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Wind transport of foraminiferal tests into subaerial dunes: an example from western Ireland

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INTRODUCTION

The empty tests of dead foraminifera behave as sedimentary particles and are subject to transport, although their different shapes and effectively low density means that their hydraulic equivalence is greater than that of spherical quartz grains (see Haake, 1962). Their estimated traction velocities range from *c*. 4 cm s^{-1} to *c*. 13 cm s^{-1} (Snyder *et al*., 1999). The presence of calcareous foraminiferal tests in a fossil sedimentary deposit would normally be taken as an indication of deposition in a marine environment. However, it has long been known that wind can transport tests from a carbonate beach into adjacent carbonate dunes as in Dogs Bay, Connemara, Eire (Murray, 1973) and Abu Dhabi, Persian Gulf (Murray, 1970). The purpose of this Notebook is to provide some details of the Dogs Bay occurrence and to comment on how such deposits might be recognized in the rock record.

In western Ireland the coastal geology consists of hard rocks, yet the beaches are commonly composed primarily of calcareous bioclastic sands (Guilcher & King, 1961; Keary, 1967). Dogs Bay (Lat. 53° 24' N Long. 9° 58' W) lies on the west-facing side of a tombola which is approximately 200 m wide and 400 m long. The tombola is made up of sand dunes that are mainly vegetated except along the margins adjacent to the beaches. Dogs Bay is exposed to Atlantic storms and the surface layer of the beach is reworked on each tidal cycle. Both the beach and the dunes are composed of bioclasts, especially those of bivalve and gastropod shells but also with echinoderm and barnacle debris and tests of foraminifera and are fairly typical of a temperate heterozoan association (nomenclature of James, 1997). The carbonate content is around 84–90% (Guilcher & King, 1961; Keary, 1967). Based on traditional sieving methods, the median grain size is 0.152 mm and 0.150 mm in Dogs Bay and Gurteen Bay, respectively, and the Trask sorting 1.395 and 1.33 (Guilcher & King, 1961). These authors point out that the swash carries more material up the beach than would be the case if the sands were denser. Also, because the sand has high porosity, the water is able to penetrate more rapidly, thus reducing the volume of the backwash. These processes favour the landward transport of particles.

PREVIOUS WORK ON FORAMINIFERA OF DOGS BAY

A fairly diverse fauna of 58 species and varieties, including both benthic and planktonic forms, was recorded by Alcock (1865, 1868) from the beach sands, while Wright (1900) increased the list to 124 species and varieties. Both authors examined large volumes of material in order to compile their faunal lists. Although he did not specifically mention the presence of foraminiferal tests in the sand dunes backing the bay, Wright noted that the sand ‘extends for a long distance beyond high water mark, being blown inland by the prevailing westerly winds’. In 1965 I was given a sample (#502) of the Dogs Bay dune sand. This has an abundance of foraminifera dominated by *Cibicides lobatulus* and has been used as an example of wind transport in my books (Murray, 1973, 1991, 2006).

NEW MATERIAL

In May 2008 I had the opportunity to collect samples from Dogs Bay. With a hand lens it was possible to see that foraminifera were common in both the beach and dune sands. Because the beach sand is reworked by waves on every tide it was not likely that any forms would be living, so the samples were not preserved in alcohol. Sample 3897 was taken from the beach close to high water, sample 3898 about 4 m above beach level between marram grass in the dunes on the seaward side of the tombola. A further sample (#3899) from the dunes was taken on the landward side of the tombola facing the beach in Gurteen Bay. The beach sample 3897 was washed on a 63 μm sieve to remove salt and dried; the dune samples were already dry. All samples were picked without carrying out a flotation. Size analysis was carried out in a settling column (after treatment in a sonic bath to ensure that no air bubbles were trapped in hollow particles) and the statistics were calculated (assuming a density of 2.65) according to the methodology of Folk & Ward (1957) and grain size according to Soulsby (1997).

DATA

The foraminiferal and sedimentological data are summarized in Table 1. The beach sand is finer than the dune sands but all are well sorted; skewness is negative in the beach sand and positive in the dune sands. The proportion of foraminifera to other calcareous bioclasts is higher in the beach sample (25–28%) than in the seaward dune sample (8–19%) and the landward dune sample by Gurteen Bay (2–3%). By far the most abundant species is *Cibicides lobatulus* (#3897 69%; #3898 70%; #3899 55%). Species attaining 5% include *Textularia truncata* and *Rosalina* sp. in the beach sample (#3897), *Textularia sagittula* group and *Gaudryina rudis* in both dune samples and *Elphidium crispum* in the dune by Gurteen Bay (#3989). Species diversity is low in all the samples but marginally higher in the beach than in the dunes (Fisher α 5.0 compared with 3.7). The proportion of attached forms is very high: 91% in the beach and seaward dune and 96% in the dune by Gurteen Bay.

The proportion of damaged benthic tests increases from 90% in the beach to 99–100% in the dune samples. The damage includes not only breakage or loss of the final chamber but also breakage of earlier chambers, and abrasion of the test margin sometimes leaving just the central axis of the test as in some miliolids. The maximum diameter of *Cibicides lobatulus* is much

	Beach #3897	Dune #3898	Dune #3899
Foraminifera			
Percentage			
Gaudryina rudis	0	8	10
Textularia sagittula	1	5	13
Textularia truncata	11	0	0
Cibicides lobatulus	69	70	55
Elphidium crispum	0	4	8
Rosalina sp.	7	2	0
Count	273	274	273
Number of species	20	16	16
Fisher alpha	4.97	3.7	3.7
% Planktonic	7	0	0
% damaged benthic tests	90	99	100
% attached forms	91	91	86
Sediment			
Mean diameter (mm)	0.147	0.287	0.317
Sorting	0.419	0.424	0.379
Skewness	−0.170	0.178	0.379

Table 1. Summary of sediment size analysis and species present ≥5%.

the same in all samples at *c*. 300 μm. Two species with robust tests, *Gaudryina rudis* and *Elphidium crispum*, are absent from the counted beach assemblage (although they are probably present in very low abundance and hence not encountered in a count of 250 individuals); their maximum diameter is 300 μm and 400–500 μm, respectively, in the dune assemblages. Although planktonic tests constitute 7% of the foraminiferal assemblage in the beach sand, they are absent from the dune samples. The planktonic tests are small (generally <150 μm in diameter) and most are damaged.

DISCUSSION

Because these biogenic sands are not composed of near-spherical grains but flat and discoid particles, it is more meaningful to carry out size analysis using a settling column rather than sieving. Contrary to the views of Guilcher & King (1961), the beach sand is well sorted, as are the dune sands and the latter are coarser. Furthermore, the negative skewness of the beach sand is typical of surf beaches and the positive skewness of the dunes is typical of dunes (<0.1 and >0.1, respectively, Tanner, 1991).

In their study of nearby Mannin and Clifden Bays, Connemara, Lees *et al*. (1969) found *Cibicides lobatulus* to be dominant living on the sediment except in the inner part of the bays and also on seaweeds especially from the outer parts of the bays; '*Discorbis columbiensis*' is commonest on the shallow-water seaweeds. Both species are present on pebbles, together with *Discorbis bradyi*, *D. columbiensis*, *Gavelinopsis praegeri* and *Textularia conica*. The dead assemblages from the outer bay sediments are dominated by *Cibicides lobatulus*, *Gaudryina rudis* and *Eponides* cf. *E. concameratus*. Fine sands are dominated by *C. lobatulus* and *D. columbiensis*. Transport is considered to be an important process, with size of deposited tests varying with that of the enclosing sediment; tests are transported towards the shore and are most abundant in the inner part of the sand blanket. It seems likely that the living foraminiferal faunas of the inner shelf off Dogs Bay and the transport processes operating there are very similar to those described from Mannin and Clifden bays.

How might it be recognized that the foraminferal assemblages of the beach and dunes are not *in situ*? There are several lines of evidence.

- Planktonic tests are not normally present in beach assemblages so their occurrence here is unusual; however, because of their mode of life the presence of planktonic tests in sediment is always the result of transport (even if only vertical descent).
- The majority of individuals are of benthic species that live attached or clinging to firm substrates such as rocks and weeds but their tests are now loose in sediment. At the minimum they have been released from attachment but they may also have been transported laterally away from the source area.
- A very high proportion of the tests are damaged, indicating bed-load transport; evidence of abrasion is more obvious in robust forms, such as *G. rudis* and *E. crispum*; the thinner-walled, lighter tests of *C. lobatulus* may be more readily transported partly in suspension in the water and therefore suffer less damage.
- The size distribution of tests with a predominance of larger forms indicates post mortem loss of smaller forms.
- Species diversity is low for such a marine assemblage.

If the foraminiferal assemblages are recognized as not *in situ*, the next question to ask is what is the source of the material? By analogy with nearby Clifden and Mannin bays, the majority of taxa in the Dogs Bay sediments are epifaunal from a high energy inner-shelf setting; mud-loving species are conspicuous by their rarity or absence.

If these beach and dune sediments were preserved in the rock record how might the depositional environment be recognized? The most obvious environmental options are subtidal inner shelf or intertidal beach because of the faunal make-up. However, it is not unusual for dunes to be present along coastal regions so perhaps these should always be considered as a further possible depositional environment. This raises the question of whether it is possible to distinguish between the water-lain assemblages of the beach and the subaerially deposited assemblages of the dunes. There are no obvious microfaunal criteria to make this distinction. Although the enclosing bioclastic sediment of the dunes is essentially the same as that of the beach, they show significant differences of skewness. There may also be evidence from sediment geometry and/or the presence of cross-bedding that will contribute to determining the most likely depositional setting.

Both the Dogs Bay and Abu Dhabi examples of foraminiferal tests in contemporary dunes are in carbonate sands. The same transport processes operate in areas of clastic sedimentation and, in the Thar Desert of NW India, foraminifera have been blown as far as 800 km inland (Goudie & Sperling, 1977). However, there may be a smaller chance that calcareous foraminiferal tests will escape post-depositional dissolution in areas subject to heavy rainfall and corrosive pore waters.

In summary, when attempting to make a palaeoecological interpretation of foraminiferal assemblages that show clear evidence of strong transport (high proportion of broken tests and test abrasion; size sorting) do not automatically assume subaqueous deposition but also consider wind transport and subaerial deposition as alternative options, especially if the sediments are carbonates and if they show skewness >0.1.

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