AEOLIANITES AND CYCLES OF ARIDITY DURING OIS 4 AND 5, ARCH ROCK, SOUTHEASTERN AUSTRALIA

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INTRODUCTION

Coastal Australia has undergone many Quaternary cycles of aridity (Bowler, 1976). A sequence of aeolianites observed along two kilometers of sea cliffs at Arch Rock on Cape Liptrap (for location, see Figure 1b, Gardner, this volume) is indicative of such episodic aridity. This project correlates these arid landforms to known global sea levels using Optically Stimulated Luminescent (OSL) dating techniques. Aeolianite units are lithified dunes composed of quartz and shell fragments and are separated by paleosols formed between periods of dune activity. A complete schematic stratigraphic section from Cape Liptrap showing nine aeolianites (units 1-9, oldest to youngest) separated by eight paleosols (units A-H, oldest to youngest) is shown in figure 1a. The alternation between intervals of dune activity and stability in this stratigraphic sequence reflects a cycle of intermittent aridity. Variation in cross-bed orientation, carbonate content, and grain size of aeolianite units follow trends indicative of longer-term paleoenvironment changes. Four OSL ages indicate that deposition of this sequence occurred during the earliest part of the last glacial cycle.

Dune fields once extended from the continental interior to the southeastern coastline (Hill and Bowler, 1995). During arid phases sparse vegetation allows the mobilization of dunes over large areas. Episodes of aridity are often correlated with glacial periods; greater latitudinal temperature gradients result in intensified atmospheric circulation causing higher wind speeds, and cooler ocean temperatures reduce precipitation (Bowler, 1976). Vegetation dominates during wetter periods stabilizing sand dunes and facilitating pedogenesis (Zhou et al., 1994).

Methods

Along the sea cliff exposures at Arch rock, no single vertical transect exposes the entire sequence of paleosols; units may be below sea level, merge together, or have been eroded. Forty-five transects spaced at 20m intervals along the cliff were correlated to create a map defining each dune building phases. From this map, a complete stratigraphic column was the constructed. The dip directions of cross-beds in each aeolianite unit were measured.

OSL ages were obtained for four aeolianite samples collected in PVC piping. Radioactive dose rates were measured at each sample location and used in the calculation of sample ages at two laboratories in Australia, CIRSO and Bequerel (Smith, pers. com.). Aeolianites are ideal for OSL dating because exposure to sunlight during transport resets the internal electron structure. The correlation of OSL ages with global sea level is based on compiled sea level curve from Darter (2000).

Inorganic carbon content was measured with a coulometer, as an indicator of the amount of shell fragments in dunes. Particle size analysis was conducted using a Coulter LS 230 laser particle-size analyzer. A qualitative description of angularity and the freshness of concoidal quartz fractures was preformed using a binocular microscope.

LITHOLOGY

Individual aeolianite units are less than 40 m thick and are well cemented (except units 3 and 4). During wetting and drying cycles $CaCO_3$ in shells is dissolved by rainwater. This $CaCO_3$ is precipitated during subsequent evaporation forming cement. Aeolianite units display large tabular planar cross bed sets less than 10 m high characteristic of linear dunes. However, trough cross bedding in units 3 and 4 are consistent with parabolic dunes.

Paleosols are dark colored horizons devoid of bedding or cement. Three horizons can be distinguished within individual paleosols. The upper horizon is darkest with the most organic material. The middle horizon is tan sand. The lowest horizon contains well-cemented calcite nodules with knobby root systems formed from the precipitation of $CaCO_3$ leached from the upper two horizons. Paleosols contain sand and atmospheric dust that accumulates through time on stabilized dunes (Zhou et al., 1994). Longer periods of soil development cause increasingly thick and well-defined horizons. The relative development of paleosols is schematically represented in Figure 1a by the thickness of lines showing paleosols. Paleosol D is particularly well developed while C and H are the most poorly developed.

RESULTS

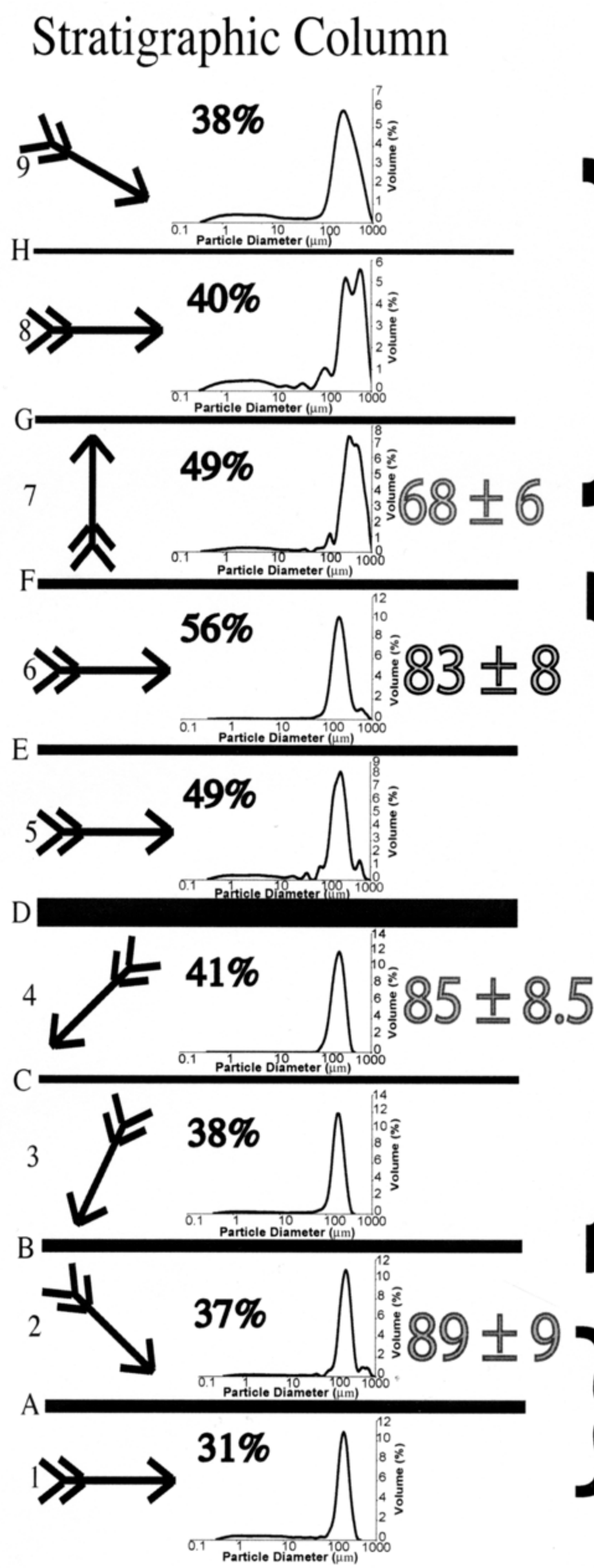
A summary of results is shown in Figure 1a. The OSL ages of aeolianite units 2, 4, 6 and 7 were calculated to be 89 ± 9 ka, 85 ± 8.5 ka, 83 ± 8, and 68 ± 6, respectively. The deposition of aeolianite and paleosol units 1-F occurred during Oxygen Isotope Stage (OIS) 5, an interglacial period with high sea levels. Units 7 and younger were deposited since the beginning of OIS 4, a glacial period with rapidly falling sea levels. Lack of stratigraphic inversion strengthens our confidence in the reliability of OSL ages.

Bimodal grain size distributions are observed in some units. Sand grains between 100 and 400 μm are present in all aeolianites. Coarser sand is present in significant amounts in aeolianite units 7, 8 and 9. Units 8 and 9 also have a substantially higher dust content than other aeolianites. Carbonate content increases systematically through units 1-6, but then decreases through units 7-9. The orientation of cross bedding indicates westerly winds in aeolianite unit 1, gradually shifting clockwise to northeasterly by unit 4. Units 5 and 6 again show westerly winds. Units 7-9 show a switch from southerly to northwesterly winds.

DISCUSION

The influx of coarse-grains beginning in unit 7 reflects a drop in sea level by 68 ka. Presently, Cape Liptrap is pounded by a large swell from the southwest that travels through the Bass Straight separating Australia and Tasmania. This creates a powerful surf zone that can produce sand between 100 and 400 μm. The King Island Rise is currently a submerged ridge extending north from Tasmania, but was exposed during the sea level drop of OIS 4 and blocked oceanic swell from reaching Cape Liptrap (Jennings, 1959). At lower sea levels a regressing shore face moved onto a flat region called the Bassian Depression causing a significantly lower shore face gradient. As a result, wave energy was dissipated over a long distance by bottom friction, greatly reducing the power of breaking waves. Sand grains on beaches abandoned during the OIS 4 sea level fall were exposed to a lower wave energy resulting in a general coarsening. The sand source for units 7, 8 and 9 may have extended 100s of km onto the continental shelf exposed during low sea levels. This is in sharp contrast to units 5 and 6 whose sand source is relatively proximal sand deposits plowed up from the continental shelf by a transgressing coastline (Webb and Grimes, in press). The greater thickness of units 5 and 6 is the result of suddenly mobilizing a closer sand source.

Poor cementation and parabolic dune type observed in aeolianites 3 and 4 reflects periods of dune construction unrelated to aridity. Poor cementation indicates a decrease in the number of wetting and drying cycles because dunes remained consistently moist (Yaalon 1967). In addition, parabolic dune structure is often associated with wetter climates (Hill and Bowler, 1995). This dune type suggests units 3 and 4 are like modern day parabolic dunes that extend back from the shore a short distance before vegetation stabilized them. If so, units 3 and 4 were deposited at a location comparable to the modern shoreline. This is



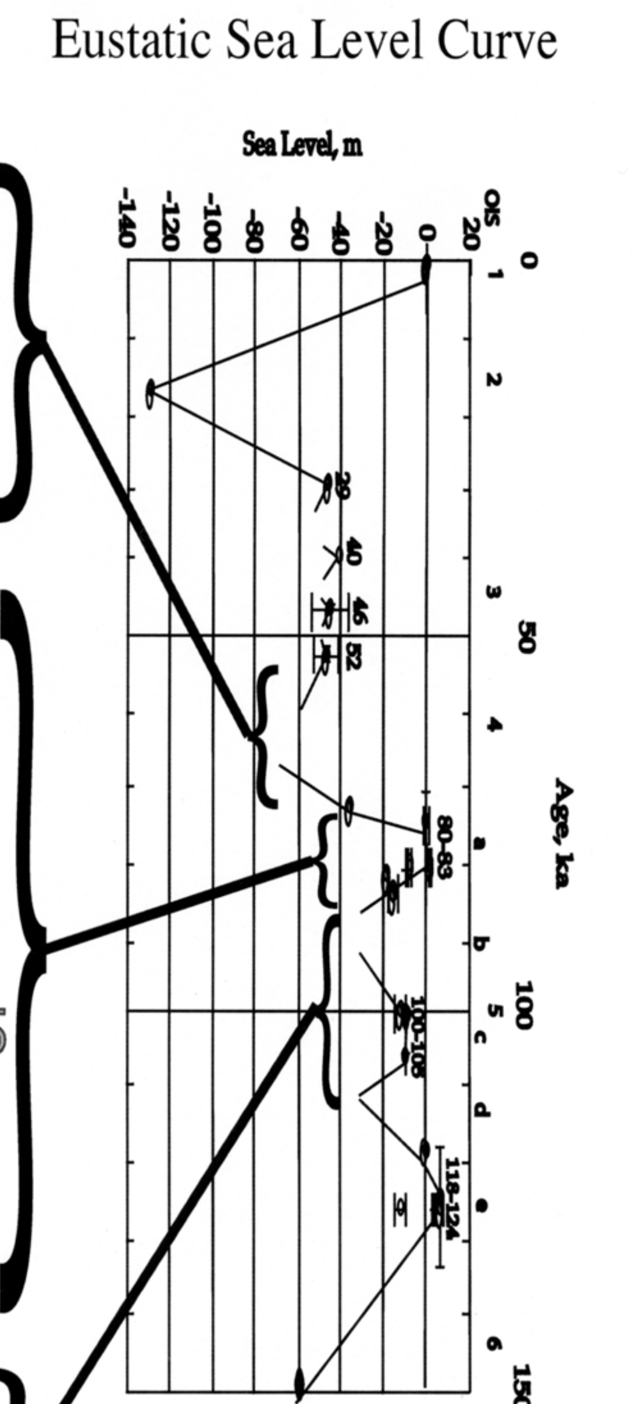
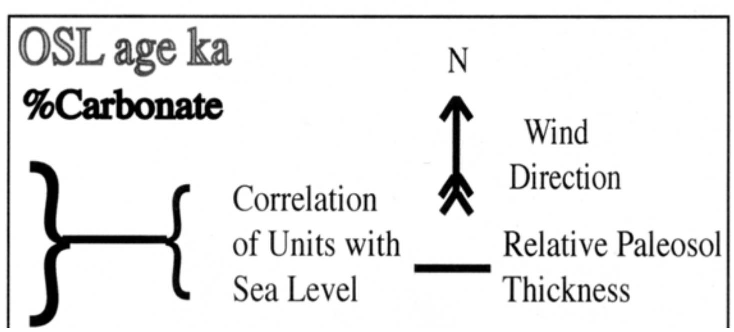


Figure 1b. Eustatic Sea level from Darter (2000) correlated with stratigraphy and OSL ages. OIS are displayed on sea level curve.

Figure 1a. A schematic stratigraphic column. Aeolianite units labeled 1-9, paleosol units labled A-H, oldest to youngest, respectivly. Calculated wind direction, carbonate percentage, and grain size distribution for each aeolanite unit



likely because OIS 5a sea level was similar to modern sea level. This interpretation is supported by the highest occurrence of angular grains with fresh concoidal fractures in units 3 and 4 and suggests a short aeolian transport distance.

Figure 1 shows the correlation of (a) stratigraphic units with (b) a eustatic sea level curve. Correlations are based on stratigraphic evidence and OSL ages. The OSL age of 89 ± 9 ka for unit 2 suggest it formed during OIS 5b. It is likely that paleosols A and aeolianite 1 also formed during OIS 5b, but they may be correlated to OIS 5c and 5d, respectively. Paleosols B-F and aeolianites 3-6 were deposited during OIS 5a based on two OSL ages of 85 ± 8.5 ka and 83 ± 8 ka and evidence that units 3 and 4 were deposited during sea level high stand. However, only units 5 and 6 represent certain periods of aridity within this stage. The 68 ± 6 ka aeolianite unit 7 was deposited during OIS 4 based on the influx of larger sand grains. A large spike in the dust flux in Antarctic ice cores is associated with increased aridity during the glacial period of OIS 4 (Petit et al., 1990). This may be used as a stratigraphic marker indicating the elevated dust levels observed in units 8 and 9 can also be correlated to OIS 4 or the onset of OIS 3.

The seven, arid dune building events observed at Arch Rock occur more frequently (on the order of one every 7 ka) than glacial cycles making it is imposable to correlate dune building with a specific eustatic sea level. The two observed periods of dune building during OIS 5a must be brief because the high degree of soil development requires significant periods of dune stability. Paleosols may form during glacial periods despite a general increase in aridity. However, the poor development of paleosol H suggests that periods of stability are relatively short during glacial periods. The general increase in aridity causes dune activity to last relatively long with brief episodes of stability. In a wetter inter-glacial climate the opposite occurs producing longer periods of stability with short bursts of dune activity.

CONCLUSION

A strong correlation between aeolianite formation and a eustatic sea level curve can be made based on OSL ages and stratigraphic observation. Dune formation alternates regularly with periods of stability independent of sea level. A minimum of seven distinct dune building phases during a single interglacial to glacial transition are exposed, indicating more frequent cycles of aridity superimposed on large scale climate change. Glacial cycles may determine the duration and extent of dune building but are not the sole cause of dune activity. The large number of temporally distinct dunes enables a detailed reconstruction of wind patterns between OIS 5b and OIS 4 that may greatly aid climatic reconstruction of this period.

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