

Linear dunes, their structure, age and migration

The aims of this project are to solve a long-standing debate on the development and migration of linear dunes, to use GPR to image the internal structure of linear dunes and test models for the structure of linear dunes and determine their age. The objectives are to answer questions such as:

1. How are linear dunes formed?
2. Do linear dunes move sideways?
3. Are linear dunes Pleistocene relics?
4. Why are linear dunes so common in modern deserts but rarely recognised in the rock record?

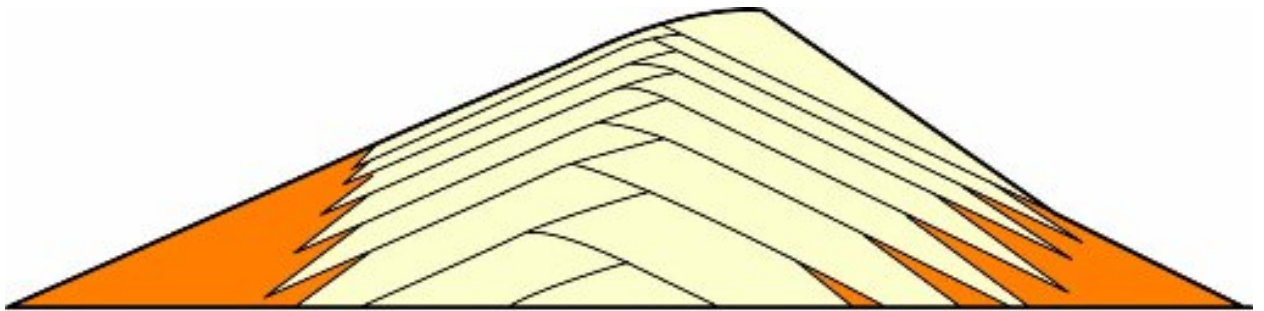


Why are linear dunes rarely recognised in the rock record?

The debate was crystallised in a paper by Rubin and Hunter (1985) who recognised that while linear dunes form around 40% of the dunes in modern sandy deserts they are rarely recognised in the rock record. Rubin and Hunter suggested that the apparent lack of linear dunes in the rock record might be because the existing models for the structure of linear dunes are incorrect, i.e. linear dune deposits are present in the rock record but we can't recognise them because we don't know what their deposits look like and therefore we don't know what we are looking for.

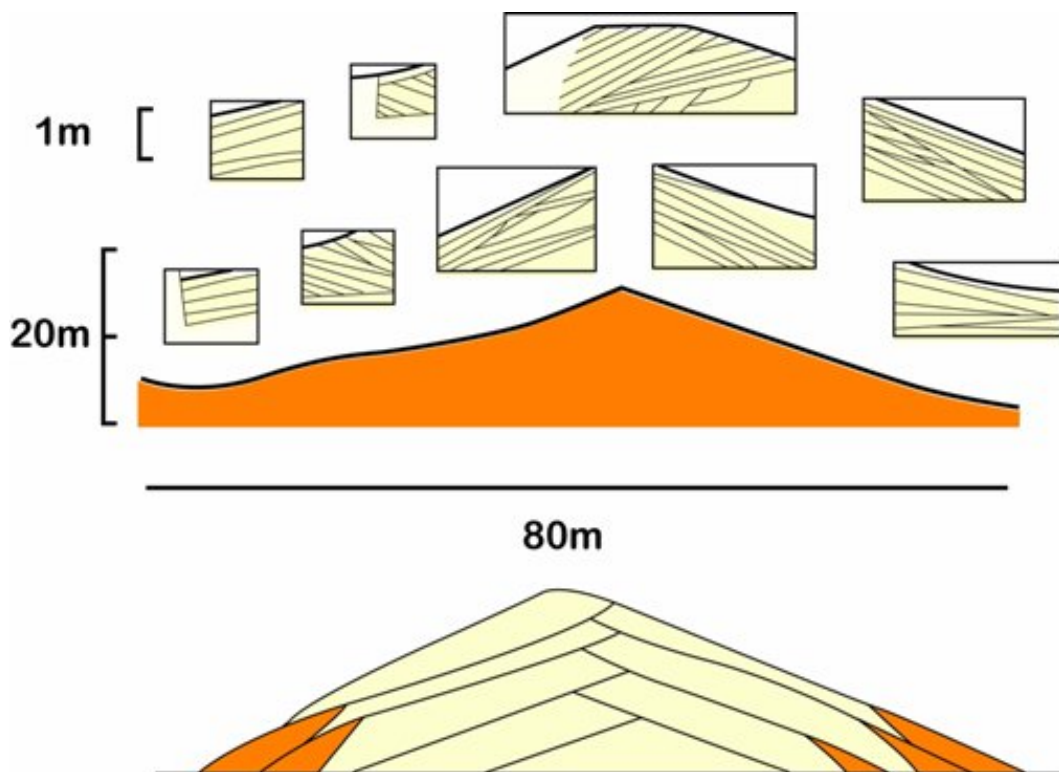
While the structure of most other dunes has been determined from observations of trenched sections through sand dunes most notably by Ed McKee (e.g. McKee 1979), the large size of linear dunes had prevented any in depth study of their structure.

There have been at least four different models for the internal structure of linear dunes starting with Bagnold (1941) who thought that opposing winds would converge causing the dune to accrete vertically with strata dipping parallel to the dune flanks in a tent like structure overlapping at the crest.



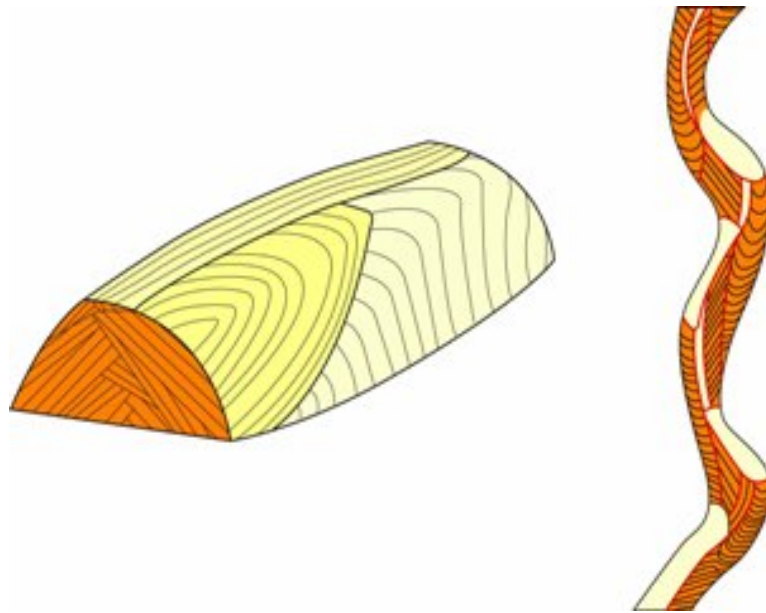
Bagnold (1941)

This view was supported by McKee and Tibbitts (1964) who inspected cross-strata in shallow trenches dug into a linear dune in Libya.

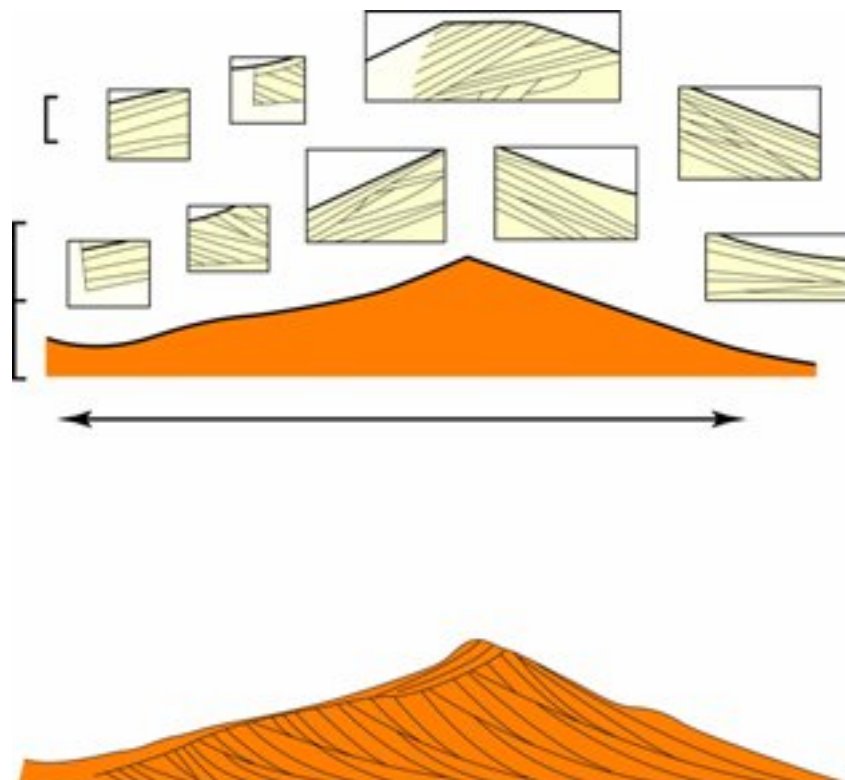


McKee and Tibbitts (1964)

Haim Tsoar used observations of cross-strata exposed on the flanks of a sinuous linear dune after a rain storm to develop a model where the strata are formed within the sinuous curves of the linear dune (Tsoar 1982).



Rubin and Hunter (1985) reinterpreted the field evidence from McKee and Tibbitts and used computer models to simulate the structures within linear dunes. They produced alternative models showing that lateral migration of linear dunes could generate structures that would resemble cross-strata in transverse dunes. In addition they also illustrated the effects of superimposed dunes migrating along the flanks of linear dunes.

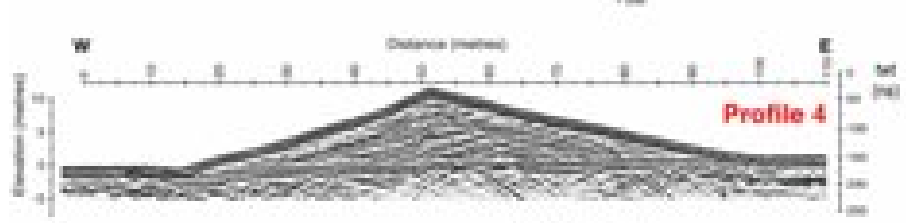
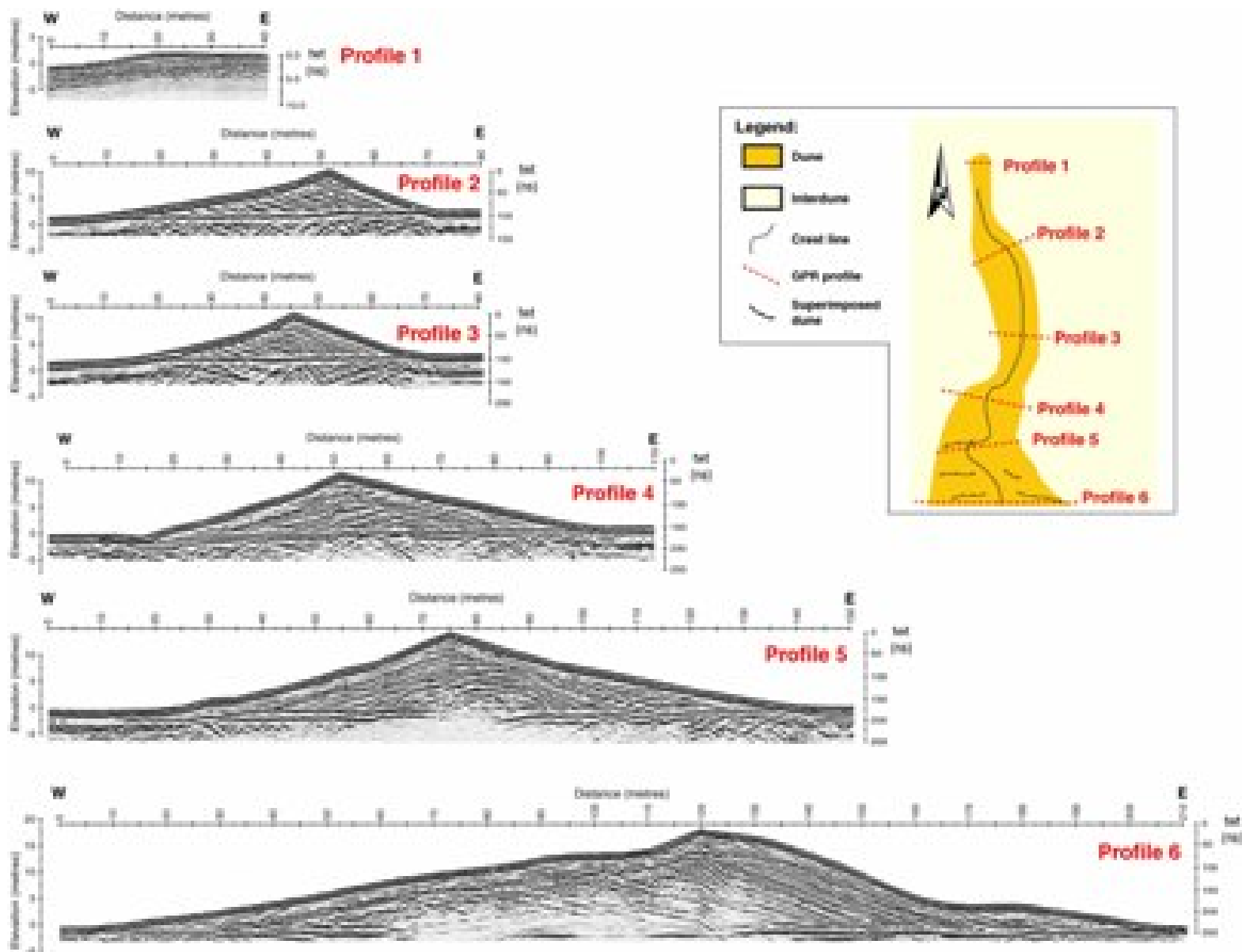


Namibia 1999

In order to test the models for the internal structure of linear dunes I used Ground Penetrating Radar (GPR) to image the internal structure of three linear dunes near Gobabeb in Namibia.



The results show that GPR can image cross-strata within sand dunes. The cross-strata within the dune show three patterns. 1) unimodal cross-strata (profiles 2 and 3) which could be mistaken for sets of cross stratification formed by a transverse dune as suggested by Rubin and Hunter (1985). 2) bimodal dips (profiles 4 and 5) which are dip towards the outside of the sinuous curves in the dune crest and are most likely produced as sinuous curves propagate along the length of the dune. 3) Trough cross-strata from superimposed dunes.

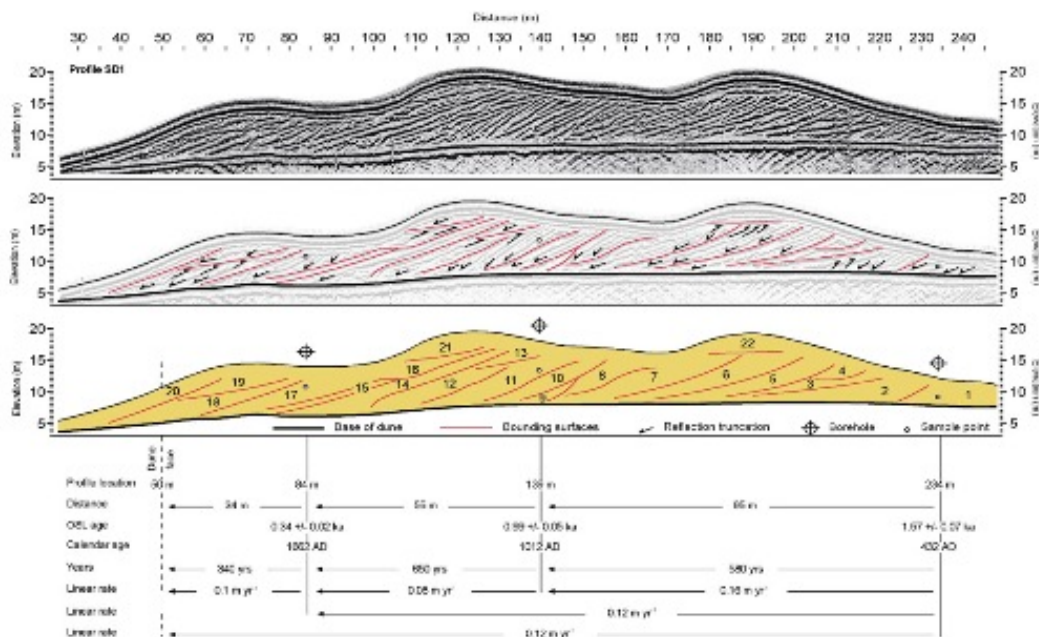


The results are published in Nature magazine (Bristow et al. 2000).



Namibia 2002

Having successfully demonstrated that GPR could be used to image sedimentary structures within linear dunes in Namibia the next objective was to find out how old the dunes are and determine the evolution of the dunes and their past rates of migration. Cross-strata within dunes imaged on GPR profiles show which way a dune has been migrating and bounding surfaces between sets of cross-strata indicate erosion and breaks in deposition. Interpretation of cross-cutting relationships between sets of cross-strata within the dunes and the laws of superposition provides the basis for working out the relative age of the dune. This provides the basis for working out the relative age of the dune deposits, which strata were deposited first, second, third etc.



Sampling Strategy

Having established a relative chronology for the dune deposits from the sets of cross-strata and bounding surfaces the next objective was to select locations for dating. Two strategies for selecting sample locations were devised. First to sample either side of major bounding surfaces; this would show the duration of time gaps represented by the bounding surfaces, and bracket sets of cross-strata giving the best record of the dune chronology with constraints upon both the periods of deposition represented by the cross-strata as well as the duration of hiatus represented by bounding surfaces. The problem with this strategy was that it required very accurate sample location to ensure samples were either side of the bounding surfaces. Ensuring accuracy in the subsurface is an issue due to uncertainties surrounding the time to depth calibration of the GPR signal velocity and the resolution of the GPR at between $\frac{1}{2}$ and $\frac{1}{4}$ of the wavelength of the signal in the dune. In addition, there were practical concerns regarding the accurate location of the drilling rig on the dune and accurate sample depth. As a consequence we chose an alternative sampling strategy, avoiding bounding surfaces and sampling the larger sets of cross-strata. This strategy avoided the resolution issues, allowed some flexibility in positioning the drilling rig and sample depth, and directly sampled the dune when it appeared to have been most active forming large sets of cross-strata.

Drilling dunes

Having selected sample locations the next problem was getting the samples. Drilling sand dunes is not easy because the sands flow filling in the boreholes and OSL samples have to be kept in the dark and not exposed to sunlight. We rented a percussion auger mounted on the back of a 4x4 Mercedes truck from the Council for Geosciences in South Africa with Alf the driller. Getting a large Mercedes truck into the dunes presented formidable logistic problems but with a lot of hard work from the locals at Gobabeb we made it across the Kuiseb river, through some soft sand and into the Namib Sand Sea.



We succeeded in getting the drilling rig into position on Station dune where we drilled three boreholes, the results are reported in Bristow et al.(2005).



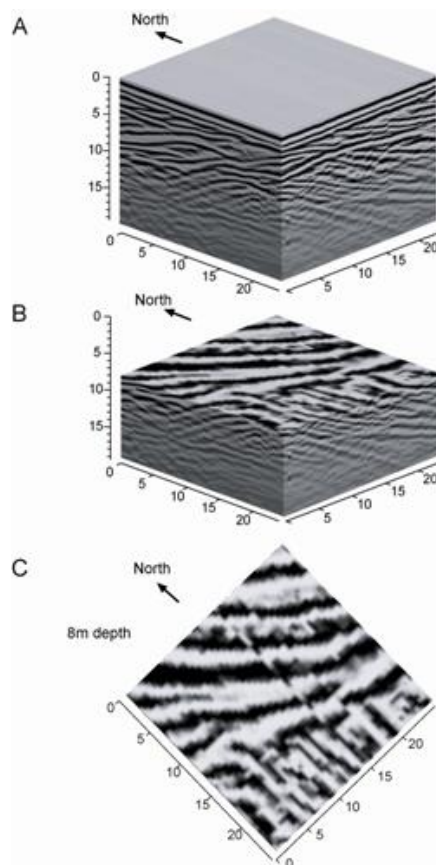
We also got the rig up Warsaw Dune where we drilled seven holes and collected 20 samples for optical dating. The results are reported in Bristow et al. (2007).



The drilling rig on Puff Adder dune (samples from this location have not been dated).



Having got the truck 250m up the side of 65m high linear dune the drilling stopped at 10m and despite repeated efforts that was as far the percussion auger would go. Ten m was not enough and we had to try again (see 2004 Return to Namibia).



We also collected 3-D data sets in 25 x 25m blocks on the flanks of the dune. The data cubes show the geometry of sets of cross-strata produced by the superimposed dunes migrating along the flanks of the big linear dune. This shows some similarities with the models of Rubin and Hunter (1985).

Namibia 2004

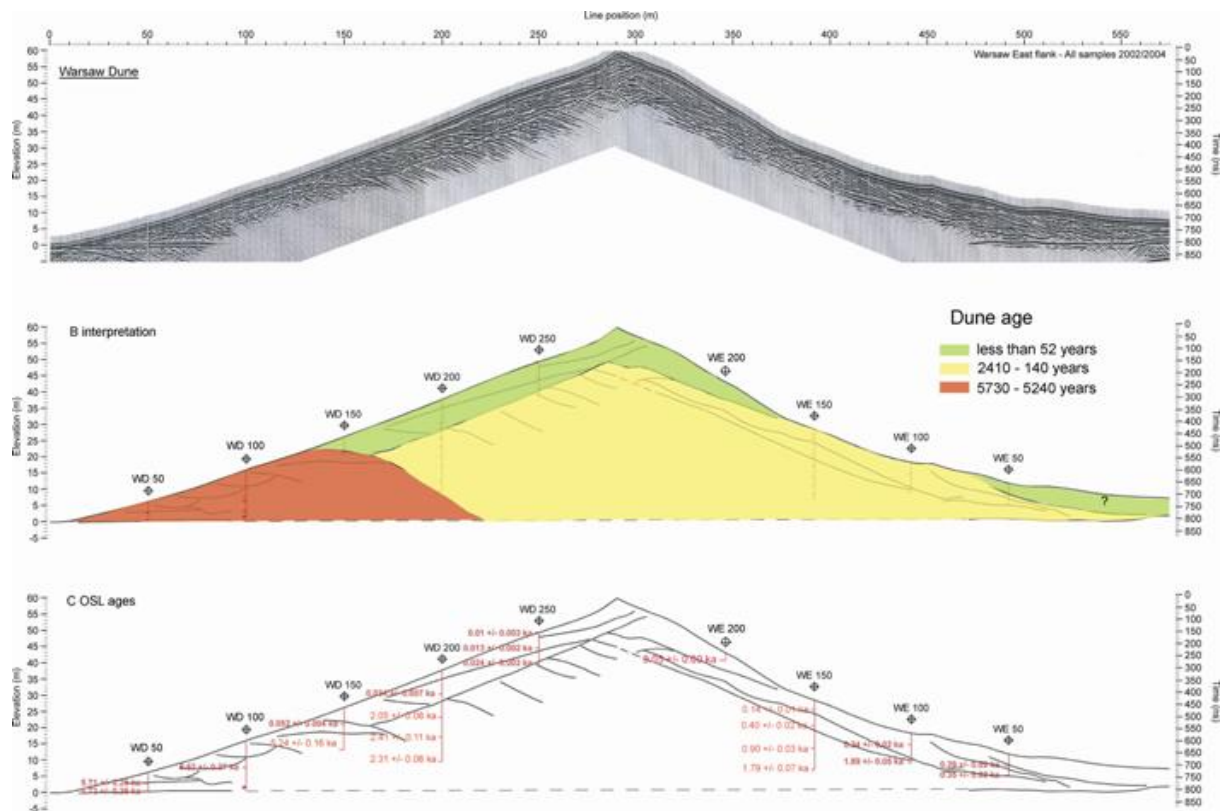
Penetrating to the core of the dune:

Return to Namibia with Geoff Duller, Simon Bailey and seven undergraduate students from UCL. In order to complete the sampling at Warsaw dune we rented a Doremr Sand Auger with Roelph and Tim the drillers who drove up from South Africa. This time the drilling was more successful and we augered down to 28.5m in the dune well below the unconformity visible on the GPR profile. The reason that we stopped at 28.5m was concern that we might not be able to pull the auger out if we went much deeper. With three new auger holes on Warsaw dune and nineteen more samples for optical dating we now had 45 samples from the two drilling campaigns. Of these Geoff Duller dated 21 enabling us to reconstruct the history of the dunes evolution (Bristow et al. 2007).



Dune evolution and climate

The results show that the oldest part of the dune is 5700 years old. The age is significant because it is a mid Holocene age, this refutes ideas that the large linear dunes might be remnants of the last glacial maximum. It does not mean that they did not exit during the LGM but it shows that the dunes have moved to their present position during the Holocene. The oldest samples come from the lower west side of the dune and the ages decrease vertically and towards the east. These younging trends indicate that it has migrated from west to east corroborating reflections on the GPR profiles that dip from west to East. Most of this migration appears to have occurred between 2410 ± 110 and 140 ± 10 years ago. There appears to have been an hiatus in the dune development between 5240 ± 160 and 2410 ± 110 suggesting that the climate was different at that time, either wetter or with a different wind regime which prevented dune construction. The youngest sets of cross-strata, less than 50 years old are produced by superimposed dunes migrating along the flanks of the linear dune.

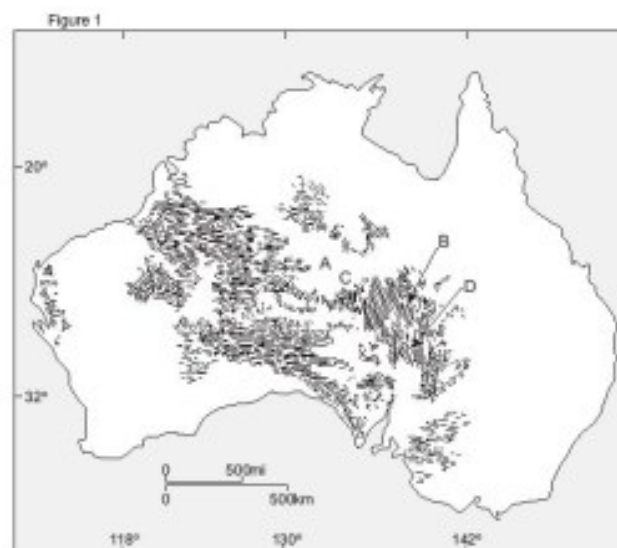


In addition, we collected a GPR profile across a star dune at Harubes.



Field work in Namibia was funded through a NERC small grant to Bristow and by the American Chemical Society Petroleum Research Fund through a grant to Lancaster and Bristow.

Accretion on Vegetated Linear Dunes in Australia

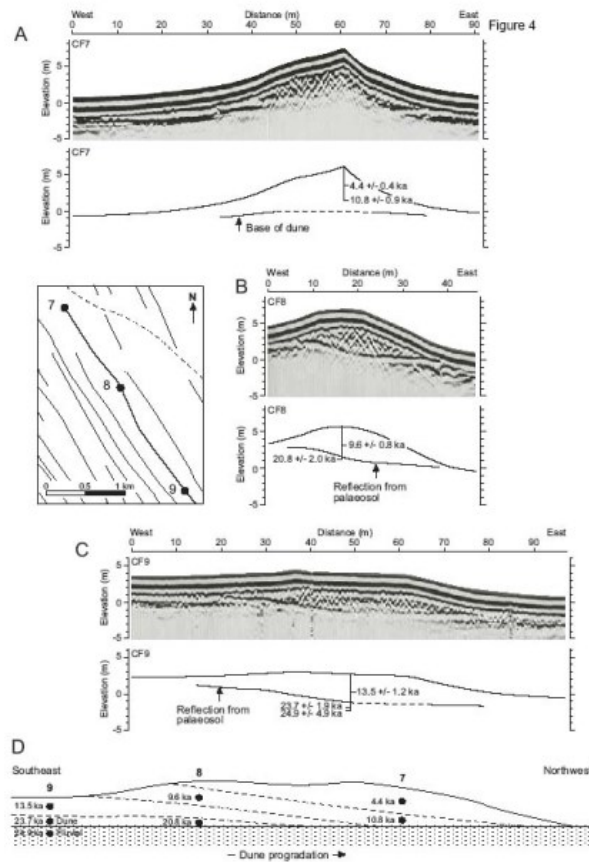


Linear dunes cover around 40% of the land area of Australia and dominate much of the continental interior especially in the Simpson and Strzelecki deserts.

I made an extensive tour of these deserts with Cameron Hollands and a Toyota Hilux in 2003 and we collected GPR profiles across many linear dunes. In Australia the linear dunes are largely vegetated and this helps to stabilise the dunes which can be can be thousands of years old (e.g. Hollands et al 2006).



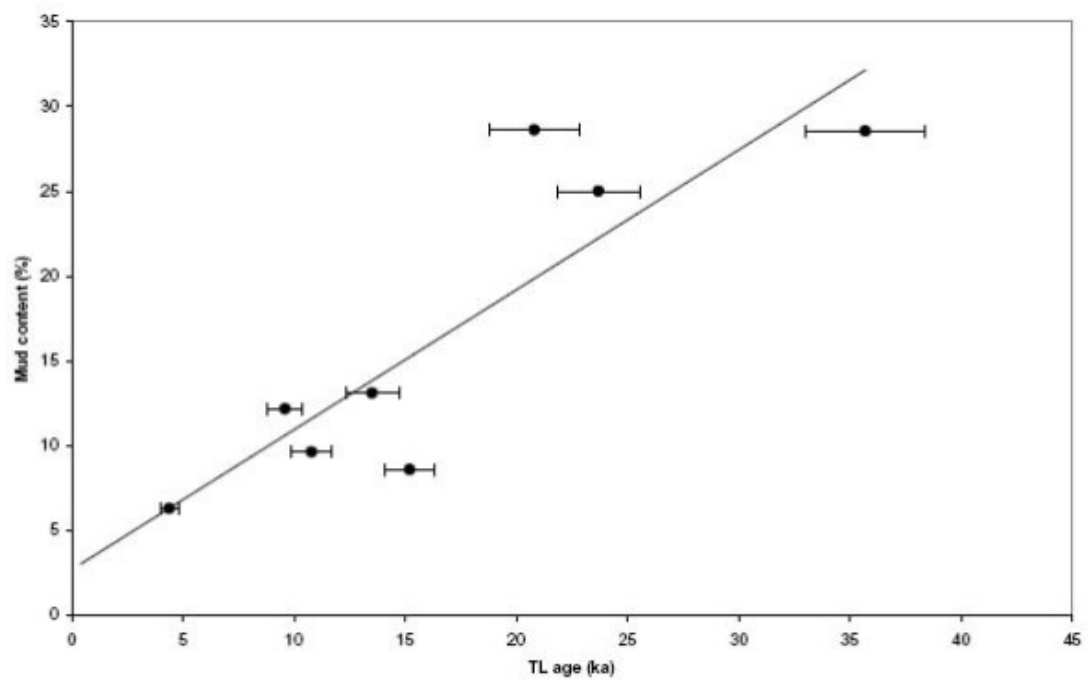
In contrast to other desert dunes the results of GPR surveys in Australia were disappointing with depths of penetration limited to 5m. In addition there was little or no imaging of sedimentary structures (Bristow et al 2007).



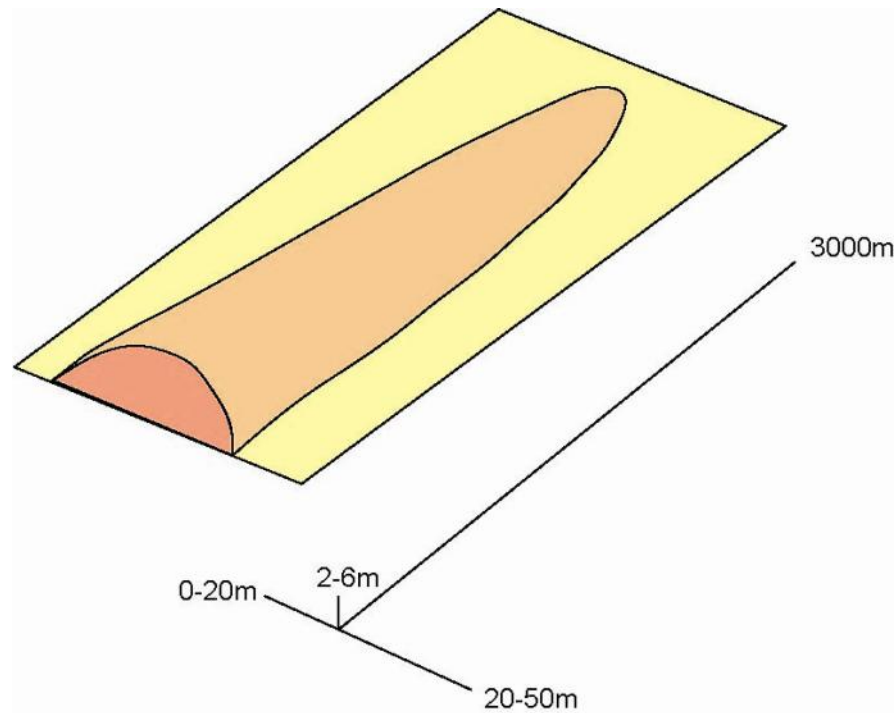
There appear to be two reasons why GPR was not very effective in the linear dunes of Australia. Firstly the linear dunes sometimes lack internal sedimentary structures due to pedogenic alteration and bioturbation which has destratified the dune sands. Secondly there is a high clay and silt (mud) content which has attenuated the GPR signal.



However, GPR was able to image some palaeosols within the dunes and using thermoluminescence ages some useful results were produced from the field work.



Results show that fine grained silt and clay sized particles can exceed 35% of a dune sand and that the fines increase with dune. The most likely explanation is that suggests that clay illuviation causes a progressive increase in clay content through time within Australian desert dunes. The high clay content has several effects; the clay minerals attenuate GPR signals, in addition, the clay probably helps to indurate and stabilise the dunes reducing their mobility.



Linear dune accretion on vegetated linear dunes in Australia
(modified from Bristow et al 2007)

Age profiles through and along linear dunes combined with GPR indicate that dune extension is the dominant mechanism of dune accretion; with vertical accretion (2-6m), lateral accretion 90-50) both exceeded by dune extension at 3000m in the past 10,000 years (Bristow et al 2007)

Publications

Bagnold, R.A. 1941, *The Physics of Blown Sand and Desert Dunes.*, Methuen, London.

Bristow, C. S., Lancaster, N. & Duller, G. A. T., 2005, Combining ground penetrating radar surveys and optical dating to determine dune migration in Namibia. *Journal of the Geological Society*, Volume 162, Part 2, p. 315-322

Bristow, C.S., Bailey, S.D., & Lancaster, N. 2000, The sedimentary structure of linear sand dunes. *Nature* 406, p.56-59.

Bristow, C.S., and Lancaster, N., 2004, Movement of a small slipfaceless dome dune in the Namib Sand Sea, Namibia. *Geomorphology* 59, p.189-196.

Bristow, C.S., Duller, G.A.T., & Lancaster, N., 2007, Age and dynamics of linear dunes in the Namib desert. *Geology* G23369AR

Bristow, C.S., Jones, B.G., Nanson, G.C., Hollands, C., Coleman, M., Price, D.M., 2007, GPR surveys of vegetated linear dune stratigraphy in central Australia: Evidence for linear dune extension with vertical and lateral migration. In Baker, G.S., and Jol, H.M., Eds. *Stratigraphic analysis Using GPR*, Geological Society of America Special Paper 432, p.19-34, doi: 10.1130/2007.2432(02).

Hollands, C.B., Nanson, G.C., Jones, B.G., Bristow, C.S., Price, D.M., Pietsch, T.J., 2006, Aeolian–fluvial interaction: evidence for Late Quaternary channel change and wind-rift linear dune formation in the northwestern Simpson Desert, Australia. *Quaternary Science Reviews*, 25, p. 142-162

McKee, E. D., 1979, *A Study of Global Sand Seas*, USGS Prof Pap1052.

McKee, E. & Tibbitts, G.C., Jr. 1964, Primary structures of a seif dune and associated deposits in Libya. *J Sed. Pet.* **34**, p.5-17

Rubin, D.M. & Hunter, R.E. 1985, Why deposits of longitudinal dunes are rarely recognised in the geologic record. *Sedimentology* **32**, p.147-157.

Tsoar, H., 1982, Internal structure and surface geometry of longitudinal seif dunes. *J Sed. Pet.* **52**, p.823-831.

