Hand specimen of archaeocyathid floatstone with a dolomite mudstone matrix. Note large archaeocyathid fragment at (S). (carbonate buildup, subunit 1d, Mount Fury section).

e. Hand specimen of archaeocyathid rudstone with dolomite mudstone matrix (carbonate buildup, subunit 1e, Mount Fury section).

f. Hand specimen of **Pycnoidocyathus**. Large archaeocyathid are common in carbonate buildup of subunit 1e. (carbonate buildup, subunit 1e, Cloutier Creek section).

(GSC 203328-Y)

SUMMARY AND CONCLUSIONS

The early Early Cambrian to late Early Cambrian succession exposed in the Ketza River area, central Yukon is a 700 m thick, miogeoclinal sequence of clastic and carbonate rocks. The shallow marine sequence was deposited on the continental shelf adjacent to the North American craton within the "middle carbonate belt" of Palmer (1960) and Robison (1960). The succession spans the first Lower Cambrian "Grand Cycle" (Fritz, 1975) and the lowest part of the second.

Five lithostratigraphic subdivisions (subunits 1a and 1e) are recognized in the succession. During the early Early Cambrian, the Mount Fury quartzite (1a) was deposited in the northeast part of the area while an equivalent argillite accumulated in the southwest. Mount Fury sedimentation occurred in an intermittently agitated environment, within the transition zone between high energy coastal sands and offshore muds. At the end of subunit 1a time argillite was deposited over the entire area, reflecting a transgression toward the craton of lower energy, deeper water facies.

Near the beginning of the middle Early Cambrian, the influx of terrigenous clastics was reduced and restricted conditions developed on the shelf. Dark, poorly fossiliferous, laminated mudstone (subunit 1b) reflects this period of stagnation.

Renewed accumulation of argillite began with deposition of subunit 1c although the sea remained semirestricted. This argillite differs from that of subunit 1a; it lacks sand and is calcareous. Toward the end of 1c time the influx of terrigenous clastics decreased, and mudstone and wackestone were deposited under quiet normal marine conditions. Archaeocyathids, trilobites, echinoderms, and algae began to flourish.

Subunits 1d and 1e are particularly interesting because they envelop local archaeocyathid carbonate buildups. Dominant archeocyathids include **Pycnoidocyathus, Protopharetra, Coscinocyathus** and a binding algal-like structure related to **Renalcis**. These organisms are enclosed by a mudstone matrix. The stromatoporoid-like **Altaicyathus**? is present locally in buildups of subunit 1d.

Carbonate facies dominate subunit 1d. Lower strata are mudstone and calcareous argillite deposited under low energy, shallow, normal marine, subtidal conditions. The seafloor was not favourable to profuse organic activity, but archaeocyathids and **Renalcis**? constructed local large buildups. These have a patch reef shape and some had minimum relief of 8 m above the surrounding muddy seafloor during growth. They grew in quiet water below the surf zone and normal wave base. Local lenses of skeletal debris indicate that periodic, storm-generated, currents swept their upper surfaces. The buildups exhibit a bound texture and are "potential reefs" (sensu Heckel, 1974).

Reefs are absent in the upper part of subunit 1d, probably because the water became shallower and more agitated as indicated by widespread mudstone with interbedded floatstone and rudstone containing oncoids and cryptalgal-coated grains. This shoaling trend did not culminate in supratidal or intertidal conditions.

Near the beginning of late Early Cambrian time, noncalcareous mud, represented by argillite of subunit 1e, was deposited in quiet water. Periodic strong currents swept ooids, oncoids, and skeletal detritus from turbulent shoal areas depositing them as lenses and tabular deposits in the argillite. Locally, small archaeocyathid carbonate buildups developed. These have an archaeocyathid fauna like that of the reefs of subunit 1d but **Renalcis**? is not as abundant and **Altaicyathus**? is absent. Because the buildups lack a rigid, organic framework they are interpreted as archaeocyathid mud "banks" (sensu Heckel, 1974).

Subunit 1e is unconformably overlain by late Cambrian fine grained carbonate and argillite.

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