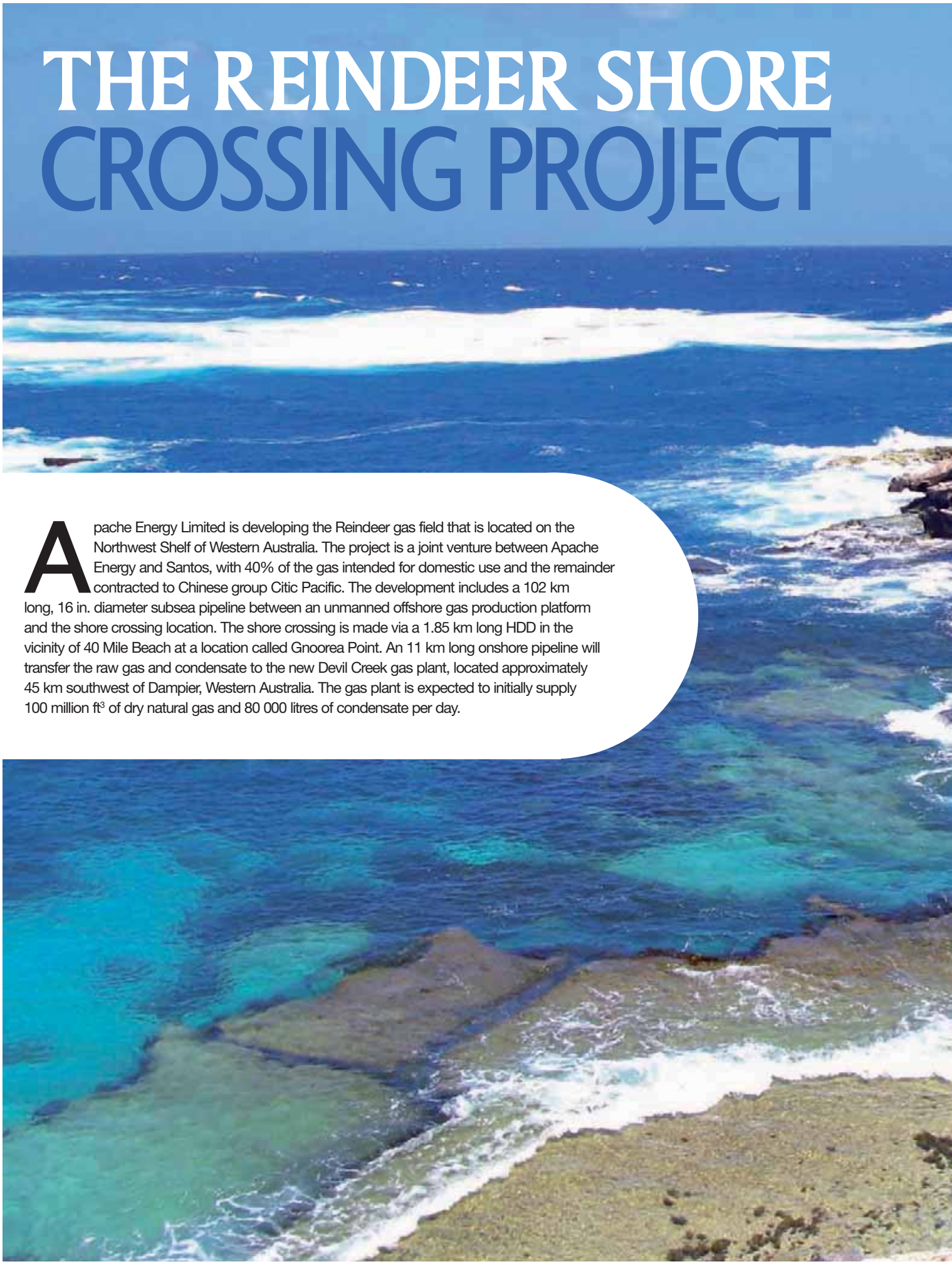
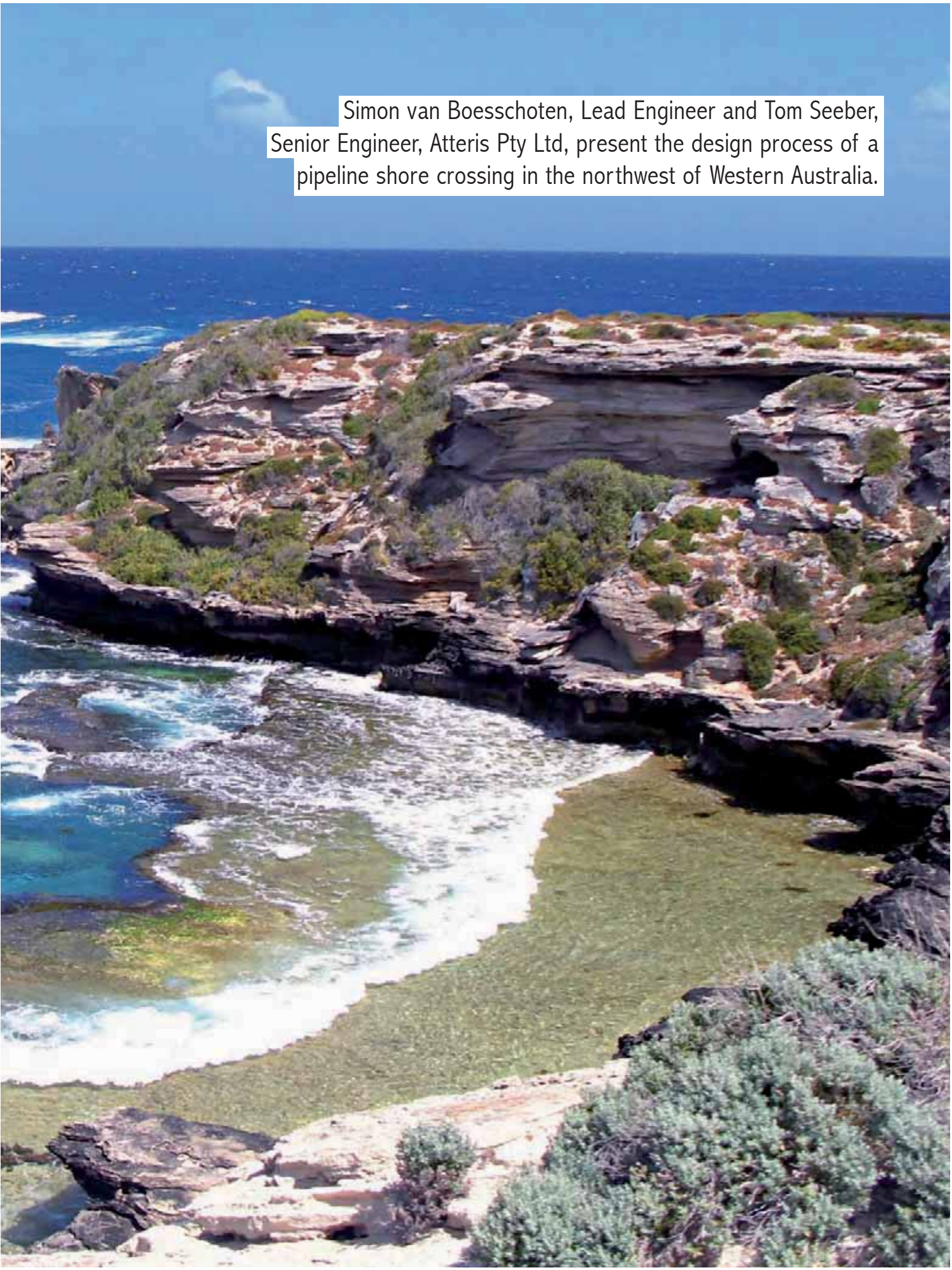
THE REINDEER SHORE CROSSING PROJECT



Apache Energy Limited is developing the Reindeer gas field that is located on the Northwest Shelf of Western Australia. The project is a joint venture between Apache Energy and Santos, with 40% of the gas intended for domestic use and the remainder contracted to Chinese group Citic Pacific. The development includes a 102 km long, 16 in. diameter subsea pipeline between an unmanned offshore gas production platform and the shore crossing location. The shore crossing is made via a 1.85 km long HDD in the vicinity of 40 Mile Beach at a location called Gnoorea Point. An 11 km long onshore pipeline will transfer the raw gas and condensate to the new Devil Creek gas plant, located approximately 45 km southwest of Dampier, Western Australia. The gas plant is expected to initially supply 100 million ft^3 of dry natural gas and 80 000 litres of condensate per day.



Simon van Boesschoten, Lead Engineer and Tom Seeber, Senior Engineer, Atteris Pty Ltd, present the design process of a pipeline shore crossing in the northwest of Western Australia.

Site conditions

The shore crossing site that was selected for the HDD has been used for the fabrication and tow-outs of offshore pipeline strings in the past. It is accessed via a 12 km long unsealed road from the North West Coastal Highway. The spot is used by campers and travellers, and has a public boat ramp for recreational use. The site is level, has ample space for a large HDD rig, and a suitable pipeline stringing corridor and launchway. Furthermore, fresh water was obtained from the gas plant temporary water storage pond, which was fed by numerous water bores under an annual license from the Department of Water.

The nearshore area however, is not so accommodating. The seabed bathymetry from the shore is very shallow, and when combined with the 4 m tidal range, the result is a tidal flat over 1 km long. Beyond the low water mark, it is another 1 km before the 4 m water depth contour is reached. The shallow water makes the intertidal area very difficult to access using either marine or terrestrial equipment. This occurs over very complex geology, including unusual sedimentary formations that are not widely known in the regional geological setting. Granite is present in various stages of weathering, intersected by dolerite dykes that increase the probability of fractured rock at the intrusions. The dolerite dykes range in size, but one major dyke crosses the pipeline route about 1 km from the shore.

During the winter months of May through to July, the Point is exposed to weather driven by the strong northeasterly winds. The workability of small marine craft is limited in these conditions. During the summer months of November through to April, ambient conditions are much better; however tropical storms (cyclones) affect the region.

Method selection

In light of the site conditions, HDD was selected as the preferred shore crossing method. An open cut trench would require significant disturbance to the shoreline, and excavation in a difficult tidal zone.

In combination with HDD, the forward thrust pipeline installation method was selected for the Reindeer pipeline shore crossing to minimise the use of floating equipment and avoid possible delays to offshore pipelay. This method offered the least health, safety, and environmental risks. Forward thrust also has a proven track record for medium diameter pipeline shore crossings up to approximately 2 km long.

The design process

The HDD design process began with a review of the available site information; onshore topography, nearshore bathymetry, geotechnical information, metocean data, and social and environmental constraints. This review fed into a concept design phase that used an inferred geological engineering model to define the HDD entry and exit points and a preliminary drilling profile. An onshore site layout was drafted, and the construction concept was used to outline the scope for an additional site data collection programme.

Comprehensive geotechnical data along the drill profile is essential for a successful HDD. A rotary coring campaign was executed, comprising 11 boreholes in the nearshore area along the proposed route. The information from the boreholes was compiled and a detailed geological engineering model was prepared. It was identified that the drilling trajectory would traverse three separate formations;

- Onshore sedimentary rock.
- The basement rock mass, mostly made of weathered and fresh granite but with at least one major dolerite intrusion.
- Offshore sedimentary rock, underlain by claystone.

The granitic rock formation comprising the majority of the HDD alignment had a wide range of engineering properties. With little or no weathering, the rock would be strong and stable. However, the upper granite showed increased weathering and fractures, with some clay that is common on geological defects. Weak zones can present risks to the HDD operation in the form of loss of drilling fluid or hole collapse. Another observation was a distinct contrast

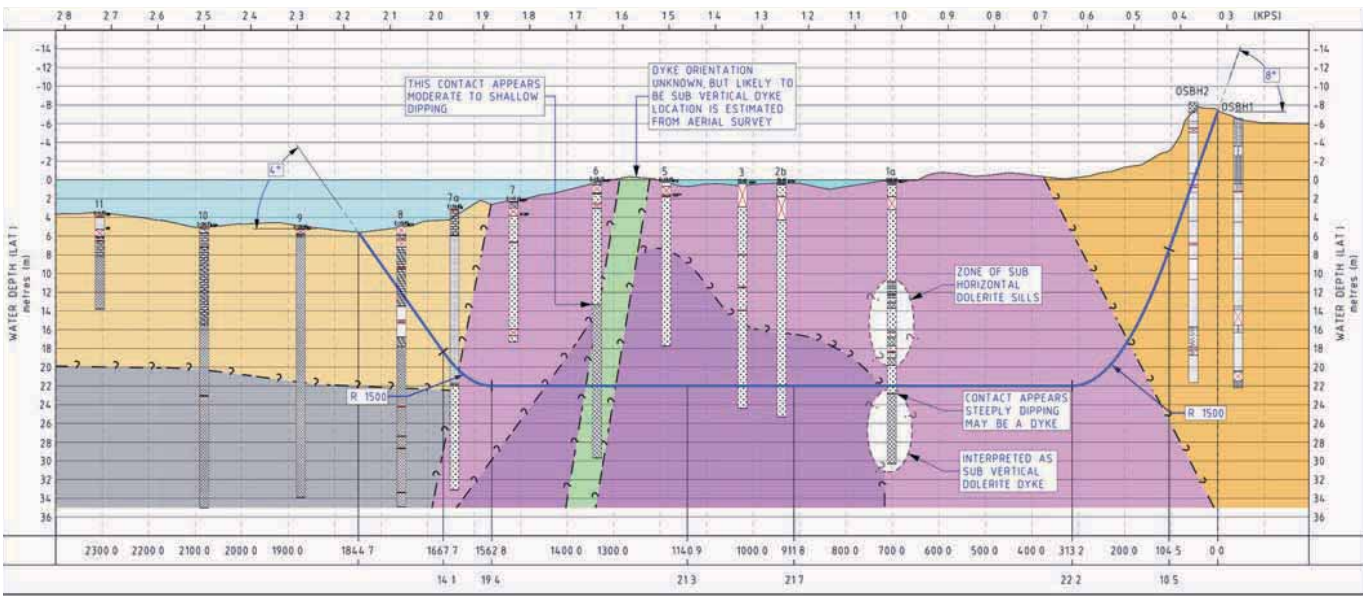


Figure 1. HDD profile showing the geological formations and rotary coring locations.

Figure 2. The pipeline over-bend for the forward thrust installation.

in material and engineering characteristics when large veins or dykes were encountered, adding complexity to the structure. Some of the worst fractures were evident at the contact between granite and dolerite, offering poor drilling conditions. Once the geology was well defined, the construction concept could be developed and the HDD alignment and entry and exit points optimised.

The geotechnical sampling campaign was complemented by hydrographic, environmental and visual surveys. Metocean data was collected and detailed definition of the sea state was undertaken. With the construction concept now well advanced, the pipeline design could be finalised, including coatings for corrosion and abrasion, field joint coatings, cathodic protection, and on-bottom stability of the pipeline section at the subsea HDD exit point. A pipeline stress analysis was performed to determine installation and operational stresses on the pipeline material, to verify compliance with the relevant codes.

Drilling fluid management was an important consideration. Apache desired to minimise the release of drilling fluid into the environment, and a range of strategies were identified and assessed for feasibility. It was planned to delay the drill head punch-out to the seabed, however the risk associated with this approach would require careful management. A strategy was prepared using a decision tree for the drilling method framework, so that planned fall-back methods were immediately available throughout execution.

Execution

The shore crossing works were successfully undertaken during the first half of 2010. A 350 t push/pull capacity HDD rig was mobilised, and the pilot hole drilled using a conventional positive displacement motor and rock bits for the range of formations. Forward reaming using hole openers was successfully applied along the entire 1850 m drilling trajectory. Upon completion of the borehole, it took just one day to install the pipeline string through the reamed borehole.

Atteris provided a team of three engineering professionals and an engineering geologist to design the shore crossing and provide support to Apache Energy in relation to the regulatory approvals process. Atteris also provided HDD expertise to Apache Energy throughout the tender and award periods, to assist with HDD contractor selection. Furthermore, Atteris supported the Apache site team with advice during construction. WP