

Impact case study (REF3b)

<p>Institution: University College London (UCL)/Birkbeck College</p>
<p>Unit of Assessment: 7 – Earth Systems and Environmental Sciences</p>
<p>Title of case study: Methods to determine sand dune migration benefiting engineering and hydrocarbon companies</p>
<p>1. Summary of the impact (indicative maximum 100 words)</p> <p>Research conducted within Birkbeck’s Department of Earth and Planetary Sciences led to the development of remote sensing and geophysical/geochronological methods to determine the movements of sand dunes. These techniques are now used by engineering and petroleum companies to plan pipeline routes and infrastructure in deserts, where migrating sand dunes are a problem because they can bury or damage infrastructure. For example, ARUP Consulting have already used the new methods to inform recommended alignments of pipelines in two multi-million pound engineering projects, and have changed their business practice to include the techniques in their tender documents for infrastructure projects in desert regions.</p>
<p>2. Underpinning research</p> <p>The use of ground-penetrating radar (GPR) to study sand dune stratigraphy was pioneered by Birkbeck’s Charlie Bristow (Lecturer 1989-2008; Reader 2008-12; Professor of Sedimentology 2012-present) [1]. This geophysical technique is effective at imaging the large-scale sedimentary structures in sand dunes, and can also be used to identify buried objects within a dune and to locate the base of a dune so that its thickness can be estimated.</p> <p>Bristow’s first GPR study of sand dune stratigraphy, conducted in 1996, imaged sedimentary structures within dunes in Abu Dhabi, and included a comparison of the radar images with trenched sections to provide ground truth and to check the accuracy of the radar interpretation [1]. This work was followed by an investigation of the structure of linear dunes in Namibia, which found clear evidence that this type of dune can migrate laterally [2]. Further investigation of the migration of sand dunes was then conducted using a novel combination of GPR with optically stimulated luminescence (OSL), a technique that enables dune sands to be dated. GPR profiles were used to deduce a relative chronology of the sands within a dune, and then this data was used to design an efficient strategy for dune dating using OSL [3], enabling the longer-term rates of dune migration to be determined. This new methodology was then used to document long-term (greater than 1,000 years) dune aggradation and to test models of dune stratigraphy [4]. This work was conducted in collaboration with Geoff Duller at the University of Wales, who conducted the OSL dating, and Nick Lancaster at the Desert Research Institute in the US, who participated in the fieldwork.</p> <p>Whilst the migration of sand dunes over long timescales can be effectively quantified using Bristow’s GPR technique, their short-term dynamics have traditionally been monitored through detailed field surveys or long-term surveillance of stakes planted in dune fields. Recognising that short-term surveys are labour and time intensive, Birkbeck’s Pieter Vermeesch (RCUK Academic Fellow 2007-2011; Senior Lecturer 2012) developed a new and more convenient approach to monitor the speed and sand flux of migrating dunes, building on the hand-based methods employed by King’s College’s Nick Drake, who introduced the then-current methodology to Vermeesch [5]. The approach uses a change detection algorithm, known as COSI-Corr (Co-registration of Optically Sensed Images and Correlation), that extracts displacement fields from pairs of optical satellite imagery. COSI-Corr was developed in 2007 by Caltech geophysicists Sebastien Leprince and Francois Ayoub, and has been applied in various fields of geomorphology, the most important of which are studies of earthquakes, glaciers and slow-moving landslides.</p> <p>By applying the COSI-Corr change detection algorithm to pairs of high-resolution optical satellite images taken at different times, Vermeesch was able to monitor the migration of dunes in the Bodélé Depression of northern Chad over time intervals of one month to 6.5 years [5]. The displacement maps generated from each pair of satellite images were then used to automatically distinguish dunes from interdunes. By interpolating a surface between the interdune areas and</p>

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subtracting it from the surface observed by the satellite images, dune heights and volumes were then obtained over fine spatial and temporal scales. From this, pixel-by-pixel estimates of sand flux were generated, confirming that the Bodélé contains some of the world's fastest moving dunes [5]. Dune migration rates are a sensitive proxy for the 'effective windiness' of desert areas because sand flux scales with the cube of wind speed. To take advantage of this proxy, Vermeesch extended the COSI-Corr algorithm to compare several satellite images sequentially. In collaboration with Caltech's Sebastien Leprince, who provided access to COSI-Corr's source code, the new technique was then applied to a 26-year long sequence of archival satellite imagery from the Bodélé Depression [6]. The results showed for the first time that dune velocity, and therefore wind speed, have remained remarkably constant in this region since 1984.

3. References to the research

- [1] Internal structure of aeolian dunes in Abu Dhabi determined using ground penetrating radar, C. S. Bristow, J. Pugh and T. Goodall, *Sedimentology*, 43, 995-1003 (1996) doi:[10.1111/j.1365-3091.1996.tb01515.x](https://doi.org/10.1111/j.1365-3091.1996.tb01515.x)
- [2] The sedimentary structure of linear sand dunes, C. S. Bristow, S. D. Bailey and N. Lancaster, *Nature*, 406, 56-59 (2000) doi:[10.1038/35017536](https://doi.org/10.1038/35017536)
- [3] Combining ground penetrating radar surveys and optical dating to determine dune migration in Namibia, C. S. Bristow, N. Lancaster and G. A. T. Duller, *Journal of the Geological Society*, 162, 315-322 (2005) doi:[10.1144/0016-764903-120](https://doi.org/10.1144/0016-764903-120)
- [4] Age and dynamics of linear dunes in the Namib desert, C. S. Bristow, G. A. T. Duller and N. Lancaster, *Geology*, 35, 555-558 (2007) doi:[10.1130/G23369A.1](https://doi.org/10.1130/G23369A.1)
- [5] Remotely sensed dune celerity and sand flux measurements of the world's fastest barchans (Bodélé, Chad), P. Vermeesch and N. Drake, *Geophysical Research Letters*, 35, L24404 (2008) doi:[10.1029/2008GL035921](https://doi.org/10.1029/2008GL035921)
- [6] A 45-year time series of dune mobility indicating constant windiness over the central Sahara, P. Vermeesch and S. Leprince, *Geophysical Research Letters*, 39, L14401 (2012) doi:[10.1029/2012GL052592](https://doi.org/10.1029/2012GL052592)

References [2], [4] and [5] best indicate the quality of the underpinning research.

Relevant research grants:

- (i) NERC small grant to Bristow GR9/04055 (£13,250), The structure of linear dunes: A GPR survey in the Namib sand sea (1999-2000)
- (ii) American Chemical Society Petroleum Research Fund, GLRW2 grant to Bristow and Lancaster (US \$160,000), Internal Sedimentary Structure of Linear Sand Dunes (2001-2004).

4. Details of the impact

The migration of sand dunes can be a huge problem for the construction of pipelines through desert terrain. This is because a dune could migrate on to a pipeline and bury it, or migrate away from a pipeline and leave it suspended ('free-spanning'), which could result in a fracture and a damaging leak of oil or gas. Wind-blown sand is also a hazard to pipelines as it causes abrasion and blocks filters. In addition, safety regulations in the countries concerned often demand that pipelines be buried to a specific depth (e.g. 2m in Algeria), which is difficult to achieve in a mobile dune field.

The method developed by Birkbeck's Vermeesch allows hydrocarbon companies to use COSI-Corr to identify desert areas with the greatest sand flux (where dunes are most active) and areas with

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low sand flux (where dunes are least active). They can then use this information to plan the location of pipelines and other desert infrastructure to militate against damage from wind-blown sand.

The determination of the thickness of active dunes using GPR, as first demonstrated in Birkbeck research, is also useful to the hydrocarbon industry. It helps to constrain pipeline construction cost estimates, which depend on the volume of sand that has to be moved during construction, and also helps determine the safe burial depth for a pipeline. Past practice was to route pipelines around dune fields, but this is not possible in parts of Arabia and the Sahara where oil and gas fields are directly overlain by dune fields. Given typical construction costs of \$1-\$5 million per kilometre, deviating pipelines is inherently expensive, so it is critical to know the safest, most direct route.

Following publication of the underpinning research and presentations at conferences, links were formed in 2009 with a geomorphology consultancy, Ebor Geoscience Ltd., which advises the hydrocarbon industry on the natural hazards posed by migrating sand dunes. This led to a number of pilot studies being commissioned by leading hydrocarbon companies to evaluate the commercial benefits of the new methodologies.

In 2010, BG commissioned and invested £68,818 in a study (through Birkbeck's research office) of sand dunes in the Grand Erg Occidental using the GPR method. The aim of the study was to determine the thickness of active sand dunes within a sand sea where dune migration is identified as a hazard for oil and gas pipelines and the construction of processing facilities. Within the Grand Erg Occidental, GPR was used to determine if dune sands were thick enough for pipeline construction, to test models of dune stratigraphy and to determine if there is a layer of mobile dunes migrating over older stabilised dunes, as well as to pick sample points for OSL dating to determine longer-term rates of sand dune migration. The results provided a demonstration that the methodology is suitable for identifying areas that are most prone to wind-blown erosion and sand accumulation (i.e. where dunes are most active), as well as for locating stable areas that are better suited to construction. Companies also commissioned and invested money in pilot studies using the COSI-Corr method in Algeria and Libya in 2010-11: £13,000 by BP, £5,000 by ARUP Consulting and £3,500 by Pipeline Routing Ltd.

The Director of Ebor Geoscience, which served as an intermediary between the companies (BP, BG, ARUP and Pipeline) and the Birkbeck researchers who conducted the pilot studies, reports that these studies "confirmed that GPR and COSI-Corr represent a cost-effective way to quantify the mobility of sand dunes over annual to millennial time scales, providing key constraints on the assessment of geo-hazards in arid areas." [A]

Although recent political instability in North Africa has set back many new infrastructure projects, with some companies withdrawing from the area, companies have recognised from the pilot studies that these new methods provide an advantage over competitors, and have therefore adopted the technology. ARUP has used the new techniques on two separate, very large multi-million pound pipeline engineering projects in the Algerian desert in 2010 (In Salah Gas for BP [B] and Hassi Ba Hamou for BG [B, C]). Both methodologies were used to inform the recommended alignment of the route for construction of the pipelines [B]. The work has also informed decisions that will result in long-term maintenance cost savings, estimated by ARUP to be in the order of several millions of US dollars. The feedback from their clients (BP and BG) on the results of these techniques has been very favourable [B]. The Associate Director of ARUP reported: "Our clients benefit from application of these techniques through the better informed decisions and subsequent cost savings that are made by refining the alignment of major infrastructure." [B]

Furthermore, as a result of these initial studies and the recognition that these methods provide an advantage over competitors, companies have changed their practices to include assessment of future damage by wind-blown sand in their tender documents for infrastructure projects in desert regions.

For example, Pipeline Routing Ltd. has changed their business model and will include the COSI-

Corr methodology in future tender documents. In addition, they are developing an asset management model based on constant modelling of sand dune migration [D]. The company's Director said: "COSI-Corr has had a tangible impact on our work because we can now quantify the movement of the 'terrain', enabling a classification process to feed in to a Geo-Hazard risk register" [D]. Pipeline Ltd. produces maps of natural hazards for engineers to use when picking optimal routes for new pipelines that minimise the risk at an affordable cost; the company sees COSI-Corr as an important tool to quantify the risk posed by migrating sand dunes.

In 2012, ARUP also changed their practice to include assessment of future damage by wind-blown sand in their tender documents for infrastructure projects in desert regions. Their Associate Director said: "Working with Professor Bristow and Dr Vermeesch, and application of these new techniques, has resulted in a step change in our practice for this type of work." [B] ARUP has tendered for multi-million pound projects using the new methodologies, including a railway in the Emirates (2013) and two projects for which contracts had been won by the end of July 2013: a BG pipeline, and a pipeline and gathering station for Petroceltic, all in Algeria [E].

ARUP has also benefited from the enhanced reputation brought about by the success of their COSI-Corr and GPR work. The Associate Director said: "ARUP benefits by gaining technical advantage that helps us win future work. We cannot estimate the amount of commercial work that has been won directly as a result but we do feel our work with UCL has enhanced our reputation and this does protect existing workload and lead to future work with our clients." [B]

5. Sources to corroborate the impact

[A] Supporting statement from the Director of Ebor Geoscience Ltd. – corroborates that the pilot studies with BP, BG, ARUP and Pipeline confirmed that GPR and COSI-Corr represent a cost-effective way to quantify the mobility of sand dunes. Available on request.

[B] Supporting statement from the Associate Director of ARUP Consulting – corroborates the use of the techniques to inform recommended pipeline routes and decisions that will result in long-term maintenance cost savings. Also corroborates the favourable client feedback, the change in practices at ARUP and the impact on ARUP's reputation and workload. Available on request.

[C] Hassi Ba Hamou Algeria Project, Preliminary Engineering Geological and Geotechnical Reconnaissance Interpretative Report (for BG North Sea Holdings Ltd.), ARUP (2011) – corroborates ARUP's use of the GRP technique on the Hassi Ba Hamou project for BG and that this informed the recommended pipeline route (e.g. see the Executive Summary, pages i-v). Available on request.

[D] Supporting statement from the Director of Pipeline Routing Ltd. – corroborates that the research has had an impact on the work of Pipeline. Available on request.

[E] The Associate Director of ARUP Consulting can be contacted to corroborate the use of the new methodologies in three tenders by ARUP in 2013. Contact details provided separately.