# GPR stratigraphy of a large active dune on Parengarenga Sandspit, New Zealand

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The Parengarenga Sandspit (Figure 1) is New Zealand's only coastal source of silica sand for glass manufacturing. Concerns about the environmental effects of sand extraction from the harbor mouth in the last two decades led the extraction companies to instigate a monitoring program. The Parengarenga beach-dune-monitoring program started in 1982; since that time cross-profiles have been surveyed twice a year from below chart datum (CD) to landward of the sparsely vegetated foredune system. This is the longest continuous record of beach profile measurement in New Zealand, and provides important information on the behavior of this coastal spit system (Parnell, 1997). The sedimentary material in Parengarenga Sandspit consists of 93.5% quartz and has a very uniform fine, sandy grain size (median 193 microns) from near shore to the beach and in the dunes.

The interior of the spit is characterized by several solitary, unvegetated dunes separated by flat sparsely vegetated interdune areas (Figure 2). The solitary dunes, with the dominant morphology of star dunes, were not originally incorporated into the monitoring program, as it was not part of the aim of the survey and their variability was considered small (time scales of a few years). However, the longer the program is maintained, the larger the role of the inland dunes as sediment source or sinks may become. The dominant wind direction in New Zealand's Far North is from the southwest to south (Figure 3), which explains the presence of the largest eolian dunes on the windward west coast. Parengarenga Sandspit is on the leeward side of the island, where strong secondary winds from the east-northeast interfere with the dominant winds from the southwest (Figure 3) and sector the driving force for coastal dune development.

In addition to the beach-dune-monitoring program, our research on the spit over the past years has focused on its long-term (Quaternary) evolution. The interdune area covers around 70% of the spit and is characterized by occasional outcrops of so-called "coffee rock" (Figure 4). This semi-consolidated paleosol formed at the top of a sequence of beach and dune sediments. These sediments have been dated by thermoluminescence to 69 400 ± 13 900 years BP, which is regarded as a minimum age. Organic material in the podzol-type paleosol has been dated by $^{14}$C to 32 900 ± 1650 to 20 600 ± 50 years BP and suggests that the spit was densely vegetated at the time of formation. However, at present little is known about the extent of the coffee rock surface on the sandspit and under the solitary dunes. Furthermore, it is unclear whether the coffee rock consists of one single surface or that multiple levels can be recognized.

With these considerations in mind, a ground-penetrating radar (GPR) survey was undertaken to (1) explore the possibilities for mapping the lateral continuity of the coffee rock, (2) study the sedimentary architecture and stratigraphy of the solitary dunes, and (3) reconstruct the wind regime on the sandspit.

**Method.** In recent years, GPR has become a more popular geophysical technique to study subsurface sediments as it allows for rapid acquisition of high-resolution images of the sedimentary architecture. GPR measures changes in the electromagnetic properties of subsurface features that cause reflection of transmitted electromagnetic waves. These changes are mainly caused by variations in water content, which are in turn dependent on the textural properties (e.g., grain size distribution, porosity, organic matter content) of the sediment.

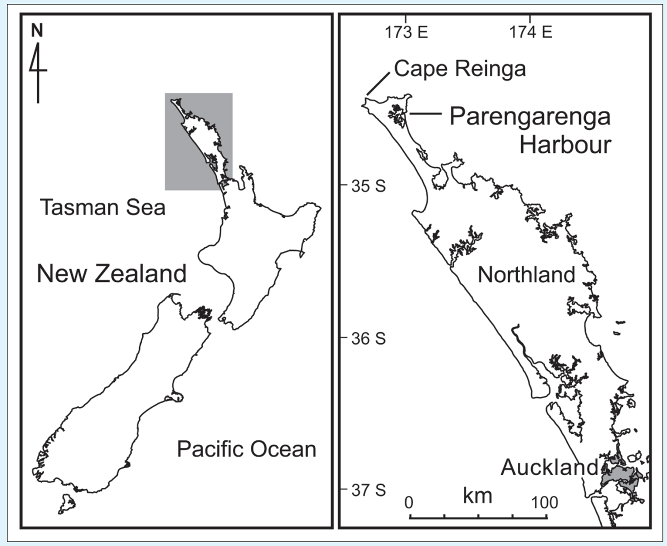


*Figure 1. Maps showing the location of Parengarenga Harbour in New Zealand.*

We used a GSSI SIR 2000 GPR system at two frequencies (a 35-MHz monostatic antenna and 200-MHz bistatic antennae) to survey one of the large solitary dunes on the spit (Figure 2). Survey line 1 follows the trend of the long axis (~300 m) of the dune and was measured with the 200-MHz antennae only. Survey line 2 is the inland extension of one of the topographic profiles measured in the beach-dune-monitoring program (3-3' Figure 2) and lies almost perpendicular to the long axis of the dune, spanning its 150-m long eastward face. The 35-MHz antenna survey along line 2 was extended to image the top part of the active western slipface of the dune. The interdune flat and foredune system were surveyed using both frequencies (dashed line in inset of Figure 2), but the results are not included here. The data were processed using the software RADAN-NT, manufactured by Geophysical Software Systems. The 200-MHz data needed little processing and are presented here after application of a time-zero correction, time-to-depth conversion, horizontal stacking, and distance normalization. The 35-MHz data were further processed using a high pass filter, a low pass filter, and migration.

**Results coffee rock.** The complete cross-section of the dune in GPR survey line 1 shows that the coffee rock is laterally continuous under the solitary dune (Figure 5). The radar signature for the coffee rock displays numerous hyperbolae, which can be attributed to its irregular surface (Figure 4). The

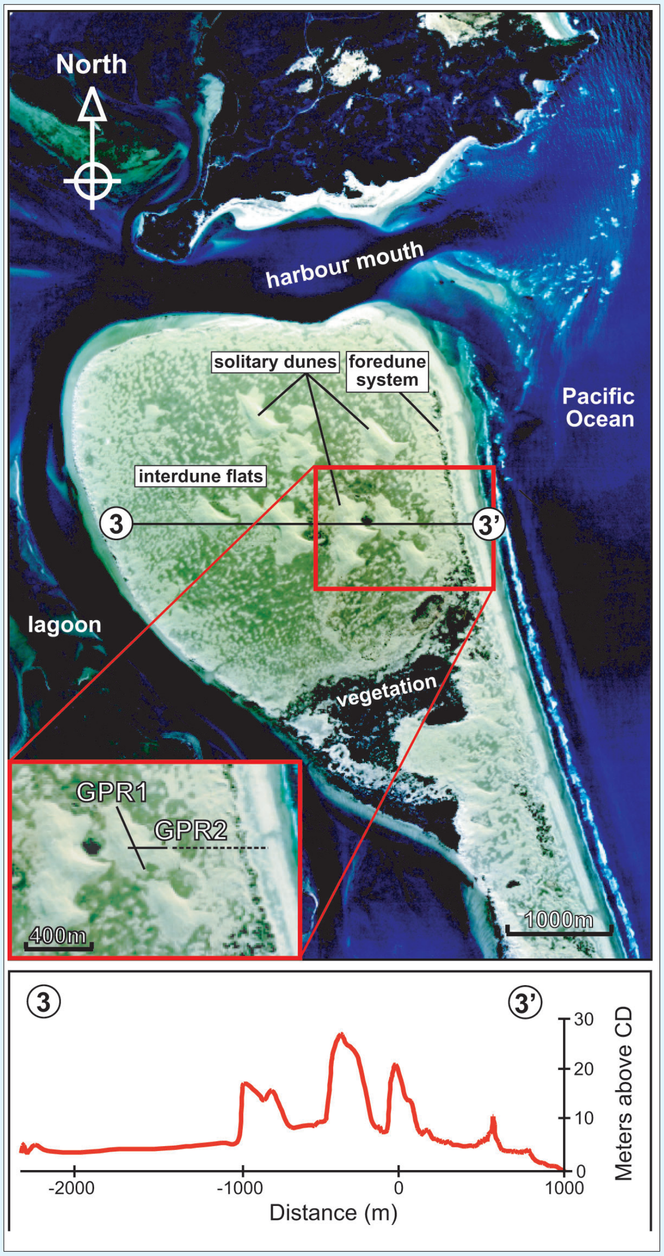


*Figure 2. Aerial photograph of Parengarenga Sandspit showing the harbour mouth, foredune system, solitary dunes, and interdune flats. The box and inset outline the location of the two GPR survey lines. The topographic profile (3-3’) across the full width of the sandspit shows the dimensions of the foredune system and the solitary dunes.*

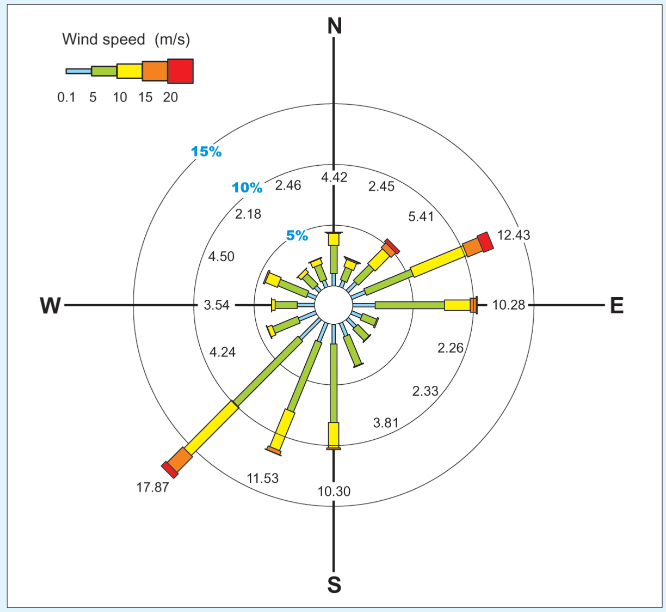


*Figure 3. Joint frequency distribution for hourly wind data from Cape Reinga (see Figure 1 for location) over the period May 1999 to May 2003. The length of the rods and the associated values show the percentage of time that the wind blew from each direction. The width and the color of the rods indicate the strength of the wind. Data were provided by NIWA. The plot was generated using RoseWorks 1.0, UAI Environmental, Inc.*

*Figure 4. Exposed coffee rock surface at Parengarenga Sandspit. Note the irregularly weathered surface.*

low permeability of the semiconsolidated paleosol causes perched groundwater tables and in Early Holocene this led to the formation of peat ($^{14}C$ dated at 7000-8000 years BP) on top of the coffee rock. The radar signature of the peat bodies, which seem to occupy irregularities in the coffee rock surface, is relatively transparent (Figures 5 and 6). The fact that diffraction hyperbolae occur beneath it demonstrates that the erosion and weathering of the coffee rock must have occurred prior to peat formation, in Late Pleistocene or Early Holocene. The topography observed in the coffee rock surface underneath the dune may result from this weathering or may be due to erroneous time-to-depth conversion (as caused by lateral variation in wave velocity).

The GPR data show that the interdune flats are also underlain by the coffee rock (Figures 5 and 6), which we confirmed by shallow trenching. The perched water table immobilizes the overlying dune sediments, which leads to the relatively flat sand sheet surface of the interdune area. Occasional small dunes move inland over this surface. They appear as small lighter spots on the aerial photograph in Figure 2.

**Results dune stratigraphy.** The solitary dune we studied

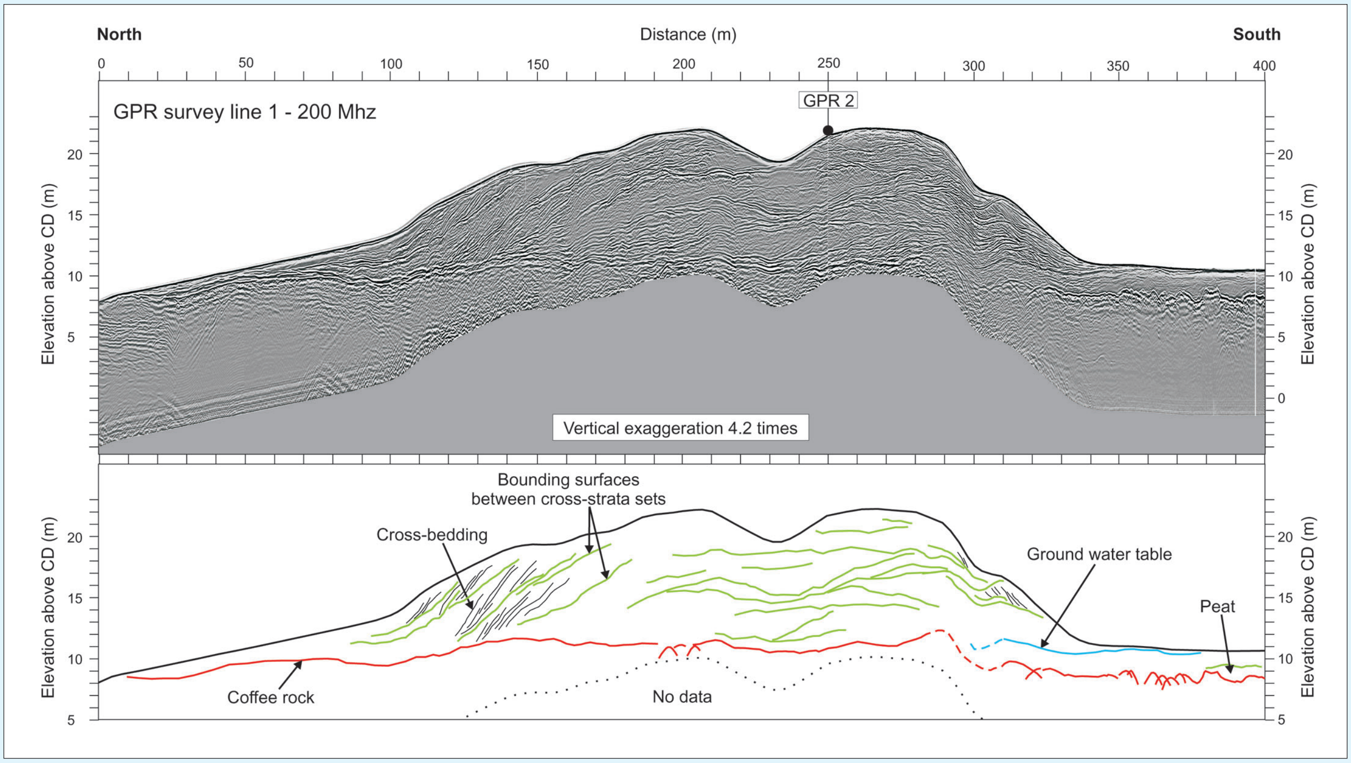


*Figure 5. Results for 200-MHz GPR survey of line 1 (top) and interpretation (bottom). Time-to-depth conversion was performed using a velocity of 0.11 m·ns$^{-1}$.*

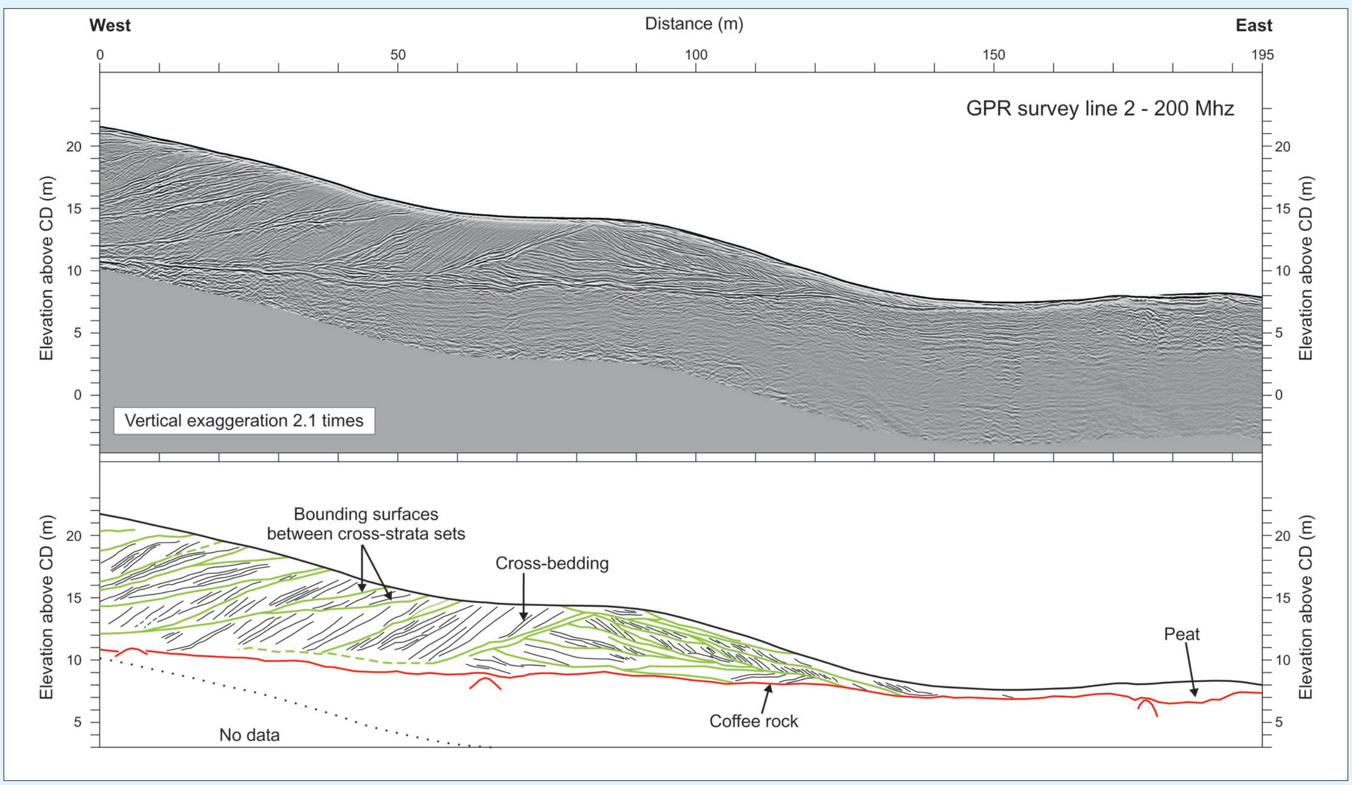


*Figure 6. Results for 200 MHz GPR survey of line 2 (top) and interpretation (bottom). Time-to-depth conversion was performed using a velocity of 0.11 m·ns$^{-1}$.*

has a maximum height of approximately 12 m, measured from the top of the coffee rock. Its arms radiating in different directions away from the center are a strong indication of a star dune origin. A striking feature of the sedimentary structures in the dune, interpreted from the GPR images, is that it contains steep foreset reflectors dipping in all windrose directions (Figures 5 and 6). Even though not all arms of the dune have been surveyed, the GPR images obtained indicate several phases of dune development.

The small plateau at around 90 m in the eastward-facing dune ramp (survey line 2) forms the core of the dune and is characterized by mainly eastward dipping cross-bedding in cross-strata sets of maximum 1.5 m thickness, which are separated by gently downwind dipping bounding surfaces

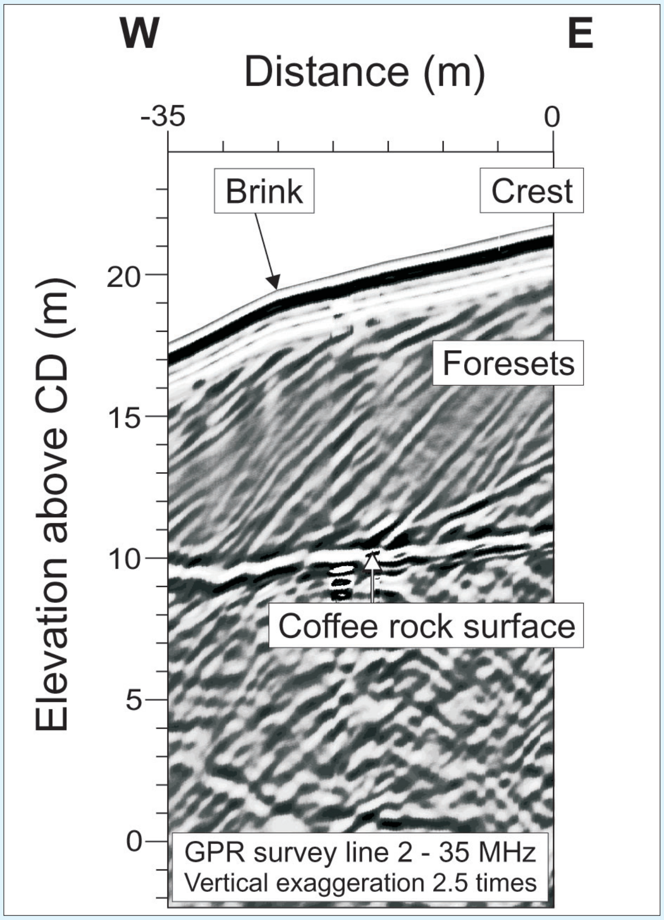


***Figure 7.*** *Image of the 35-MHz GPR survey of the westward extension of Line 2, across the largest active slipface of the dune. The dune brink is located at -25 m. Time-to-depth conversion was performed using a velocity of 0.11 m·ns$^{-1}$.*

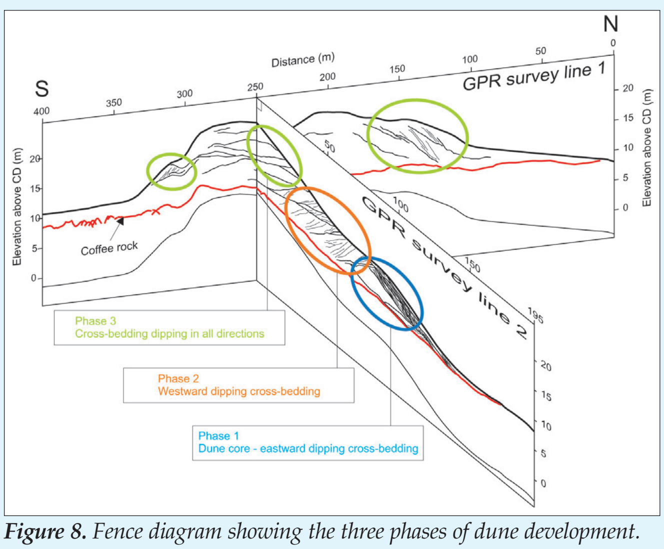


***Figure 8.*** *Fence diagram showing the three phases of dune development.*

(Figure 6). Some of the cross-bedding is less steeply inclined, especially in the lower part of the core. This indicates either horizontal sand sheet deposition (as occurs in the interdune flats) or a foreset dip direction which is not parallel with the GPR line.

The dune core is overlain and partly transected by a sediment body with large cross-strata sets of up to 4 m in height. The sets consist of predominantly steeply westward dipping cross-bedding (Figure 6). In the north-south trending profile (Figure 5) this section is characterized by mainly subhorizontal bounding surfaces (180-280 m), and no clear reflections from cross-bedding are visible. The westward migration of the dune is still active and forms the largest active slipface on the dune (Figure 7).

The most recent phase of dune development involves lateral expansion in both a northerly and southerly direction. Figure 5 clearly shows cross-bedding dipping in both directions. While the progress is dominantly toward the north, at the southern end of the dune the picture is partially obscured by an incorrect topographic correction at around 300 m. This phase of lateral dune growth coincides with the ongoing process of westward progradation.

**Discussion of dune development.** The Parengarenga Sandspit is exposed to wind from a wide range of directions (Figure 3). Therefore, it is not surprising that star dunes form to record variable directions of sand movement. Star dunes are characterized by slipfaces pointing in all directions and by arms spreading in opposing directions, so that star dunes often make little overall progress in terms of transgressing a surface (Livingstone and Warren, 1996). Most of the solitary dunes on Parengarenga Sandspit have several arms radiating from the center (Figure 2). The studied dune has active slipfaces to both west (Figure 6) and east (along the crest of the northward facing dune slope). In addition, the GPR survey indicates that the dune has been recently expanding to both the north and south (Figure 8), so that the geomorphological and radar evidence all strongly point toward a star dune morphogenesis.

Notwithstanding the above, the dominant feature on the GPR profiles is westward dipping cross-bedding (Figure 8). Together with the most active and largest slipface of the dune, this suggests that the studied dune is of combined star and transverse origin. The configuration and morphology of the other dunes on the spit support this model. The spit features two series of dunes that are lined up along east-west oriented lines (Figure 2). A total of five dunes are stacked along the east-west oriented topographical profile 3-3′ (the westernmost two dunes are positioned just north of the topographic survey), and all have a steeper westward than eastward face. Hence, although morphology of the dunes may be of star dune type, the predominant sand transport direction is toward the west.

**Conclusions.** This study demonstrated the potential of GPR to improve our knowledge of the Parengarenga Sandspit stratigraphy and its mode of development. In particular, the radar images show the ability of the technique to map the extent of the coffee rock on the spit, both in the interdune areas and under the solitary dunes. However, as these results are based on only a few survey lines, more fieldwork is needed to map the true extent and paleotopography of the coffee rock.

The GPR imaging outlined the sedimentary structures in the large solitary dune and, in combination with geomorphological observations, allowed us to create a preliminary model of dune development. Since the dune is migrating to the west, as well as growing in northerly and southerly directions, the dune may be a major location of sand deposition. However, the interpretation of phases of dune development currently lacks any absolute age control. Further understanding of modes and rates of dune development on the Parengarenga Sandspit will incorporate luminescence dating of the dune units, as well as integrating GPR data from the solitary dune system with the foreshore and foredune topographic survey data.

*(Continued on p. 881)*

(Van Dam, from p. 870)

**Suggested reading.** "Ground penetrating radar in sediments," by Bristow and Jol (Geological Society, *Special Publication 211*, 2003). "Geomorphic development of the southern Aupouri and Karikari Peninsulas" by Hicks (In: *Soil Groups of New Zealand*, 1977). *Aeolian Geomorphology* by Livingstone and Warren (Addison Wesley Longman, 1996). "Resource consents and the geomorphic monitoring of coasts" by Parnell (13th Australasian Coastal and Ocean Engineering Conference, *Expanded Abstracts*, 1997). "Reconnaissance survey of silica sands, Parengarenga" by Schofield (In: *Industrial minerals and rocks*, Department of Scientific and Industrial Research, Wellington, New Zealand, 1968). "Identifying causes of ground-penetrating radar reflections using time-domain reflectometry and sedimentological analyses" by Van Dam and Schlager (*Sedimentology*, 2000). TLE

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