

SURVEYS FOR THE MAUI-B PIPELINES: TOW ROUTES, HAZARDS AND ROCKBERM STABILITY

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Abstract

Shell Todd Oil Services Ltd, as operators of the Maui gas and condensate field, Taranaki, investigated several options for the development of the Maui B platform, some 15 km from the existing Maui A platform, and associated gas and condensate pipelines. One pipeline option involved assembly of the pipelines in 5 km lengths onshore near Foxton on the Manawatu coast and then towing the assembled pipelines almost 200 km over the seabed to the Maui field.

Surveys were undertaken jointly by the DSIR and BTW Associates to assess: seafloor conditions along the Maui A to B pipeline route; seafloor conditions along the proposed tow route; and the condition of the existing rock-berm protected pipeline to shore. Results of high resolution seismic reflection profiling, side-scan sonar, echo-soundings, geotechnical tests on piston cores and an environmental assessment revealed no significant problems to installation on the A-B pipeline route and no damage to the existing pipeline. They revealed an unexpected hazard to the safe towing of long, brittle lengths of pipeline over the seabed.

In 70-90 m deep water off the Manawatu coast, sand ridges had crests with a radius of curvature that was less than the radius of safe bending of the assembled pipeline. A safe route around the sand ridge field was found in an area where modern river muds had buried the 12,000 year old sand ridges. It is inferred that the sand ridges, as well as much of the other topography along the tow route, is a product of tidal and storm-generated currents soon after flooding of the Cape Farewell to Cape Egmont landbridge during the post-glacial rise of sea-level.

Side-scan sonographs showed anchor-drag marks in the Maui area radiating from old well sites, as well as a few small items of debris. They showed considerable detail of the protective and supportive work on the existing pipelines, which appeared to be in good order after a decade in a very hostile environment.

Introduction

Background to the Surveys

Since it was commissioned in June 1980, the Maui-A platform (Figure 1) has been New Zealand's major internal source of hydrocarbons. Its production is piped in separate gas and condensate pipelines to the shore at Oaonui, which is some 33 km to the northeast and on the lower slopes of the active volcanic cone of Mt Egmont (Taranaki). Production platform and pipelines have weathered the full force of the Tasman Sea's hostile wave climate (Pickrill and Mitchell, 1979) for a decade. Now, Shell Todd Oil Services Ltd, operators of the Maui field, plan further development of the field to fulfil their contractual commitments for the supply of natural gas. They propose building:

- (i) an additional production platform, Maui-B, some 15 km further offshore from Maui-A; and
- (ii) linking the new platform to existing pipelines to the shore. A full description of the proposed development and its social and ecological implications is given in the environmental impact report (Shell BP and Todd Oil Services Ltd, 1988).

To assist with planning, Shell Todd Oil Services contracted the joint venture partnership between National Institute of Water and Atmospheric Research Wellington and Buxton Tuder and Waugh (BTW, New Plymouth) to survey and report on the following:

- (i) the condition of the inner halves of the existing pipelines commissioned in 1980 with their rock berm armouring added in 1986;
- (ii) the seabed hazards, stability, thermal conductivity and lateral and vertical variability at both the site of the proposed Maui-B platform and along the pipeline installation route linking Maui-B to the existing pipelines at Maui-A; and
- (iii) the seabed conditions, including fauna and hazards, along a 200 km long corridor via which preassembled pipeline segments might be towed along the seabed from a gently sloping, dune-backed beach to the installation site. A full description of the seabed tow installation technique has been given by Mollison (1987). The clients subsequently decided against use of the bottom tow technique. Our reports to them (BTW & NZOI Joint

Venture Project, 1989a, b, c) are summarised here with their permission.

Marine Geological Setting

The wide continental shelf at the western approaches to Cook Strait rests on a thick pile of sediments that has built up and out into the Tasman Sea ever since the New Zealand continental block split away from the Australian coast of Gondwana some 80 million years ago. For much of the time, the supply of sediment was slow and coal measures formed in a shallow, subsiding, NW-facing basin, providing the source of hydrocarbons that have accumulated to form the Maui field (Palmer, 1985).

After a convergent boundary between two of the world's major crustal plates propagated through the New Zealand continental block, mountains and volcanoes began rising to the east and to the north, and the Southern Alps grew to the south. Over the last 1 - 2 million years, the pace of uplift, volcanism and the resultant rate of sediment input to the adjacent seas has increased dramatically. The western approaches to Cook Strait have been particularly affected by the rise of the Egmont volcanic centre on one side and by the flood of sediment that the prevailing southwesterly swells, storm waves and oceanic net drift have moved northwards from the foot of the Southern Alps at the other.

After erupting through the thick Tertiary succession for the last 2 million years, Mt Egmont itself only reached only its present height about 35,000 years ago (Neill, 1979). It has produced minor lava and ash eruptions but the most dramatic effect on the surrounding ring plain has been from the catastrophic debris avalanches known as lahars. Lahars

carried boulders at high speed from the upper slopes and dumped them in mounds around the foot of the mountain. Lahar deposits continue beneath the sea indicating either that the lahars flowed beneath the sea or that they crossed the 10 km wide inner continental shelf when it was exposed during glacially lowered sea level. Waves have sorted these deposits, leaving boulders behind, carrying mud offshore and transporting "ironsands" and other dark minerals along the coasts, where they have been mined at Waipipi (Figure 2). Dark sands may also have been carried offshore to form sand banks and ridges. The lag boulder mounds that remain around the foot of the mountain were a formidable barrier to the original pipelines from Maui-A to the shore, requiring the pipelines to be supported between spans in some areas and protected by massive rock-rubble berms at others. The sand banks and ridges, although remote from the Maui site, nevertheless were important in this survey as they constituted a hazard to successful towing of assembled segments of pipeline from the chosen assembly locations. The mud constitutes the seabed into which the pipelines are to be installed at the Maui field.

Drift from the Southern Alps accumulates now on the sand spit at Cape Farewell. During the last glacial period of maximum lowered sea level, a much larger sand spit grew out towards Mt Egmont and either almost closed, or completely closed, the western approaches to Cook Strait. As this sandy landbridge breached with the post-glacial rise

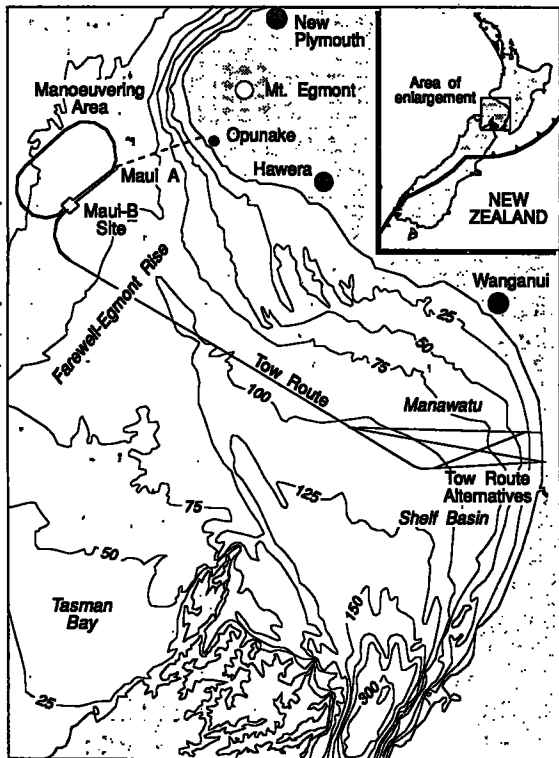


Figure 1: Location of the Maui surveys showing bathymetry at 25 m intervals, the Maui-B site and pipeline installation route (open block), tow route (solid lines) and pipeline inspection survey (broken lines).

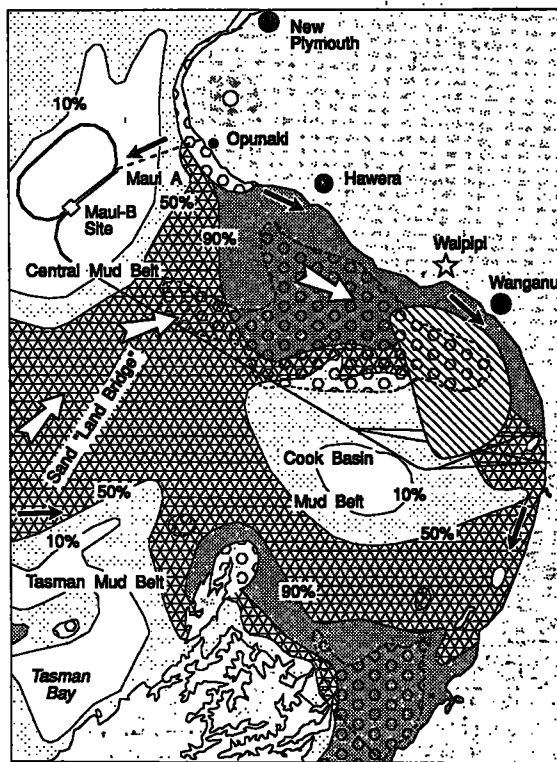


Figure 2: Sediment map of western Cook Strait showing modern sediment transport paths (solid arrows) and last glacial age paths (open arrows). Sediment contours are at 5 % gravel and at 90 %, 50 % and 10 % sand in the non-gravel fraction. Gravel off Opunake is mainly lahar boulder mounds. That south of Hawera is mainly relict shell. Asterisk is position of Waipipi ironsand workings. Diagonal hatching off Wanganui is the field of dune-like sand ridges.

of sea level, storm waves and strong tides sorted and carried mobile constituents eastwards towards the Manawatu coast.

Beach to Outer Shelf Survey Methods

Vessels: The surveys were undertaken from the 3,000 tonne, ocean-going research vessel, *Rapuhia*, which was equipped with a 7 m launch for inshore work. This large and well-equipped research vessel gave flexibility to operate 24 hours per day even in large swells. The onboard launch enabled inner-shelf work to be undertaken without a hazardous passage through the surf zone.

Helm-guidance Navigation: The *Rapuhia's* position was logged continuously with a Syledis-B medium range radio-positioning system operating at 441 MHz to an accuracy of about 3 m. The position of the launch was logged with a Racal "Micro-Fix" microwave positioning system operating at 5 GHz to an accuracy of 1 m. Each system had a helmsman's track guidance facility and logged data to a navigation computer and plotting system. Much of the position fixing was undertaken by Buxton Tuder and Waugh, New Plymouth.

Heave-compensated Depths: The *Rapuhia* was equipped with a gimbal-mounted, gyro-stabilised, narrow-beam sounder with a heave-compensated output logged directly to the navigation computer. The launch was equipped with a swell-filtered sounding systems.

Seismic Profiling Methods: The offshore surveys were undertaken with an Ferranti-ORE, 16 transducer, high power, high resolution profiling system, tuned to 3.5 kHz. The system shows layering to between 20 m and 80 m beneath the seabed, with 0.4 m resolution, at most places on the shelf. For some parts of the survey the echoes were heave compensated. Inshore surveys used a lower power, single transducer ORE system with a boomer system available as backup.

Side-scan Sonar: A Klein dual-frequency side-scan sonar system was used from both ship and launch to give seabed images of a 300 m swath width. The position of the tow-fish behind the vessel was monitored with an ORE "Trackpoint II" range and bearing system and incorporated into the helm display and computer log.

Sampling Techniques: A piston corer and Shipek grab were used to collect samples of the seabed with a vibrocorer available for compact sands. A Seabed Wilson *in situ* cone penetrometer and thermal conductivity device was operated by Fugro-McClelland.

Maui-B Site and Pipeline Route

The basic objectives of the first survey were to obtain information on the nature of the seabed so that anchor holding conditions at the Maui-B site might be appraised and so that the design and route of the buried gas and condensate pipelines between Maui-B and Maui-A might be finalized. The survey area comprised a 1.5 km wide by 25 km long corridor between and beyond the platforms and a 4 km quadrant around the Maui-B site.

A closely-spaced grid of high-resolution seismic tracks showed a consistent sequence of layering that can be correlated with worldwide glacial/interglacial changes of sea level (Figure 3). Seismically transparent layers correlate with muds in cores and borehole data (Green, 1987) and more strongly reflective and layered units correlate with sandy and shelly units sampled in boreholes and cropping

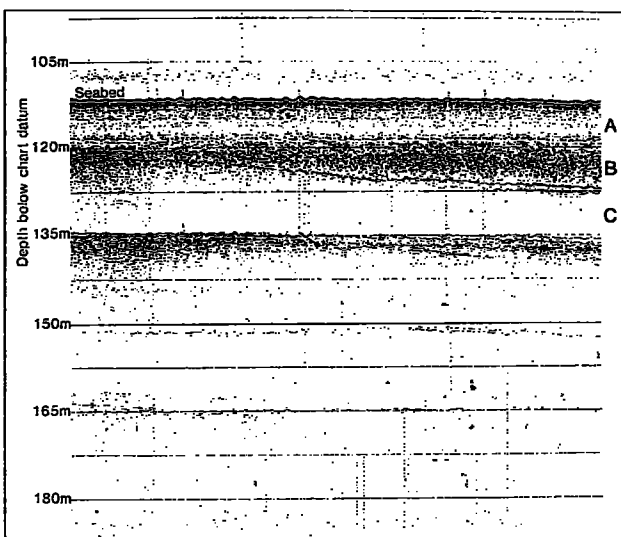


Figure 3: Heave-compensated high resolution profile showing A-post-glacial mud, B-more strongly reflective last glacial low sealevel sand, C-last interglacial age mud. Layers of strongly reflective and weakly reflective sediment beneath this represent sandy glacial and muddy interglacial sedimentation respectively.

out at the shelf edge west of the Maui field. The muds are interpreted as the deposits of high sea level and the sands as the deposits of low sea level when a sand spit built northwards from South Island.

The surface mud unit is uniformly seismically transparent and varies in thickness from 5 m thick southeast of Maui-B to 16 m thick inshore from Maui-A. Geotechnical tests on cores show that these inorganic clayey silts are normally consolidated, are of medium-high sensitivity and are highly plastic. Triaxial tests suggest an angle of friction of 32-41° with failure achieved with axial stress of less than 6%. In situ tests indicated cone resistance increases gradually up to 0.18 MPa at 2.7 m deep and thermal conductivity ranges from 1.19 to 1.29 W/mK. In general, the surface layer varied only slightly in physical and geotechnical properties throughout the area so that sampling was adequate for the completion of trench and pipeline design.

Overlapping side-scan sonographs showed the surface mud to be free of natural bedforms but heavily scarred by trawl and large anchor drag marks, particularly around the sites of exploratory wells. They show a few small items of debris presumably left from old fishing and drilling operations but none appeared to present a significant obstruction to the proposed operations.

The underlying shelly sand unit has internal reflectors that indicate advancing foresets of large sand bodies and filled channels cut into underlying layers. The sand is the right depth (114-124 m below present sea level) to have been close to surf zone during the height of the last glacial age and it is inferred that the sand was part of a complex spit perhaps with storm-generated, shore-face connected shoals.

The sequence of transparent and reflective layers, each up to a few tens of metres thick, continues in the profiles and correlates with alternating mud and sand layers in existing bore logs. The Maui site is at a critical depth to record sea level changes; shallower areas have much of the record wiped during each post-glacial transgression and deeper sites are always beyond the effects of nearshore processes.

Pipeline Tow Routes from Shore

It was necessary to find and survey a route along which 5 km long segments of prefabricated gas pipeline could be towed safely over the seabed from fabrication sites on the dune-backed Manawatu coast to the Maui site. The route had to be free of obstructions, tight turns and sharp changes of slope. The plan was to undertake a thorough high-resolution seismic, side-scan and sampling survey of:

- (i) two beach launch sites,
- (ii) route corridors, some 750 m wide by 200 km long, from the beach sites to the pipeline installation site, and
- (iii) a 1500 m wide by 100 km long overshoot corridor from the Maui-A site back to the Maui-B site (Figure 1).

Launch surveys revealed no impediment to towing operations on the shoreface or innermost shelf; the surface expression of an active fault was buried by mobile sand that is locally formed into sand ribbons. However, direct routes towards the Maui field ran into dune-like bedforms on the mid shelf (Figure 4). These bedforms occurred extensively at depths between 90 m and 105 m with a possible isolated example at about 65 m deep. Each "dune" is only 2-6 m high above the adjacent flat seabed and 300-700 m wide. They appeared to trend sub-parallel with the coast and with the regional contours, however their total length cannot be estimated from the data available. Internal reflectors showed bedding within some of the dunes to be sub-parallel to one or other of the dunefaces rather than to the underlying flat seabed. It is inferred that the features are large sand ridges that were formed by storm-generated, coastal-parallel currents during the post-glacial rise of sea level from 14,000 to 9,000 years ago (Lewis, 1979). Some of these fossil ridges had ridge-crests or troughs with curvature that exceeds the bending tolerances of the towed pipelines. Therefore alternative routes had to be found.

Archive data suggested that similar ridges are well developed to the north of the direct route but smooth mud occurs to the south. The survey was therefore diverted southward in search of a route around the sand-ridge field. It showed that there were still sand ridges to the south but that they were buried, and their surface expression obliterated by a layer of mud up to 5 m thick.

The rest of the tow-route corridor was hazard-free despite crossing a variety of seabed types and the trace of the active Cape Egmont Fault, which has limited surface expression. Simple geotechnical tests on 22 cores were sufficient to give an indication of relative penetration of a towed pipeline. Biological sampling and archive data indicated a diverse fauna but few living samples, many being relict from glacially lowered sea level. This survey was only part of an evaluation

of the bottom-tow method and the client has now opted for a lay-barge method instead.

Checking the Existing Pipelines

Before linking the new pipelines into the existing gas and condensate pipelines that extend from Maui-A to the shore, the operators required a thorough examination of the condition of the vulnerable inner half of the existing pipelines (Figure 1). They wished to verify that the rock-rubble protective berms covering parts of the pipelines had not been displaced by wave and current action sufficiently to expose the pipeline.

The plan involved obtaining overlapping sidescan tracks down each side of the each pipeline and accurately corrected, heave (accelerometer) compensated, bathymetric traverses at 50 m intervals across the pipeline using, where possible, the gyro-stabilised sounder. The inshore end was to be completed from the launch. The results were to be compared with pre-existing traverses made with a ROV and later checked by a new ROV survey.

The constructed heights of the berms are not significantly different from the prevailing swell so their height is difficult to measure in normal echo-soundings; only in accelerometer (heave) corrected narrow-beam sounding can they be measured accurately (Figure 5A).

After crossing a sandy beach and sublittoral zone, the rockberm protected pipelines must cross the field of lahar boulders that surrounds Mt Egmont. The sidescan sonographs show a dark speckled image from an undulating field of boulders (Figure 5B). Shadow lengths suggest that some individual boulders are up to several metres in height. The pipeline positions are indicated by strong reflections from the near face of their covering bouldery berms. The berm's total width can be estimated from the images from each side and its height may be estimated, using simple geometry, from the length of its shadow, (although this estimate must assume a flat seabed). Widths generally range from 8 to 12 m and heights from 2 to 5 m above the adjacent seabed. However, at its inner end the gas pipeline berm is wider and flatter than elsewhere. This is thought to be a constructional character rather than a result of flattening of the berm, except that the adjacent condensate pipeline does not seem to be similarly affected.

At mid-shelf depths, more finely speckled areas are sometimes formed into waves perpendicular to the coast and occur between the boulders (Figure 5B). These are interpreted as patches of pebble gravel. At depths of more than 60 m and distance of more than 6 km from shore there are increasingly large areas of low reflectivity interpreted as sand grading seaward to mud (Figure 5C). In these areas, the pipeline is

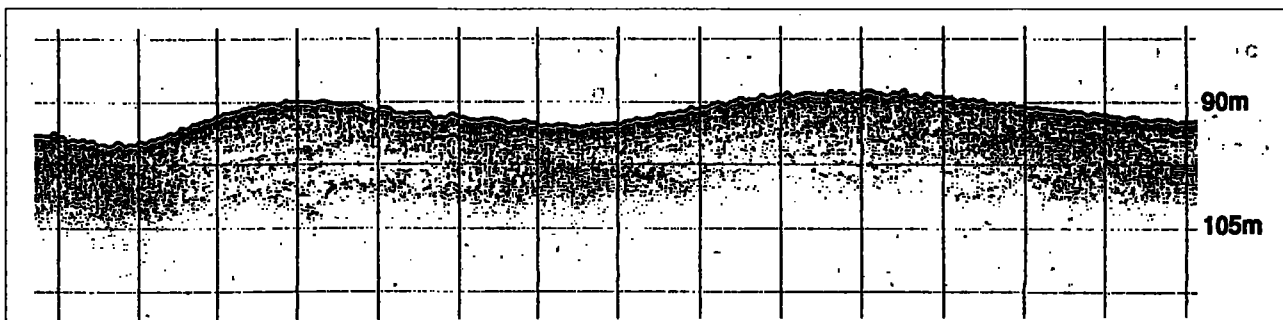


Figure 4: High-resolution seismic profile of a "fossil" sand ridge east of the Maui field. Note the internal bedding. Vertical scale lines at 7.5 m (10 ms) intervals. Horizontal lines at 50 m intervals.

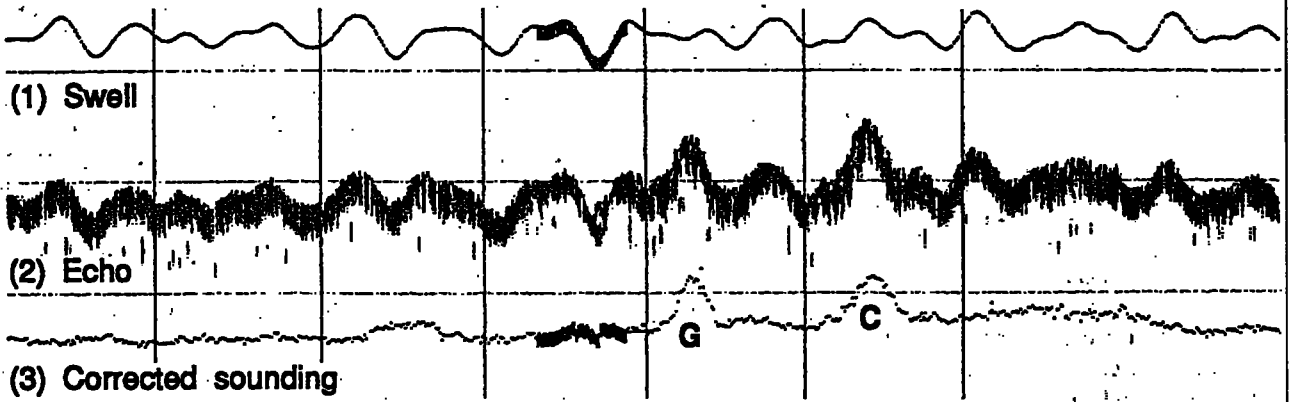


Figure 5A: Heave compensated soundings across the rockberms. (i) measured swell. (ii) uncorrected echo-sounding -the berms can not be recognised with certainty. (iii) heave compensated sounding showing height of the gas rockberms (G) 3.5 m above the surrounding seabed and the 3.1 m high condensate rockerm (C).

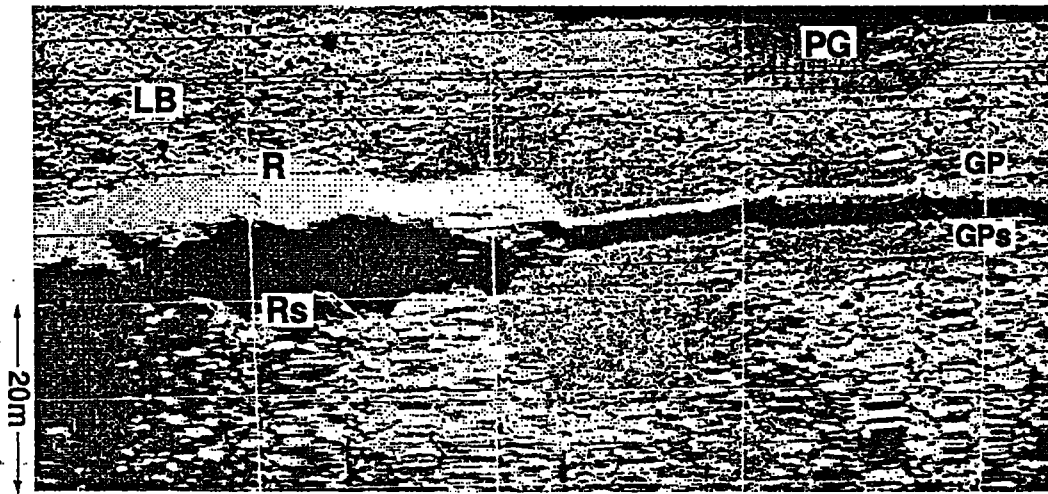


Figure 5B: Sidescan sonograph of an area about 50 m X 200 m showing lahar boulders (LB), pebble gravel with gravel waves (PG), rockerm (R), rockerm's shadow (Rs), gas pipeline (GP), pipeline's shadow (GPs). Note separation between segments of the pipeline and shadow indicating suspension between lahar boulders.

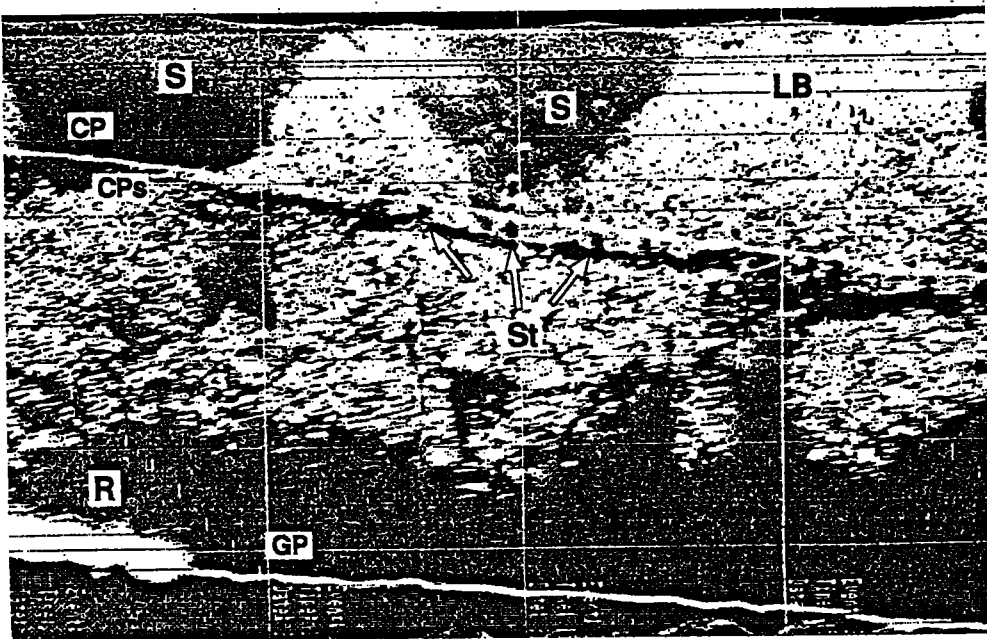


Figure 5C: Sidescan sonograph showing area of seabed about 60 m X 200 m with lahar boulders (LB), sand (S), condensate pipeline (CP), condensate pipeline's shadow (CPs), stanchions supporting suspended segments of pipeline (St), gas pipeline (GP) and rockerm (R).

rarely covered by rockberm and there are many places where the image of pipeline and its shadow are separated, indicating that the pipeline is suspended above the seabed. Gaps between pipeline and seabed of less than 0.2 m are clearly imaged by sidescan despite the fact that the gas and condensate pipeline are 0.6 m and 0.25 m in diameter respectively. In segments where the pipelines are otherwise unsupported for 40 m or more, artificial support stanchions are clearly imaged between pipe and seabed (Figure 5C). In very few places, the width of the pipeline's shadow appears to decrease, thus indicating its partial burial.

The heave-compensated soundings (Figure 5A) show no significant difference from earlier surveys and generally confirm the continuous sidescan estimates, except where nearby mounds, or depressions between mounds, produce anomalous shadow lengths on the sonographs.

Summary of Results

The *in situ* and laboratory geotechnical tests showed the stability characteristics of a 2 m deep pipeline trench and anchoring characteristics at the Maui-B site. The *in situ* thermal conductivity tests provided the necessary information for the design of pipeline lagging. Sampling is at only a

single point but values may be interpolated using high resolution seismic stratigraphy. Interpretation of layering beneath the seabed is based on an understanding of nearshore processes during repeated glacial lowerings of sea level. Periods of high sea level, such as the present, are represented by seismically transparent mud whereas the period when sea level was 100 m or below present are represented by nearshore sands of South Island origin. Since the last rise of sea level beginning 15,000 years ago, the sands have been slowly covered by mud to a depth ranging from 5 m to 13 m thick at the Maui site.

A route was found and surveyed along which prefabricated segments of gas pipeline might be towed over the seabed from assembly points on a low dune coast to the Maui field. It was necessary to find a new route around dune-like sand ridges formed during the last post-glacial rise of sea level and still unburied on the direct route between possible assembly points and the Maui field. After a thorough assessment of the options, the clients decided against this method of installation.

The protective rockberms and support stanchions on the existing pipelines between the Maui field and the shore remain intact.

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