HABIT, FORMATION, AND IMPLICATIONS OF ELONGATE, CALCITE CONCRETIONS, VICTORIA, AUSTRALIA

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INTRODUCTION

Elongate calcite concretions are exposed in cliffs composed of semi-consolidated Pleistocene beach and eolian dune sands on the western side of Cape Liptrap in Victoria, Australia (Fig. 1). Two models of concretion formation are considered in this study: 1) an event-based model with increased flow velocities and gradients due to a tectonic event and 2) a continuous flow model under normal groundwater flow conditions. Both models are based on formation in the phreatic zone parallel to groundwater flow gradients.

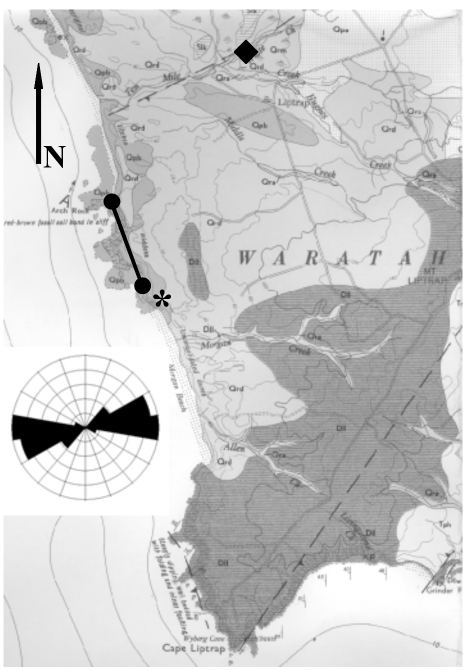

Figure 1. Map of study area with rose plot showing concretion orientations. The line represents best development of concretions in the study area. The diamond shows the location of the inland outcrop and the asterisk marks the location of the kink bands. (Map modified from Geological Survey of Victoria, 1975).

If concretions were formed according to the event-based model, they provide additional evidence for recent tectonic activity in the area. If they were formed according to the continuous flow model, their current exposure above the present day water table holds important implications for the interactions between paleo-groundwater flow, sea level change, climatic oscillations, and shoreline erosion since the Pleistocene.

The objectives of this study are to: 1) describe the occurrence and morphology of elongate concretions in the Cape Liptrap area, 2) evaluate the two formation models, 3) describe the formation of the concretions on both microscopic and macroscopic levels, and 4) discuss possible implications of concretion formation with respect to local landscape evolution since the Pleistocene.

METHODS

The morphology of the concretions, including diameter, length, and longitudinal variation, was documented at each outcrop. Orientations, including trend and plunge of concretion long axes and the strike and dip of any visible bedding planes, were also measured. When concretions were present, outcrop dimensions and the location of concretions within the outcrop were recorded. The location of each outcrop was documented relative to mean sea level and cliff stratigraphy. Axial plane orientations of kink bands observed in a 15-20 m stretch of consolidated dune sands near the north end of Morgan Beach were also measured (Fig. 2).

Figure 2. Kink bands in Pleistocene consolidated dune sands. D. Merritts for scale.

Standard petrographic thin sections were made of multiple orientations of concretion samples and of the overlying consolidated dune sand. Before thin sectioning, tabs were impregnated with blue epoxy to display porosity. Carbonate mineralogy of the samples was determined by staining methods described in Freidman (1959).

RESULTS

Elongate concretions in the study area occur along a seven-kilometer stretch of shoreline extending from the northern half of Morgan Beach to approximately 1.5 km north of Ten Mile Creek (Fig. 1). The concretions are best developed within the 2.5 km of shoreline from the northern edge of Morgan Beach to Arch Rock. A small inland outcrop was also observed on the north bank of White Creek near its confluence with Ten Mile Creek (Fig. 1).

In outcrop, concretions located lower in the section are large, well cemented, and are dominantly coalescing masses (Fig. 3). Those located higher in the section are smaller, less well cemented, and are usually isolated individuals (Fig. 4). In longitudinal view, the concretions resemble rods or pencils that taper towards the shore and vary in length from several centimeters to over a meter. The landward end is often enlarged or bulbous. Individual concretions are circular in cross section and range in diameter from less than a centimeter to several centimeters. Concretion outcrops are found as low as the intertidal zone to several meters up in the cliff face. In several outcrops concretions occurred in association with calcified tree roots. In the intertidal zone, the concretion outcrops were isolated from the retreating cliff face, the surrounding sediment removed by wave action. Concretions in the cliff face were most commonly surrounded by unconsolidated sediment; however, outcrops occasionally contained preferentially cemented bedding planes or cross bed sets.

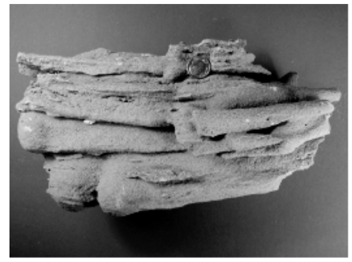

Figure 3. Example of amalgamated concretions found low in the section. Dime for scale.

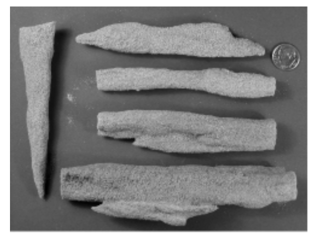

Figure 4. Example of isolated concretions found high in the section. Dime for scale.

Trend and plunge data shows the concretions inclined nearly horizontal with long axis orientations approximately perpendicular to the modern day shoreline (Fig. 1). Concretion orientations are similar throughout the study area and do not seem to be affected by the presence of primary sedimentary structures or cemented bedding planes.

Thin sections show sand dominated by quartz and calcareous biogenic grains. No growth structures, such as banding, are visible. Mineralogical analysis of stained sections is currently in progress.

FORMATION

The event-based model of formation is supported by the presence of a 15-20 m outcrop of kink bands in Pleistocene consolidated, eolian dune sediments in the study area (Figs. 1 and 2). These kink bands provide direct evidence for recent tectonic events in the study area. This model is based on the understanding that a tectonic event could provide a mechanism for increased flow velocities and/or gradient, without which concretion formation would not occur. The effects of such an event would be most noticeable in close association with other evidence of deformation, such as the kink bands, would support groundwater levels in the immediate area with steeper flow gradients, and cause flow patterns radiating outward from the disturbance. These expectations, however, are incompatible with field evidence in several ways: 1) the unconsolidated sediments in which the concretions occur show no evidence of soft-sediment deformation or other disruption that would most likely accompany high fluid velocities; 2) concretions are found near the kink bands, but also occur several kilometers away from the localized area of kinking; 3) concretions in the area do not reflect high flow gradients as they have nearly horizontal inclinations; and 4) concretions are found orthogonal to the shore, not radiating from a central point. The above observations and the lack of discussion of similar formative mechanisms for elongate concretions in the literature do not support this model.

The literature on similar concretions does, however, present overwhelming evidence for formation in the phreatic zone parallel to regional groundwater flow under normal flow conditions (Gell, 1995; McBride et. al., 1994; McBride and Parea, 2001; Mozley and Davis 1996; and Mozley, 2002). The nearly horizontal inclination and shoreline normal orientation, as well as similar growth habits and outcrop characteristics, suggests that concretions in the study area formed in an analogous manner.

The enlarged, landward end of many of the concretions that then tapers seaward agrees with a down-gradient growth model presented by Mozley (2002). Elongation is in the direction of flow. Mozley (2002) suggests that this down-gradient growth might result from fluid pressure differences from flow around a low permeability object, such as the growing concretion. The absence of visible zonation in hand samples and in thin sections suggests that concretions behaved as open systems during precipitation, allowing both early and late stage cements to precipitate in multiple sites throughout the concretion body. It is likely that more detailed analysis would show small-scale zonation of early and late stage cements (Mozley 2002).

Due to solubility differences between the low magnesium calcite cement and biogenic calcite, carbonate biogenic grains within the deposits are the most likely source of calcite for cementation (Walderhaug and Bjorkum, 1998). Aggressive, undersaturated pore-waters dissolved these more soluble biofragments and precipitated a less soluble low magnesium calcite cement (Curl, 2002). The availability of calcite in the system suggests that the reaction rate and not the availability of solute may be the rate-limiting step controlling growth.

IMPLICATIONS

This study has interesting paleohydrogeologic implications that may provide pertinent information on late Quaternary landscape evolution in the study area. If concretions were formed in the phreatic zone and are now exposed above the present day water table, the regional water table must have been higher in the past. Possible mechanisms that might have allowed for a higher water table include: 1) a higher sea level, 2) a wetter climate, or 3) a more seaward shoreline.

Optically Stimulated Luminescence (OSL) dating of deposits in the study area places the age of some of the highest concretion bearing zones as young as 85 ka. Higher sea levels since then are restricted to a rise of less than 2 m above present level around 6 ka (Beaman et. al., 1994). Consequently, if the concretions were formed as a result of higher past sea level, they must be less than 6,000 years old.

Formation of the concretions as a result of a wetter climate is also plausible. Several studies in southeast Australia have shown evidence of climatic oscillations throughout the Quaternary, with dryer conditions corresponding to dune formation during lower sea levels and wetter conditions corresponding to soil formation during higher sea levels (Spiers, 1992; Thom et. al., 1994; and Zhou et. al., 1994). It is possible that as sea level was rising to its current level at the end of the last glacial period and climate was oscillating towards wetter conditions, the deposits containing the concretions were inundated due to a rising water table, allowing for formation.

Since the water table follows topography, higher water tables may also have been tied to a more seaward coastline regardless of changes in climate or sea level. By this logic, the most likely scenario that allows for the present exposure of the concretions is shoreline erosion. As shore material is removed the water table is lowered, allowing for the exposure of previously inundated deposits. Erosion rates on aeolianite coasts can be as high as 4cm/year (Gill, 1973). The aeolianite cliffs in the study area are subject to vigorous wave energy and are actively retreating. Isolated cliff remnants such as Arch Rock exhibit the location of previous shorelines, during which time the concretions were certainly inundated.

CONCLUSIONS

Elongate, calcite concretions exposed on the western side of Cape Liptrap in Victoria, Australia are oriented horizontal to subhorizontal and perpendicular to the present shoreline. Field and laboratory data and relevant literature support formation of these concretions in the phreatic zone parallel to normal regional groundwater flow. The morphology of the concretions indicates a down-gradient growth model with elongation in the direction of flow. The absence of visible zonation suggests that the concretions behaved as an open system during formation. Abundant carbonate biogenic grains in the host sediment are the most likely source of calcite cement. Concretion formation may be the result of higher water tables from a higher sea level or wetter climate. Higher past water tables may also be explained by a more seaward coastline. Current exposure of the concretions above the present day water table is best explained by subsequent shoreline erosion and cliff retreat, causing a simultaneous retreat of the water table.

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