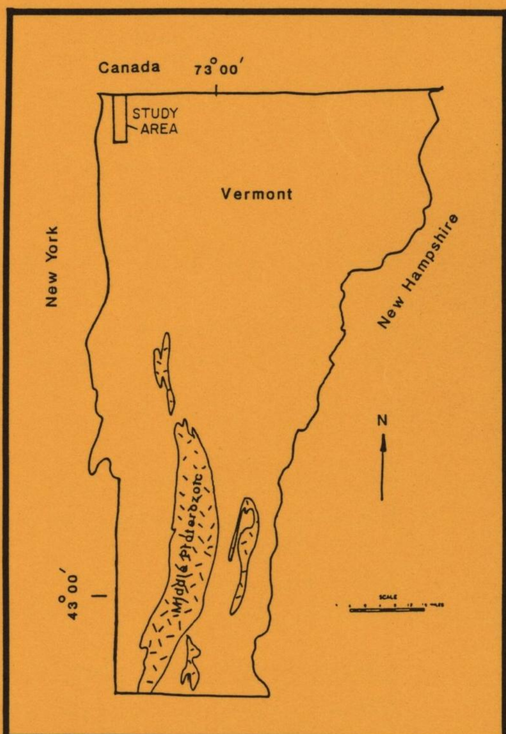
Stratigraphy and Bedrock Geology of the Northwestern Portion of the St. Albans Quadrangle and the Adjacent Highgate Center Quadrangle, Vermont

Charlotte J. Mehrtens and Rebecca J. Dorsey



Editors:

Charles A. Ratté
Robert Cushman

Special Bulletin No. 9, 1987
Vermont Geological Survey
Charles A. Ratté, State Geologist

Vermont Agency of Environmental Conservation
Office of the State Geologist

TABLE OF CONTENTS

FIGURES

STRATIGRAPHY AND BEDROCK GEOLOGY OF THE NORTHWESTERN PORTION OF THE ST. ALBANS QUADRANGLE AND THE ADJACENT HIGHGATE CENTER QUADRANGLE, VERMONT

Charlotte J. Mehrtens
Department of Geology
University of Vermont

Rebecca J. Dorsey
Department of Geological and Geophysical Sciences
Princeton University

ABSTRACT

Detailed field mapping at 1:24,000 and 1:12,000 in the St. Albans and Highgate Center region has resulted in the redescription and revision of Cambro-Ordovician stratigraphy in northwestern Vermont. Rock units in the study area represent platform, platform margin and basinal deposits and an analysis of their spatial and temporal distribution has been used to document the existence of intrashelf basins active during the Cambro-Ordovician, each of which accumulated a unique stratigraphic sequence. A coherent model is presented which illustrates how the sedimentation in the basins are related.

INTRODUCTION

The study area is in the northwestern part of the St. Albans Quadrangle and the western part of the adjacent Highgate Center Quadrangle. It is underlain by Lower Cambrian to Lower Ordovician clastic and carbonate rocks that record the evolution of the Lower Paleozoic platform and platform margin of Cambro-Ordovician age in eastern North America. These rocks are part of an extensive belt of similar facies extending from Newfoundland to Alabama along what Rodgers (1968) recognized as the margin of the Lower Paleozoic North American platform. They consist of carbonate deposits characteristic of a shallow-water platform, bordered to the east by shales interbedded with conglomerate and breccia horizons that are interpreted as deeper marine basinal deposits (Figure 1).

The bedrock geology of the study area is dominated by the west limb of the St. Albans Synclinorium, a broad, open syncline plunging gently to the south. All the units within the study area are contained on the upper plate of the Champlain Thrust, the base of which lies to the west of the study area, near Lake Champlain. The Champlain Thrust has emplaced rocks of Cambro-Ordovician age on Middle Ordovician shales. Within the study area the Highgate Springs Thrust has emplaced Late Cambrian-Early Ordovician (?) Clarendon Springs Dolomite on top of Early Ordovician Highgate Shale.

PREVIOUS WORK

The geology of the region around St. Albans and Highgate Center has been studied extensively for more than 100 years, mostly for paleontological interests. The most important of these earlier works was that of Walcott (1886, 1891), who studied the trilobite faunas of the Lower Cambrian units. Subsequent stratigraphic studies through the late 1950's are summarized in Shaw (1958), but Schuchert's contributions (1933 and 1937) are noteworthy. Shaw (1958) defined each of the rock units within in the study area, described the distribution and thickness of each and determined the age of each based primarily on trilobite zonations. Some of the trilobite zonations were subsequently refined by Palmer (1970). Within the study area, Shaw recognized

MEHRTENS AND DORSEY, 1987

ERRATA:

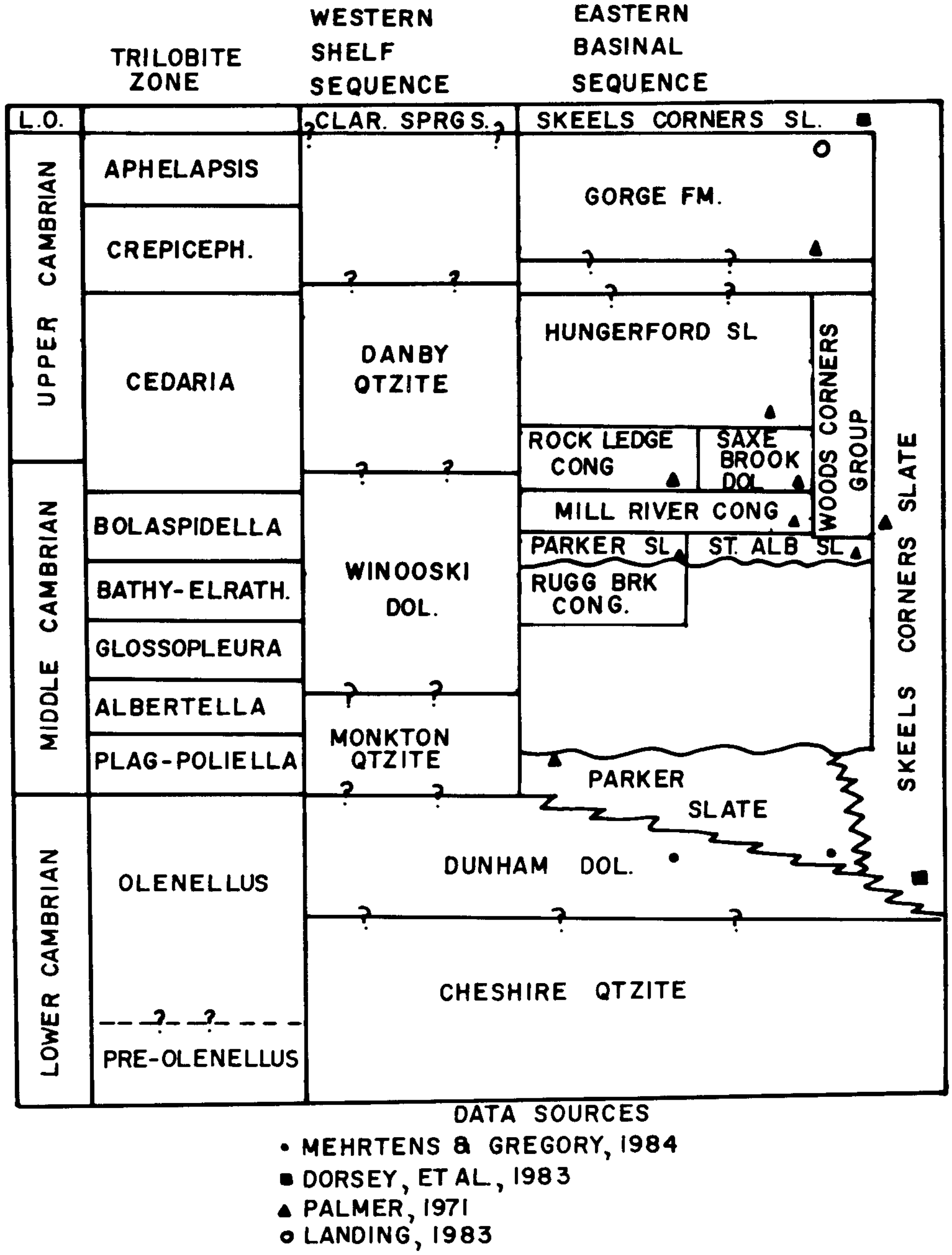
Plate 1, Figure 1. HST should read HFT for Highgate Falls Thrust.

Text page 24. Highgate Springs Thrust should read Highgate Falls Thrust.

p. 2 Highgate Falls Thrust

p. 3 Londery (1983)

Figure 1. Correlation chart showing the stratigraphic relationships between units in northwestern Vermont, incorporating original data from Shaw (1958) and revisions by Palmer (1971), Dorsey, et al. (1983), Landing (1983), and Mehrtens and Gregory (1984). This study revises the stratigraphy within the Eastern Basinal Sequence (Plate 2, Figure 3), including the elimination of the St. Albans and Hungerford Slates, and the Mill River Conglomerate. The age of the Rugg Brook Formation is also revised.



TRILOBITE ZONE
WESTERN SHELF SEQUENCE
EASTERN BASINAL SEQUENCE
L.O.
CLAR. SPRGS.
SKEELS CORNERS SL.
UPPER CAMBRIAN
APHELAPSIS
CREPICEPH.
CEDARIA
GORGE FM.
DANBY QTZITE
HUNGERFORD SL
ROCK LEDGE CONG
SAXE BROOK DOL
WOODS CORNERS GROUP
MILL RIVER CONG
PARKER SL
ST. ALB SL
MIDDLE CAMBRIAN
BOLASPIDELLA
BATHY-ELRATH.
GLOSSOPLEURA
ALBERTELLA
PLAG-POLIELLA
WINOOSKI DOL.
RUGG BRK CONG.
SKEELS CORNERS SLATE
MONKTON QTZITE
PARKER SLATE
LOWER CAMBRIAN
OLENELLUS
PRE-OLENELLUS
DUNHAM DOL.
CHESHIRE QTZITE
DATA SOURCES
• MEHRTENS & GREGORY, 1984
■ DORSEY, ET AL., 1983
▲ PALMER, 1971
o LANDING, 1983

Figure 1

the existence of both west-to-east and north-to-south facies changes from shallow (west and north in the study area) to deeper water deposits (south and east in the study area), based on trilobite biostratigraphy.

The Highgate area has received less attention. Important exposures of the Dunham Dolomite and the overlying Saxe Brook Dolomite are mentioned by Gregory (1982). Pingree (1982) described the stratigraphy within the Highgate region, including the Saxe Brook and Clarendon Springs Dolomites, Gorge and Highgate Formations and Morses Line Slate. More recently, Landing (1984) measured and described a section of the Gorge and Highgate Formations and developed a combined conodont and trilobite zonation for these units.

STRATIGRAPHY

Rocks in the study area can be divided into two groups (Figure 1): the Western Shelf and Eastern Basinal Sequences (terminology after Dorsey, et al., 1983). The Western Shelf Sequence is the name applied to the group of rocks characterized by thick sequences of alternating siliciclastic and carbonate sediments of shallow water (platform) origin. The Western Shelf Sequence forms the westernmost belt of Cambro-Ordovician deposits, bordered to the west by the Champlain Thrust. It is bordered to the east by rocks of the Eastern Basinal Sequence. The Eastern Basinal Sequence is composed of rock units which are predominantly shale, sandstone, conglomerate and breccia in composition. The contact between the Western Shelf and Eastern Basinal Sequences is exposed in the western portion of the study area, and important lateral facies changes occur between rocks of the Eastern Basinal Sequence in the south and the Western Shelf Sequence to the north (Plate 1, Figure 1).

DEPOSTIONAL ENVIRONMENTS

Units within the study area can be broadly grouped as representing deposits formed in one of three regions: platform or shelf, shelf margin, and basin. The term "platform" is a general one, used here to describe any thick accumulations of carbonate sediment, including both shelves and gently sloping ramps. "Shelf" is defined as a type of platform in which a narrow, steep slope has developed on the margin of a flat-topped, shallow platform (Ahr, 1973). This "platform margin" or "shelf margin" is characterized by the development of downslope facies recording sediment gravity flows and bioclastic sedimentation (standard facies belts 3 & 4 of Wilson, 1975) which pass gradationally into basinal deposits (shales and distal sediment gravity flows; standard facies 1 & 2 of Wilson, 1975).
Rocks within this study area represent possible debris flows and high and low density turbidity current deposits, all of which represent portions of a continuum of flows in which turbulence of the interstitial waters becomes more important as a transporting mechanism. Lowe (1982) contains a thorough review of the classification and hydraulics of sediment gravity flows.

Western Shelf Sequence

Dunham Dolomite (Ɛdu)

The pink to buff colored Dunham Dolomite outcrops in a north-south trending belt along the extreme western margin of the study area (Plate 1, Fig.1). It is the only carbonate unit of the Western Shelf Sequence which extends from south of St. Albans up to and across, the Canadian border. The lithofacies of the Dunham Dolomite and their environmental interpretations was presented by Gregory (1982), and summarized in Gregory and Mehrtens (1983) and Mehrtens (1985), and is not repeated here. All four lithofacies which comprise the Dunham (peritidal, subtidal/open shelf, channel, and shelf margin) can be seen within the study area (see Gregory, 1982, for some localities), however the location of the shelf margin lithofacies is most important because it defines the edge of the Dunham shelf, and the transition into the adjacent basin.

An excellent exposure of the platform margin transition is seen along Interstate 89 north of St. Albans (Plate 1, Fig.1, A5). Here, poorly-bedded polymictic breccias in a sandy-dolomite matrix with erosional bases pass vertically into more shaley-matrix breccias. The breccias are separated by a small covered interval of about 2 meters in thickness, from laminated silty slates and sandstones of the overlying Parker Formation. This sequence, approximately 10 meters thick, represents the transition from the Dunham platform margin into shaley deposits of the Eastern Basinal Sequence. Another thick exposure of Dunham Dolomite (Plate 1, Fig. 1, C 11) has a covered interval at its top but the uppermost beds are thick cross-bedded sandy-dolomites interpreted by Gregory (1982) as shelf margin sand bodies. Clasts of the buff, sandy dolomite Dunham Formation are found in the Parker Slate at several localities in the study area (Plate 1, Fig.1,B 3 & 4; see also Gregory, 1982 for additional locations in the St. Albans area). These deposits are interpreted as more distal flows in the same shelf margin environment.

Because the base of the Dunham Dolomite is not seen in the study area its thickness could not be determined, however to the south, in the Milton area, Gregory (1982) measured a section of the Dunham which was approximately 400 meters thick.

The age of the Dunham Dolomite has been difficult to determine due to the paucity of trilobites. However, Mehrtens and Gregory (1984) recovered specimens of Salterella conulata that indicate that the Dunham is, at least in part, Olenellus zone (Lower Cambrian) in age.

Saxe Brook Dolomite (€Sb)

The Saxe Brook Dolomite is a buff-to- white weathering sandy dolomite to dolomitic sandstone found only north of the Missiquoi River, stratigraphically between the Dunham Dolomite and the Gorge Formation. Although the basal contact with the Dunham Dolomite is covered everywhere in the study area, the two units are separated by only a few meters at one locality (Plate 1, Fig.1, B9). Here, the uppermost beds of the Dunham Dolomite comprise the shelf margin lithofacies: polymictic breccia clasts in a sandy dolomite matrix. In contrast, the basal beds of the Saxe Brook Dolomite consist of structureless sandy dolomite. Pingree (1982) noted that the Saxe Brook was locally brecciated, and these horizons may represent shelf margin facies of the Saxe Brook as it passes into basinal shales to the south.

The Saxe Brook was estimated by Shaw (1958) and Pingree (1982) to be approximately 210 meters thick. This study estimates the thickness to be 300m.

The age of the Saxe Brook was determined by Shaw to be Dresbachian on the basis of presumed correlation to the fossiliferous Rockledge Conglomerate. This early Upper Cambrian age is younger than the Middle Cambrian age estimated by Palmer (1970) from ages of possibly correlative under-and overlying shale units. Field mapping relationships of this study indicate that the Saxe Brook Dolomite lies stratigraphically below the Rockledge Conglomerate, and that it is probably a northern equivalent of the Rugg Brook Dolomite (Middle Cambrian).

Clarendon Springs Dolomite (Є-Ocs)

The Clarendon Springs Dolomite outcrops in the extreme northern part of the study area and it overlies the Saxe Brook Dolomite. The Clarendon Springs is a buff white, structureless recrystallized dolomite that can be distinguished from other dolomite units by the presence of chert pods. The upper contact between the Clarendon Springs and the overlying Highgate Formation is conformable, and not a thrust as previously interpreted by Pingree (1982). The Clarendon Springs-Highgate contact is important because it represents a rapid transition from carbonate platform to shaley basin depositional environments.

In this study, a significant north-to-south facies change from the Clarendon Springs into the Gorge Formation (Є-Og?) is recognized (Plate 1, Fig. 1, C 11). The paleoenvironmental significance of this stratigraphic relationship is discussed under the description of the Gorge Formation. The Clarendon Springs Dolomite was correlated by Stone and Dennis to the basal dolomite horizon of the Gorge Formation.

Gorge Formation (Є-Og)

The Gorge Formation overlies the Saxe Brook Dolomite, lies laterally to the south of the Clarendon Springs Dolomite, and is in turn overlain by the Ordovician Highgate Formation. The basal contact is not exposed but the upper contact with the Highgate Formation is exposed in the Missisquoi River gorge (Plate 2, Fig. 1, D7). The Gorge-Highgate contact was interpreted by Pingree (1982) to be everywhere a thrust, but this study has shown that it represents a rapid facies change from shelf margin to basin environments. There is no structural evidence of a thrust along this contact and it is interpreted here as conformable (a sliver of Gorge Formation is contained within thrusted Highgate Formation in the Missisquoi River Gorge). The Gorge Formation consists of two lithologies, a recrystallized dolomite and a dolomite-clast conglomerate in a quartz-rich dolomitic matrix. The first lithology is found north of the village of Highgate Falls (Plate 1, Fig.1, E7) while the latter is exposed in Highgate Gorge

(Plate 1, Fig.1,E7). This north to south facies change, along with the north to south facies change of the Clarendon Springs Dolomite into the Gorge Formation, record two kinds of shelf to shelf margin transitions. The Clarendon Springs Dolomite, a shallow water carbonate platform deposit, passes southward into the recrystallized dolomite, proximal platform margin deposits of the Gorge Formation. The continued southward lateral transition from recrystallized dolomite southward into dolomite-clast conglomerates in the Gorge Formation in turn records the transition from proximal to distal facies of the shelf margin environment as it passes into the basin to the south.

The Gorge Formation was first assigned an Upper Cambrian age (Franconian) by Shaw (1958), and Palmer (1970) recognized that the base of the unit was late Dresbachian in age. Landing (1984) redefined the Gorge and Highgate Formations on the basis of combined trilobite and conodont zonations, and assigned an Upper Cambrian (Dresbachian) through Lower Ordovician (*Symphysurina* Zone) age to the Gorge Formation at its type section in the Missiquoi River gorge.

Eastern Basinal Sequence

The Eastern Basinal Sequence outcrops in a north-south trending belt in the study area and includes rocks formerly assigned to the Parker, Rugg Brook, St. Albans, Mill River, Skeels Corners, Rockledge, Hungerford, Highgate and Morses Line units. These units, with the exception of the Highgate and

Morses Line Slate, were included within the Woods Corners Group of Shaw (1958). In this study, the St. Albans Slate has been included within the Parker Slate. The Rugg Brook and Mill River Conglomerates have been combined into facies within the Rugg Brook Formation. The Rockledge and Highgate Formations and Morses Line Slate are still recognized as discrete units, but the Hungerford Slate has been reassigned to the Skeels Corners Slate. The contacts between all slate units (Parker, Skeels Corners and Morses Line Slates) are gradational and are recognized by subtle, but mappable changes in lithology.

Parker Slate (€p)

The Parker Slate is recognized as the oldest, lowermost unit in the basinal sequence and it overlies and lies basinward (eastward) of the Dunham Dolomite. The Parker Slate was described by Shaw (1958) as a gray to black micaceous slate containing horizons of limestone, dolomite, quartzite and limestone "bioherms". In his description of this unit, Shaw (1958) recognized several other shale units overlying the Parker Slate, which are separated from one another by dolomite horizons, but these shales have been included within the Parker in this study.

Palmer (1970) and Palmer and James (1980) reviewed the trilobite zonation of Shaw (1958) and determined that the lower Parker is early Middle Cambrian in age while the upper Parker contains a late Middle Cambrian fauna. The St. Albans Slate, a unit that Shaw described as overlying the Parker, is included in the Parker in this study and is dated by Palmer as also bearing a late Middle Cambrian age fauna. The St. Albans Slate was described by Shaw as a black, micaceous slate overlying a dolomite unit (Rugg Brook Dolomite) which separates it from the Parker Slate. In this study the dolomite horizons are recognized as a series of discrete carbonate flows interbedded within the Parker Slate matrix. Where dolomite is not present, it is impossible to distinguish the St. Albans Slate from the Parker Slate.

Parker Conglomerate (Єpc)

The Parker Conglomerate is a new unit recognized in this study. It is characterized by a typical Parker Slate matrix of detrital micaceous, arenaceous slate containing clasts of dolomite and quartz sand-rich dolomite. The clasts are usually buff-orange in color, and are well rounded and unsorted, and are up to 30 cm in diameter. This unit is found immediately overlying the Dunham Dolomite (Plate 1, Fig.1, B4-5) and slightly up section (Plate 1, Fig.1, B3). Gregory (1982) shows additional localities for the Parker Conglomerate outside of this study area. Based on its stratigraphic position this unit is interpreted as representing shelf margin detritus derived from the Dunham Dolomite carbonate platform. The characteristics of more proximal Dunham shelf margin debris were discussed earlier; this unit is interpreted as being a more distal deposit on the basis of a smaller clast size, rounder clasts and a fine-grained, turbiditic matrix than its proximal dolomite breccia counterpart.

Rugg Brook Formation (Єrbd, Єrbq, Єrbs, Єrbsh, Єrbsc)

The Rugg Brook Formation was the name applied to dolomite horizons that lay stratigraphically between the Parker and St. Albans Slates, and which were northern equivalents of the Winooski Dolomite south of Milton (Shaw, 1958). In this study the Rugg Brook Formation is recognized as consisting of five facies: 1) recrystallized dolomite (Ꞓrbd); 2) white weathering, coarse-grained dolomitic quartzite (Ꞓrbq); 3) sandy matrix, dolomite clast conglomerate (Ꞓrbs); 4) shaley-silty matrix, dolomite clast conglomerate (Ꞓrbsh), and 5) sandstone clast conglomerate in a dolomite matrix (Ꞓrbsc). These facies form the majority of mappable units in the western part of the study area. They stratigraphically overlie the Dunham Dolomite, and they extend up to and are interbedded with the Rockledge Conglomerate. In this study the name Rugg Brook Formation is taken to include what was formerly recognized as Mill River Conglomerate. The five mappable facies of the Rugg Brook Formation are interbedded within the Parker Slate. The facies do not appear to have any pattern of distribution that may record mode of emplacement, rather all facies appear to be randomly interbedded with one another, and with the Parker Slate and the Rockledge Formation. The Rugg Brook Formation is found entirely to the south of the Missisquoi River, south of the platform facies of the Saxe Brook Dolomite. In the Milton area, Stone and Dennis (1964) described the Rugg Brook Formation as outcropping in the basin to the north of the Winooski Dolomite. Shaw (1958) found no fauna in the Rugg Brook in the St. Albans region, but assigned it to the Middle Cambrian on the basis of its stratigraphic position between the Parker and

St. Albans Slates. This study expands the definition of the Rugg Brook Formation, extending this unit up into the Rockledge Formation. It is suggested that the Rugg Brook Formation, as the name is used in this study, represents a mappable group of rocks and is not a time-stratigraphic unit. The base of the Rugg Brook Formation in this study is probably late Middle Cambrian, on the basis of its interbedding with the Parker Slate. The top of the unit, as it is defined in this study, extends up into the Rockledge Formation, which would make it early Upper Cambrian (Dresbachian, Shaw, 1958) in age.

Rockledge Formation (Ɛrlm, Ɛrls, Ɛrlsh)

The Rockledge Formation is an easily recognizable unit of limestone clast conglomerates that run in a relatively continuous narrow north-south outcrop belt in the middle of the study area. Shaw (1958) described the unit as being composed of sandstone beds which grade up into limestone conglomerates in a sandy-carbonate matrix. The Rockledge is also characterized by "biohermal fragments" of recrystallized limestone up to 100 feet in length (1958, p.542). In this study the Rockledge Formation has been subdivided into three facies: 1) massive, structureless micrite beds (Ɛrlm); 2) sandy-matrix, limestone clast conglomerates (Ɛrls), and 3) shaley-matrix, limestone clast conglomerate (Ɛrlsh). A study of the distribution of these facies in a portion of the study area was made by Hillman (1985), who was able to recognize an organized pattern to the interbedding of the facies which he interpreted to represent variations in the mechanics of sediment gravity flow deposition.

This study documented that the dolomite conglomerates of the Rugg Brook Formation laterally interfinger with the limestone conglomerates of the Rockledge Formation (see Plate 2, Fig.1, C2 & 3). This suggests that, as defined here, the two units are at least in part, coeval. It also suggests that although the first appearance of limestone clasts in the Eastern Basinal Sequence may be easily recognizable, it may also just represent a diagenetic horizon and its value as a stratigraphic marker is questionable.

The Rockledge Formation was assigned a Dresbachian age by Shaw (1958), and a refined early Dresbachian age by Palmer (1970). In the study area the unit can be seen to lie immediately below the Gorge Formation, the base of which was assigned a late Dresbachian age by Palmer.

Skeels Corners Formation (Є-Osk)

The Skeels Corners Formation is recognized as the slate unit that immediately overlies the Rocklege Formation. It is in gradational contact with the underlying Parker and with the overlying Morses Line Slate. The Skeels Corners can be differentiated from the Parker Slate because it is less arenaceous, consisting instead of black, calcareous shale containing parallel laminae of limonitic quartz silt and dolomite. Cross laminae are present, but rare. The slate beds exhibiting both the parallel and cross laminated horizons are interpreted as distal turbidites (Bouma divisions Bd and Bc, respectively). The Skeels Corners Formation can be distinguished from the overlying Morses Line Slate based on the less calcareous nature of the Morses Line and fewer laminae of limonitic quartz silt and dolomite.

Dorsey, et al. (1983) redefined the stratigraphy of the Skeels Corners Formation, recognizing that this unit depositionally overlies both the Dunham Dolomite (lower Middle Cambrian) and Clarendon Springs Dolomite (Cambro-Ordovician) in different parts of the Milton region. This interpretation differs from that of Shaw (1958) who first assigned a Cedaria Zone (Middle Cambrian) age to the unit, and later revised this to Late Cambrian (Dresbachian) in age. In his stratigraphic revision of the Cambrian trilobite zonations of the northern Appalachians, Palmer (1970) recognized a late Middle Cambrian to early Upper Cambrian fauna from the Skeels Corners. The discrepancy between observed stratigraphic relationships seen by Dorsey and her coworkers, and the trilobite data of Shaw and Palmer could be due to several factors. One of these would be possible age diachroneity of the Skeels Corners from the Milton region (Dorsey, et al., 1983) and the St. Albans region studied by Shaw and Palmer. A second possible explanation, and the one favored here, is that trilobites were recovered from a narrow stratigraphic interval in the Skeels Corners Formation in the St. Albans region. Thus, it is likely that in the larger Milton-St. Albans region, the Skeels Corners has an age range from lower

Middle Cambrian to Lowermost Ordovician. In the present study area, however, it has a more restricted age of late Dresbachian to early *Symphysurina* zone (Upper Cambrian to Lower Ordovician).

Highgate Formation (Ohg)

Landing (1984) reviewed the nomenclatural history of the Highgate Formation and redefined the unit as the basal Lower Ordovician formation overlying the Upper Cambrian-Lowermost Ordovician Gorge Formation. He described it as exhibiting a variety of lithofacies, including coarse-grained limestone (intraclast packstone), mudstone with floating limestone pebbles, dolomite clast conglomerate in sandy dolomite matrix, and parallel laminated mudstones. Landing interpreted these lithologies as representing distal carbonate slope deposits. The Highgate Formation is spectacularly exposed in Highgate Gorge on the Missisquoi River (Plate 1, Fig. 1, C7: Plate 2, Fig. 1, D6). The Highgate Formation was dated by Landing as Tremadocian in age. This study recognizes that conformable contacts exist between the Highgate Formation and the underlying Clarendon Springs and Gorge Formations, and that this contact represents a rapid shelf to basin transition.

Morses Line Slate (Om)

The Morses Line Slate is poorly exposed in the eastern portion of the study area where it occupies the core of the St. Albans Synclinorium. The Morses Line Slate is a non-calcareous, black slate, commonly containing laminae of quartz silt which produce a faint "pinstripe" pattern. Occuring within the Morses Line Slate are outcrops of limestone breccia and associated quartzose sandstone horizons as well as structureless micrite beds, all of which are assignable to the Rockledge Formation (Plate 2, Fig.1, E3). The limestone breccia horizons were previously attributed to the Corliss Conglomerate, a member within the Morses Line Slate, but they are lithologically identical to the Rockledge Formation, and are included within the Rockledge in this study.

The Morses Line Slate was dated by Shaw (1958) as Lower Ordovician (Canadian) in age, based on identification of fossils within clasts in the limestone breccia. These breccias are included within the Rockledge Formation, suggesting that the sediment gravity flows composing the Rockledge Formation continued into the Lower Ordovician and span an Upper Cambrian to Lower Ordovician age. The Morses Line Slate represents the basinal muddy matrix into which the flows were emplaced, and is assumed to also be Lower Ordovician in age.

INTERPRETATION

The significance of lateral facies changes that occur in Lower Paleozoic rocks of northwestern Vermont has already been recognized by earlier workers. Most notably, Shaw (1958) realized that the shallow water facies in the Burlington region pinch out to the north and are replaced by deeper water shales and breccias. He termed the basin defined by this facies change the Franklin Basin, in recognition of Franklin County, Vermont, in which the basin is located. In this report the Franklin Basin is renamed the St. Albans Reentrant. The term reentrant aptly describes the horseshoe-shape of the basin in map view and reflects its relationship to larger-scale reentrants and promontories along the continental margin (Thomas, 1977). Shaw postulated that the abrupt facies change from platform to basin was generated by a sedimentologic pinchout of shallow water deposits against a structural arch that he termed the Milton High. Subsequent work by Dorsey, and others (1983) and Mehrtens (1985) has documented that the abrupt facies change in the Milton region is due to a localized shelf margin-to-basin transition in this region, a concept first proposed by Rodgers (1968). Facies associated with the shelf margin are characteristic of a vertically aggrading platform (Figure 2), in which platform facies do not prograde into the adjacent basin, nor do basinal sediments drown the platform. This stationary, localized shelf margin accreted on the edge of the carbonate platform in the Burlington and the Highgate areas, and was bordered by a down-dropped block, or series of blocks, which formed the St. Albans Reentrant.

A schematic diagram illustrating the evolution of a portion of the carbonate platform through the Cambrian and Ordovician is shown in Figure 3. In Figure 3A the platform is shown broken up into a series of blocks inherited from older rift terrain. Similar lithofacies were being deposited along the platform (Lower Cambrian Cheshire and Dunham Formations). This reconstruction is based on the distribution patterns of Lower Cambrian

Figure 2. Schematic diagram after Read (1985) illustrating the evolution of the carbonate platform morphology through the Cambro-Ordovician. The Dunham Dolomite records vertical aggradation through the accumulation of prograding shallowing-up cycles on the platform interior, with a shelf margin rimmed by sand shoals. The contact between the Dunham Dolomite and the basinal deposits is very sharp, with shelf margin talus passing abruptly into turbiditic shales. This indicates that a shelf morpohology existed (sharp gradient change). Continued vertical upbuilding throughout the remainder of the Cambrian is evidenced by the localization of the shelf margin as carbonate and siliciclastic sediments were deposited on the platform interior. The shelf to basin transition in Monkton through Clarendon Springs time is characterized by abrupt facies changes from platform talus to turbiditic shales, indicating that the platform margin was a bypass type. The carbonate platform ultimately drowned as platform margin talus and basinal shales mantle the shelf in Lower Ordovician time. Vertical aggradation on the platform commenced again during the Ordovician (example, Chazy reefs).

EVOLUTION OF THE CAMBRO-ORDOVICIAN RIMMED SHELF IN WESTERN VERMONT

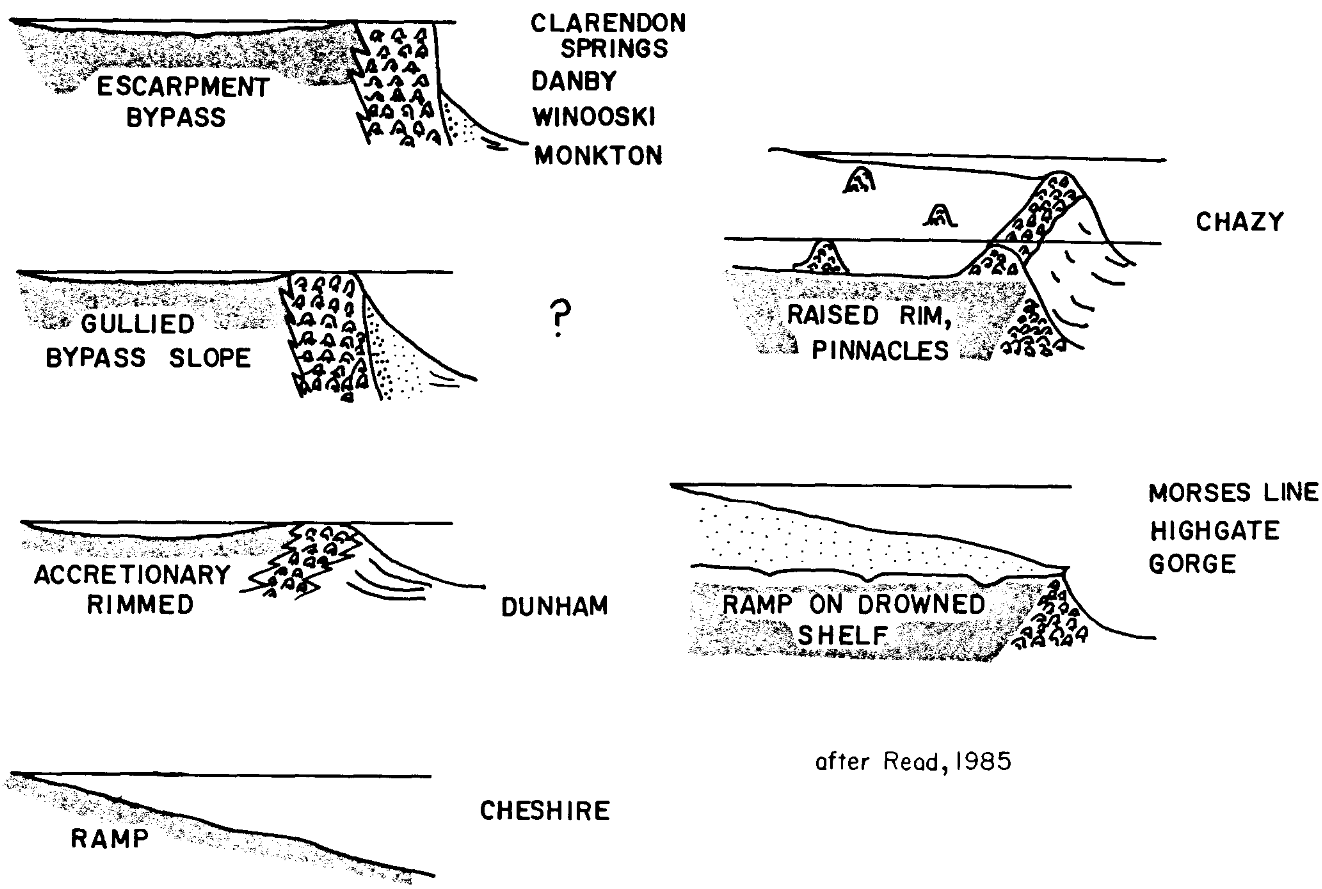
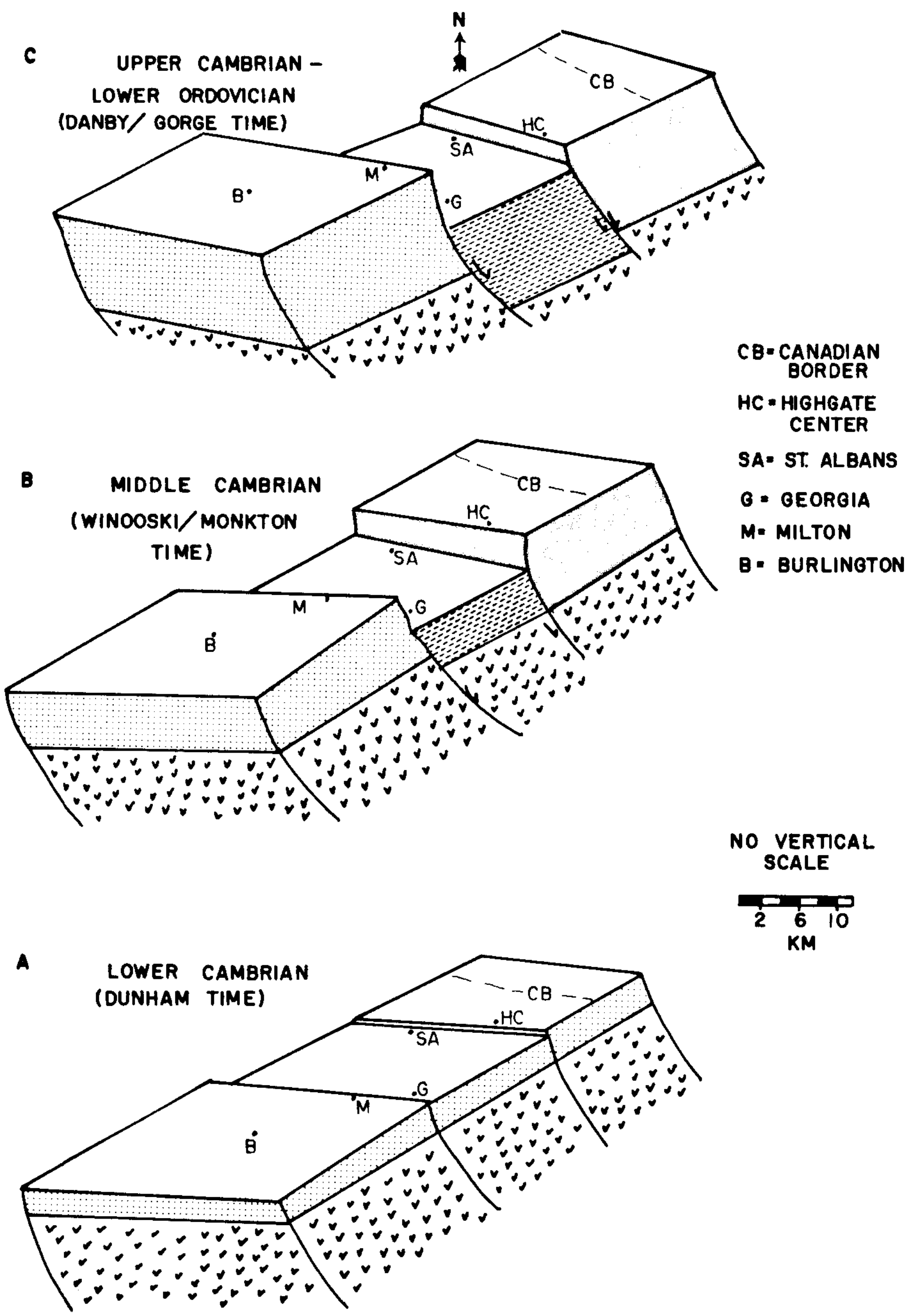


Figure 2

Figure 3. A schematic diagram illustrating a hypothetical sequence of events which could have generated the geometry of the Cambro-Ordovician platform in northwestern Vermont. In Lower Cambrian time (Fig. 3A) the entire platform was mantled by the Dunham Dolomite, suggesting that localized bathymetric differenced had not yet developed. By Middle Cambrian time (Fig. 3B) platform margin facies in the Milton to Highgate Center region indicate that the St. Albans Reentrant had developed. Different rock units were being formed to the north and south of this basin. By the Upper Cambrian to Lower Ordovician, bathymetric differences were pronounced, with continued shallow water sedimentation in the south, basinal sedimentation in the Reentrant, and deeper-water platform margin and basinal sedimentation in the north.

SCHEMATIC DIAGRAM ILLUSTRATING THE EVOLUTION OF A PORTION OF THE CAMBRO-ORDOVICIAN PLATFORM IN NORTHWESTERN VERMONT



units across the entire region. In Figure 3B the platform is shown broken into three regions, a southern block from Milton south, a central block (Milton north to Highgate Center) and a northern block (Highgate Center north towards the Canadian border). This geometry resulted in the accumulation of different stratigraphic sequences on each block: platform carbonates and siliciclastic sediments to the north and south with a shale basin between. The breakup of the platform to this configuration must have occured following deposition of the widespread Lower Cambrian Dunham Dolomite. The platform sediments in the Milton-Burlington region (Middle Cambrian Monkton and Winooski Formations) are distinct from those which accumulated to the north (Middle Cambrian Saxe Brook and Clarendon Springs Dolomites), indicating that the intervening shale basin prevented distribution of platform sediments from south to north, parallel to depositional strike. Earlier workers failed to recognize the significance of the facies changes in the Highgate region which define the northern margin of the St. Albans Reentrant described in this study. In the vicinity of Highgate Center the Dunham, Saxe Brook and Clarendon Springs Dolomites of the Western Shelf Sequence lie to the north of the time-equivalent Parker Slate, Rugg Brook and Rockledge Formations, belonging to the Eastern Basinal Sequence. Thus the shelf margin is located somewhere between exposures of the platform deposits north of the Missisquoi River and basinal deposits south of the river. Figure 3C illustrates the geometry of the platform in Upper Cambrian-Lower Ordovician time, when bathymetric differences between blocks was greatest. Shallow water carbonate and siliciclastic lithofacies continued to be deposited in the Milton-Burlington region, shales and breccias accumulated in the deeper water basin, and the northern block foundered, ending shallow water platform sedimentation in this region as the platform margin retreated northward. In the Highgate region, the Clarendon Springs-Gorge-Highgate stratigraphic sequence records the onlap of the platform with basinal shales, recording the shifting of the shelf-to-shelf margin transition northward. Platform drowning continued in Late Cambrian-Early Ordovician time (=Gorge to Morses Line), as the shelf margin facies of the Gorge Formation records a facies change from proximal talus (north of the village of Highgate Center) to the more distal debris (Missisquoi River gorge). The Gorge Formation is subsequently overlain by the shales of the Highgate Formation and Morses Line Slate, indicating that the drowning of the platform continued into Lower Ordovician time. The history of the platform within this study area records vertical aggradation from Dunham through early Clarendon Springs time with subsequent drowning in the early Ordovician (Figure 3).

As mentioned earlier, the stratigraphy of the St. Albans and Highgate portions of the platform differ from that which is recorded further to the south in the Burlington area (Figure 3). In this latter region, lithofacies recording supratidal, intertidal and shallow subtidal environments are recognized. Lithofacies characteristic of the shelf margin and basinal environments are not found. The differences between these areas is interpreted to represent localized foundering of the northern portion of the platform in the St. Albans and Highgate area (along inherited rift block faults?) and is not the result of shelf-wide subsidence.

The stratigraphy and sedimentology of the Eastern Basinal Sequence can also shed some light on the sea level history of the platform. It could be assumed that the conglomerate and breccia horizons found within the basinal shales are emplaced during periods of major sea level fall and resulting platform erosion. Sea level history of the platform can also be deduced by analysis of the continuity of trilobite zonations within the basinal shales. Palmer and James (1980) recognized such a hiatus within the Parker Slate which they attributed to a major regression during the lower Middle Cambrian (Hawke Bay Event). Palmer and James suggested that the Hawke Bay Event was a regional regression which corresponded to the deposition of the Monkton Quartzite in Vermont and the Hawke Bay Sandstone in western Newfoundland.

Outcrop patterns suggest that conglomerate horizons are stratigraphically distributed from above the Dunham Dolomite continuously up through the Gorge Formation (Plate 2, Fig. 1). They are not confined to any one horizon or horizons that would suggest an origin related to isolated regressive events (sea level falls, for example) on the adjacent platform. Inspection of the chronostratigraphic relationships between units

(Plate 2, Fig. 3) also confirms this observation. A case could be made, however, that the **bulk** of conglomerate sedimentation was associated with two intervals: 1) Middle Cambrian Saxe Brook and Rugg Brook deposition in the shelf and basin, respectively; and 2) Late Cambrian and Early Ordovician Clarendon Springs, Gorge and Skeels Corners Formations. However, this interpretation is strongly dependent on existing estimates of the age of the platform units, which in the case of the Saxe Brook Dolomite, is still ambiguous. If, as the map patterns suggest, influx of conglomerates in the St. Albans Reentrant was relatively continuous during Middle and Late Cambrian time, it provides evidence against the concepts that: 1) major regressive events were responsible for stratigraphic changes on the platform, and 2) major regressive events on the platform were necessary to generate the conglomerate and breccia horizons. If, however, the age determination of the Saxe Brook Dolomite is incorrect and the unit spans a longer time interval than is currently estimated, it is possible that more of the conglomerate horizons in the basin are associated with contemporaneous and post-Saxe Brook deposition. The youngest breccias (Rockledge Fm.) could be considered basinal equivalents of Clarendon Springs/Gorge Formation deposition, effectively limiting major conglomerate sedimentation to two intervals in time. A constraint on potential source areas for the conglomerates and breccias is provided by their composition. A mixture of both quartzite and carbonate clasts and an association with quartzite horizons indicates that both the Rugg Brook and Rockledge Formations were derived from a mixed siliciclastic/carbonate source on the platform. On the northern margin of the St. Albans Reentrant the only mixed unit is the Saxe Brook Dolomite. To the south the Monkton and Danby Quartzites are mixed siliciclastic and carbonate deposits.

Even if two eustatic sea level drops can be distinguished from the basinal stratigraphy, there should be some record of these events elsewhere along the Cambro-Ordovician platform as well. Analysis of the Cambrian stratigraphy in the Burlington area suggests that contacts between units (Monkton/Winooski and Winooski/Danby Formations) are all conformable and gradational (Mehrtens, et al., 1983; Mehrtens, 1985), and show no evidence of eustatic sea level fall. Rather, it appears that the periodic influx of siliciclastic sediment (represented by the Monkton and Danby Formations) generated prograding facies on the platform and probably was a source for sand in the basin, but would not have provided a mechanism for initiating debris flow sedimentation in the basin.

Analysis of the distribution of dolomite and limestone horizons within the basinal shales indicates that the two lithologies are interbedded with one another and show no unique stratigraphic distribution. This suggests that the Rugg Brook and Rockledge Formations are genetically similar and that the present map distribution reflects dolomitization patterns.

STRUCTURE

Because of its position well within the Quebec Reentrant, deformation in the St. Albans Reentrant is minimal. All the rock units within the study area lie on the upper plate of the Champlain Thrust, and on the west limb of the St. Albans Synclinorium. Two small-scale tight anticlines are present (Plate 2, Fig.1), but in general beds dip gently and uniformly to the east. This study reinterprets the extent of the Highgate ~~Springs~~ Falls Thrust (Plate 1, Fig.1,C 7 & 8); maximum displacement on it occurs within the Highgate Formation in Highgate Gorge, decreasing and dying out into the shales of the Highgate Formation to the north and south. Maximum displacement on the fault is inferred to be a minor amount because similar facies occur above and below the fault at Highgate Gorge, in rocks representing an environment known for rapid lateral facies changes.

REGIONAL SYNTHESIS AND SUMMARY

Significant findings of this study include: 1) the stratigraphy of the Woods Corners Group of Shaw (1958) has been redefined, with several rock units abandoned and other redescribed; 2) lateral facies changes are recognized between the Rugg Brook Formation and Rockledge Conglomerates; 3) a major lateral transition from platform to basin facies occurs from Highgate Center southward across the Missisquoi River into the St. Albans area; 4) the sea level history of the northern platform is different from the Burlington region to the south; 5) the St. Albans Reentrant originated following deposition of the Dunham Dolomite, because the Dunham extends across what later became the basin; 6) the St. Albans Reentrant apparently was receiving conglomerate and breccia flows continuously throughout Middle to Upper Cambrian time.

Because of these findings and earlier published works (Dorsey, et al., 1983; Mehrtens, 1985), it is possible to summarize the paleogeography of the Cambro-Ordovician platform in northwestern Vermont in some detail. The platform can be characterized as a broad, flat-topped, low gradient shelf dissected in the St. Albans region by an intrashelf basin in which shale and platform-derived breccias were being deposited. The shelf also passed eastward into a deep shale basin, and this shelf to basin transition is noted by the absence of significant breccia horizons, suggesting that it is a bypass margin (Read, 1985). Regardless of siliciclastic or carbonate composition, all platform deposits appear to record similar facies: supratidal to shallow subtidal in the platform interior, and platform margins characterized by carbonate or siliciclastic shoal deposits and proximal talus slope breccias. Significant lateral migration of facies between rock units is not seen, suggesting that sedimentation on the platform was continuous and able to keep pace with subsidence: no evidence for major eustatic sea level drops is present. The different stratigraphies on the platform south of St. Albans and north of the Missisquoi River indicates that significant south-to-north, parallel to strike facies changes existed. In northwestern

Vermont, three regions of the platform can be recognized (Burlington, Milton to Highgate Center, Highgate Center north), each with a separate depo-tectonic history and resulting stratigraphy.

Within the St. Albans Reentrant, poor biostratigraphic control in the breccia and conglomerate horizons prevents us from choosing whether there was continuous debris flow sedimentation through the Middle and Late Cambrian, or two primary pulses of deposition corresponding to Saxe Brook Dolomite (early Middle Cambrian) and Clarendon SpringsDolomite/Gorge Formation (Cambro-Ordovician) time.

References

Ahr, W., 1973, The carbonate ramp-an alternative to the shelf model. Gulf Coast Assoc. of Geol. Soc. Trans., vol. 23, p. 221-225.

Dorsey, R., P. Agnew, C. Carter, E. Rosencrantz, R. Stanley, 1983, Bedrock geology of the Milton Quadrangle, northwestern Vermont, Vt. Geol. Surv. Sp. Bull. no. 3.

Gregory, G., 1982, Paleoenvironments of the Lower Cambrian Dunham Dolomite, northwestern Vermont, unpub. M.S. Thesis, Univ. of Vermont, 91p.

Gregory, G. and C. Mehrtens, 1983, Paleoenvironmental reconstruction of the Dunham Dolomite (Lower Cambrian) in northwestern Vermont, Geol. Soc. Am. Abstr. With Prog., vol. 15, p. 129.

Hillman, D., 1985, The Rockledge Formation: a possible carbonate slope deposit. unpub. Honors Thesis, Univ. of Vermont, 45p.

Landing, E., 198~~4~~3, Highgate Gorge: Upper Cambrian and Lower Ordovician continental slope deposition and biostratigraphy, northwestern Vermont, Jour. Paleo. vol. 57, p. 1149-1187.

Lowe, D., 1982, Sediment gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents. Jour. Sed. Pet., vol. 52, p. 279-297.

Mehrtens, C., 1985, The Cambrian platform in northwestern Vermont. Vt. Geol.,, vol. 4, p. E1-E21.

Mehrtens, C., P. Myrow, G. Gregory, 1983, Cyclic sicliciclastic and carbonate sedimentation in the Lower Cambrian of northwestern Vermont, Geol. Soc. Am. Abstr. with Prog., vol. 15, p. 201.

Mehrtens, C. and G. Gregory, 1984, An occurence of Salterella conulata in the Dunham Dolomite (Lower Cambrian) and its stratigraphic significance. Jour. Paleo., vol. 58, p. 1143-1150.

Palmer, A., 1970, The Cambrian of the Appalachians and eastern New England regions, eastern U.S., in, The Cambrian of the New World, C. Holland, ed., p. 169-217.

Palmer, A. and N. James, 1980, The Hawke Bay Event: a circum-Iapetus regression near the Lower Middle Cambrian boundary, in, Wones, D., ed., the Caledonides in the USA, Intern. Geol. Caledonides Proj, p. 15-18.

Pingree, R., 1982, Paleoenvironments of the Hungerford Slate and Gorge Formations in northwestern Vermont, unpub. M.S. Thesis, Univ. of Vermont, 90p.

Read, J., 1985, Carbonate platform facies models, Am. Assoc.

Petrol. Geol., vol. 69, p.1-21.

Rodgers, J., 1968, The eastern edge of the North American continent during the Cambrian and early Ordovician, in, Zen, E-An, W. White, J. Hadley, J. Thompson, eds., Studies in Appalachian Geology, northern and maritime, Wiley Interscience, p. 141-149.

Schuchert, C., 1933, Cambrian and Ordovician stratigraphy of northwestern Vermont, AM. Jour. Sci. vol. 25, p. 353-381.

Schuchert, C., 1937, Cambrian and Ordovician of northwestern Vermont, Geol. Soc. Am. Bull., vol. 48, p. 1001-1078.

Shaw, A., 1958, Stratigraphy and structure of the St. Albans area, northwestern Vermont, Geol. Soc. Am. Bull., vol. 69,p. 519-567.

Stone, S. and J. Dennis, 1964, The Geology of the Milton Quadrangle, Vermont, Vt. Geol. Surv. Bull. 26.

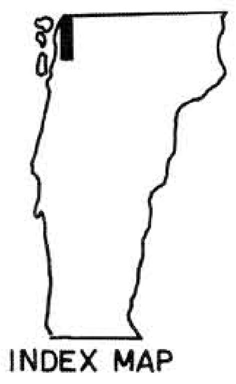
Thomas, W., 1977, Evolution of Appalachian-Ouachita salients and recesses from reentrants and promontories in the continental margin, Am. Jour. Sci., vol. 277, p. 1233-1278.

Walcott, C.D., 1886, Second contribution to the studies on the Cambrian faunas of North America, Bull. U.S. Geol.Surv. no. 30.

Walcott, C.D., 1891, Correlation papers-Cambrian. Bull. U.S. Geol.Surv., no. 81.

Wilson, J., 1975, Carbonate facies in geologic history, Springer-Verlag, New York, 471pp.

PLATE 1



INDEX MAP

EXPLANATION

Platform

- O-Єcs Clarendon Springs Dolomite
- Єsb Saxe Brook Dolomite
- Єdu Dunham Dolomite

Basin

- Oml Morses Line Slate
- Ohg Highgate Fm.
- Є-Og Gorge Fm.
- Є-Osk Skeels Corners Slate
- Єrl Rockledge Fm.
  - rlm massive micrite
  - rls sandy matrix cong.
  - rlsh shaley matrix cong.
- Єrb Rugg Brook Fm.
  - rbd massive dolomite
  - rbs sandy matrix cong.
  - rbsh shaley matrix cong
  - rbsc sandy clast cong.
  - rbq dolomitic qtzite
- Єp Parker Slate
  - pc cong.

LITHIC CONTACT (DASHED WHERE INFERRED)

THRUST FAULT, TEETH ON UPPER PLATE (DASHED WHERE INFERRED)

REPRESENTATIVE OUTCROP

PRESENT TOPOGRAPHY

BEDDING

CLEAVAGE

TRACE OF ANTICLINE

HST HIGHGATE SPRINGS THRUST

FIGURE 1

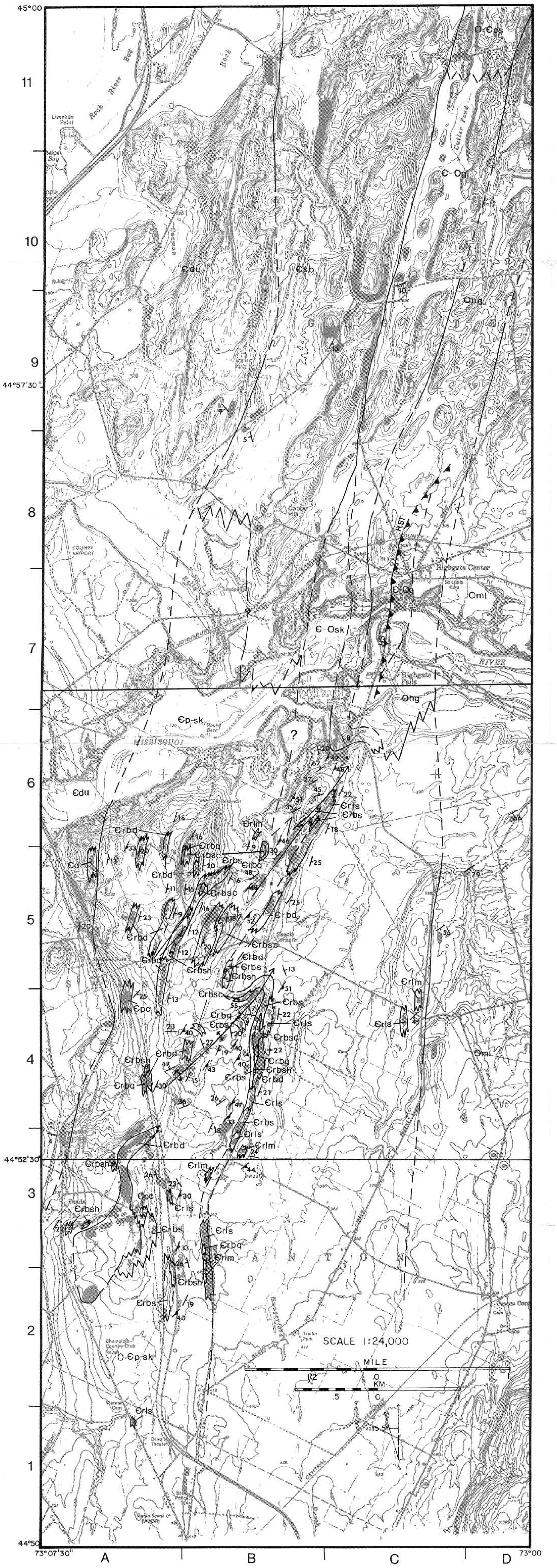
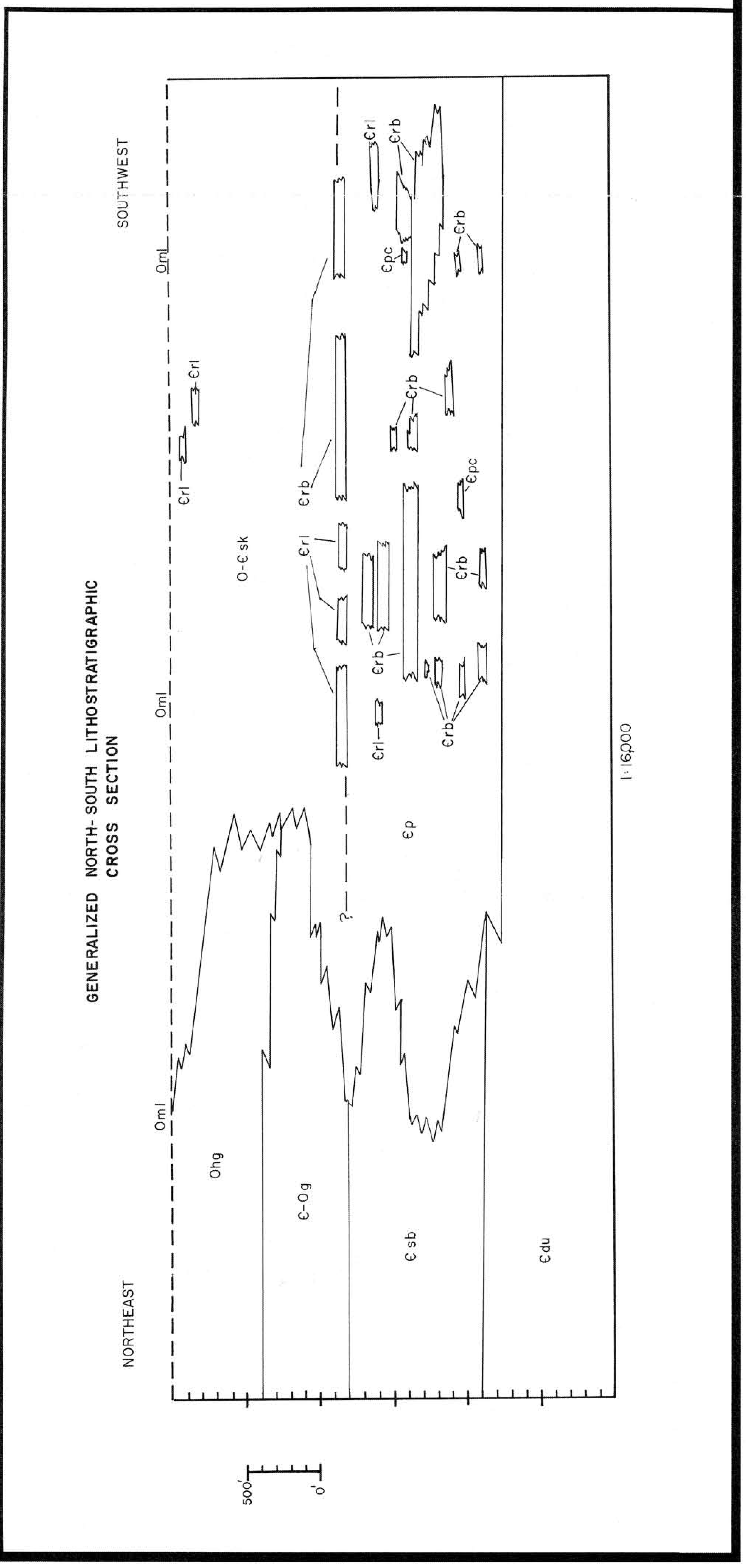


FIGURE 1

FIGURE 2



Mehrtens and Dorsey, 1987

PLATE 2

FIGURE 1

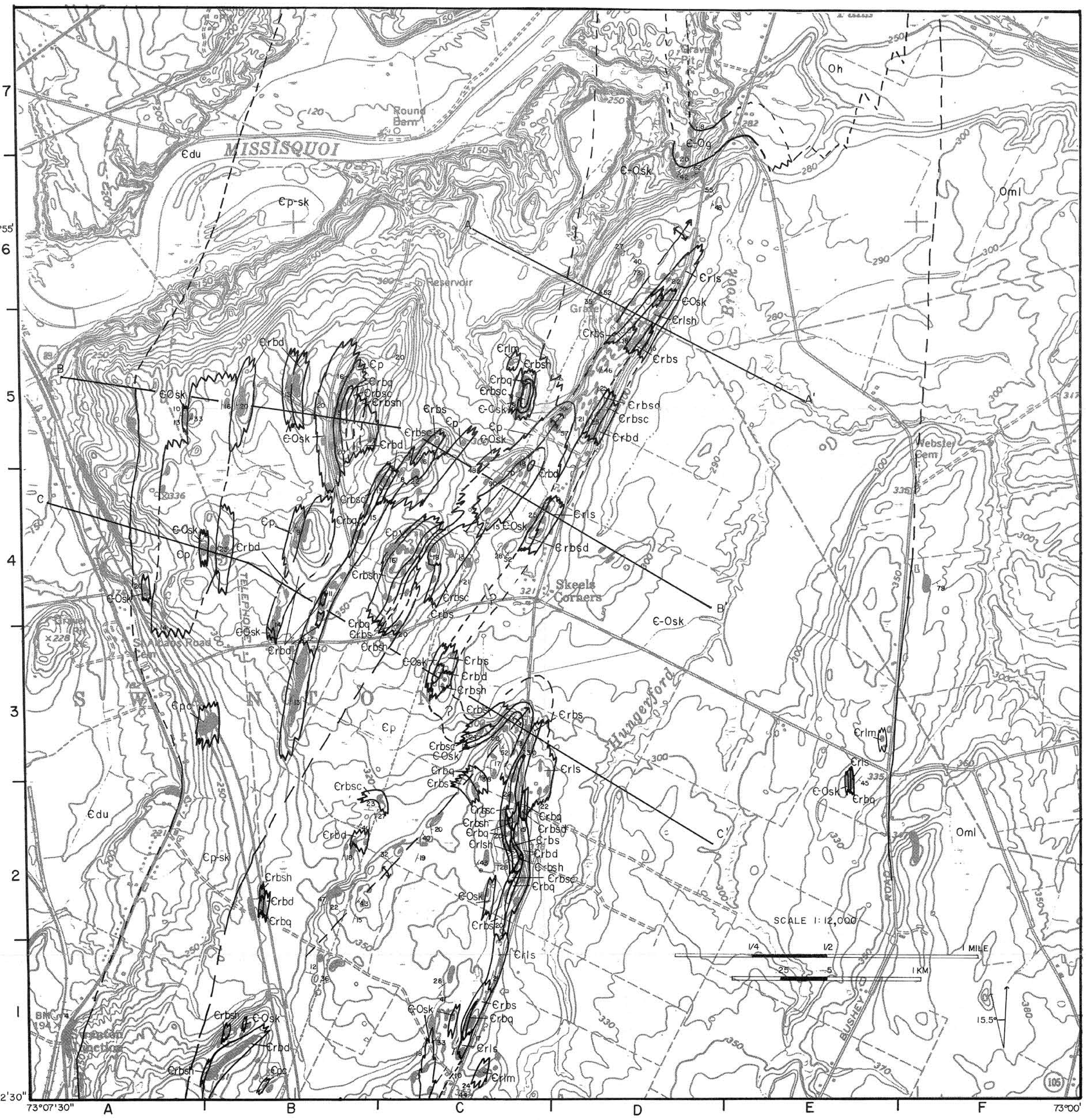
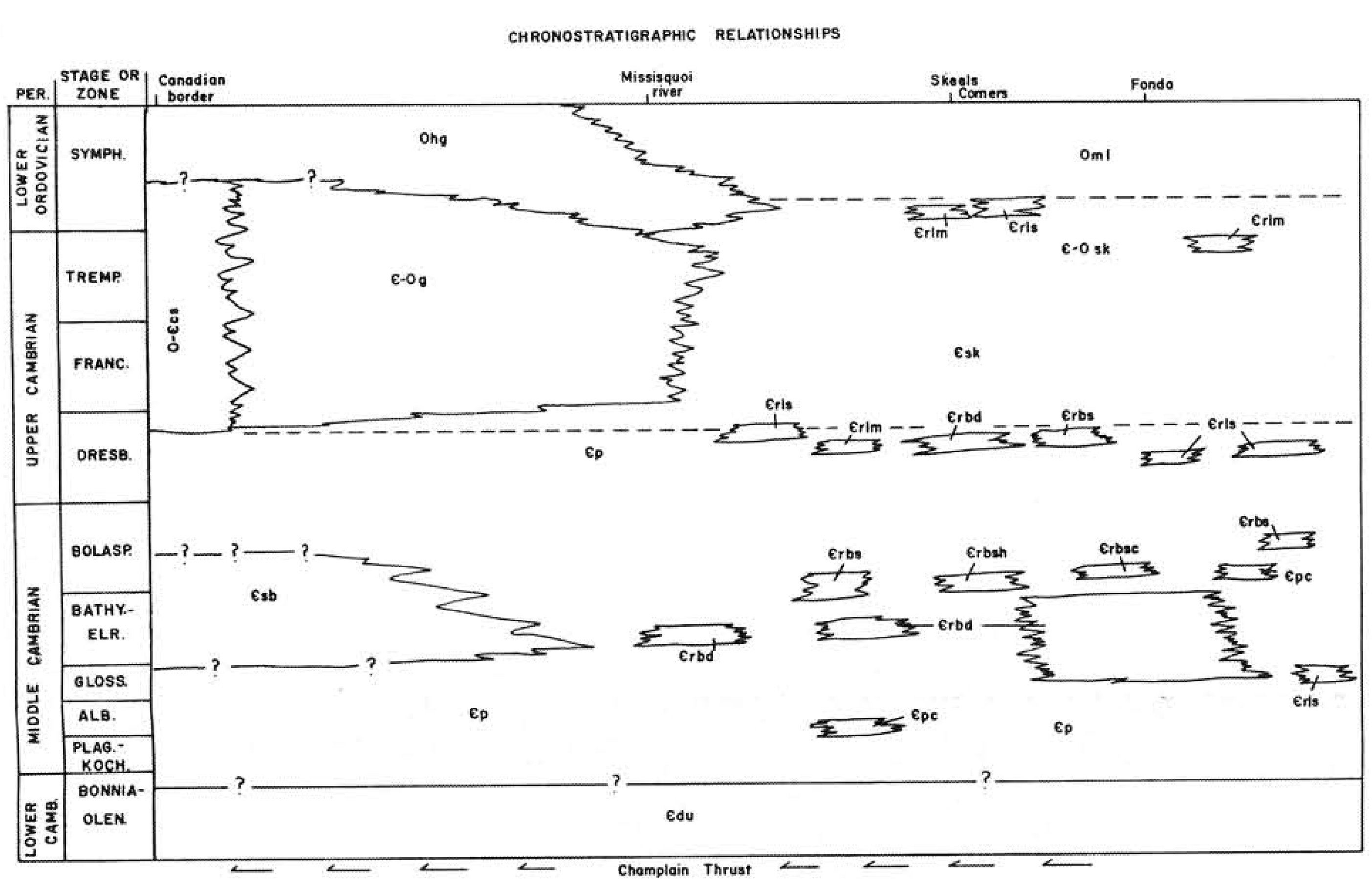


FIGURE 3



EXPLANATION

Platform		Basin	
		Oml	Morses Line Slate
		Ohg	Highgate Fm.
O-Ɛcs	Clarendon Springs Dolomite	Ɛ-Og	Gorge Fm.
		Ɛ-Osk	Skeels Corners Slate
		Ɛrl	Rockledge Fm.
		rlm	massive micrite
Ɛsb	Saxe Brook Dolomite	rls	sandy matrix cong.
		rlsh	shaley matrix cong.
		Ɛrb	Rugg Brook Fm.
		rbd	massive dolomite
		rbs	sandy matrix cong.
		rbsh	shaley matrix cong
		rbsc	sandy clast cong.
		rbq	dolomitic qtzite
Ɛdu	Dunham Dolomite	Ɛp	Parker Slate
		pc	cong.

- LITHIC CONTACT (DASHED WHERE INFERRED)
- THRUST FAULT, TEETH ON UPPER PLATE (DASHED WHERE INFERRED)
- REPRESENTATIVE OUTCROP
- PRESENT TOPOGRAPHY
- BEDDING
- CLEAVAGE
- TRACE OF ANTICLINE
- HST HIGHGATE SPRINGS THRUST

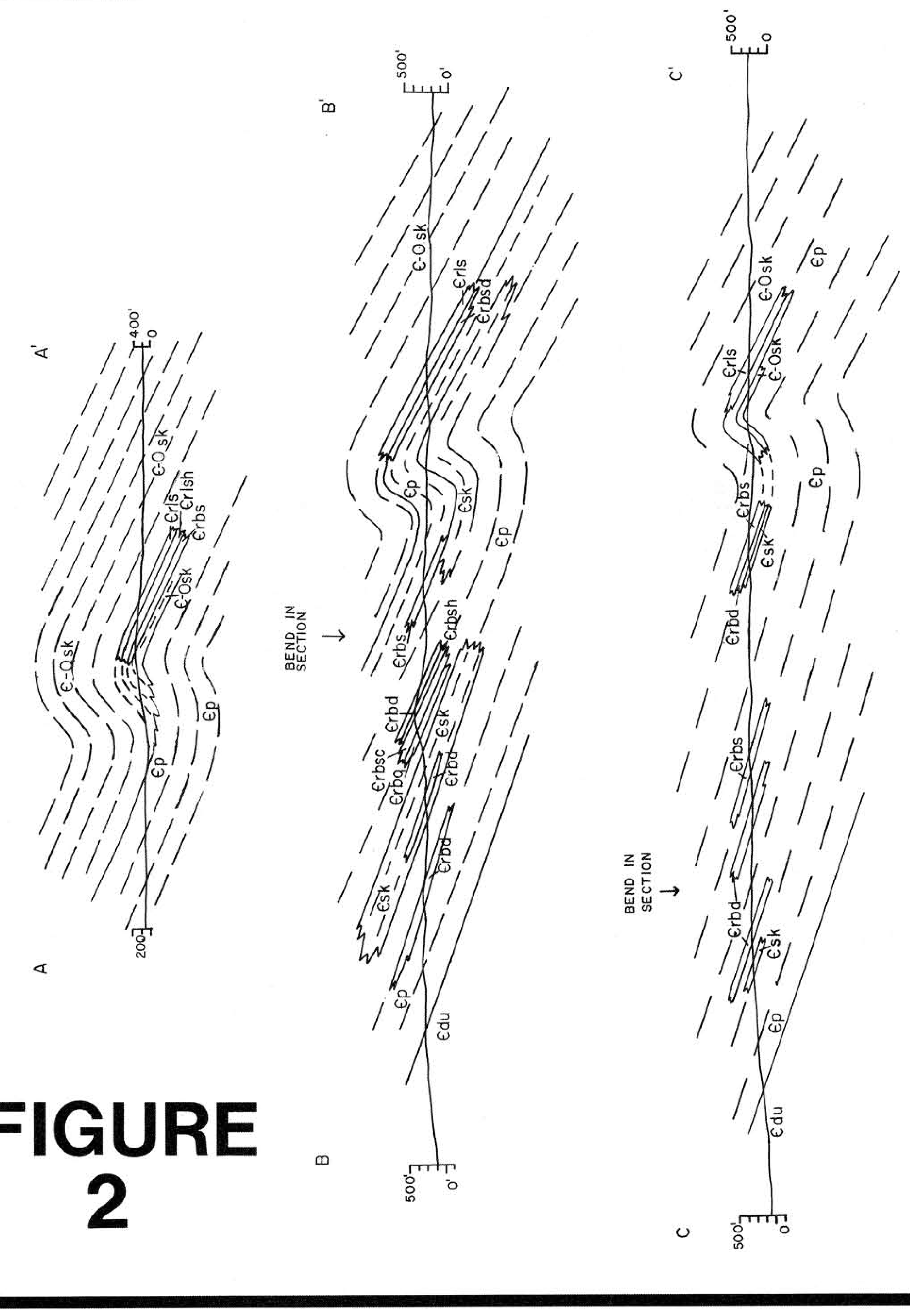


FIGURE 2