Algal Stromatolites: Use in Stratigraphic Correlation and Paleocurrent Determination

Abstract. *Algal stromatolites are used for detailed rock-stratigraphic correlation for a distance of 160 kilometers in the Pethei Formation, of Aphebian (Precambrian) age, in the Northwest Territories, Canada. Laterally linked stromatolites are initiated by the draping of successive laminations over intraclasts or other irregularities in the bedding surface. Stromatolite shapes and orientations are related to paleocurrent direction determined from associated sedimentary structures. Thus stromatolite geometry is at least in part environmentally controlled.*

Stromatolitic limestone and dolomite of the Pethei Formation (*1*) were examined as part of a stratigraphic, sedimentological, and paleocurrent study (*2*) of the East Arm fold belt (*3*) in the Canadian Precambrian Shield. The Pethei Formation, 340 to 460 m thick along the northern margin of the 240-km-long fold belt, is part of an unmetamorphosed sedimentary and volcanic rock sequence deposited between 2370 (*4*) and 1845 (*5*) million years ago in what is now the East Arm of Great Slave Lake, District of Mackenzie, Northwest Territories. The formation, reportedly (*1*) absent along the southern margin of the fold belt, is of Aphebian (*6*) age.

Most stromatolites have been considered to be of algal origin ever since the term was introduced by Kalkowski (*7*) in 1908. Although some types of algae precipitate calcium carbonate organically (*8*) or induce inorganic precipitation, Recent structures analogous to ancient stromatolites are formed by the trapping and binding of preexisting particulate carbonate sediment in predominantly blue-green algal mats (see *9*).

Debate persists as to whether variation in form between stromatolites is biologically controlled or a function of the physical environment of the individual stromatolite or stromatolite bed. Those favoring biologic control have attempted to make regional biostratigraphic correlations by use of stromatolites (*10*). On the other hand, some aspects of the form of stromatolites have been thought to be controlled by environmental factors such as the direction of sunlight (*11*) or the tidal range (*12*). To advocates of environmental influence, stromatolites offer a means of paleogeographic reconstruction.

Stromatolite shape and orientation in the Pethei Formation are related to the direction of transport of sediment during formation. Nevertheless, detailed rock-stratigraphic correlations of sections 160 km apart can be made on the basis of distinctive stromatolite beds.

Donaldson (*13*) found that stromatolites could be used for correlation between stratigraphic sections for 8 km in the Aphebian Denault Formation of Labrador. In the East Arm, stromatolite beds were treated as distinct lithofacies in ten measured sections through the Pethei Formation along the linear outcrop belt that parallels the depositional strike of the formation. The extreme abundance and

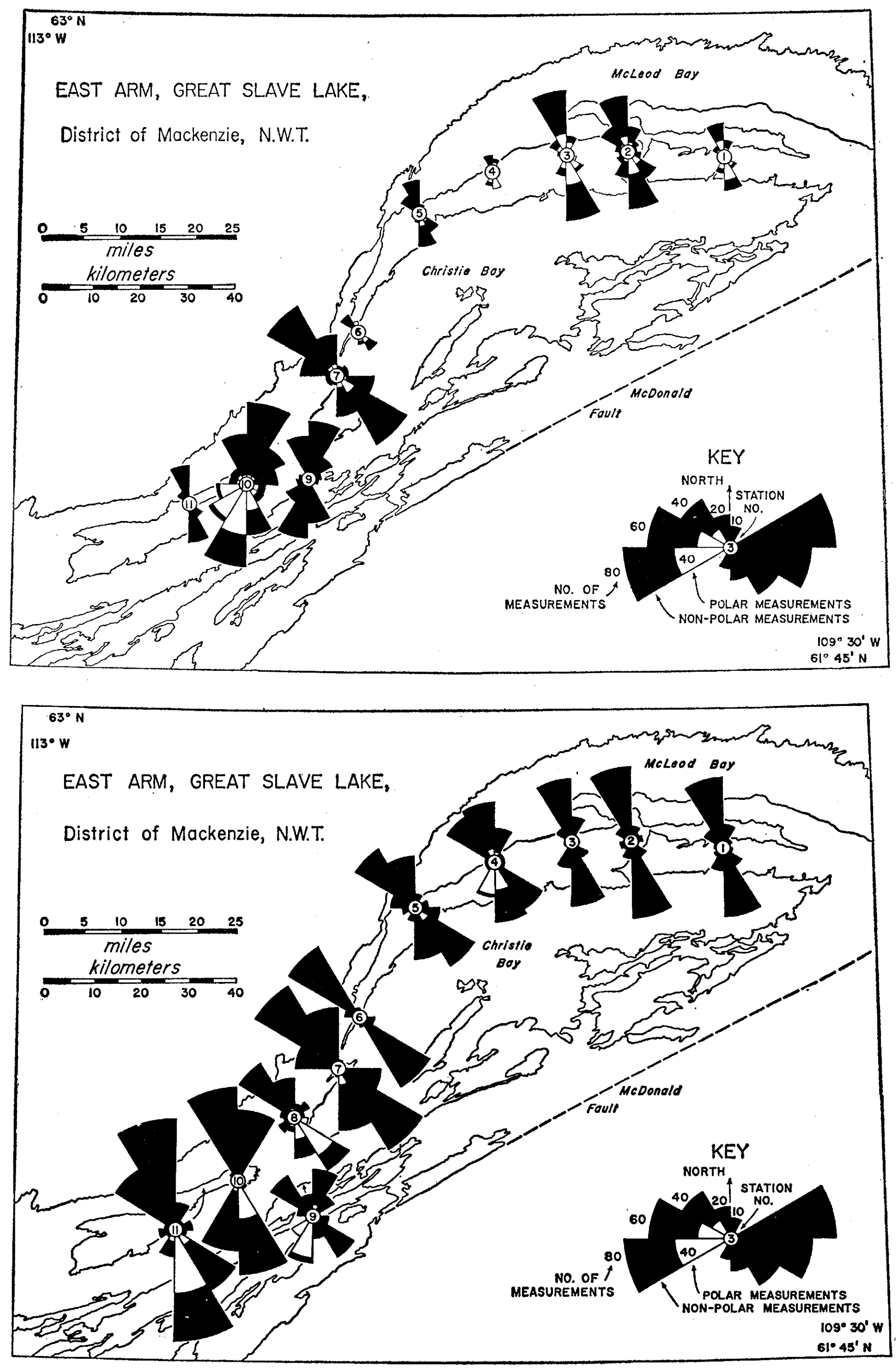

Fig. 1. Paleocurrent rose diagrams of 679 measurements of directional sedimentary structures (top) and 1377 measurements of stromatolites (bottom) in the Pethei Formation.

diversity of well-exposed stromatolite beds facilitated the correlations. Some stromatolite beds 1 m thick were traced for 130 km. I emphasize that the correlations are of a rock-stratigraphic nature only.

The shapes of several different types of stromatolites are related to paleocurrent direction. This fact was documented by more than 2000 measurements in the Pethei Formation and by 500 measurements in two other stromatolitic formations in the area. At each of the stratigraphic sections in the Pethei Formation, paleocurrent determinations were made from ripple marks, cross-bedding, rill channels, and clast orientation in intraformational edgewise conglomerate beds; the resulting paleocurrent pattern is shown in Fig. 1.

Current-controlled stromatolite shape and orientation are best seen on the many extensive bedding-plane exposures (Fig. 2). Stromatolite "heads" with elliptical outlines are preferentially oriented with the long axes of their ellipses of section parallel to the prevailing paleocurrent direction. This deviation from radial symmetry is not a result of tectonism. The degree of ellipticity and, to a certain extent, its orientation vary from bed to bed and between different stromatolites in the same bed.

Furthermore, in the area of the measured sections, the formation has a regional dip of less than 20 deg, and no tectonic fabric other than jointing is present. The current-controlled forms range in size from hemiellipsoidal stromatolites a few centimeters in diameter to complex stromatolite bioherms 80 m long, 45 m wide, and 20 m thick. That the bioherms had no more than 2 m of relief above the sea floor during deposition is indicated by thin stromatolitic beds on the flanks of the bioherms. Axial ratios of the elliptical stromatolites in the bedding plane are as great as 20 to 1 in some beds; stromatolites there have columnar form in vertical sections perpendicular to the paleocurrents, but appear only as nearly horizontal, undulatory laminations in sections parallel to the paleocurrent direction.

Simple elliptical forms reflect only the trend of the currents and not their sense. Many beds contain stromatolites whose asymmetry reflects both current trend and sense. This type of stromatolite is most common in beds containing laminations that are continuous from each stromatolite "head" to the intervening area between the heads; Logan *et al.* (*12*) term this type "laterally linked." The laminations consist of alternating fine- and coarse-grained layers of sediment. The fine-grained layers contain carbonate mud and silt, in many beds dolomitic, and are about 0.5 mm thick. The coarser-grained layers are of more variable thickness (mostly less than 5.0 mm) or may be absent altogether, in which case the fine-grained layers are directly superposed. The coarser-grained layers consist of loosely packed recrystallized oolites, laminated intraclasts, dolomite rhombs, and lime-mud pellets surrounded by sparry calcite. The stromatolite form is generated by lateral variation in the thickness of the individual layers of coarse-grained sediment (shown in Fig. 2).

The stromatolite heads of this type invariably contain a pebble-sized intraclast, oncolite, ripple mark, desiccation crack, or other projection on the bedding surface, over which successive laminations are draped. In general the layers of coarse-grained sediment are thicker where they pass over the projections than in the intervening areas. The thickening occurs in many suc-

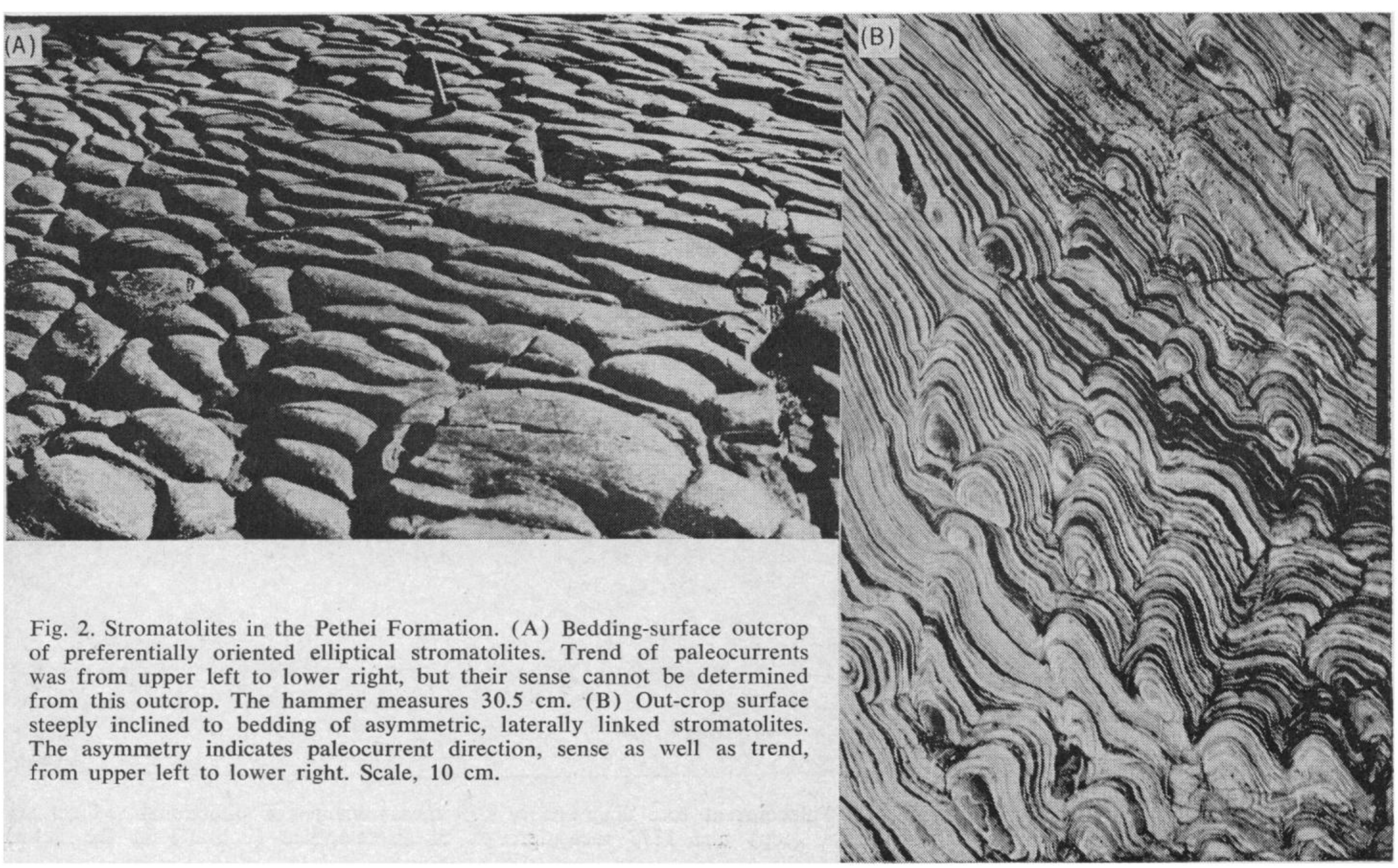

Fig. 2. Stromatolites in the Pethei Formation. (A) Bedding-surface outcrop of preferentially oriented elliptical stromatolites. Trend of paleocurrents was from upper left to lower right, but their sense cannot be determined from this outcrop. The hammer measures 30.5 cm. (B) Out-crop surface steeply inclined to bedding of asymmetric, laterally linked stromatolites. The asymmetry indicates paleocurrent direction, sense as well as trend, from upper left to lower right. Scale, 10 cm.

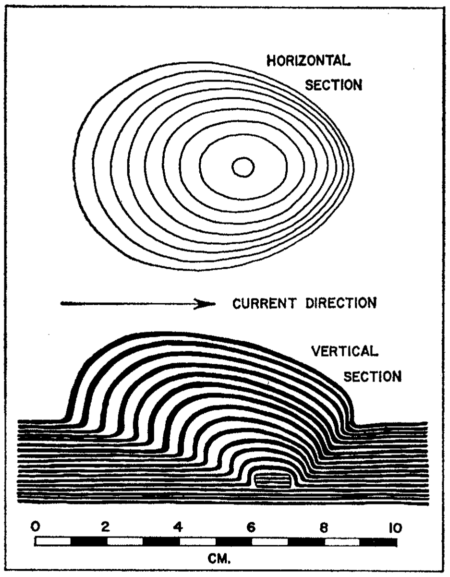

Fig. 3. Idealized horizontal (top) and vertical (bottom) sections of an asymmetric, laterally linked stromatolite, showing the relation of shape to current direction. The thin dark layers represent fine-grained sediment; the clear areas, the coarser-grained layers of sediment. A laminated intraclast serves as a nucleus.

cessive laminations and thus the original relief and morphology of the projection are greatly enlarged and modified (Fig. 3).

Commonly the drape-over lamination surfaces are hemispherical or hemiellipsoidal. In some beds, however, the layers of coarse-grained sediment are thickest of all on the side of the drape-over stromatolite head that faces up-current as indicated by the foreset laminations in ripple-sand lenses in the same bed (Fig. 3). These stromatolites possess an asymmetry related to current trend and sense that is readily seen in outcropping surfaces either parallel or perpendicular to the bedding (Fig. 2).

Stromatolite studies in the Pethei Formation show that (i) single stromatolite beds are continuous for as far as 160 km and are amenable to rock-stratigraphic correlation; (ii) stromatolite shape and orientation may be used to determine paleocurrents; and (iii) stromatolite geometry is controlled at least in part by physical factors of the local environment. Attempts to determine the taxonomic or time-stratigraphic usefulness of stromatolites should therefore be made with caution.

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Sinkhole Formation by Groundwater Withdrawal: Far West Rand, South Africa

Abstract. *Sinkholes up to 125 meters wide and 50 meters deep have developed catastrophically in thick unconsolidated debris above pinnacle-weathered dolomite after lowering of the groundwater surface by at least 160 meters. They are caused by shrinkage of desiccated debris, downward migration of debris into bedrock openings, and upward growth of multiple debris "caverns" by roof spalling.*

Coincident with the beginning in 1960 of a major dewatering program on a portion of the Far West Rand mining district, near Johannesburg, South Africa, many sinkholes were formed, including some that must qualify as the world's largest "man-made" sinks. Between December 1962 and February 1966, eight sinkholes larger than 50 m in diameter and deeper than 30 m have formed.

Subsidence of the ground caused by the withdrawal of fluids from alluvial and weathered debris, as well as from detrital sedimentary rocks, has been measured and described, particularly in the San Joaquin (*1*) and Santa Clara valleys in California and near Long Beach, California (*2*). Within these areas of subsidence, seldom has there been any occurrence of sudden surface collapse. However, within areas of carbonate bedrock, the removal of fluids from the overlying unconsolidated debris has been accompanied by catastrophic collapse and the creation of sinkholes. Although this phenomenon has been described (*3*), it is not well known or understood.

The Far West Rand gold-mining district, situated about 65 km west of Johannesburg, is on a western extension of the reef-bearing Witwatersrand rocks (*4*). A thickness of 900 to 1000 m of Transvaal dolomite and dolomitic limestone unconformably overlies the Witwatersrand system and dips gently south. These are overlain by the Pretoria series of quartzites and shales. All mining on the Far West Rand is done by shafts that must extend through the thick carbonate section.

Deep weathering characterizes the Transvaal rocks where they are not overlain by Pretoria rocks. The depth to bedrock is known to range up to 400 m and commonly is more than 100 m. The ease of movement of groundwater through the dolomites and the remarkably uniform gradient of the groundwater surface, as determined from drill holes, indicates an almost continuous network of interconnected solution cavities within the dolomites. The overlying residual debris includes large unweathered blocks of dolomite and masses of chert ranging at least from 1 to 15 m in diameter. Mixed with the matrix of clay and silt-sized material is considerable soft black manganese oxide.

Cutting across the south-dipping dolomites and shales is a series of thick vertical syenite dikes 35 to 65 m thick and nearly impermeable even in their upper weathered zone. They create essentially watertight compartments that confine the movement of groundwater. The Oberholzer compartment is situated in the middle of the mining district. It includes the town of Carletonville, a number of smaller mining communities associated with three different companies, and ten shafts belonging to the three mines (Fig. 1). Prior to 1960, large springs rose on the upstream side of the dikes and flowed across them