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Evolution of a Late Proterozoic Carbonate Ramp (Ymer Ø and Andrée Land Groups, Eleonore Bay Supergroup, East Greenland): Response to Relative Sea-Level Rise

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THEME 7: Problems of the Caledonian / Ellesmerian Junction

Summary: The up to circa 14.5 km thick Eleonore Bay Supergroup (Upper Proterozoic) forms a fundamental unit of the East Greenland Caledonides. The upper part consists of mixed carbonate and siliciclastic ramp sediments (Ymer Ø Group; circa 1200 m) and carbonate ramp sediments (Andrée Land Group; circa 1300 m thick). The Andrée Land Group is overlain by glacio-marine diamictites of the Varangian Tillite Group. The lower circa 1100 m of the Andrée Land Group include various types of intertidal and subtidal back ramp lagoonal stromatolites; shallow ramp oolitic/pisolitic shoal/barrier complex limestones and tidal channel dolomite breccias and conglomerates, and deep ramp limestone tempestite couplets. These deposits are overlain by a circa 200 m thick interval of shale and shaly limestone deposited in a deeper marine slope environment. The Ymer Ø and the Andrée Land Groups reflect an overall transgressive evolution from a mixed carbonate and siliciclastic ramp over a carbonate ramp to a drowned ramp. The evolution from a mixed carbonate and siliciclastic ramp to a carbonate ramp probably reflects submergence of siliciclastic source during relative sea-level rise. The sedimentary contact to the overlying glacio-marine diamictites of the Tillite Group is generally knife-sharp but may be transitional at some localities suggesting no major hiatus between the Andrée Land Group and the Tillite Group. It is thus proposed that the main control of carbonate platform drowning resulted from a rise in relative sea-level due to rapid pulses of tectonic subsidence combined with a climatically controlled environmental deterioration. The increase in tectonic subsidence governing carbonate ramp evolution reflects initial crustal extension prior to the opening of the Iapetus Ocean in late Proterozoic time.

INTRODUCTION

Carbonate ramps are defined by AHR (1973) as carbonate platforms having a low-gradient slope (slope angle <1°) which extends from the shoreline, or a platform surface, to the adjacent basin. A number of studies have demonstrated that the sedimentary evolution of ramps offers excellent opportunities to study the influence of tectonics and climate on sedimentary basins (e.g. READ 1980, HURST & SURLYK 1983, 1984, BEUKES 1987, BURCHETTE & WRIGHT 1992). Only minor sea-level fluctuations are needed to shift the shoreline several kilometres due to the low-gradient slope of carbonate ramps, and hence cause rapid and marked changes in the siliciclastic input, carbonate production and distribution of sedimentary subenvironments (e.g. GROTZINGER 1986).

The ramp deposits of this study are represented by the Sturtian Ymer Ø and Andrée Land Groups (Eleonore Bay Supergroup) which crop out in the East Greenland Caledonides in the central fjord zone between 71° 30' and 74° 40' N (Fig. 1). During Late Proterozoic time an extensive, uniform marine ramp area existed in East Greenland, either along the western margin of the Iapetus Ocean (e.g. HARLAND & GAYER 1972, SWETT & KNOLL 1989) or within ensialic basins formed during initial crustal extension prior to the opening of the Iapetus Ocean (e.g. WINCHESTER 1988, HARLAND et al. 1992). This study presents sedimentological data from an ungoing study of the ramp sequence, which was temporally drowned prior to the Varangian glaciation and opening of the Iapetus Ocean.

STRATIGRAPHIC SETTING

The up to circa 14.5 km thick Eleonore Bay Supergroup forms a fundamental unit of the East Greenland Caledonides (Fig. 2). The lower circa 12 km (Nathorst Land and Lyell Land Groups) mainly consist of siliciclastic shelf sediments (SMITH & ROBERTSON 1999, TIRSGAARD & SØNDERHOLM 1997). In addition, a circa 4 km thick succession of metasediments (Petermann Bjerg Group) correlating with the Nathorst Land Group is exposed in the area between the Inland Ice and the inner fjord zone (SMITH & ROBERTSON 1999) (Fig. 1). The upper circa 2.5 km consist of mixed carbonate and siliciclastic ramp sediments (Ymer Ø Group; *sensu* SØNDERHOLM & TIRSGAARD 1993 circa 1200 m thick) overlain by ramp carbonates (Andrée Land Group; *sensu* FREDERIKSEN & CRAIG 1998a circa 1300 m thick). The Andrée Land Group is overlain by glaciomarine diamictites of the Varangian Tillite Group (Fig. 2).

The age of the Ymer Ø Group is poorly constrained. Based on Oxygen isotopes, SCHIDLOWSKI et al. (1975) proposed an age between 750 and 800 Myr, minimum and maximum respec-

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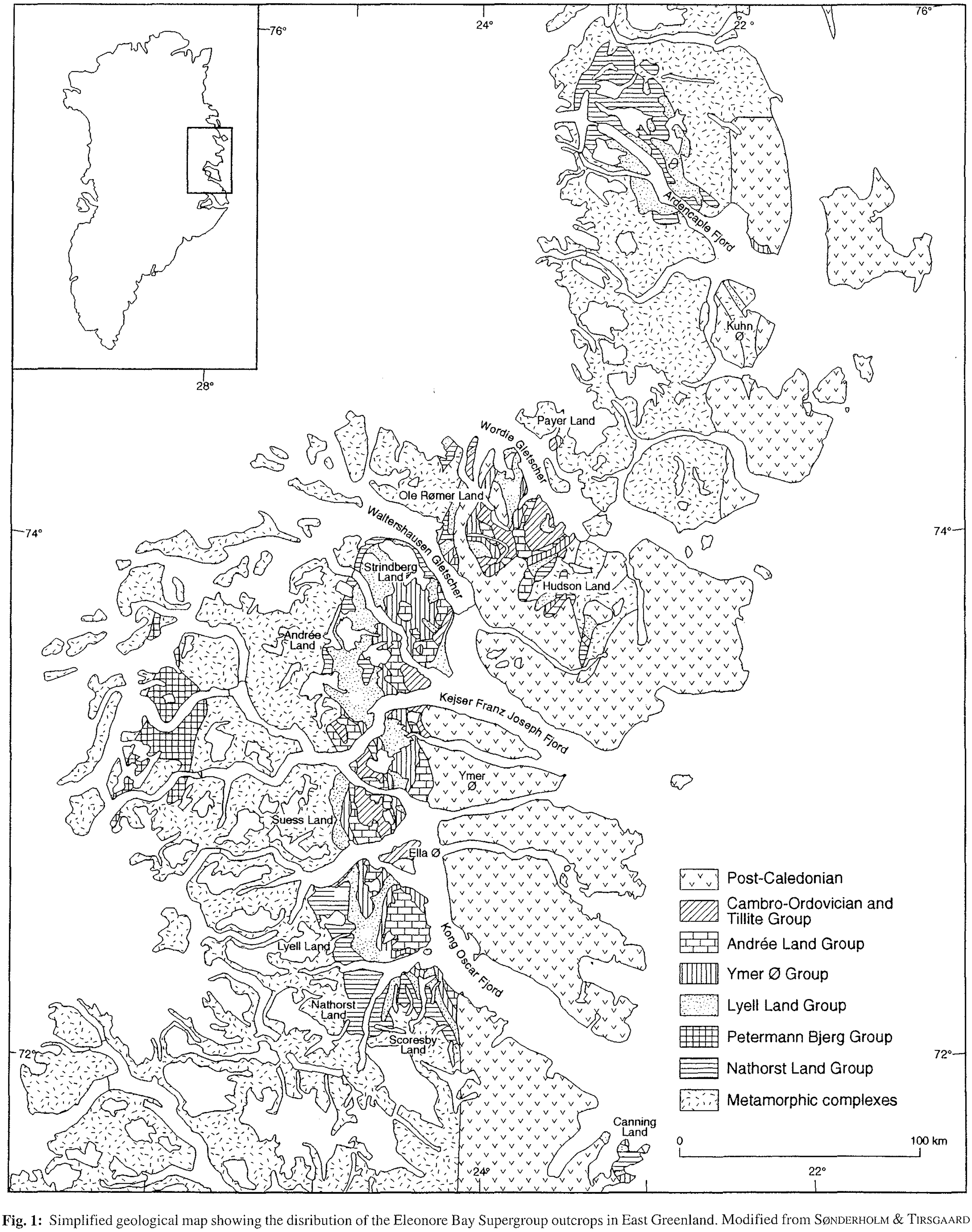

Fig. 1: Simplified geological map showing the disribution of the Eleonore Bay Supergroup outcrops in East Greenland. Modified from Sønderholm & Tirsgaard (1993).

tively of Antarctic Sund Formation, which occurs circa 280 m above the base of the group. The age of the Andrée Land Group is constrained upward by dating of the overlying Tillite Group as (Varangian) 610 Myr (Harland et al. 1989). This upper age seems consistent for the uppermost part of the Andrée Land Group, since no sedimentological data suggest a major hiatus between the two groups (Hambrey & Spencer 1987, Herrington & Fairchild 1989, Moncrieff 1989, Frederiksen & Craig 1998b).

DEPOSITIONAL SETTING

The Ymer Ø Group

The Ymer Ø Group is composed of six formations (Fig. 2). Sedimentological studies by Sønderholm et al. (1989) and Tirsgaard (1996) and by the present author during the field season 1998 show that the various carbonates and siliciclastic rocks from the upper part of the Ymer Ø Group (Skildvagten and Elisabeth Bjerg Formation) were deposited on a mixed carbonate and siliciclastic ramp. Characteristic deposits include domal, columnar and bulbous dolomitic biostromes in laterally continuous beds or dolomitic bioherms, various structureless, cross-bedded and wavy laminated limestones and dolomites, structureless siliciclastic conglomerates, and structureless, cross-bedded and wavy laminated sandstones.

The Andrée Land Group

The Andrée Land Group is composed of seven informal formations AL1-AL7 (Fig. 2). AL1-5 and AL7 are composed of limestones and dolomites reflecting deposition in various sedimentary sub-environments characteristic of carbonate ramps, whereas AL6 consists of various shales deposited on a slope.

Back ramp lagoon deposits

Various stromatolite-types including horizontally laminated, wavy laminated, domal, columnar and bulbous forms are cyclically arranged as biostromes in laterally continuous horizontal beds, 20-50 cm thick or as bioherms with heights up to circa 3.5 m and diametres up to circa 10 m. Stromatolitic mounds are usually separated by breccias with abundant stromaclast material or by shaly limestones. The geometry of the intermound breccias follows the palaeotopography of the stromatolitic mounds. Usually the spacing between mounds ranges from 1-5 m. The mounds are commonly elongated in the SW-NE direction.

The stromatolites are the product of successfull algal mat growth probably in lagoons more or less sheltered from the open sea. Tidally and probably storm-induced erosion of algal mat caused subsequent deposition of stromaclast breccias in tidal inlets located between the back ramp lagoon and the shoal/barrier complex.

Shallow ramp shoal / barrier complex deposits

Moderately to poorly sorted oolitic and pisolitic carbonates occur in beds up to circa 1 m thick. The ooids/pisoids are usually between 1-4 mm in diameter, but large pisoids up to 12 mm occur. Beds are structureless, normally or inversely graded, wavy laminated, or cross-bedded. Oolitic/pisolitic rocks are commonly interbedded with intraformational breccias up to circa 1 m thick. The breccias have angular clasts of fine-grained carbonate up to 20 cm in diameter. Many intraformational breccias are rich in ooids and pisoids. In outcrops with horizontal bedding surfaces exposed, 5-7 m longitudinal lenses rich in clasts and ooids and pisoids are orientated approximately N-S.

The presence of oolites, pisolites and breccias indicates deposition in a high energy environment. The deposits are interpreted as the product of aggradation of a shallow ramp shoal / barrier complex dominated by sediment transport in submarine channels across and accretional deposition on bars. The interpretation of the lenses as bars indicates palaeoflow approximately N-S. Much of the deposits derived their sediment during the stormal or tidal interchange with the algal mat-dominated inner back ramp lagoon.

Mid to outer ramp deposits

Couplets 40-50 cm thick of interbedded massive low-angle, cross-bedded or hummocky cross-bedded carbonate rocks and marly horizontally laminated carbonate rocks with wave ripples make up the main part of the Andrée Land Group. The contact between the two carbonate facies is usually sharp.

The couplets are interpreted as the product of storm deposition between fairweather wave base and storm wave base on the mid to outer ramp. During storms large volumes of sediment were transported from the shallow inner ramp to the deeper mid and outer ramp. During fairweather periods deposition of marly carbonate took place.

Ramp evolution

Numerous features characteristic of carbonate ramps are present in the sedimentary deposits. They include: incised tidal channel deposits, the presence of widespread cyclic inner back ramp lagoonal stromatolites, numerous different deposit types of wave-agitated structures, absence of deposits indicating a significant slope break, and region-wide distribution of sub-environments. The sedimentary evidence therefore suggest the presence of a carbonate ramp rather than a rimmed shelf. The northward decrease of stromatolites and siliciclastic material of aeolian origin in the carbonates, N-S orientation of tidal channel bars, and SW-NE orientation of bioherms suggest that deposition took place on a broad and gently northward dipping ramp.

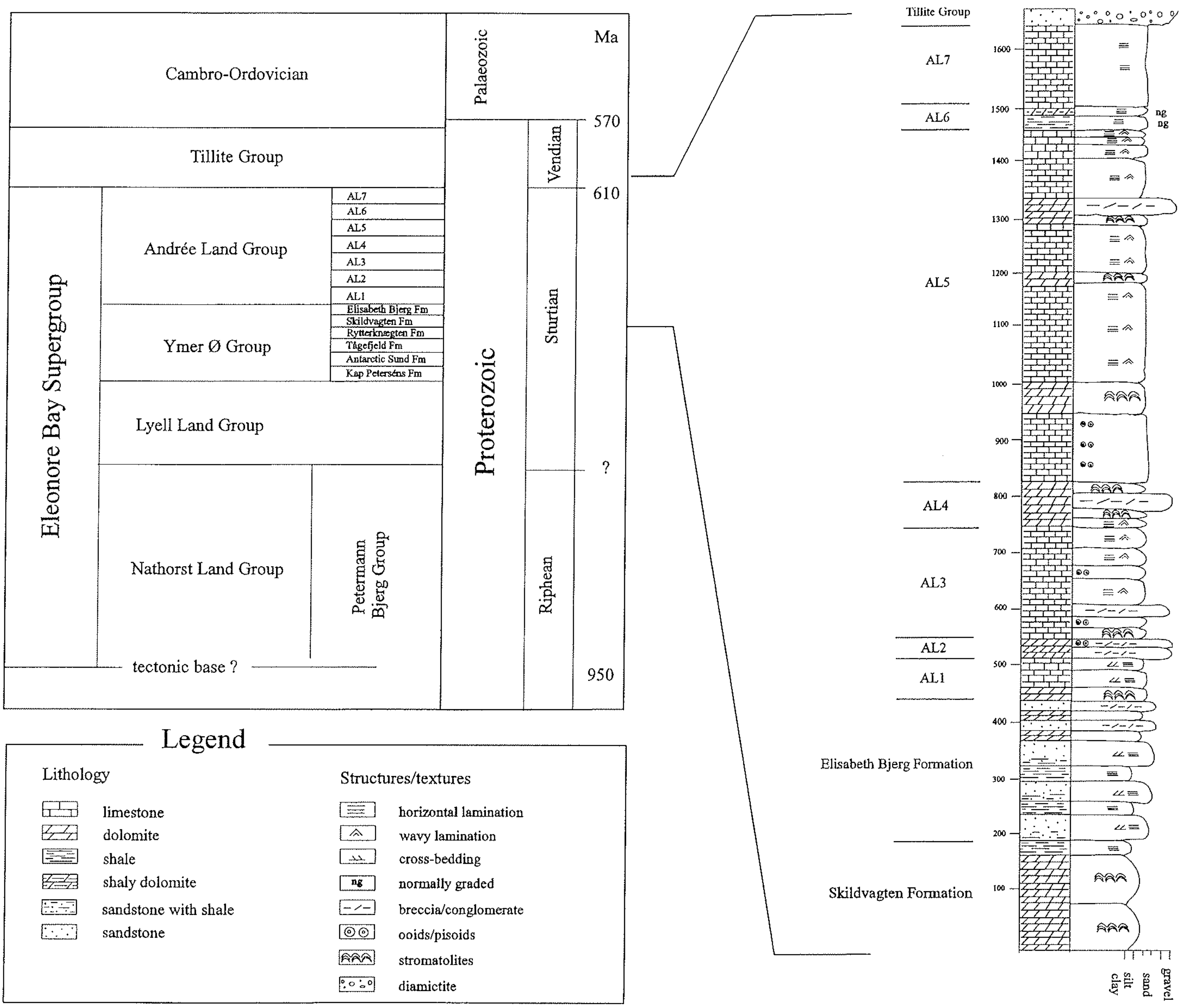

Fig. 2: Present lithostratigraphic scheme for the Eleonore Bay Supergroup, slightly modyfied after SØNDERHOLM & TIRSGAARD (1993), and a generalised composite sedimentological log of the Skildvagten and Elisabeth Bjerg Formations (Ymer Ø Group) and the Andrée Land Group.

During major lowstands in relative sea-level extensive areas of the ramp were subaerially exposed, and continental run-off by local rivers transported siliciclastic sediment across a major by-pass zone towards the lowstand shorelines (TIRSGAARD 1996). The siliciclastic input to the ramp reduced the carbonate production. TIRSGAARD (1996) suggested the carbonate-siliciclastic ramp cycles in the Elisabeth Bjerg Formation were climatically controlled, since the consistent architecture of the cycles indicated recurring changes in relative sea-level of similar magnitude. The sedimentary evolution from mixed carbonate and siliciclastic ramp deposits of the upper Ymer Ø Group to carbonate ramp deposits of the AL1-AL5 of the Andrée Land Group reflects an overall transgressive ramp evolution. The lack of siliciclastic deposits within AL1-AL5 reflects cessation of siliciclastic input to the ramp system because of submergence of the siliciclastic source during relative sea-level rise. The carbonate ramp deposits of AL1-AL5 are cyclic on several scales; centimetre to metre-scale shallowing upward inner back ramp lagoonal cycles, centimetre-scale interbedded fairweather-storm sediments and decametre-scale cycles reflecting progradation and retrogradation of the inner back ramp lagoon, shallow inner ramp barrier/shoal complex, and mid to outer ramp. However, in spite of sedimentary changes in the ramp environments the ramp continued being an efficient carbonate factory during this time interval.

The transition from the carbonates of AL1-AL5 to the shales of AL6 reflects an abrupt environmental change from carbonate production on a ramp to distal, deeper marine slope deposition. The region-wide boundary between AL5 and AL6 is associated with numorous iron-stained horizons from centimetre up to circa 1 m in thickness, and indicate a rapid relative rise in sea-level, which resulted in a major drowning of the carbonate ramp where relative sea-level rise outpaced carbonate accumulation so that the platform became submerged below the euphotic zone of prolific carbonate production (cf. SCHLAGER 1981). Characteristic features of drowned platforms include abrupt or stepwise transitions from carbonates to shales with associated hardgrounds commonly encrusted by ferro-manganese minerals. Mechanisms responsible for drowning of carbonate platforms include short-term geological processes such as rapid pulses of tectonic subsidence, rapid climatic-controlled glacio-eustatic sea-level fluctuations, and reduction of carbonate production by deterioration of the environment (SCHLAGER 1981).

The mechanisms responsible for the drowning of the Andrée Land Group carbonate ramp seem obscure. The contact to the overlying glacio-marine diamictites of the Tillite Group is generally knife-sharp but may be transitional at some localities suggesting that there is no major hiatus between the Andrée Land and the Tillite Groups. It therefore seems unlikely that the drowning was caused by a climatically-controlled glacio-eustatic rise in sea-level, since unset of glaciation would cause a fall in sea-level. However, climate probably did play a major role. The evolution from a possibly more tropical-like climate to a cool climate reduced the ability for the carbonate factory to produce the amount of carbonate necessary to keep pace with sea-level rise. The sedimentary thickness of the shales of AL6 varies from 10 m in the northern part to circa 200 m in the southern part of the region suggesting differential subsidence during deposition. It is thus proposed that the main control of carbonate ramp drowning resulted from a rise in relative sea-level due to rapid pulses of tectonic subsidence combined with a climatically-controlled environmental deterioration. The latter was probably due to decreasing temperatures, higher input of siliciclastic mud possibly enhanced by tectonic instability and reduced light transmission through the water column due to rising sea-level and siliciclastic input. In the northern and central parts of the region inner ramp shoal/barrier complex and mid to outer ramp limestones of AL7 are sandwiched between AL6 and the Tillite Group. The occurrence of the limestones indicates that reestablishment of carbonate ramp growth took place in parts of the region. This supports the tectonically-controlled sea-level rise interpretation as climatically-controlled glacio-eustatic sea-level oscillations would have affected the whole region in the same manner. The increase in tectonic subsidence governing carbonate ramp evolution possibly reflects initial crustal extension prior to the Late Proterozoic opening of the Iapetus Ocean

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