

# The Ogdensburg Dolostone of the Ottawa-St. Lawrence Lowlands (Lower Ordovician): Reconstruction of Paleoenvironments From Sedimentologic Evidence

By Carol A. Morgan and Ronald L. Parker

**ABSTRACT:** The Ogdensburg Dolostone exhibits evidence of deposition in a marginal marine setting influenced by hypersalinity and arid climatic conditions.

During the course of this investigation, it became evident that lithologies of the western outcrop belt differed greatly from those observed in the central outcrop belt.

The western outcrop belt exhibits the following environments (lithofacies): subtidal lagoon (gastropod-bearing dolomitic packstones and wackestones); barrier bar/shoal (cross-laminated quartz arenites); storm surge deposits (intraclastic quartz arenites); intertidal mudflat (ribbon and ripple-laminated dolomitic siltstones); algal flat (stromatolitic and algally-laminated lime mudstones and wackestones); and supratidal sabkha (cherty dolostones with collapse breccias and abundant irregular fenestrae filled with authigenic minerals).

The central outcrops are dominated by subtidal shelf lagoon facies. The lithofacies encountered in this region include: ripple-laminated dolomitic siltstones; bioturbated dolomitic packstones, wackestones, and mudstones; bioturbated dolomitic grainstones and occasional thin shales with horizontal feeding trails.

A number of features point to deposition under abnormally high salinity conditions. Evidence of hypersalinity includes: extremely low faunal diversity, preservation of algal structures, dessication features, solution collapse brecciation, and authigenic replacement of minerals in irregular fenestrae. An arid climate and restriction of open marine circulation are clearly indicated.

## INTRODUCTION

The Ogdensburg Dolostone (Canadian, see Figure One) of the Ottawa-St. Lawrence Lowlands contains textural and compositional evidence of deposition in an arid marginal marine setting on a gently sloping carbonate shelf with restricted circulation. The Ogdensburg has received comparatively little attention in the past century due to a dearth of well-exposed outcrops and a lack of easily observable physical characteristics. Also, correlation between distant outcrops is virtually impossible without subsurface information and efforts to relate stratigraphic sequences have been fruitless.

The purpose of this paper is to analyze sedimentological signatures and diagenetic alterations as a means of reconstructing Ogdensburg deposition. Hopefully, the ideas and interpretations brought forth in this investigation will provide impetus for continued study of the Ogdensburg Formation.

## PHYSIOGRAPHIC SETTING AND BRIEF PALEOZOIC HISTORY

The Ottawa-St. Lawrence Lowlands comprise a subtle triangular depression approximately 200 kilometers long and 100 kilometers wide at its maximum (see Figure Two). These lowlands have been depressed since late Hadrynian time, apparently the result of block faulting related to the opening of the Proto-Atlantic (Kumarepeli, 1978). The lowlands are

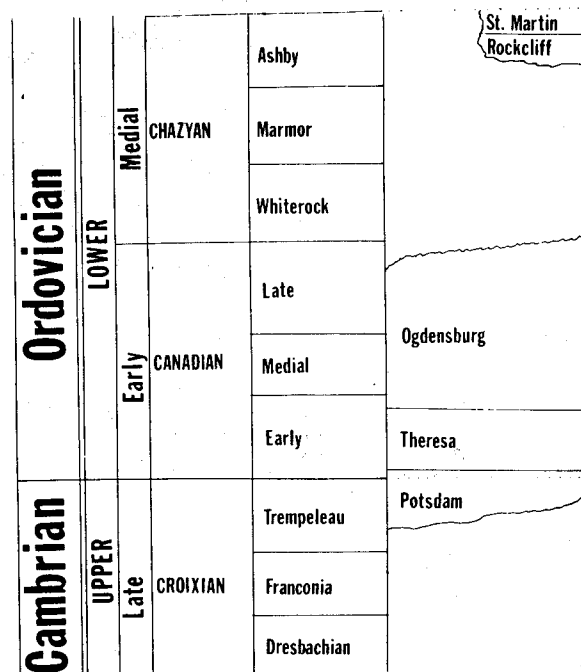


Figure One

presently bounded to the north by the Laurentian Highlands of the Canadian Shield and to the south by the Adirondack Mountains (Wilson, 1948). This depression was the site of repeated marine inundations during the Early Paleozoic (Selleck, 1980). A major control over deposition was exerted by a topographic high to the east which acted to restrict circulation with the open ocean. Known as the Beauharnois Anticline, this feature is probably the surficial expression of a documented basement feature called the Chambly Arch (Selleck, 1981).

The Ogdensburg lies conformably atop the Theresa Formation, which is in turn underlain by the Potsdam Sandstone. These three lithologies represent deposition during the first major marine transgression into the area. The transgressive sequence is inferred to have progressed from the southeast to the northwest based on age data. The Potsdam was derived from shallow marine waters and was deposited under arid climactic conditions, as evidenced by the presence of intraformational silcrete breccias (Selleck, 1977, 1978). The Theresa Formation records the advent of environmental and faunal diversification, reduction of system energy, and the appearance of lime mud, dolomite cement, bioturbation, cryptalgal lamination, and dessication features (Selleck, 1978,

1980). The Ogdensburg Dolostone represents subtidal-supratidal deposition in a restricted epicontinental trough. The complex facies associations of the Ogdensburg are attributed to minor regressive/transgressive phases caused by alternating periods of carbonate build-up and subsidence. Ogdensburg deposition was followed by a major period of regression and erosion. A second transgressive phase during the middle Ordovician deposited the Chazy normal marine limestone atop the truncated Ogdensburg (Wilson, 1948; Selleck, 1980). The absence of these three lithologies to the west of the Frontenac Axis is probably the result of initial non-deposition or subsequent erosion (Selleck, 1980).

#### PROCEDURE

Over 100 samples were collected from four outcrop exposures (see Figures Three and Four). The western outcrop belt is composed of the following: the McConville Inc. quarry, Ogdensburg, N.Y. (type section described by Chadwick in 1915); an outcrop five miles southwest of Ogdensburg, N.Y. along N.Y. Route 37; and a series of isolated outcrops appearing along Ontario Route 16. The central outcrop belt is

### Physiographic Setting of the Ottawa-St. Lawrence Lowlands

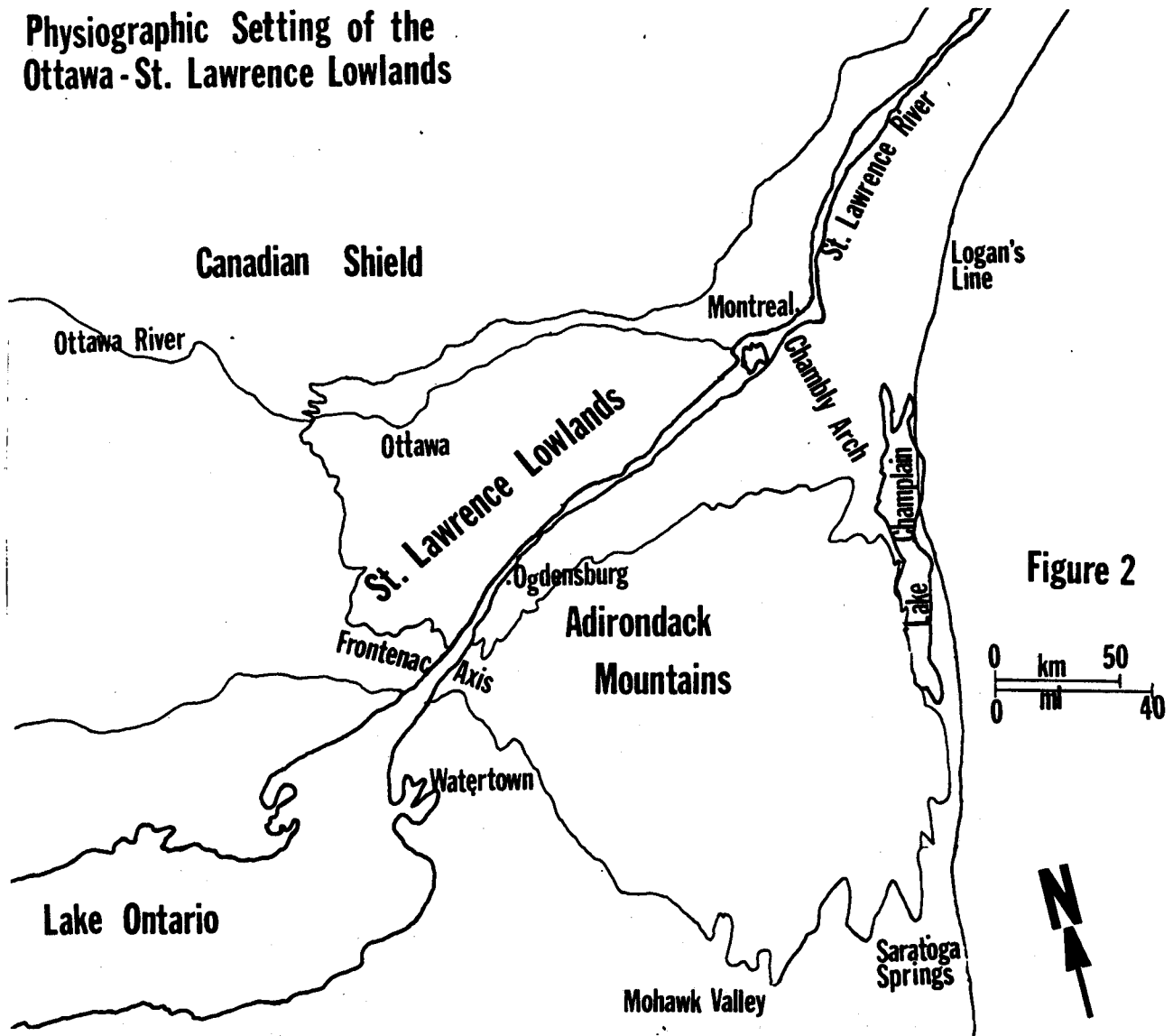


Figure 2



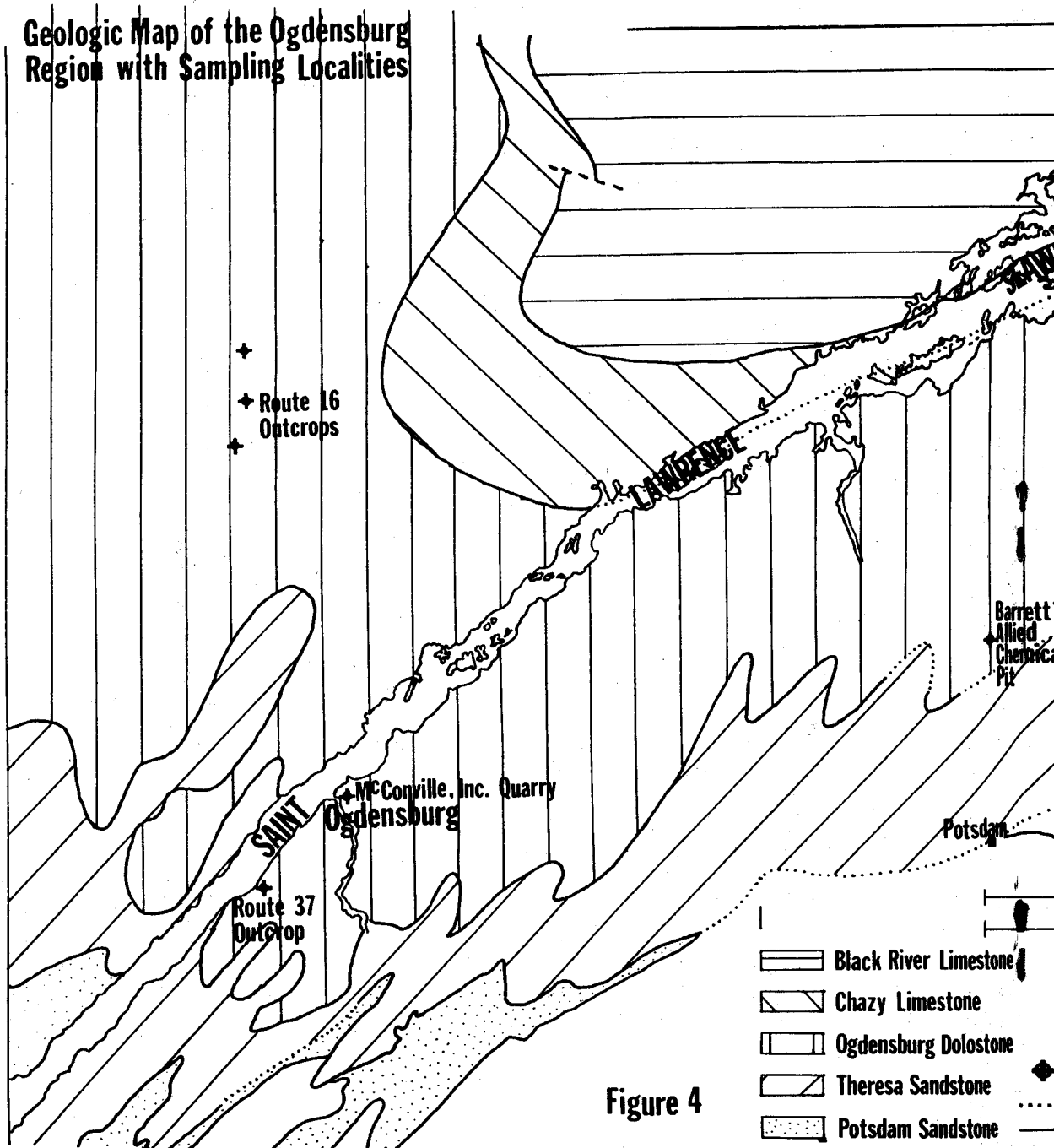
intraclasts, and peloids; and the occurrence of algal-lamination, cross-lamination, ribbon and ripple-lamination, authigenic minerals, bioturbate and fenestral fabrics, and dessication features.

#### FIELD DESCRIPTIONS AND LITHOLOGIC TYPES

The Ogdensburg consists of a variety of buff-weathering thick to thin-bedded, dark grey, blue to brown, coarse to finely crystalline dolostones, quartz sandstones, and calcareous shales. The complex sequence of lithologies observed in outcrops (Figure Three) represents the frequent and rapid (geologically speaking) changes of local depositional regimes. The original sediments deposited were calcium carbonate,

calcite, or aragonite in composition. During the long interval between deposition and the present, the original calcium carbonate sediments have become extensively dolomitized, i.e. altered to  $\text{Ca, Mg}(\text{CO}_3)$ . The Ogdensburg rock types will be discussed in terms of their pre-dolomitized states, as it is our purpose to depict the Ogdensburg as it appeared during its deposition.

During the course of the investigation, it became apparent that the localities sampled in the western outcrop belt were significantly different from those encountered in the central outcrop region. The western sections contained abundant evidence of shallow water and subaerial deposition, while the central sections exhibited lower energy offshore depositional features. The diversity of lithofacies was greater in the western



region as well.

Six lithofacies were discerned from the western belt:

- 1) Gastropod-bearing dolomitic packstones and wackestones
- 2) Cross-laminated quartz arenites
- 3) Intraclastic quartz arenites
- 4) Ribbon and ripple-laminated dolomitic siltstones
- 5) Cryptalgally laminated dolomitic mudstones and wackestones
- 6) Cherty, fenestral dolomitic mudstones

The central belt yielded three lithofacies:

- 1) Ripple-laminated dolomitic siltstones
- 2) Bioturbated dolomitic packstones, wackestones, and

mudstones

- 3) Bioturbated dolomitic grainstones

### WESTERN OUTCROP BELT: LITHOLOGY DESCRIPTIONS

**Gastropod-bearing dolomitic packstones and wackestones:** This rock is a fine to medium crystalline, poorly sorted dolomite with abundant equant fenestrae. The fenestrae are oriented along horizontal current laminations and exhibit what appears to be hydraulic size segregation. It is evident that these voids are relict molds of a transported molluscan fauna. In all cases, the fenestrae are infilled with authigenic carbonate minerals. The moldic fossils are surrounded by a fine carbonate mud admixed with a peloidal carbonate sand. The mud seems to have been deposited during resumption of equilibrium deposition after a current flow episode.

**Cross-laminated quartz arenites:** This lithology consists of a coarse to medium grained quartz sand cemented by dolomite. Quartz grains are well sorted, well rounded, and appear to be superficially frosted in some cases. Large void cavities partially or completely filled with later, chemically precipitated calcite, dolomite, and quartz are present, and seem to be oriented along certain horizons. Small fenestrae are in greater abundance and typically surround the sporadic large vugs. These small fenestrae also exhibit various stages of infilling. Some are completely clotted, others only rimmed with calcite, dolomite, and quartz euhedra. The relative sphericity of these vugs suggests early sediment lithification. Primary sedimentary structures are well-preserved. Local bands of bi-polar, low-angle, non-tangential cross-bedding are present in sets, locally attaining a thickness of 10 cm. Sinusoidal ripple migration traces are also evident. There is a noteworthy absence of intraclastic, organic, or fossil debris.

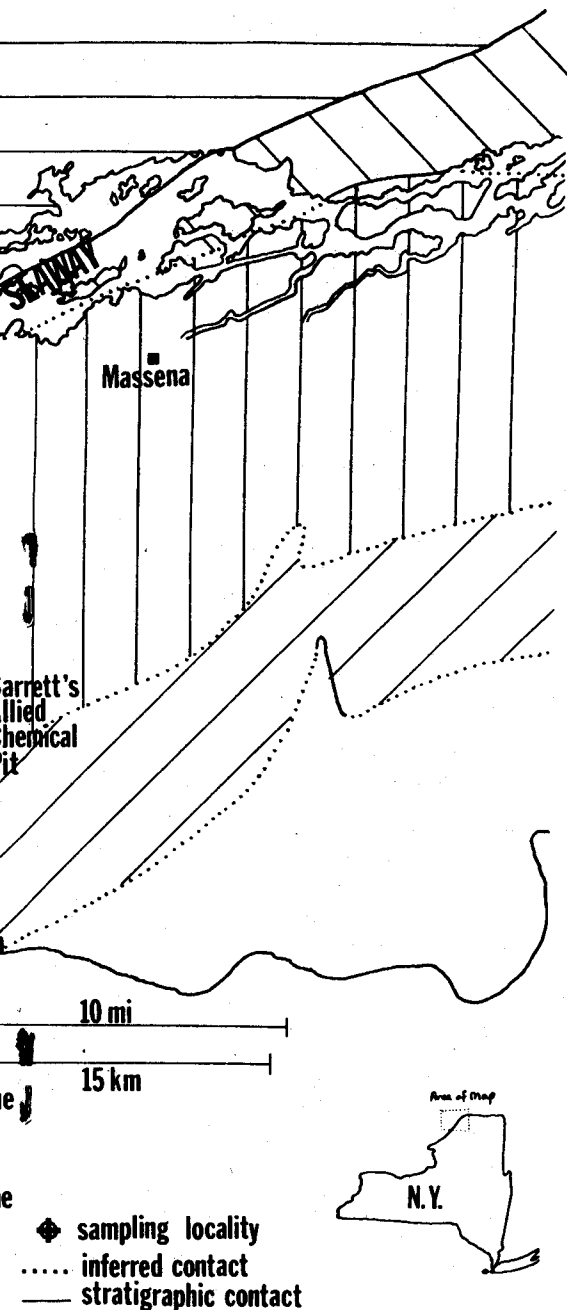
**Intraclastic quartz arenites:** This lithology is a coarse to medium grained, poorly sorted, quartz sandstone, cemented by dolomite and containing horizons of graded intraformational pebble conglomerate. The quartz sand shows a frosted surface texture and a roundness similar to that of the sand mentioned above. The planar intraclasts are composed of a finely crystalline dolomitic mud layered with fine millimeter-scale laminations. All intraclasts have been rounded and size maxima (1-5 cm) are hydraulically concentrated below smaller clasts (3 mm-1 cm). The intraclasts follow sinusoidal current structures and are locally imbricate, dipping upcurrent. Fenestrae are notably absent.

**Ribbon and ripple-laminated dolomitic siltstones:** This rock is a finely crystalline dolomite containing abundant organic debris. Pyrite is ubiquitous occurring as finely disseminated grains. Fenestrae appear sporadically, are relatively equant, and are rarely larger than 1 cm in diameter. These voids are lined or filled with calcite or dolomite—never quartz—euhedra.

Small scale current structures are evident, locally showing various degrees of disruption via bioturbation. Horizontal feeding trails, vertical burrows, and a pelleted fabric are present, but the degree of disruption, on the whole, is minimal. No fossils, intraclasts, or quartz sands appear in this lithology.

**Cryptalgally laminated dolomitic mudstones and wackestones:** These algal dolomites are fine to medium crystalline rocks which contain laminations of millimeter-scale, comprised of layers of dolomite sand, silt, and mud interfingering with residual organic bitumen. Three distinct algal structures are encountered: wavy, horizontally laminated algal mats; laterally-linked domal stromatolites (LLH type described by Logan, Rezak, and Ginsberg, 1964); and vertically stacked club-shaped stromatolites (SH type of Logan *et al.*, 1964).

**Algal mats:** This lithology is characterized by thin



alterations of hydrocarbon-rich and hydrocarbon-poor sediment. The organic-poor sediment is typically coarser grained than the algal-bound sediment. Laminae horizons roughly parallel bedding planes and contain prolific irregular bumps or waves that depart from the horizontal with amplitudes of about 5 mm. Small planar fenestrae are sparsely distributed throughout, paralleling algal mats and usually occurring under bituminous layers. Fenestrae are, without exception, totally infilled with carbonate minerals (never quartz). Mudcracks are present in most samples but are rarely of any great size or vertical extent. Vertical burrows are also present but their disruptive effect is minimal.

Laterally-linked domal stromatolites (LLH type): The sediments trapped by these structures appear to be finer than those bound by the other algal structure types. The internal lamination is on a smaller scale as well. The sediment surrounding the individual domes is intraclastic on a small scale, and contains transported fossils and peloids. Several of the domal margins have been truncated and subsequently infilled with coarser sediment. The upper portions of the domes are mudcracked on occasion. Laminations are generally lighter in color than those in the other algal associations.

Vertically stacked "club-shaped" stromatolites (SH type): These rocks contain coarse to medium grained carbonate and quartz sand intercalate with dark organic-rich bands. Laminae are characteristically oriented concave down, with the drapes pinching out at the side margins of the algal heads. The sides and base have been truncated and subsequently resedimented with coarse molluscan debris, quartz sand, intraclasts, and peloids. Bioturbation is minimal but does appear. Many of these discreet algal heads are preferentially oriented above infilled fenestral voids.

Cherty, fenestral dolomitic mudstones: The striking disarray and irregularity of features in this lithology makes an immediate impression upon the observer. The rock is a chaotic jumble of finely crystalline, poorly sorted dolomite, chert, calcite, and pyrite interspersed with abundant odd-shaped fenestrae. The dolomite is tan to buff colored (never dark) and has a high degree of porosity and permeability. Large contorted fenestrae are pervasive and exhibit various stages of infilling by calcite, dolomite, pyrite, fluorite, quartz, and chalcedony (fibrous quartz). The fenestrae are high variform and usually assume exotic, deformed shapes. Many of these oddly shaped voids are rimmed with an outer rind of chalcedony, succeeded in turn by hexagonal prisms of authigenic quartz. Chert, especially the black variety (flint), always occurs as geopetal bottom filling in these voids. The chert contains micromillimeter-scale laminations that parallel bedding planes. Grey and chalky white chert are also quite abundant, but rarely occur in geopetal relation with fenestrae. These cherts usually occur in laterally continuous, roughly nodular "stringers" and as chaotic jumbles with fenestrae and dolomite. It is interesting to note that most of these occurrences appear above disturbed algal mats or heads.

#### CENTRAL OUTCROP BELT: LITHOLOGY DESCRIPTIONS

These lithologies are entirely different from the rocks observed in the western belt. They are completely lacking in depositional signatures produced in shallow or emergent environments. Algal features, fossil remains, and dessication overprints are notably absent.

Ripple laminated dolomitic siltstones: This rock type is very

dark in appearance, suggestive of enrichment in organic carbon. The sediment is very finely crystalline dolomite that exhibits traces of slight current lamination. Bioturbation appears sporadically.

Bioturbated dolomitic packstones, wackestones, and mudstones: These are coarse to finely crystalline, dark colored (organic-rich) rocks. Extensive bioturbation has effectively eradicated any and all primary sedimentary structures that might once have been present. Enigmatic large fenestrae occur in a few samples, usually lined with carbonate minerals (calcite and dolomite).

Bioturbated dolomitic grainstones: These rocks are essentially the same as the lithology described above. The sole means of differentiation is the presence vs. the absence of lime mud. Grainstones are characterized by their lack of lime mud, whereas packstones, wackestones, and mudstones all contain lime mud. These rocks are coarsely crystalline, extensively bioturbated rocks with a high carbon content. They also contain the irregularly shaped fenestrae described earlier.

#### DEPOSITIONAL ENVIRONMENTS

The carbonate sediments produced during the time of Ogdensburg deposition have generally been regarded as the products of a shallow, clear sea (Kirchgasser and Theokritoff, 1971). The variety of rock types observed in the field demands a more detailed interpretation. Several interacting subenvironments have been recognized and identified. They are as follows:

- 1) Subtidal lagoon—Current stratified, hydraulically sorted fossiliferous horizons intercalated with finer sediments.
- 2) Barrier bar/shoal—Coarse grained quartz sand transported by active currents in the shallow offshore region.
- 3) Storm surge deposit—Poorly sorted quartz sandstones with intraformational conglomerates.
- 4) Intertidal mudflat—Ribbon and ripple-laminated, fine grained dolostones containing a high percentage of organic carbon.
- 5) Algal flat—Organosedimentary structures comprised of alternating layers of bituminous and non-bituminous sediment.
- 6) Supratidal sabkha—Solution brecciated, porous dolomites with irregular fenestrae and authigenic quartz, sulfides, and carbonates.
- 7) Subtidal shelf lagoon—Bioturbated, organic-rich rocks with local fenestrae of unusual size.

#### DEVELOPMENT OF A FACIES MODEL FOR THE OGDENSBURG

The objective of many recent studies of ancient sedimentary rock sequences has been to reconstruct the depositional setting of which these sediments originated. This reconstruction is often approached through the utilization of a "facies model." A facies model is an idealized framework which takes into account the relationships between lithologies and depositional environments and applies them to aid visualization of the complex processes which link these facies together in one physiographic setting. A facies model describes the spatial distribution of different environments and predicts the intricate vertical mosaic that results from lateral migration of these depositional environments through time. A fundamental premise of this prediction is the comparison of ancient lithologies with demonstrably similar sediment analogues

produced in modern settings. The processes which acted to deposit ancient sediments may thus be inferred. The facies model envisioned for the Ogdensburg is depicted in Figure Five.

Although it is admittedly schematic, this model establishes a plausible framework for Ogdensburg deposition. Depositional subenvironments for the western and central outcrop belts are interpreted as described below.

**Gastropod-bearing dolomitic packstones and wackestones:** These rocks are believed to be products of a subtidal lagoon region. The poorly sorted nature of these sediments represents deposition under fluctuating energy conditions. Some reworking has taken place, however, evidenced by the hydraulic size sorting apparent in the horizontal current laminations. Moldic fossils of a transported gastropod fauna dominate specific horizons in some of the laminated samples. Lack of bioturbation and the orientation of these relict molds lead to the belief that these fossils originated elsewhere and were transported into this area via high energy currents. These are obviously not the remains of an *in situ* molluscan community.

**Cross-laminated quartz arenites:** The cross-bedded quartz sandstones represent deposition in a barrier bar/shoal setting. These well-sorted quartz sands were probably derived from areas landward of the marginal marine setting and introduced into this offshore area through migration of aeolian dunes and littoral currents. Surficial frosting, relative sphericity, and the excellent sorting of these sand grains point to an original aeolian transport mechanism. Furthermore, it is likely that exceptionally high tides associated with storm episodes played a part in the transport of these sands to the offshore area. These

quartz grains were then reworked by currents, forming the crossbedding and ripple-lamination that are commonly associated with barrier bar/shoal deposits (Walker, 1979). These shoals were subject to periodic exposure, allowing evaporative processes to play a role in the formation of these sediments. Sporadic large vugs surrounded by smaller voids infilled or lined with calcite, dolomite, and quartz are interpreted to have once been filled with evaporite minerals, gypsum, and anhydrite. The relative sphericity of these vugs points to an early-stage lithification of these sands, probably due to carbonate cementation.

**Intraclastic quartz arenites:** The intraclastic quartz arenite facies is interpreted to be a storm surge deposit. Quartz sand was most likely derived from the offshore barrier bar/shoal deposits and transported landward. The poorly sorted nature of this deposit, coupled with the presence of abundant intraclasts, suggests churning and erosion of sediments by high energy storm currents. The intraclastic material, a finely crystalline dolomitic mud, was derived from adjacent desiccated mudflats. The imbricate nature of these intraclasts suggests that they were dropped from suspension as the current energy was dissipated.

**Ribbon and ripple-laminated dolomitic siltstones:** These samples are inferred to be the products of deposition on a relatively low-energy intertidal mudflat. Abundant organic carbon, creating the dark appearance of these samples, indicates that these sediments formed under reducing conditions that allowed only partial aerobic decay by bacterial putrefaction. Finely disseminated pyrite supports such an interpretation because ferrous iron and dissolved sulfide react

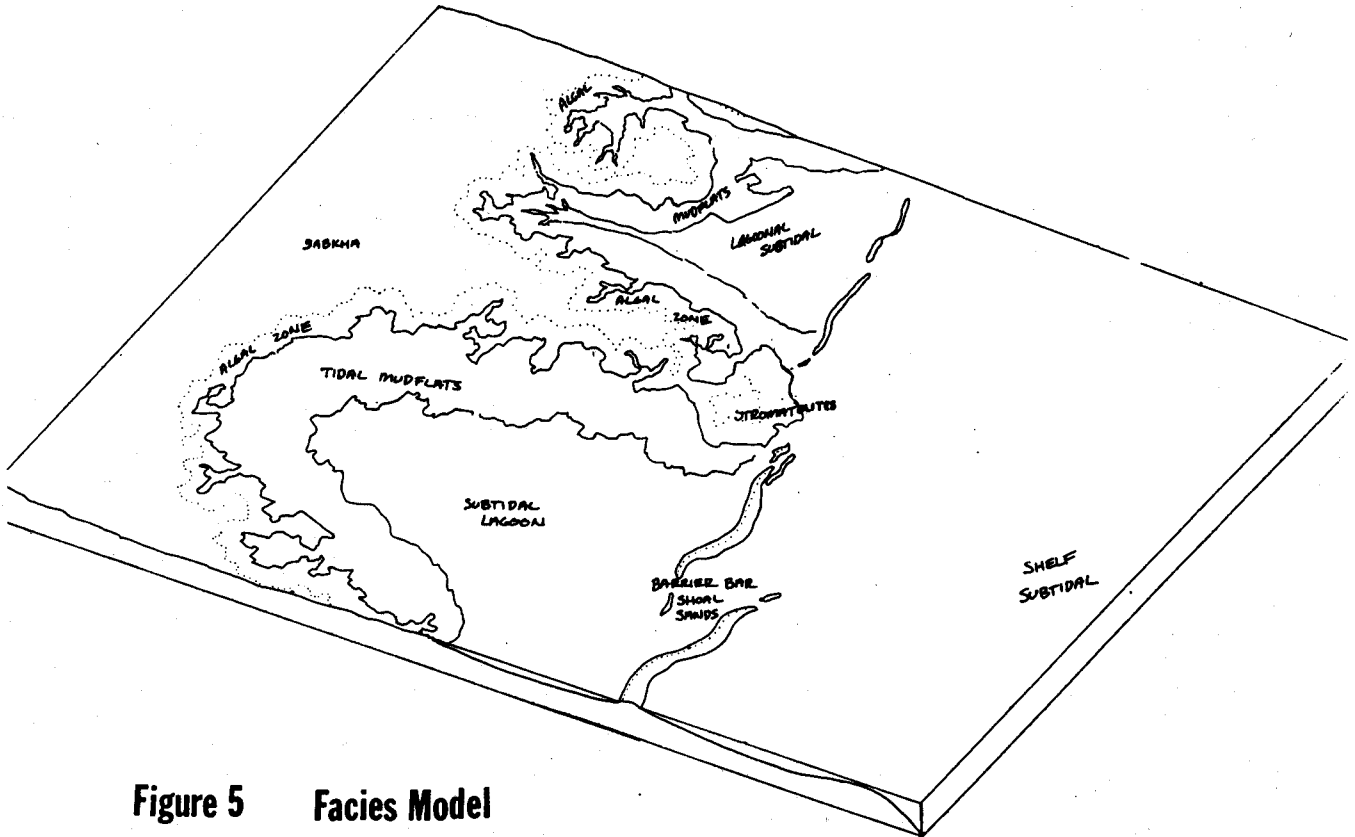


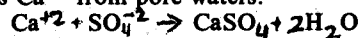
Figure 5 Facies Model

to form pyrite under reducing conditions. Horizontal feeding trails, vertical dwelling burrows, and a pelleted texture suggest biological activity. The organisms responsible for the slight degree of sediment disruption are inferred to have been soft-bodied, i.e. annelids, polychaetes, etc., as the oxygen requirements of skeleta-secreting taxa could not have been satisfied in a chemically reducing setting. The paucity of skeletal fossils further substantiates this claim. Small fenestral voids, lined with calcite and dolomite, are reminiscent of the "bird's-eye vugs" described by Shinn (1968). These result from gas bubbles trapped within cohesive or partially lithified sediment. Partial bacterial decay of deposited organic matter results in the generation of gaseous phases such as carbon dioxide, methane, and hydrogen sulfide. If the muddy sediment is sufficiently cohesive, these decay volatiles can be trapped within the sediment. Subsequent diagenesis would account for the partial to complete infilling of these voids by calcite and dolomite. Continuous millimeter-scale ripple lamination is a pervasive feature, bioturbation having caused relatively little disruption. These fine lamellae are believed to have formed by slow, current-induced migration of silt-sized sediment over the substrate surface. Gentle winds blowing over a shallow water surface could cause such sediment migration and produce minute ripple forms such as these. Protection of this area from the open sea was provided by the barrier bar/shoal system which lay seaward of this zone. A noteworthy lack of intraclasts, quartz sand, fossil debris, or other foreign particles demonstrates the effectiveness of the protective barrier bar/shoal system.

**Cryptogally laminated dolomitic mudstones and wackestones:** These rocks are believed to be derived from an intertidal algal flat region. Evaporation of pore waters during long periods of subaerial exposure elevated salinities to a level which effectively restricts colonization of this area by grazing metazoa (Horodyski, Bloeser, and Vander Haar, 1971). These substrates are thus optimal locations for blue-green alga proliferation. Modern studies reveal that algal growth is prohibited in areas where the slope is greater than 1:1000 (Till, 1978). The Ogdensburg intertidal algal flat must therefore have been a relatively low energy zone, as wave/current energy acting upon such a gently sloping surface is rapidly and effectively damped out. Algal mats themselves also serve as "baffles" to wave energy. The fine grained nature of the sediments associated with the algal mats is a direct result of these lowered energy conditions. Three distinct algal zonation are inferred to have existed within the algal belt.

The algal mat zone, consisting of wavy, horizontally-laminated algal mats, is assumed to have formed under constant intertidal energy conditions. Dessication during daily tidal fluctuation accounts for the wavy nature of these algal mats (James, 1979). Exposure during low tide periods, especially in an arid environment such as that proposed for the Ogdensburg, results in the evaporation of pore waters from the algally-bound sediment. Salinity may reach 2-10 times normal marine values, again acting to prohibit colonization by grazing herbivores. Algal filaments, however, are relatively immune to dessication, as they are coated with a protective moisture-conserving sheath of gelatinous proteins. It is this sticky sheath that enhances the trapping power of these mats, allowing them to trap and bind sediments during their growth. Prolonged exposure of the mats will eventually cause dessication, however, causing mudcracks and dessication polygons to develop within the sediment. Small calcite and dolomite filled planar fenestrae parallel algal mat layers. Those formed in a manner similar to the bird's-eye vugs discussed earlier (partial decay of organic matter resulting in gaseous phase generation and entombment of gas bubbles in semilithified sediment) (Shinn, 1968). Brine concentration via evaporation often produces hypersaturated solutions. Gypsum

is a common precipitate under such conditions and can be seen forming within sediment layers in modern settings of this sort (Till, 1978; James, 1979). Gypsum nucleation effectively removes  $\text{Ca}^{+2}$  from pore waters:



This process raises the  $\text{Mg}^{+2}/\text{Ca}^{+2}$  ratio, creating conditions appropriate for dolomite production. This ionic interplay is thought to be partially responsible for the creation of dolomite from calcite and aragonite (Blatt *et. al.*, 1980).

The laterally-linked domal stromatolites (LLH type) developed in sheltered low energy regions of the intertidal mudflat. Although evidence of episodic erosion is apparent, in general these stromatolites experienced only slight wave/current agitation. During low tide, ponded waters and sediments fill hollows, inhibiting sediment fixation by the sticky algal surfaces (Logan *et. al.*, 1964). As a result, growth occurs primarily on (but is not always restricted to) the upper surface of the algae, and a bulbous form systematically results. These algal heads are occasionally exposed subaerially and mudcracks form via evaporation of pore waters. Intraclasts, transported molluscan debris, and peloids appear to fill current scoured interdomal lows. The presence of the erosional surfaces and foreign particles indicates that this generally quiet area was affected by periodic increases in current energy, perhaps due to occasional storm events of unusually strong tidal flux. Laminations in these rocks are generally lighter in color than those of the other algally laminated samples, indicating a lower organic content in these sediments than in others.

Vertically stacked "club-shaped" stromatolites (SH type) are interpreted to have formed in less protected areas under moderate to high current energy conditions. Wave/current energy served as an erosional and depositional agent, scouring the interdomal areas often undermining algal heads and depositing coarse molluscan debris, quartz sand, intraclasts, and peloids in the eroded hollows. Again the infilled fenestrae found in these samples are inferred to have been formed by precipitation of evaporite minerals in the sediments of this region.

**Cherty fenestral dolomitic mudstones:** This lithology was deposited under conditions drastically different than the previously mentioned lithologies. This poorly sorted, contorted rock, composed of dolomite, calcite, pyrite, and chert and containing irregularly-shaped fenestrae, in interpreted to have been deposited under supratidal sabkha conditions. High evaporation rates related to excessive periods of subaerial exposure create hypersaline conditions associated with this region. Evaporite minerals (gypsum and anhydrite) are precipitated in abundance, forming the irregularly-shaped fenestrae and contributing to the contorted appearance of the surrounding sediments. Subsequent dissolution of the evaporite minerals causes partial collapse of the partially to completely lithified overlying sediments and collapse breccias result (James, 1979). This mechanism is invoked to explain the presence of collapse breccias in the Ogdensburg supratidal sabkha samples. Dehydration of gypsum to form anhydrite was also at least partially responsible for the chaotic appearance of these rocks. The volume reduction associated with this reaction would serve to further contort and disrupt the original sedimentary layers. These fenestrae have been subsequently infilled with calcite and dolomite and are rimmed with chert and pyrite.

The depositional environments associated with the central outcrop belt lithologies are all subtidal in nature. These lithologies differ greatly from those of the western belt, as they lack any textural or compositional features suggestive of deposition in an emergent setting. The environmental

interpretations of the central belt lithologies are given below.

**Ripple-laminated dolomitic siltstones:** This lithology is a product of deposition in a subtidal shelf lagoon. This very fine grained sediment was deposited under fairly constant low current energy conditions. Occasional disruption of the sediment by soft-bodied organisms is evident, although the majority of the ripple-lamination seems to have been preserved. Organic material, highly concentrated in this lithology, was introduced from suspension as finely particulate matter and, less importantly, from the *in situ* contribution of benthonic fauna.

**Bioturbated dolomitic packstones, wackestones, and mudstones:** These rocks are interpreted to have been deposited in a subtidal shelf lagoon setting similar to that of the ripple-laminated siltstones described above. Laminations in this lithology are solely the result of extensive bioturbation. Any pre-existing current-created lamination has been entirely destroyed. The fine grained nature of these sediments in general and the relative abundance of lime mud in specific samples points to deposition under very low energy conditions. Bioturbation is assumed to have been caused by soft-bodied organisms (which also contributed to the high organic content of this lithology upon death). Large fenestrae, infilled with calcite and dolomite, are inferred to be products of evaporite mineralization, subsequent dissolution, and reprecipitation of carbonate minerals within void spaces. The wave/current energy regime is thought to have been locally varied, accounting for the relatively different amounts of fine grained vs. coarser grained constituents in these rocks.

**Bioturbated dolomitic grainstones:** These sediments are similarly assumed to have been deposited in the subtidal shelf lagoon region. This lithology is dominantly medium to coarse grained and lacking lime mud, indicating that wave/current activity influenced these sediments to a greater degree than those mentioned above. High organic content and extensive bioturbation suggest a similar subjection of these sediments to biological influences. This depositional environment could be found proximal to and possibly seaward of the barrier bar/shoal system in the subtidal region.

## SUMMARY AND CONCLUSIONS

The various lithologies representing the Ogdensburg Dolostone are classic examples of products formed by the depositional processes operating on a stable, restricted carbonate shelf. The nature of these sediments has been significantly influenced by the effects of an arid climate, a low physiographic slope, and the chemical alterations associated with hypersalinity. The evidence for hypersalinity includes the following:

**Paucity of fauna and extremely low faunal diversity:** Carbonate environments are classically formed and characterized by the productivity of calcareous, hard-shelled biota. In the Ogdensburg, although some fossilized hard parts are present, there are no representatives of Echinodermata or Coelenterata, common indicators of normal marine salinities. Gastropods are the only hard-shelled fauna found in the Ogdensburg and gastropods are typically dominant in hypersaline settings. Diversity within the gastropod group itself is notably low, consisting of a maximum of three or four gastropod species. These gastropods are also abnormally scarce within the rock record of the Ogdensburg. Marine fauna of reduced diversity has been attributed to the adverse conditions of abnormal salinities (Kendall and Skipwith, 1969).

**Preservation of algal mats:** In regions of normal salinities, burrowing and grazing metazoans destroy

algal structures. In areas of elevated salinities, herbivores are unable to survive while algal mats remain unaffected. This prohibitive effect of high salinity, even on the more salinity-tolerant genera, facilitates the preservation of algal material (Horodyski and Vander Haar, 1975; Cussey and Friedman, 1976).

**Collapse breccias:** Chaotically oriented clasts of *in situ* dolomite and chert, encased in a fine matrix and occurring in fenestral bodies in the Ogdensburg, have been interpreted to be the result of dissolution of evaporites. Collapse such as this occurs when evaporites are dissolved and no support is given to overlying sediments, which fall into the newly formed void spaces (James, 1979).

**Euhedral quartz:** Euhedral crystals indicate unhindered growth within a cavity. In every instance, Ogdensburg euhedral quartz is transitional with a peripheral rim of chalcedony. Chalcedony (of the slow length variety) has a demonstrated association with pseudomorphs of evaporites (Folk and Pittman, 1971). The association of prismatic quartz with slow length chalcedony in carbonate rocks has been classified as "diagnostic" of vanished evaporites (Chowns and Elkins, 1974).

**Authigenic K-spar:** X-ray analysis of clay samples taken from Barrett's Quarry confirm the presence of microcline in the Ogdensburg. The apparent association of authigenic K-spar with hypersaline environments has been noted by Buyce and Friedman (1976) and Braun and Friedman (1969).

During Lower Ordovician time, shallow epicontinental seas controlled the deposition of carbonate sediments. The Ogdensburg Formation was deposited during this time under these influences and shows evidence of deposition in a restricted epicontinental trough under conditions of climatic aridity, hypersalinity, and emergence.

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