RESOURCE EVALUATION OF DREDGE AREAS LEASE 5 AND LEASE 6,NUKUBUCO REEF LAUCALA BAY, SUVA, FIJI ISLANDS

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SUMMARY

Mapping of Fiji Industries lease areas 5 and 6, in Laucala Bay which are dredged for sand, was carried out during the period 9th to 14th June, 1997 in order to assess resource reserves and sustainability and characteristics.

The mapping required profiling the seabed at a resolution sufficient to delineate the seabed morphology of the dredge sites and surrounding environments. Some 200 km of profile data was collected. Within the lease areas 60 jetprobe holes were drilled in the seabed in water depths ranging from 0.5 m to 12 m with penetration depths of 0.1 to 8 m to test for sediment thickness. The samples collected at each jetprobe location were analysed for grain-size, clast composition and geochemistry. From these data, an assessment of the reserves for each lease has been calculated.

A major difficulty with the assessment was the lack of preliminary baseline data, and in particular bathymetric data as this provides the basis for assessing change in seabed morphology due to dredging or natural processes. Despite this deficiency, calculations of the volumes dredged agree closely with recorded volumes.

Data sets from this survey are in digital format and can be incorporated into GIS as a working database in which to monitor dredging operations.

The main conclusions of the field study are as follows:

- The dredged areas of Nukubuco Reef represent 4% of the total estimated reef area
- The dredged areas are larger than the original lease areas prescribed
- The dredging produces open ended pits
- Dredging has occurred only in prograded sand deposits that have accumulated on the back reef slope of the Nukubuco Reef complex.
- Most of the sand resource is considered to have been generated as a result of changes in sea level during the Holocene Period from 4500 to 2000 B.P.
- Modelled estimates of volumes of sand dredged from Leases 5 and 6 are in good agreement with Fiji Industries' reported figures.
- Coral rubble is the dominate component of the sand resource
- The lack of baseline data and of appropriate studies leaves a large degree of uncertainty in the assessment of primary sediment production rates on the Nukubuco barrier reef, and thus leaves largely unanswered the question of the sustainability or, more importantly, the recovery time of the resource.

- The current levels of sand extraction, however, are considered higher than the rates of replenishment implying that the resource use is not sustainable.
- MgO contents for both lease areas show similar trends, with higher percentages occurring towards the reef crest.

General conclusions for Lease 5:

- Sand resources were initially considered by Fiji industries all but exhausted in Lease 5, based on the current parameters used for dredging.
- Modelling of the old dredge workings and surrounding sediments in lease 5 for dredging depths of 8, 10, 12 and 14 m below Lowest Average Tide (LAT) indicate that potential reserves as high as 1.4 million m^3 remain.
- Sieve analysis of the 3 deep water samples collected shows an increase in the fines content to 5 %; however, this is still considered a clean sand by the criteria used this report.

General conclusions for Lease 6

- Sand available in the resource area for a dredging depth to 10 m below LAT is estimated at 480,000 m^3.
- The high MgO values determined for the sediments in the west of the resource area may reduce this volume to 210,000 m^3
- Much of the sand reserve is vegetated by seagrass and it is estimated that dredging may affect as much as 40% of the seagrass meadows mapped in lease 6.
- Analysis of the samples yields a well sorted (sand-size) sand with a fines content under 0.5%.
- It is estimated that sufficient quantities of sand are available in the resource area to meet current demand for 2-4 years.

Major recommendations include the following:

- Proposed new dredge areas should have baseline mapping undertaken to evaluate the resource volumes, composition and geochemistry prior to exploitation.
- Detailed mapping and jetprobing in dredge areas 1, 2, 3 in lease 5 should be undertaken to confirm volume estimates and the distribution of fines in the resource.

- Techniques for removal of the seagrass beds prior to dredging for transplanting to alternate or dredged areas should be investigated.
- Studies to determine the principal sources of the high-Mg carbonates and their percentage of the resource sediments should be undertaken.
- A comprehensive study should be initiated to determine sediment composition.
- Development of a GIS database incorporating the digital data set from this survey, which will enable the monitoring and management of resource development.
- Consideration could be given to implementing position control of dredge operations using GPS (Global Positioning System), again to monitor and manage resource development.

OBJECTIVES

The field survey for this study was carried out from 9 to 14 June 1997.

The objectives of the survey were to:
1. Identify and map remaining sand resources in leases 5 and 6;
2. Estimate potential volumes of resource materials within leases 5 and 6; and
3. Determine mining sustainability.

INTRODUCTION

Fiji Industries holds the two lease areas 5 and 6 within the back reef perimeter of Nukubuco barrier reef in Laucala Bay but only currently dredges sand from lease 6 which is some 15 kilometres from the factory in Draunibota Bay, Lami (**Figure 1**).

For 35 years Fiji Industries Limited, a local industry, has been dredging coral sand from the back reef slope of the barrier complex reef fronting Laucala Bay and Suva harbour. Prior to this, and long before sand was dredged for cement manufacturing, coral sand was dredged by CSR Company in Suva harbour for cane fertiliser. Calcium carbonate ($CaCO_3$) is extracted from the coral sand for the manufacture of Portland cement. Alternative sources of $CaCO_3$ have been investigated, in particular onland outcrops of limestone, but these resources are uneconomical as they are far removed from the manufacturing centre, require quarrying and crushing prior to milling, and involve land tenure considerations.

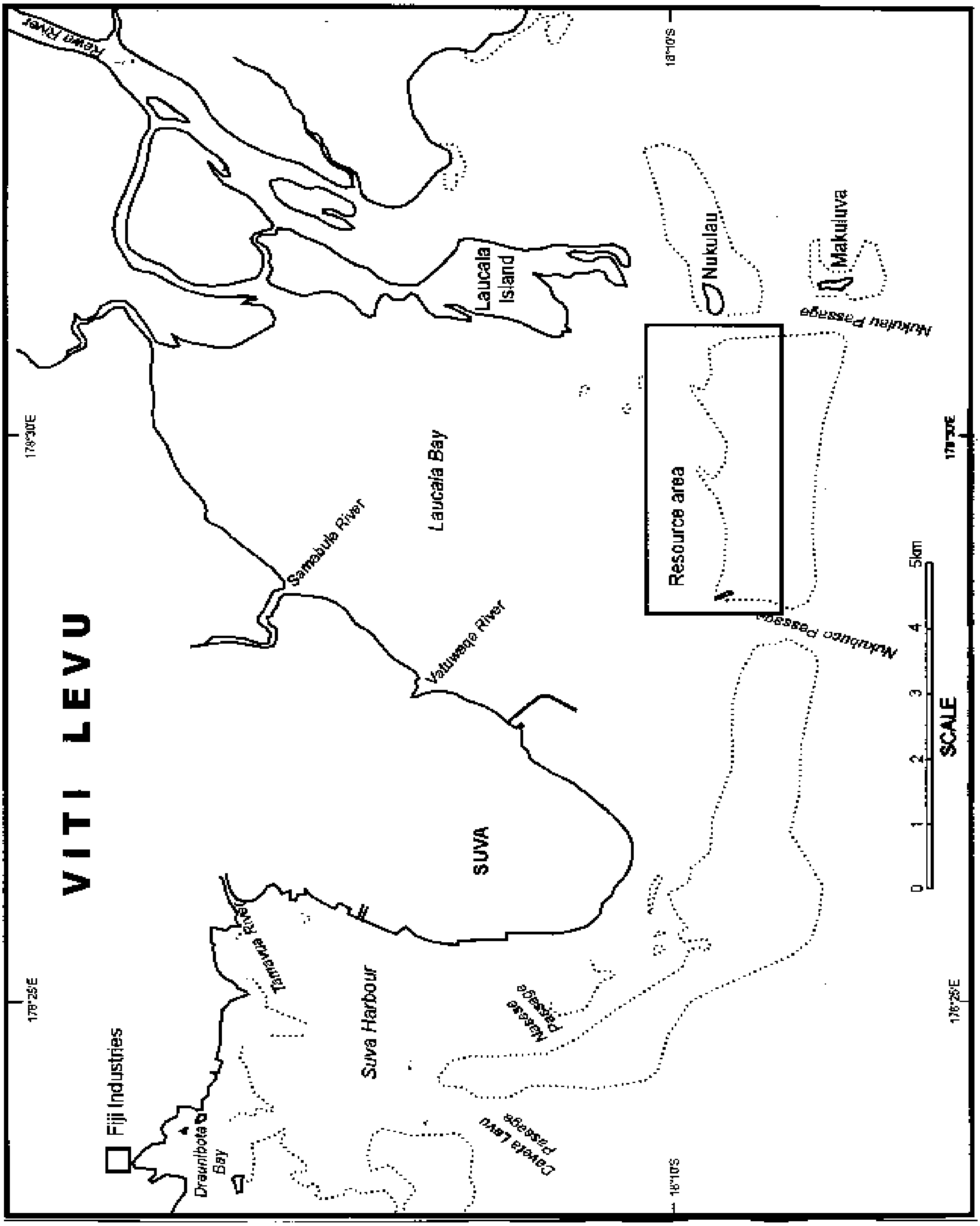

Figure 1. Location map of study area.

Today, products from the Lami factory have a major input into the **top three industries** in Fiji: **Tourism** through construction, **Sugar** through the supply of lime for fertiliser, and **Gold production** lime used in the gold extraction process. As the only established cement manufacturing industry locally and an exporter to other Pacific nations, the tenure and stability of the license to dredge is of concern to the long term viability of the industry (Ward 1997). Currently the dredging license requires annual renewal.

The Fiji Government's introduction of new legislation, a "*Sustainable Development Bill*"*,* will require a license to exploit coastal resources through a *Coastal Permitting* procedure. Though yet to be implemented, the license requirement contained in the Bill prompted the Fiji Industries to request SOPAC to evaluate the remaining resources for the two lease areas (5 and 6) in preparation for future work development.

METHODOLOGY

Navigation

Navigation control was accomplished with a Del Norte 1009+ real time DGPS unit. A position fix interval of 5 seconds was used, and all survey map data are reported in Easting and Northing metres based on grid coordinates of the Fiji Map Grid**.** The reference station was sited at the Fiji Maritime School on a location established by the Del Norte 1009+ over a time period of 48 hours. All navigation data were logged and processed on PC laptops.

Bathymetry

An Odom Mark I Echotrac precision echo sounder was used for profiling the seabed, and the digital output logged by the Del Norte 1009+. To calibrate the sounder for water velocity an Odom digibar was used. The average velocity used was 1542 msec^{-1}. All bathymetric data collected were reduced to Chart Datum, 0.97 metres below Land Survey Datum based on tidal predictions produced by the Hydrographic Unit of the Fiji Marine Department.

Grain size analysis

Determination of the particle size distribution of the samples was done by sieving. Particle size limits based on the Australian standard for engineering purposes for defining the various fractions are shown in **Table 1**. Details of the sieve analyses are given in **Appendix 2**.

Table 1. Particle Size Limits.

Fraction	Particle size limits	Equivalent AS sieve apertures for separation
Boulders	>200 mm	
Cobbles	200 mm - 60 mm	
Coarse gravel	60 mm - 20 mm	63 mm - 19 mm
Medium gravel	20 mm - 6 mm	19 mm - 6.7 mm
Fine gravel	6 mm - 2 mm	6.7 mm - 2.36 mm
Coarse sand	2 mm - 600 µm	2.36 mm - 600 µm
Medium sand	600 µm - 200 µm	600 µm - 212 µm
Fine sand	200 µm - 60 µm	212 µm - 75 µm
Coarse silt	60 µm - 20 µm	
Medium silt	20 µm - -6 µm	
Fine silt	6 µm - 2 µm	
Clay	< 2 µm	

Grading curve plots for the jet probe samples were derived from the sieve results and are shown in **Appendix 2**. From these data, the samples can be grouped according to the engineering classification of soils - *The Unified Soil Classification System*. To arrive at a group classification which best describes the type of sand a number of conditions must be met. For coarse-grained material to be grouped as a sand, more than 50% of the coarse fraction must be smaller than 2 mm. Sand can either be clean or dirty depending on the fines content. A clean sand has little or no fines while a dirty sand has an appreciable amount of fines. A clean sand can either be well graded, (Group SW) or poorly graded (Group SP). A well-graded clean sand (SW) has a wide range of grain sizes with a substantial amount of all intermediate particle sizes. A poorly graded clean sand (SP) has predominantly one size or a range of sizes with some intermediate sizes missing. Criteria to determine whether a clean sand are either SW or SP are based on the following formulae:

(i) For a well graded SW grouping $Cu=D_{60}/D_{10}$ needs to be >6 and $Cc=(D_{30})*^{2}/(D_{60}*D_{10})$ needs to be $1 \leq Cc \geq 3$.
(ii) samples not meeting all the gradation requirements for SW fall into the SP grouping.

The values for D_{60}, D_{30} and D_{10} are derived from the grading curves shown in **Appendix 2**.

A sand with an appreciable amount (>12%) of fines (≤ 0.06mm) of the whole sample is considered a dirty sand. A dirty sand may present an environmental hazard during dredging operations.

Sediment Composition

The sediments samples collected during jet probing were analysed to determine the proportions of four components: 1) Shell and coral detritus, 2) *Halimeda*, 3) foraminifera, and 4) fines of calcium carbonate.

A number of similar studies of marine aggregate resources in carbonate dominated environments throughout the region have shown that one end member often dominates the sediment composition.

Sample examination was done using a binocular microscope. A split of the samples and the sieved fractions are archived at SOPAC.

Shell and Coral Detritus

Included in this category were shell and coral rubble, whole bivalves, gastropods, sponge spicules, coralline algae and echinoid spines.

Halimeda

Halimeda sands are derived from the skeletal carbonate of marine green algae of the family *Codiaceae* of the Phylum *Chlorophyta*. The codiacean fragments consist mainly of whole or broken segments rather than entire plants. *Halimeda* is an erect plant several metres high, generally segmented, branching and with an internal structure composed of interwoven tubular filaments (Wray J.L.). Although the amount of calcium carbonate produced per plant is small, *Halimeda* is so numerous and grows so rapidly that it can produce volumetrically significant amounts of sediments. *Halimeda* deposits also tend to have a high fines content, which can result in high levels of turbidity when dredged.

Foraminifera

The more common foraminiferal sands are derived from the common reef-dwelling species of *Calcarina spengleri and Baculogypsina sphaerulata,* and these are major constituents of many beach sands in the Pacific. Beach sands are also a favoured material for sand for use as construction aggregate. *Calcarina* and *Baculogypsina* are about equal in size often (1 to 2 mm) exclusive of their spines, though C*alcarina* usually is slightly larger. Their habitat has long been inferred to be the reef flat and not the lagoon. Observations have been made confirming that *Calcarina* and *Baculogypsina* actually live together on the reef surface or in the bottom sediments closely adjacent to reefs but rarely in the shallow waters along the beach (Todd 1960). The beach sands themselves appear to be the final place of accumulation for most of the specimens. The density of living benthic foraminifera can exceed 10^6 /m^2, with wet living biomass estimates ranging from 0.02g/m^2 to more than 10g/m^2 (Culver 1993).

Fines

This end member is silt-and clay-sized carbonate material of indeterminate origin.

Resource Assessment

Computation of the potential resource volumes of the material identified was done in AutoCAD^{tm} by plotting the water depth and sediment thickness derived from the jetprobe data. The isopachs were derived by contouring the sediment thickness data from the jetprobes using QuickSurf. The calculations were performed on a volume defined by the upper and lower surfaces of the sediment body.

To convert the resource volume in cubic metres to tonnes, a value for the sediment bulk density *in situ* is required. For carbonate sediments this figure can vary considerably, as shown in **Table 2**.

Table 2. Examples of some conversion figures used for converting volume to tonnes.

SOURCE	*Tonnes per m^3*
Fiji Industries dredged coral sand (MRD, Fiji)	1.0
Tonga beach sands (Tappin et al. 1993)	2.05
Fafa sand deposit dry (Smith et al. 1991)	2.48

A value for the bulk density of 1 tonne to the m^3 has been used for reserve volume calculations in this report.

RESULTS

Physiography - Nukubuco Reef

Nukubuco barrier reef varies in width along its length but is essentially rectangular (**Figure 2**). At its narrowest point it is estimated to be about 1400 m wide and some 2200 m at its widest in the east representing an area of 6.9 million m^2 (690 hectares).

There are two separate lease areas within the Nukubuco barrier reef held by Fiji Industries for the dredging of carbonate material: Lease 5 and Lease 6. **Figure 2** shows the data coverage for Nukubuco reef complex together with the approximate boundaries of the two lease areas. No coordinates for the official lease boundaries have been defined, but survey was extended sufficiently to ensure complete coverage. Of the 6.9 million m^2 of Nukubuco reef, the central core or reef top (the area subject to flooding and drying) represents an area of about 4.4 million m^2(440 hectares). It is in this area where much of the sediment is generated. Lease 5 occupies an area of 18 hectares and lease 6 is 11 hectares (Ward 1997). The total leased area is 29 hectares, representing 0.4% of Nukubuco reef. However, the total area where dredging has taken place to date represents 4 % of the entire reef area of Nukubuco.

Lease Area – 5

Dredging in Lease 5 commenced around 1975/76 and ceased in 1992/93, with an estimated 1.7 million m^3 of sand removed during this period from water depths of 1 to 10 metres (Ward 1997).

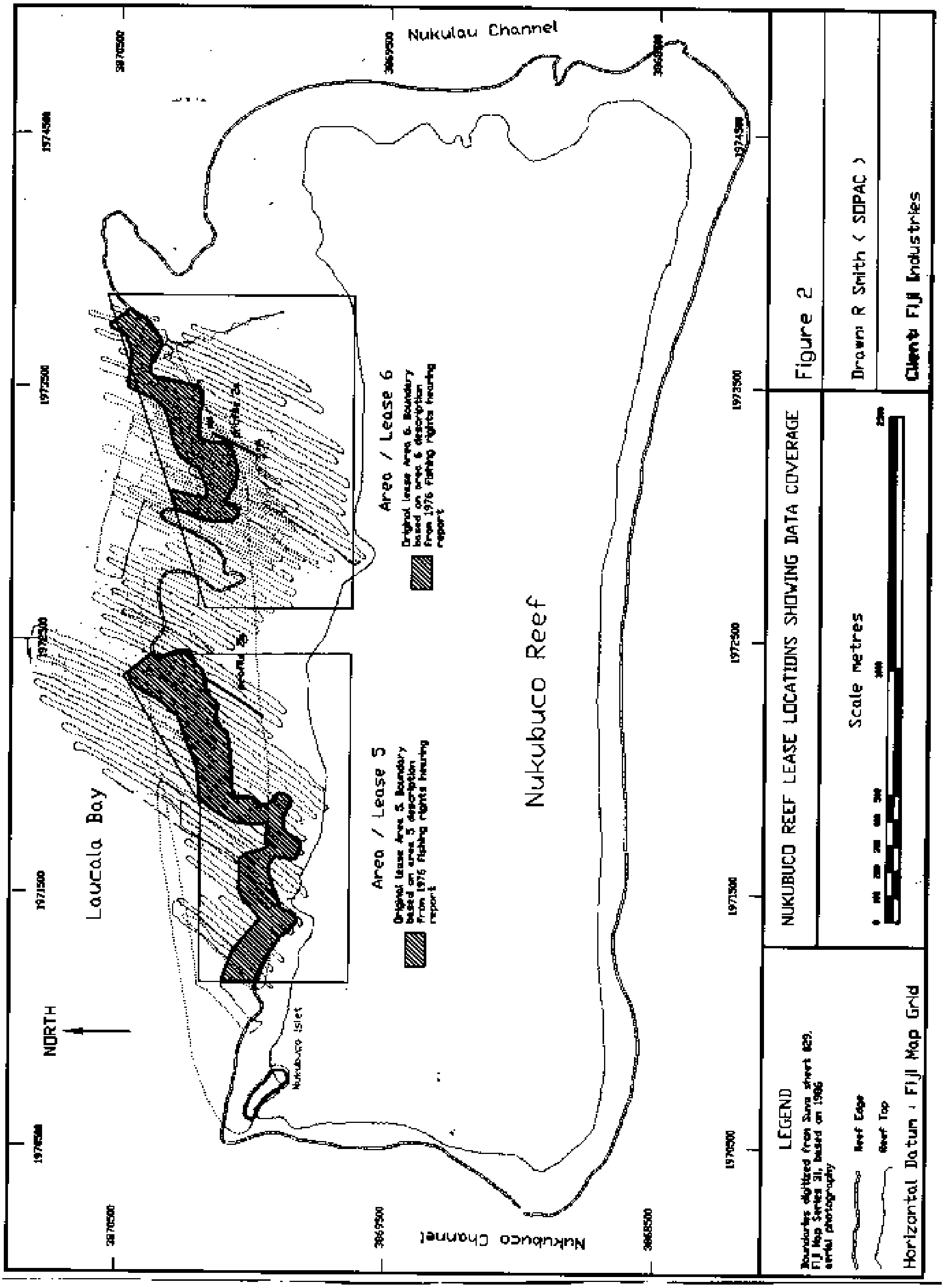

Figure 2. Nukubuco reef lease locations showing data coverage.

Bathymetry

Historical bathymetric data for this area are not available in sufficient detail to delineate conditions prior to dredging. Traditional sources of bathymetry often are from hydrographic data, but, with a focus on navigation and shipping safety, the surveys of such detail are restricted usually to shipping lanes and harbour approaches.

Figure 3 illustrates the location of the profile lines used in the analysis of lease 5. The profiles were surveyed at a 25 m line spacing with position and depth logged every 5 seconds, then processed to define the bathymetry of the sand dredging area. Bathymetric data was reduced to a common datum Lowest Average Tide (LAT) using tidal predictions. Contouring of the data set was prepared with Quicksurf ™ working inside Autocad ™. **Figure 4** shows the bathymetry of lease 5.

Figure 4 shows that the morphology of the sea floor is a steep back reef lagoon scarp sloping from the reef top to an average depth of 10 m below LAT, and from there a gentle sloping shelf from the 10m to 16m isobars dipping northwards into Laucala Bay. A number of large patch reefs are apparent on this shelf area rising from depths of 14 metres to within about a metre of the sea surface.

From the interpretation of the bathymetry the dredging in lease five can best be described as "*quarrying*" at the back reef slope margin thereby effectively of moving the seaward boundary of Laucala Bay seaward.

To examine this further, the compilation of a number of boundaries for different periods interpreted to represent the lagoon edge of the reef (for a depth range of approximately 0m to –2m wrt LAT) from various sources including a 1990 survey (unpublished) and the present survey were compared and the results are plotted in **Figure 5**. The earliest reef edge boundary plotted was digitised from Sheet 29 of the 1:50 000 Fiji Map series 31, which is based on 1986 aerial photography. Earlier boundaries could not be transferred with a great deal of confidence due to scale and the inherent problem of geographic positional errors in transcribing from older geodetic systems to the Fiji Map Grid upon which this data is based. The 1990 reef boundary was mapped with a survey boat at low tide. The 1997 boundary has been approximated by the 2m isobar for LAT. **Figure 5** shows that dredging has resulted in a shift of the lagoon reef edge within lease 5 of between 50 and 200 metres from the 1986 boundary. This variation is a function of the distribution of the resource material (sand) along the back reef slope. During the

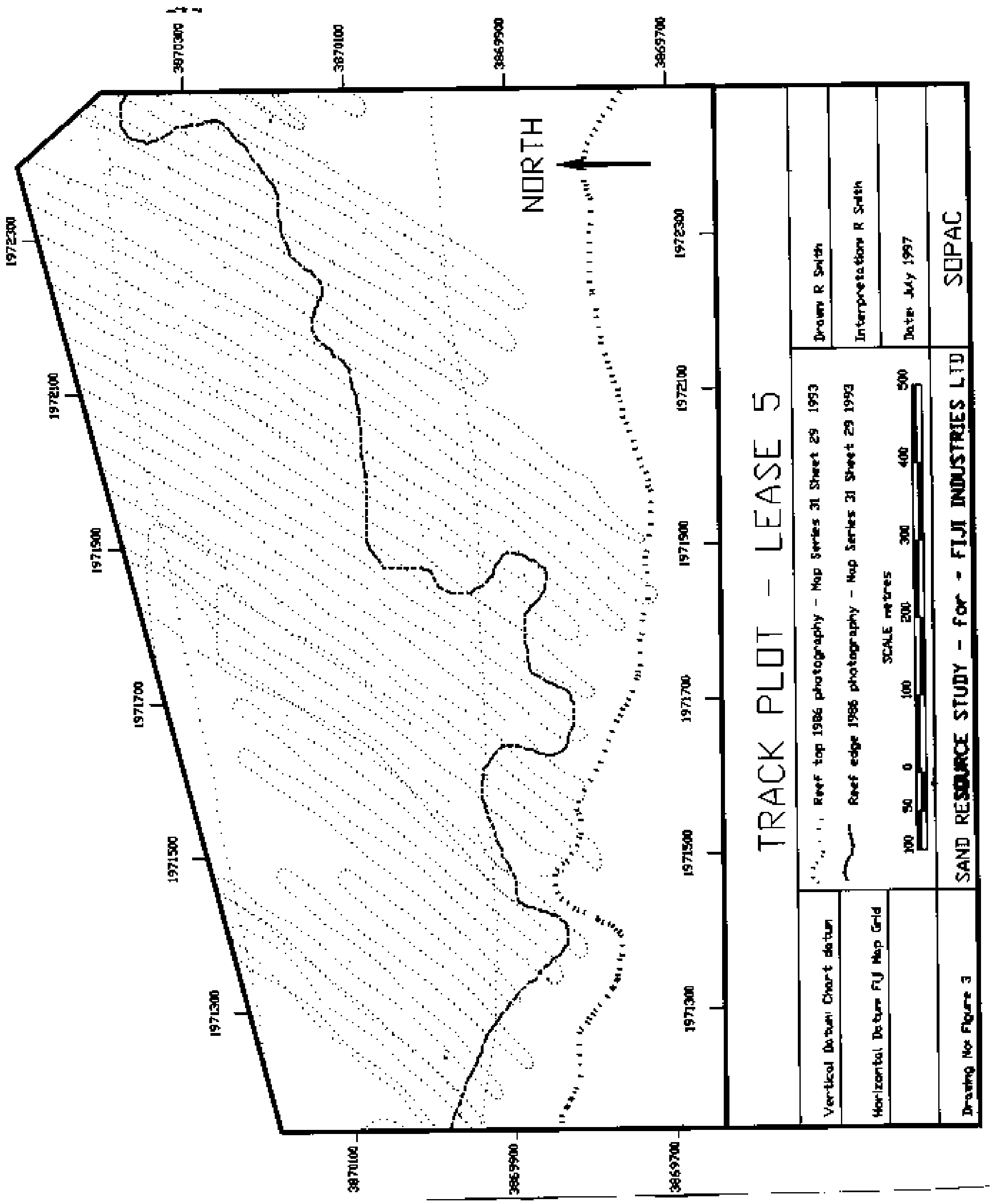

Figure 3. Track plot – Lease 5.

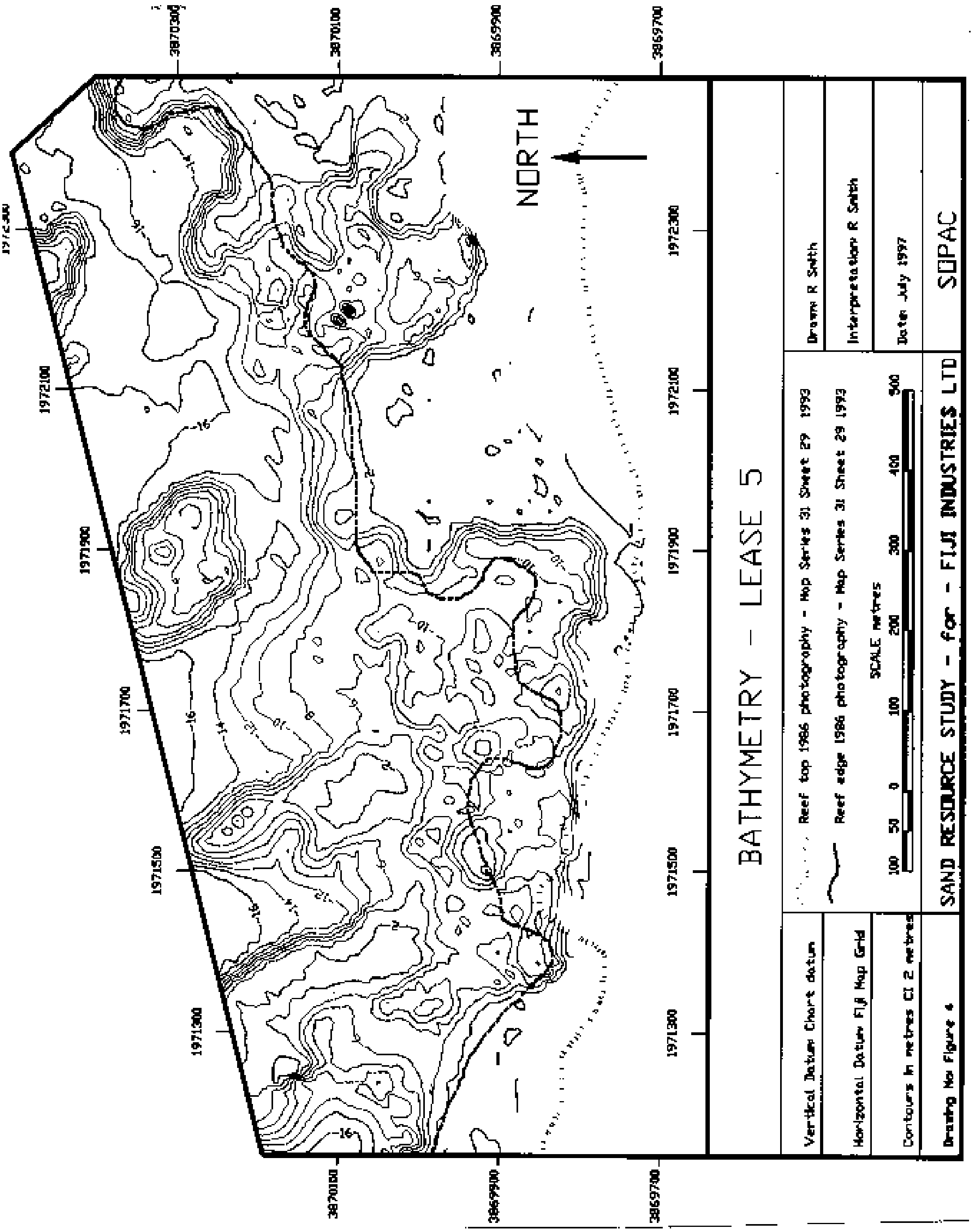

Figure 4. Bathymetry – Lease 5.

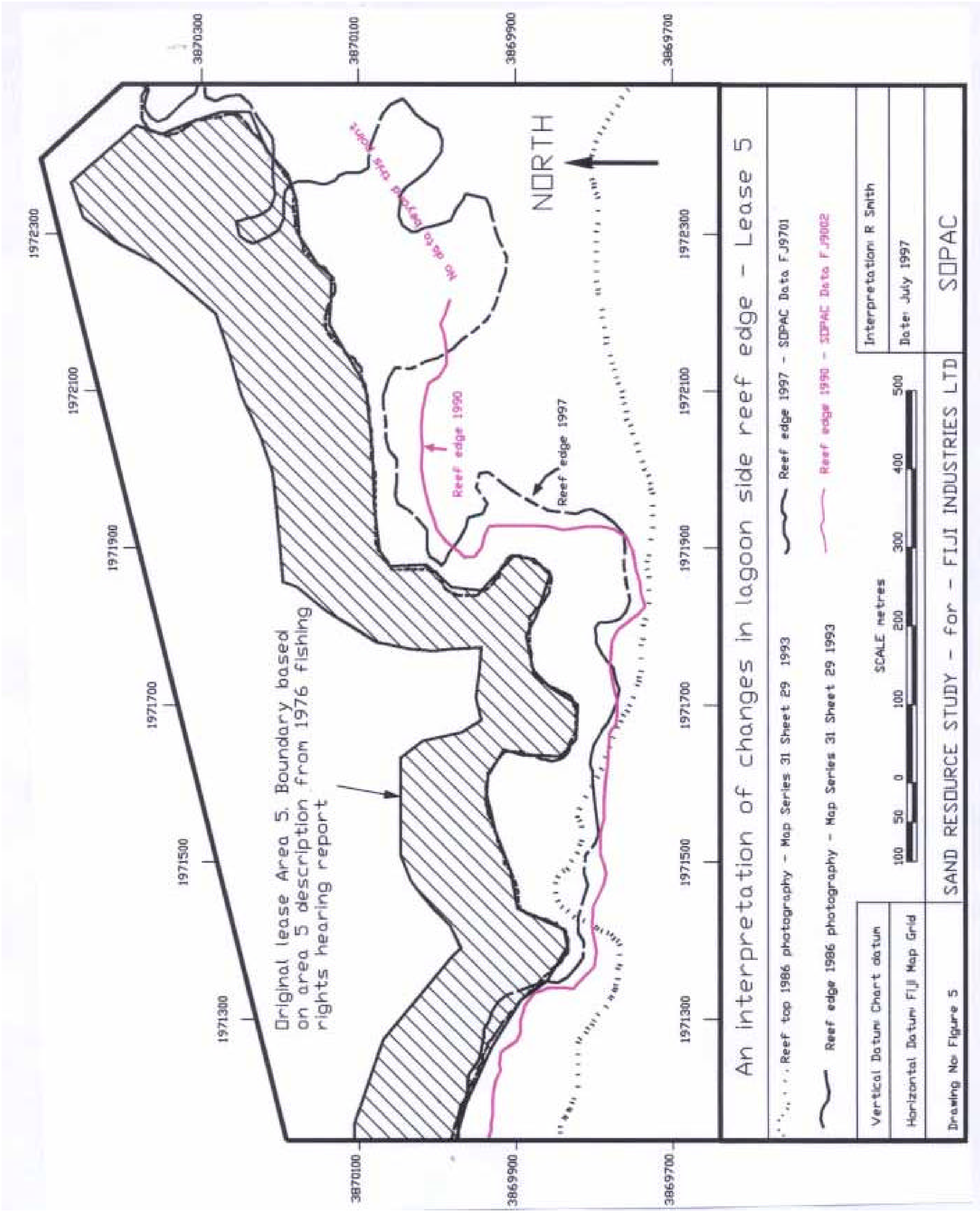

Figure 5. An interpretation of changes in lagoon side reef edge – Lease 5.

acquisition of data is 1990, dredging was occurring in the embayment seen to the east in Lease 5. The prominent spur adjacent to this embayment seen in both the 1990 and 1997 profiles of the reef boundary is interpreted as reef framework with only a surficial cover of sand, as evidenced from drilling during the present survey. The interpretation of changes in the lagoon side reef edge position in lease 5 can thus be attributed to the dredging.

Penn (1983) refers to the dredged sites as “pits”. **Figure 6** shows a 3-D perspective of the sea floor as viewed from the northwest, and shows that the true dredge site morphology has an open-ended *“pit”*-like configuration. Also apparent from the bathymetry is that dredging appears to have exposed a number of reef patches that had been buried during the deposition of the sand. The exposure of such solitary or isolated structures could affect the hydraulic regime, generating localised current eddies that may induce scouring and redistribution of bottom sediments.

These local effects become apparent when comparing the bathymetries of active and discontinued dredge sites. The typical seabed morphology resulting immediately from dredging is shown in profile 2a in **Figure 7** (current dredging site in lease six). Note the hummocky profile of the seabed. A second profile, (2b) shows the seabed changes 3 to 4 years after dredging has ceased. Here the highs are partly levelled and depressions or lows are infilling. During this process, it may be difficult for seagrass to re-establish until the seafloor has reached some form of equilibrium or stability.

Sediment analysis

Grain size analysis

Analysis of grain size, composition and geochemistry of the sediments in lease 5 was based on 20 surface and 17 jetprobe samples. Their location is illustrated in **Figure 8**. A complete log of the jetprobe and sample locations is presented in **Appendix 1.** With one exception, the 17 jetprobe samples analysed for grain size are considered to represent clean sands that are poorly graded and have a fines content (≤ 0.06 mm) less than 1.5%. The exception was Jetprobe 57B which had a fines content of 5% and a fine sand content (≤ 0.2 mm) of 34 %. Jetprobe 57B was drilled in an old dredge site in a water depth of 9.7 m. The results of the sieve analysis are given in **Appendix 2**.

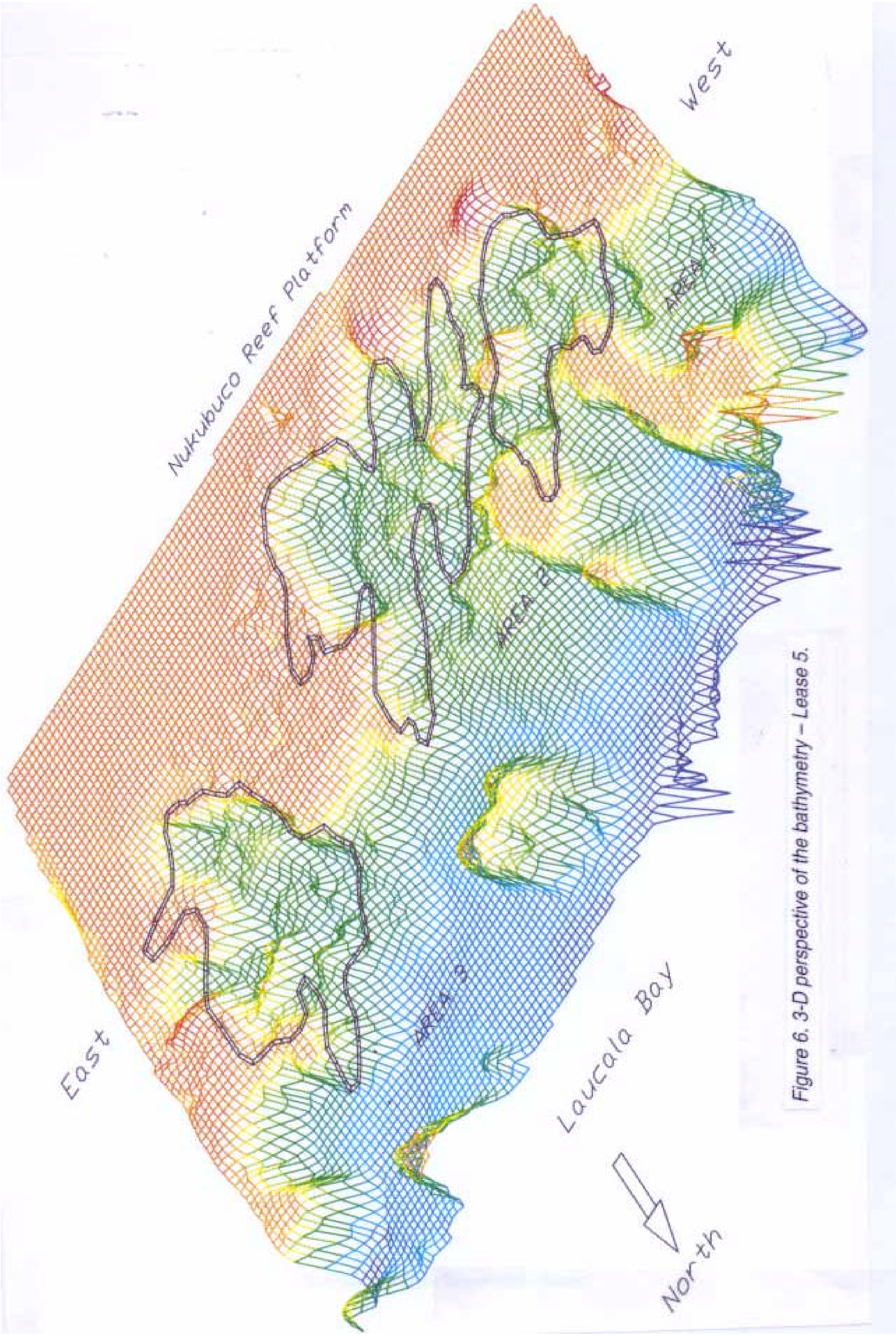

Figure 6. 3-D perspective of the bathymetry – Lease 5.

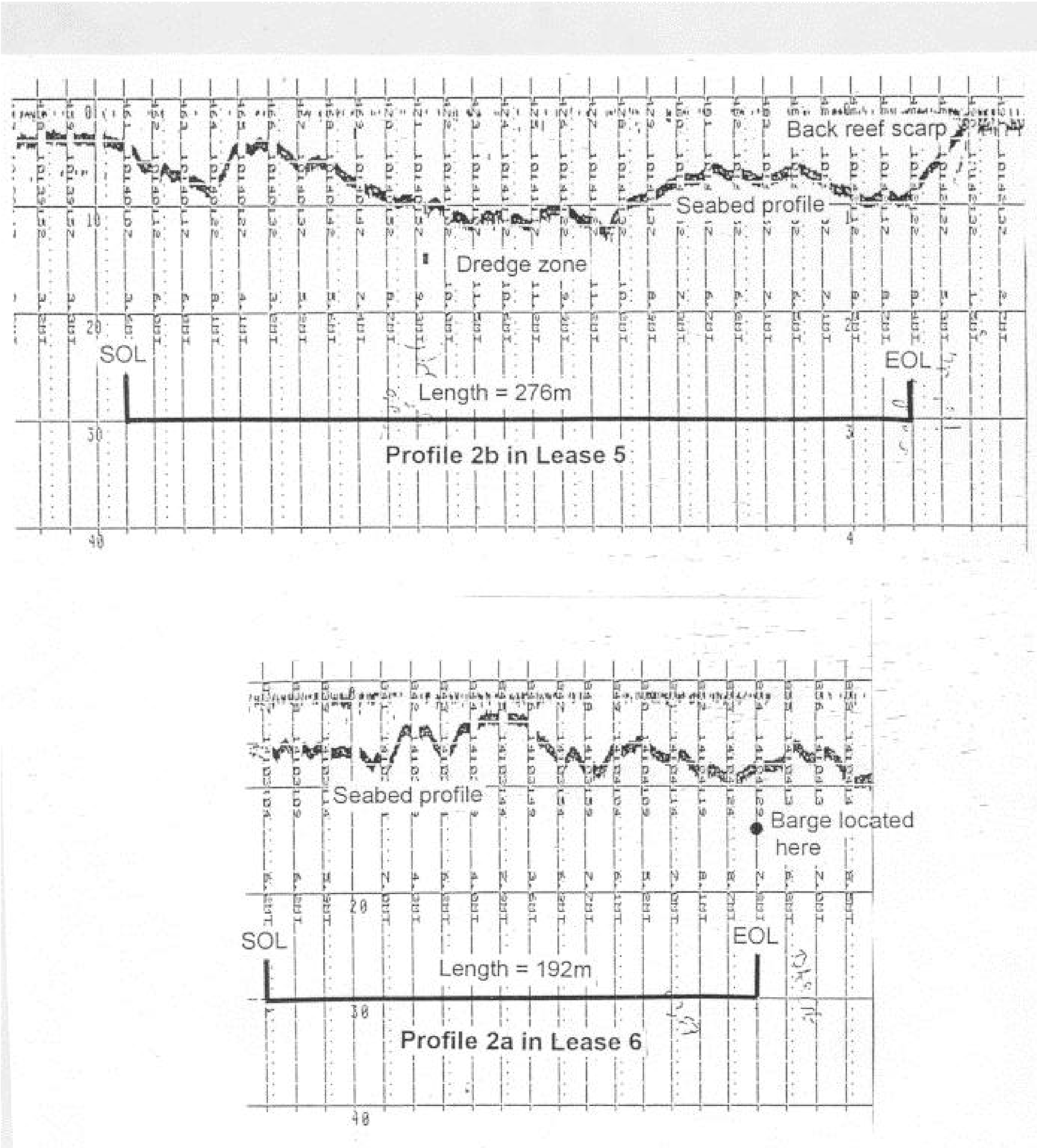

Figure 7. Profile 2a showing typical seabed morphology resulting immediately after dredging. Profile 2b is of the Lease 5 location showing seabed changes after dredging ceased.

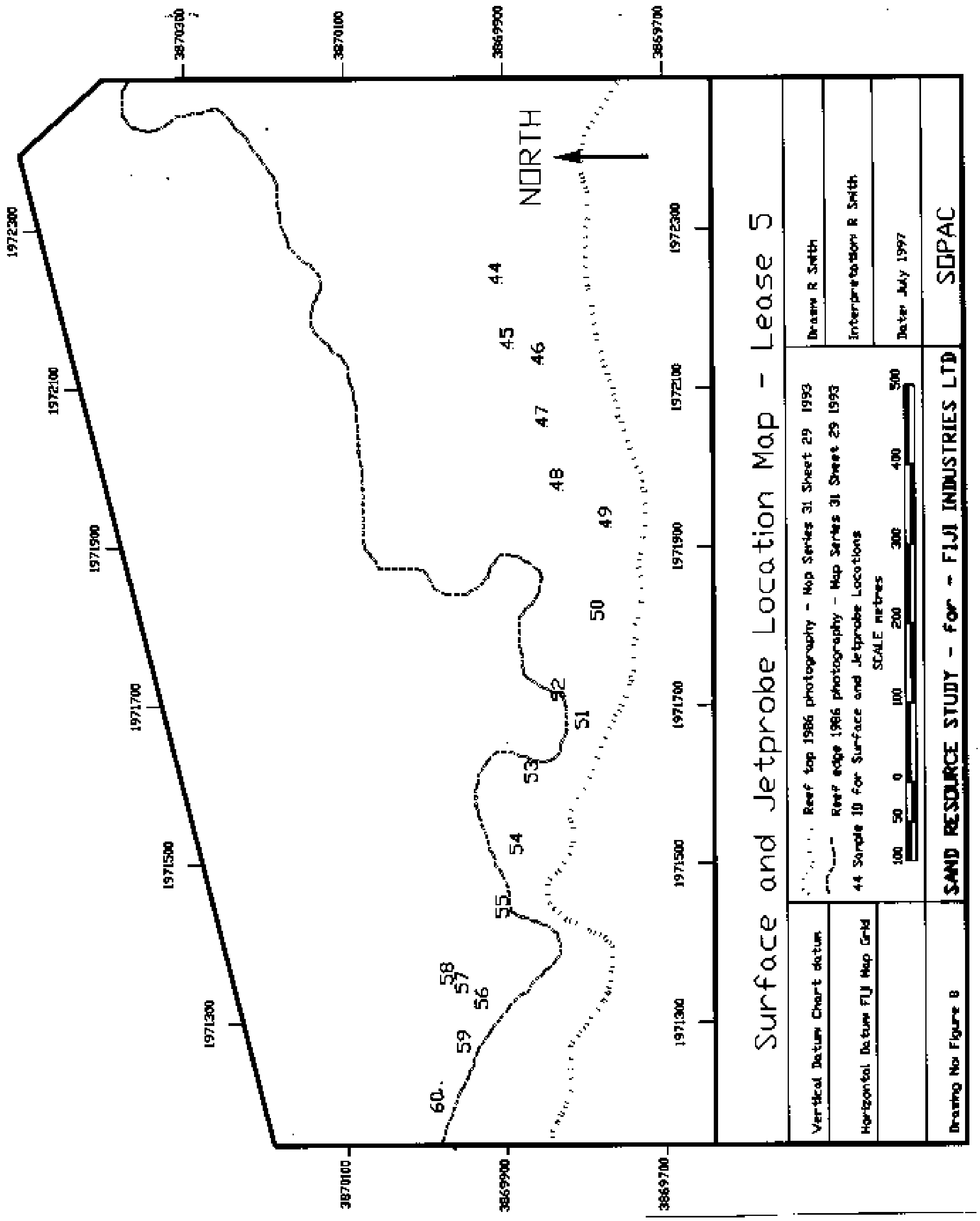

Figure 8. Surface and jetprobe location map – Lease 5.

Geochemistry

Assays of both the surface and jetprobe samples were undertaken by Fiji industries Laboratory for a suite of elements, the most important of which is magnesium oxide (MgO). The cut-off grade for MgO in the sand resource is approximately 2.8% (Pers. Comm., S. Chand 1997). **Figures 9 and 10** are plots of the distribution of MgO in surface and jetprobe samples respectively for locations shown in **Figure 8** for lease 5. Complete samples analyses are given in **Appendix 3**. For both plots, the MgO content of the sediments increases southwards into the reef platform. Studies have shown that magnesium is found to have higher concentrations in coralline algae, from 3% – 7% compared to *Halimeda* with 0.04 – 0.64% for example (Milliman 1974).

Resource assessment

The lack of baseline data describing the resource prior to dredging meant that the delineation of the dredged areas in the present study was based entirely on seabed morphology interpreted from the bathymetric profiles. Three dredged areas were identified (areas 1, 2 and 3 encompassing 4.2, 8.8 and 8 hectares respectively for a total area of 21 hectares. This represents an area 8.5% larger than approximated in the original lease license (Ward 1997). These are shown in **Figure 11.** Although a fourth smaller area shown is thought to have been dredged, this latter area was not included in the assessment of sand dredged from Lease 5. For the three dredged areas identified, it is estimated here that some 1.6 million m^3 has been mined. This figure compares well with the reported tonnage of 1.7 million tonnes takes from Lease 5 during its active life. A comparison of the 1997 data set with 1990 bathymetric data with a profile spacing of 50 m indicates some 360,000 m^3 was dredged from Lease 5 after 1990. Records from Fiji industries confirm this amount (Ward 1997).

An isopach map of sediment thickness based on the 17 jetprobe locations in Lease 5 is shown in **Figure 12.** Jetprobe penetration ranged from 0.1 m to 9 m. A digital elevation model generated from this data set was used to compute a sand resource volume of 400,000 m^3 remaining in Lease 5. However, much of this resource is in water depths of between 6 and 12 metres and contains a higher level of fines. It also became apparent that during the course of interpreting the data in the dredged areas there remained the possibility of additional material being present. Modelling each of the identified dredged areas 1, 2, 3, **Figure 11**, using the bathymetry of the dredged area as the upper surface and the lower surface defined as an optimum dredging depth with respect to LAT potential resource volumes were calculated. Results are presented in **Table 3**.

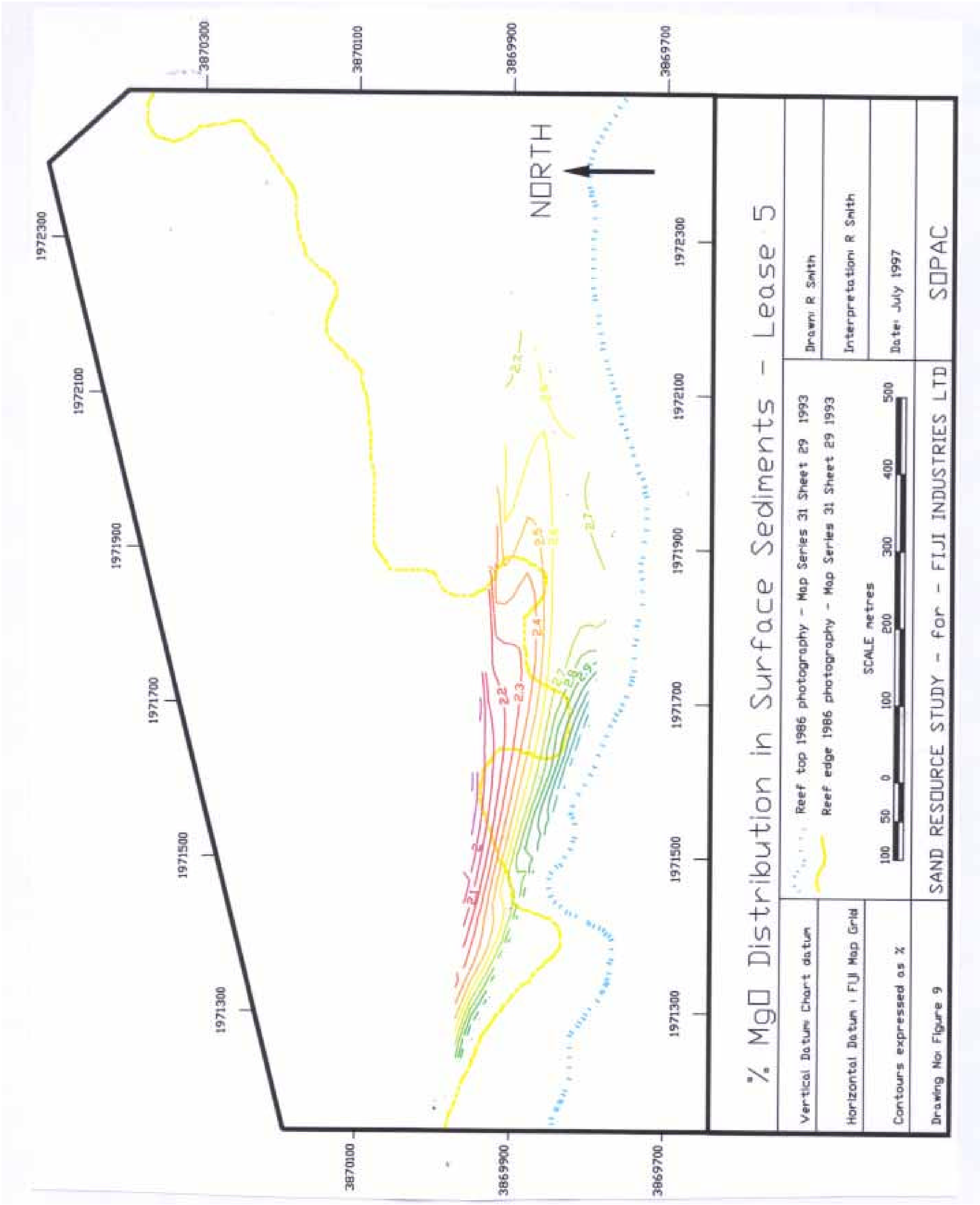

Figure 9. Percentage MgO distribution in surface sediments – Lease 5.

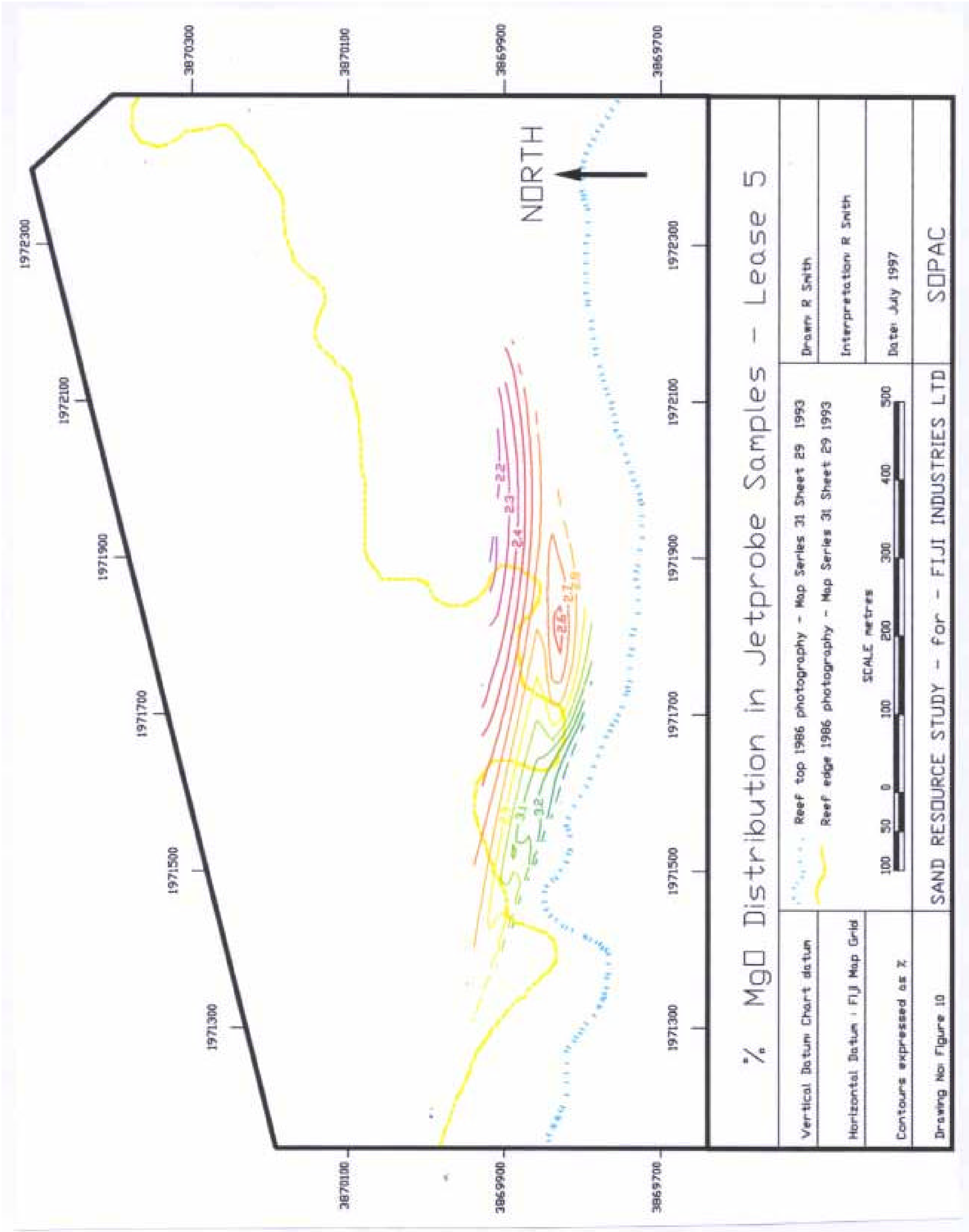

Figure 10. Percentage MgO distribution in jetprobe samples – Lease 5.

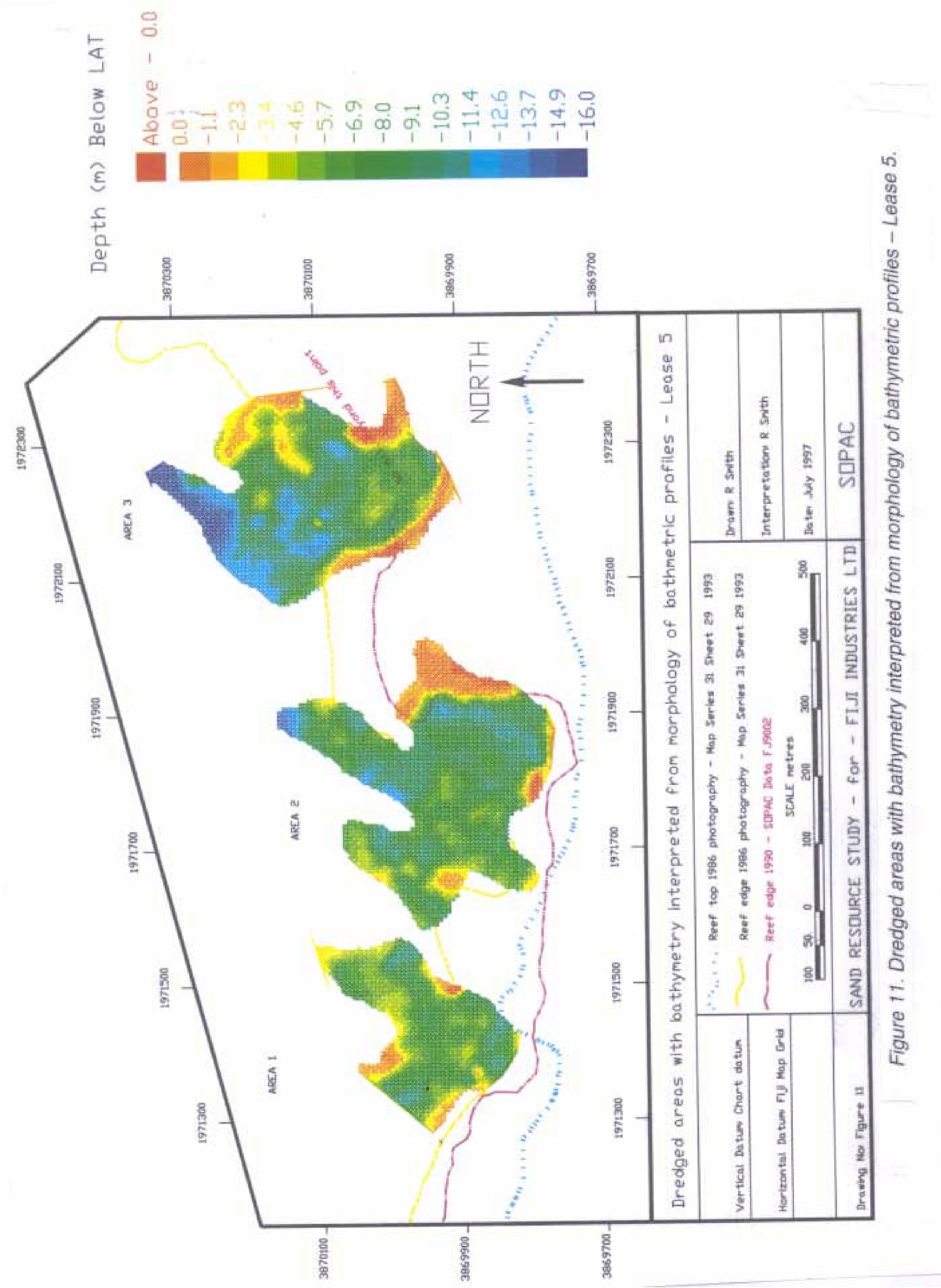

Figure 11. Dredged areas with bathymetry interpreted from morphology of bathymetric profiles – Lease 5.

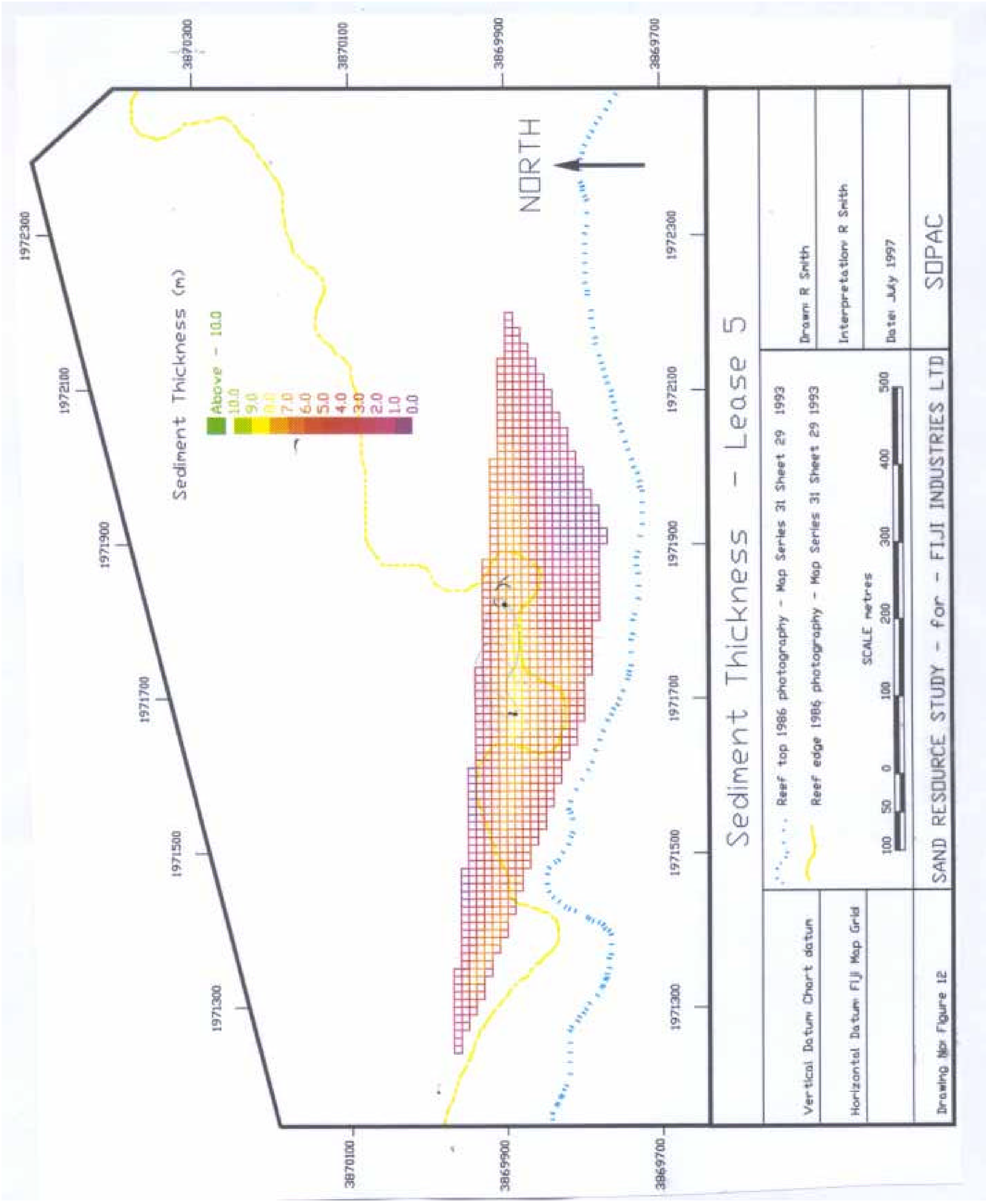

Figure 12. Sediment thickness – Lease 5.

Table 3. Estimated reserves for dredged areas 1, 2, 3-Lease 5.

Dredge Area Reference Figure 11	Average Depth m wrt LAT	Area m^2; Hectares	Resource Volume (m^3) for an optimum dredging depth wrt LAT			
			8 m	**10 m**	**12 m**	**14 m**
1	6.1	42478; 4.2	79608	152059	230925	310052
2	6.9	88307; 8.8	135573	270661	439217	613598
3	7.8	75944; 8.0	119843	211000	329378	466101
Total Resource Volume Available			335026	633721	999521	1389752

The figures presented in **Table 3** are indicative only. To substantiate them, a detailed jetprobing program is needed to validate the model of the remaining resource in the 3 dredge areas.

Lease 6

Dredging in Lease 6 commenced around1993/1994 and continues to the present. To July 1997, an estimated 0.42 million m^3 of sand has been removed (Ward 1997) in water depths of 1 to 10 metres.

Bathymetry

As in Lease 5, historical bathymetric data from prior to dredging in this area is not available in sufficient detail to delineate initial conditions.

Figure 13 shows the location of the profile lines used in the analysis of Lease 6. Profiles in this lease area were surveyed at a 12.5 m line spacing in the dredged areas, with a 25 m spacing adopted for areas of the reef flat only accessible at high tide. Position and depth were logged every 5 seconds, and were then processed to define the bathymetry of the lease area. Contouring of the data set was done by Quicksurf ™ working inside Autocad ™ (**Figure 14)**.

The sea floor morphology of Lease 6 differs from that of Lease 5. In areas in Lease 5 where dredging has not occurred, the steep back reef-lagoon scarp is replaced by a more gentle slope that blends into a shelf expressed by the 10 m and 16 m isobars with a northwards dip into Laucala Bay. Two small patch reefs are evident on the shelf area, rising from a depth of 10 m to

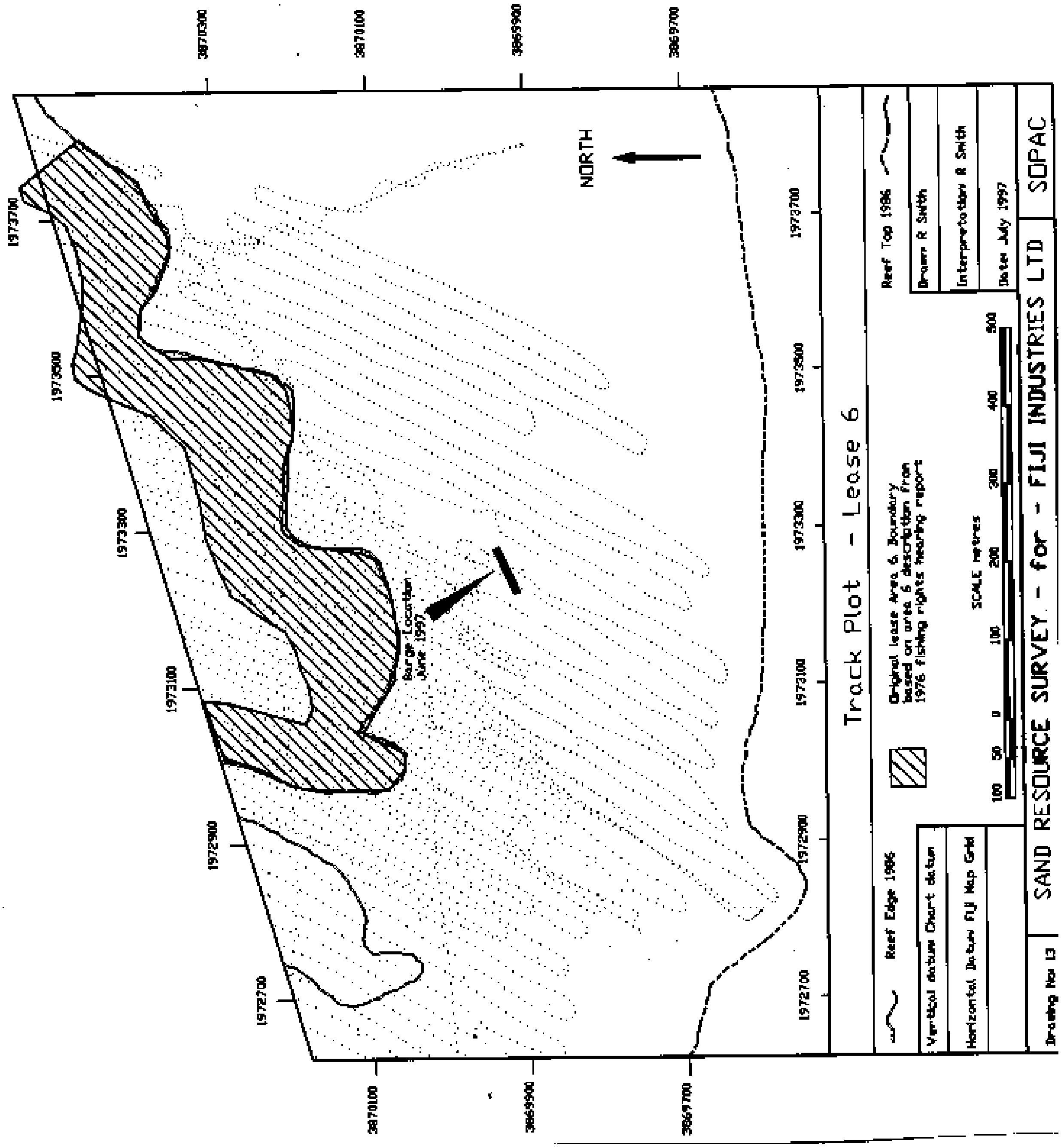

Figure 13. Track plot – Lease 6.

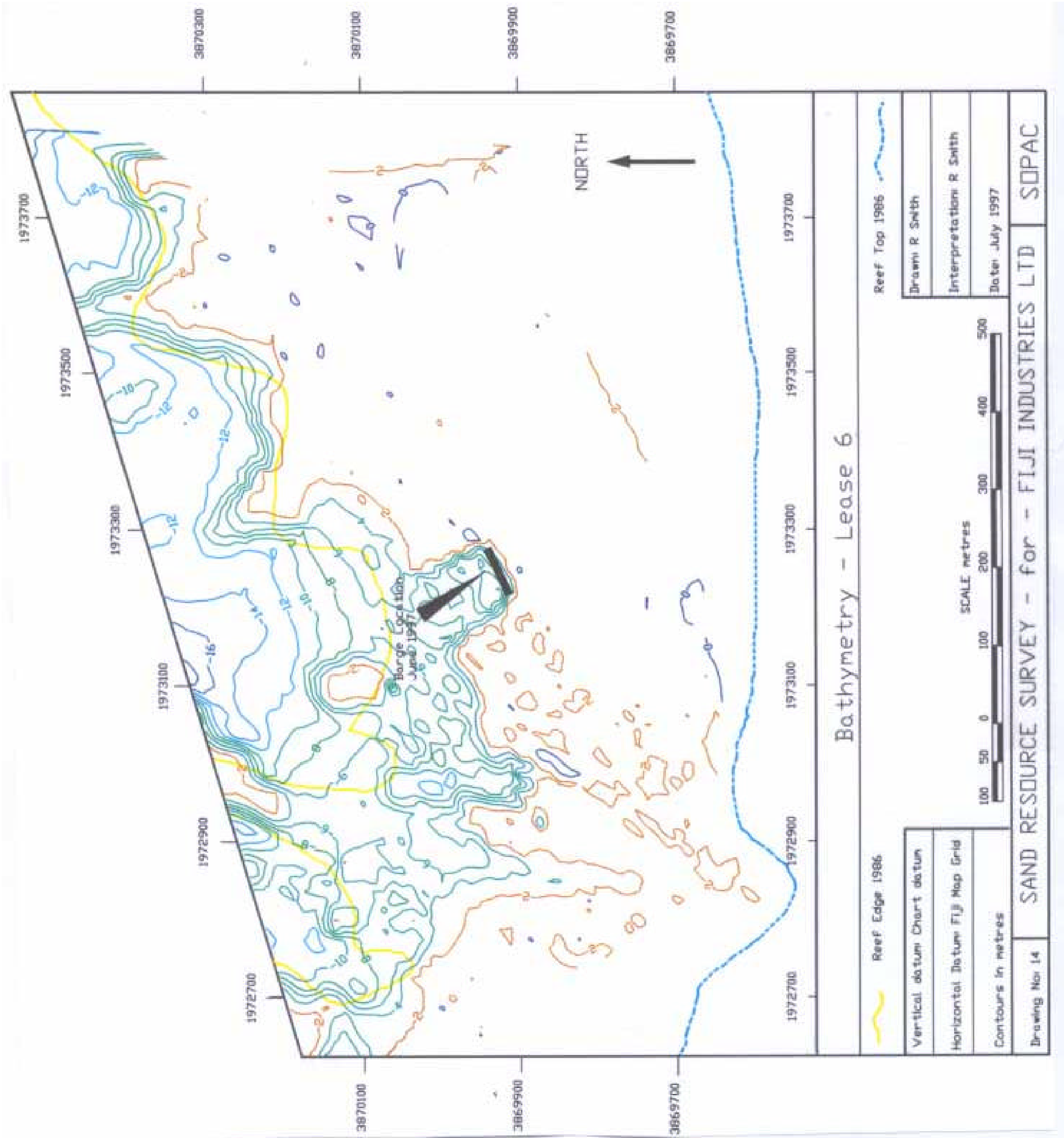

Figure 14. Bathymetry – Lease 6.

within a metre or so of the sea surface. The bathymetry clearly illustrates where dredging has taken place in the centre of the figure with the 2 m isobar outlining a rectangular cut into the sand deposit.

Seabed Morphology

An interpretation of the seabed morphology based on the profiles is shown in **Figure 15**. Six zones are classified in the area surveyed. **Table 4** lists the approximate surface area contained by each of the units defined in **Figure 15**. Penn (1983) showed that the best sand reserves are associated with seagrass meadows. Within Lease 6, seagrass meadows represent about 176,000 m^2 (17.6 hectares). For this area, dredging in the principal resource area may affect as much as 62,000 m^2 (6.2 hectares) of seagrass meadows representing 35% of the meadows mapped in Lease 6. The total seagrass area of Nukubuco Reef is unknown.

Table 4. Approximate surface area contained by units, see **Figure 15**.

Morphological unit	**Area of unit in m^2**
Area of Lease 6 defined for this study	1038336
Algal substrate (Lumi)	38000
Dredged areas	161000
Seagrass meadows	158000
Sandy substrate	20200
Reef substrate with a thin veneer of sand and rubble	48800
Seagrass meadows with coral	16000

Sediment analysis

Grain size

Analysis of grain size, composition and geochemistry of the sediments in lease 6 was based on 43 surface and 40 jetprobe samples. The location of these is shown in **Figure 16**, and a complete log of the jetprobe and sample locations is presented in **Appendix 1.** The 40 jetprobe samples analysed for grain size are all considered to be clean sands that are poorly graded and have a fines content (≤ 0.06 mm) of less than 0.5%. **Appendix 2** contains the results of the sieve analyses.

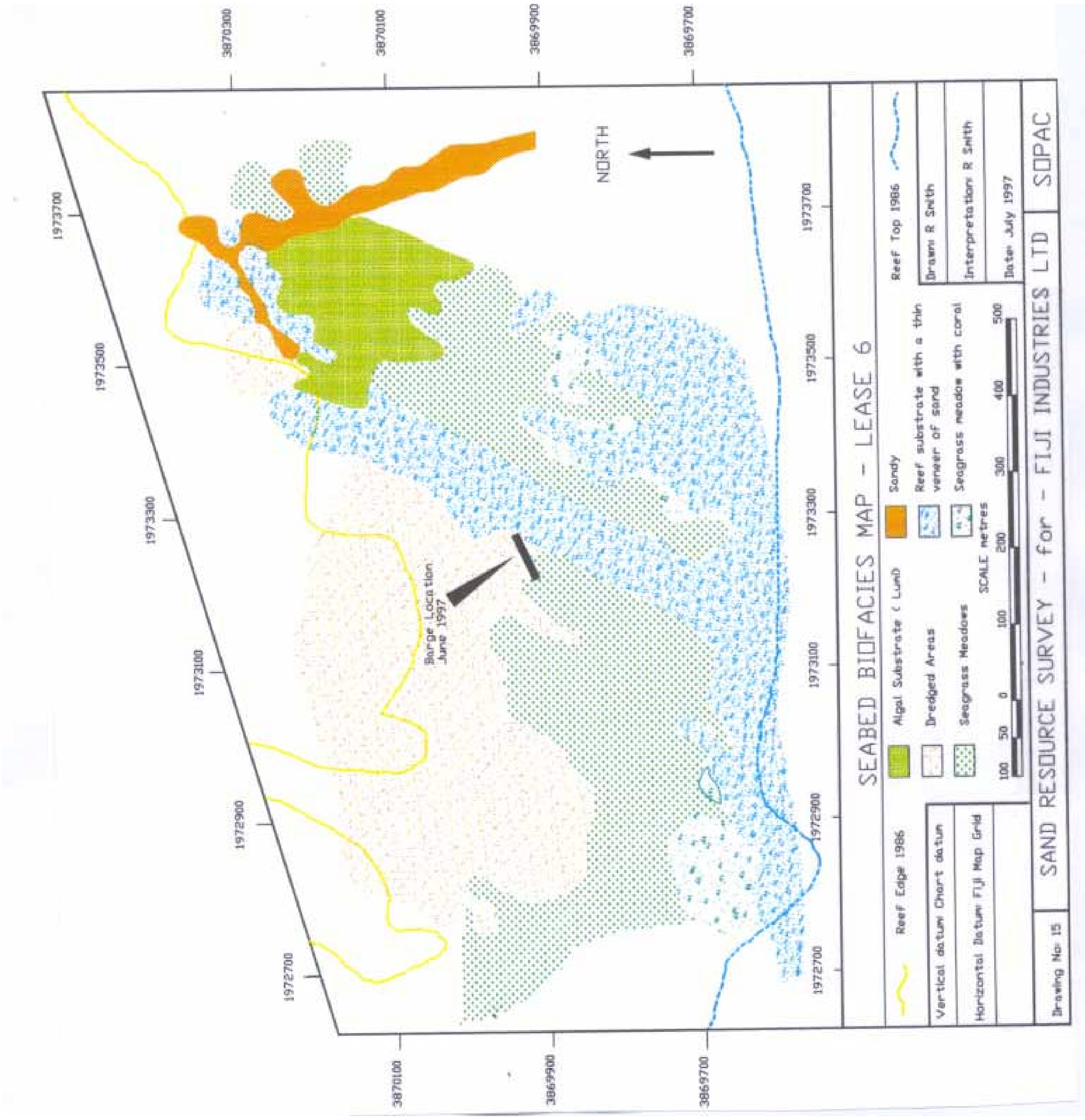

Figure 15. Seabed biofacies map – Lease 6.

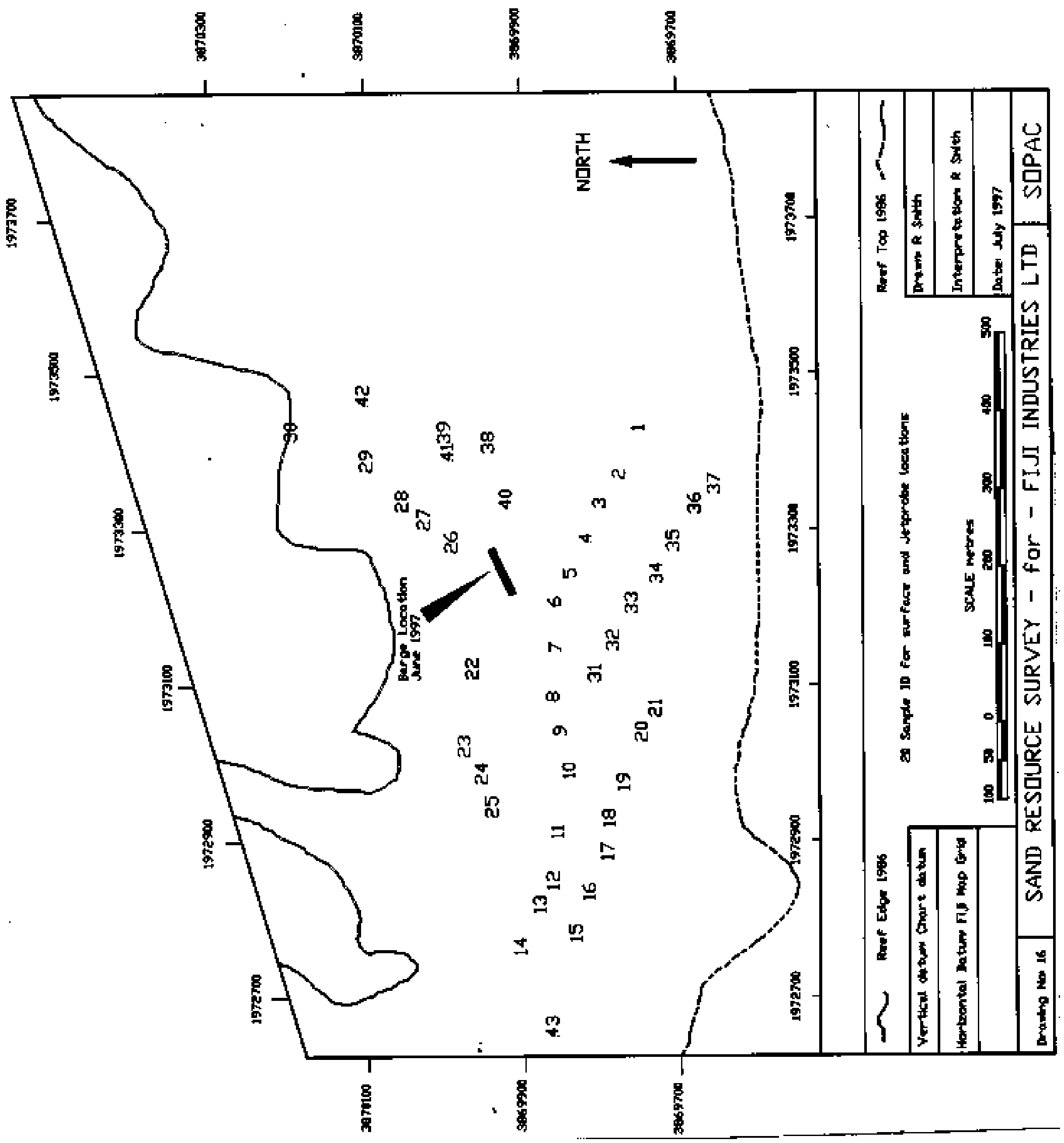

Figure 16. Sample locations.

Geochemistry

The surface and jetprobe sediment samples from Lease 6 were assayed by Fiji Industries (Appendix 3). **Figures 17 and 18** are plots of the distribution of MgO in the surface and jetprobe sediments respectively for the locations shown in **Figure 16.** The analyses show higher concentrations of MgO to the west of the lease area. In the central area where most of the sand reserves occur. The MgO content ranges between 2.6% and 3.2%.

Resource assessment

The resource assessment for Lease 6 was completed along the same lines as for lease 5. The first requirement was to gain an appreciation of the volumes extracted and remaining. Lack of baseline data describing the resource prior to dredging required delineation of the dredged areas based entirely on the seabed morphology interpreted from the bathymetric profiles. Dredging has only been undertaken in Lease 6 for 3 to 4 years. One major dredging area was identified with a smaller area to the northeast of the lease. The location of these two areas is shown in **Figure 15**. From data in table 4 the dredged area is estimated to represent 154,000 m^2 (15.4 hectares), which is greater than the original lease description of approximately 11 hectares. For the two dredged areas identified it has been estimated that some 600,000 m^3 has been mined from this lease to date. This figure compares reasonably well with the reported tonnage of 421,000 taken (Ward 1997), allowing for the fact that a constant value has been assumed for depth to seabed rather than a surface representing the true bathymetry prior to dredging. An alternative to assuming a constant level for the bathymetry in the area would be to take each profile and attempt to reconstruct the original seabed profile in order to calculate the original depth. However, this is beyond the scope of the present report.

Figure 16 shows the distribution of the 43 jetprobe holes drilled to test sediment thickness in Lease 6. Depths presented ranged from 5 cm to 8.0 m, with an average of 3.3 metres. Constraints on proving sediments thicker than 3.5 m were the length of the drill rod and the problem of hole collapse trapping the drill rod. In semi-consolidated sands deeper hole were drilled if the hole remained open long enough to pull the rod free of the substrate. A log of the drill results is given in **Appendix 2**.

An isopach map of sediment thickness was generated from the jetprobe hole data **(Figure 19).** From the digital elevation model of the sediment thickness a reserve volume of some 600,000 m^3 was calculated for water depths less than 3 m. However, not all of this material can be considered accessible due to the existence of buried patch reefs and/or extensions of the original base reef framework shown by jetprobing.

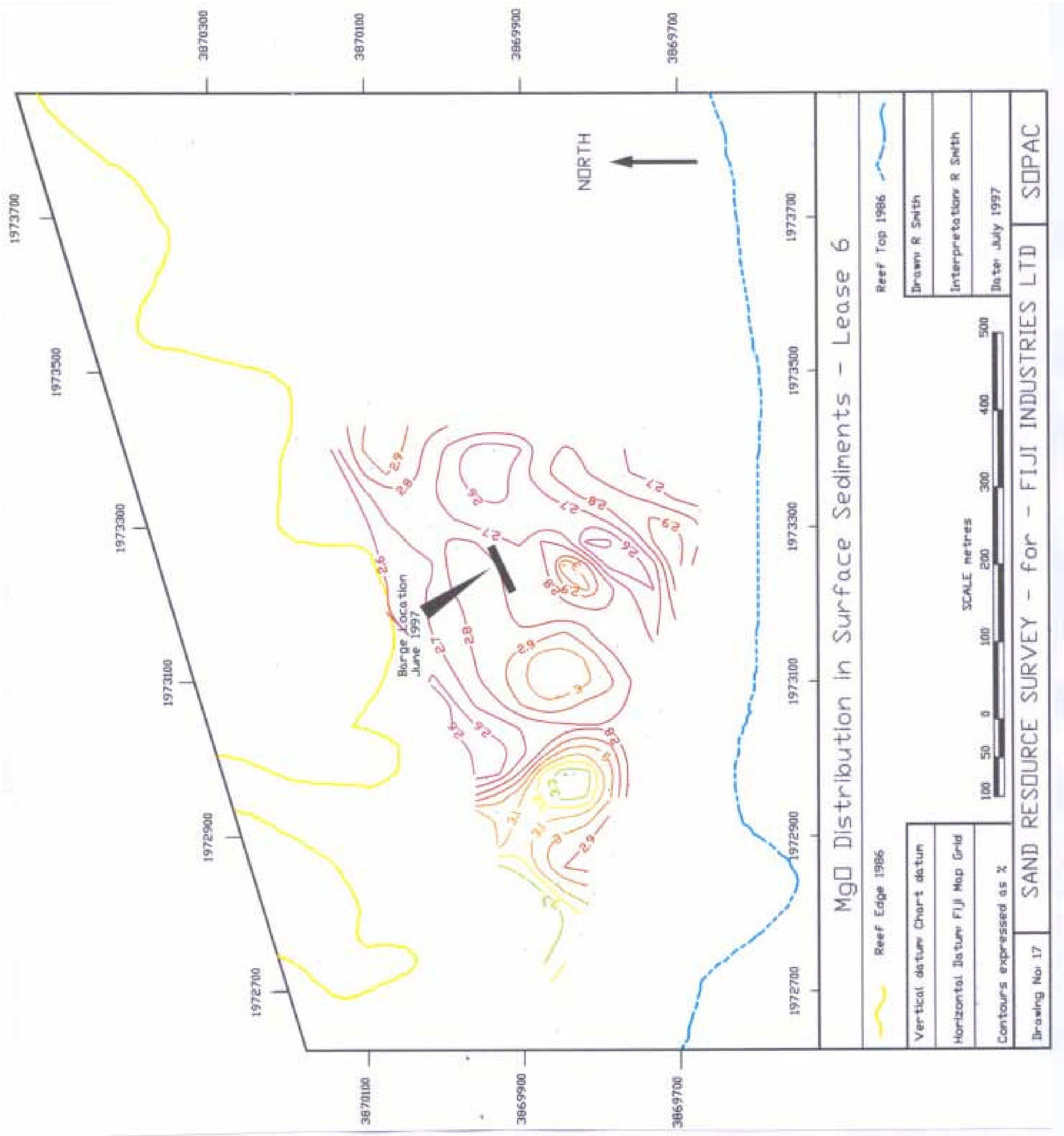

Figure 17. MgO distribution in surface sediments – Lease 6.

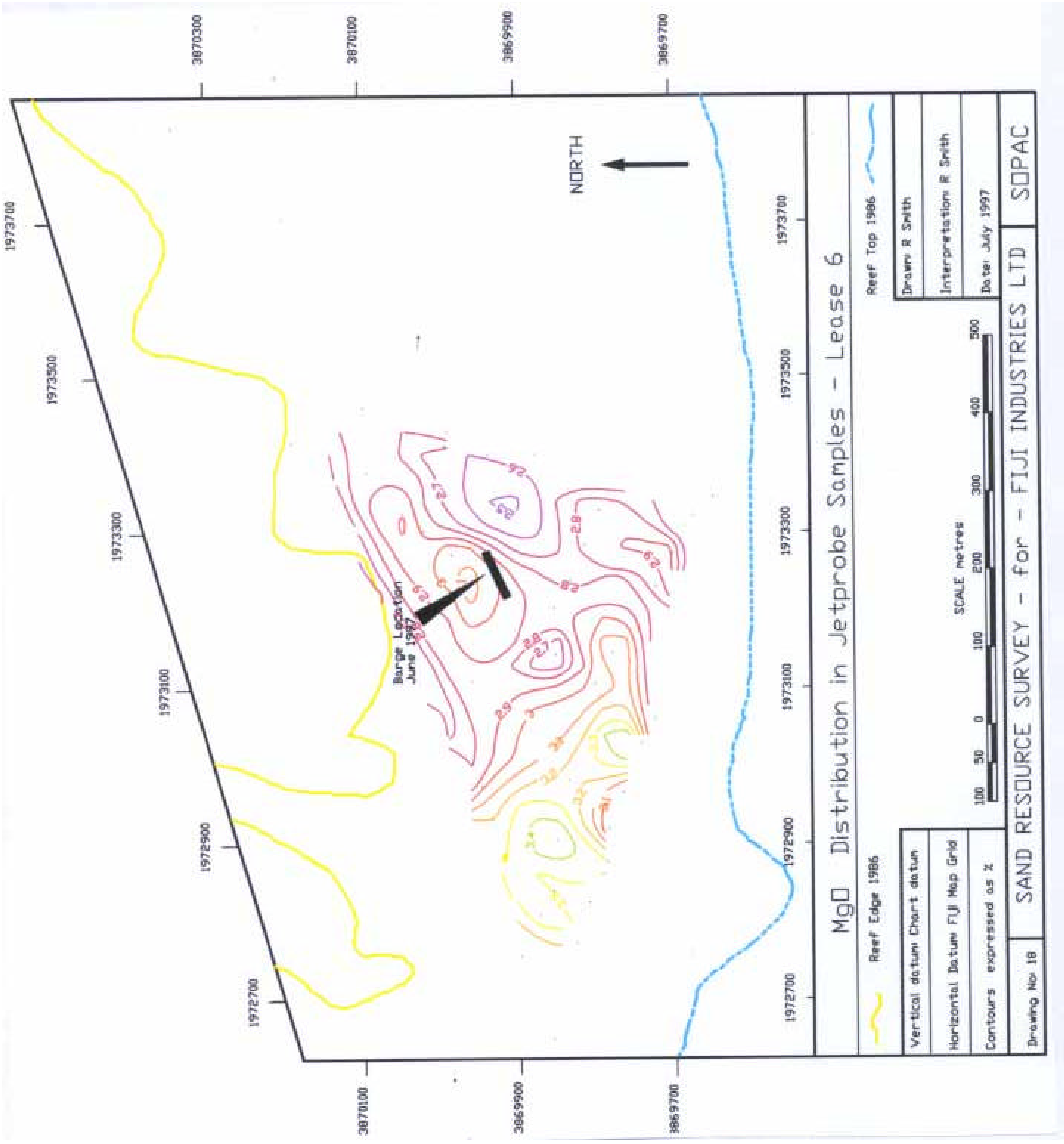

Figure 18. MgO distribution in jetprobe samples – Lease 6.

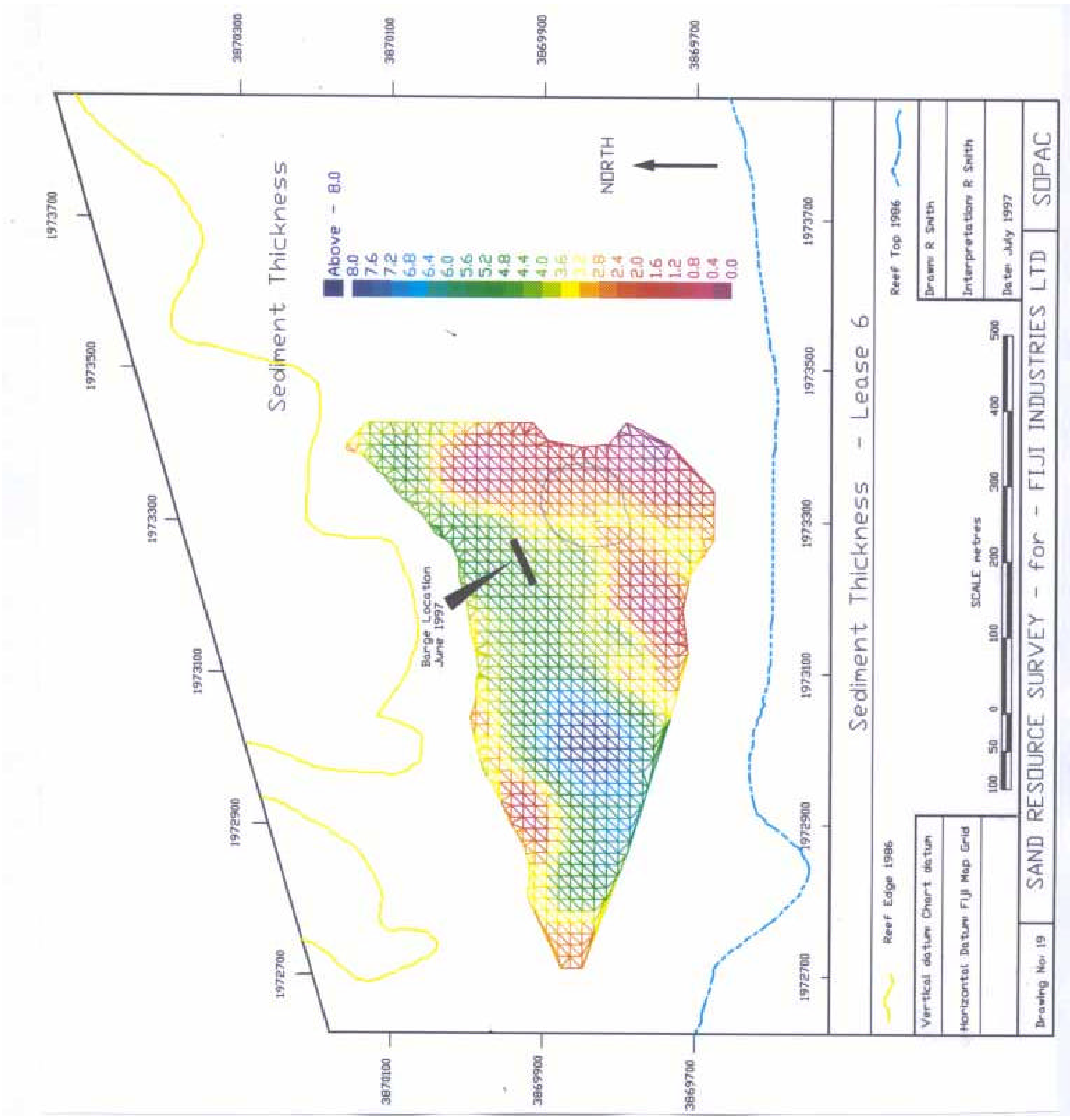

Figure 19. Sediment thickness – Lease 6.

From **Figure 19**, a resource area has been delineated which represents the zone of maximum sediment thickness based on the jetprobe values for depth of penetration into the sediments. An expected volume of 480, 000 m^3 is calculated for a dredging depth to – 10 m below LAT in this area. However, it should be noted that higher levels of MgO occur to the west of the resource area, **Figures 17** and **18** which may impact on the suitability of the sediment for processing if the industry's cut-off grade for MgO content is 2.8%. Assuming a cut-off grade of 3.0% for MgO, based on levels noted in the area currently dredged, the resource volume is then reduced to 210, 000 m^3 for a dredging depth of 10 m below LAT.

Sediment Composition for Leases 5 and 6

Selected samples from Leases 5 and 6 were examined both visually and under a binocular microscope. For the 1mm range, coral rubble was found to be the dominant component at 60 %. Other important components of the sand are molluscs (17 %; gastropods and bivalves), *Halimedia* (10 %) and foraminifera (7%; *Amphistergina* sp and the more friable *Marginopora* sp being the dominate species), with the remaining 6 % composed of volcanic fragments, worm tubes, echinoid spines, bryzoans and crustacean fragments.

Sand sources, production and sustainability

One of the most important questions often raised regarding the dredging of the sands from Laucala Bay is the sustainability of the resource, which is the relationship of the natural supply of sediment to the rate of extraction. In assessing the sustainability of carbonate sands the composition is most important because carbonate sedimentation differs from siliciclastic sedimentation in that carbonates are literally "born" (a phrase attributed to Noel P. James). Siliciclastic depositional systems are dependent on an outside sediment supply, such as a river carrying eroded material to the coast. In carbonate systems the reef rim is usually the most productive area for carbonate detritus, rubble and foraminiferal sands rather than the actual lagoon, as the growth potential of the reef rim is often significantly higher than that of the interior facies of the lagoon backing the reef complex. In addition, the reef protects the accumulation of the loose sediment on the inner lagoon slopes, which become a sink for much of the sediment produced at the reef rim. Transportation of this loose material is by wave- and wind-induced currents across the reef flat, into the lagoon. For the lease area, the principal sources typically include coral rubble, *Halimeda* and foraminiferal sands.

Carbonate sediment production is difficult to assess and values can vary from locality to locality. Typically on the seaward portion of the reef, production has been estimated in the order of 4 kg $m^{-2}y^{-1}$ (Smith and Kinsey 1976). On One Tree Reef in the Great Barrier Reef, Davies (1982) suggested a mean carbonate production of 1.5. kg $m^{-2}y^{-1}$. Gross carbonate production rates in Tonga are considered as high as 9 kg $m^{-2}y^{-1}$ which, when reduced by the amount utilised in reef growth gives a net production of 8 kg $m^{-2}y^{-1}$ (Tappin et al 1991). Adjacent to this sand mining area in Tonga there is a wide reef with windward exposure which suggest that the more optimistic figure of sediment production could be considered. For Nukubuco reef with an area of about 4.4 to 5 million m^2 possible for carbonate production adjacent to the lease areas could produce, using the figures quoted above, between 5000 to 45,000 tonnes (5000 to 45,000 m^3 assuming a 1:1 ratio 1 tonne to the cubic metre) of carbonate per year. Determining the net accumulation of sediment into the mining area is not easily answered, but indications are that at the current levels of extraction considerably exceed sediment production rates.

In the case of the sands in Laucala Bay, the dominant component appears to be coral rubble. This observation lends supports to the general conclusion that much of the sand resources found in Leases 5 and 6 is a consequence of sea-level change. Sea-level curves for southeast Viti Levu, a compilation from various authors in (Shorten 1993) are shown in **Figure 20.** From the curve, sea level around 4000-4500 yr BP was about 0.6 m above present level before falling to current levels some 2000 yr BP (Shepherd 1990). As reef growth tends to follow sea level, with the commencement of the stillstand in sea level, Nukubuco Reef was planned and grew laterally. The subsequent erosion of it produced much of the carbonate sands that are dredged today.

Other factors that may also contribute large volumes of sediment over short time frames include the impact of cyclones and tectonic events.

During cyclones, large volumes of coral rubble can be removed from the forereef slope and deposited on the reef top where they are later reworked and redistributed under normal conditions. Events of this nature are well documented, for example, the Cyclone Bebe banks of Funafuti, Tuvalu and the more recent deposits from Cyclone Ofa on the fringing reefs of Upolu, Samoa (**Figure 21**). An example of the impact of tectonics may be the 1952 Suva earthquake. Here, possible uplift of the Namuka barrier reef complex may have resulted in an increase in carbonate sediment production that has infilled the channel that once linked Namuka and Suva harbours in the 1950s and 1960s (J St Julian, pers.com). Further work is required to substantiate this hypothesis.

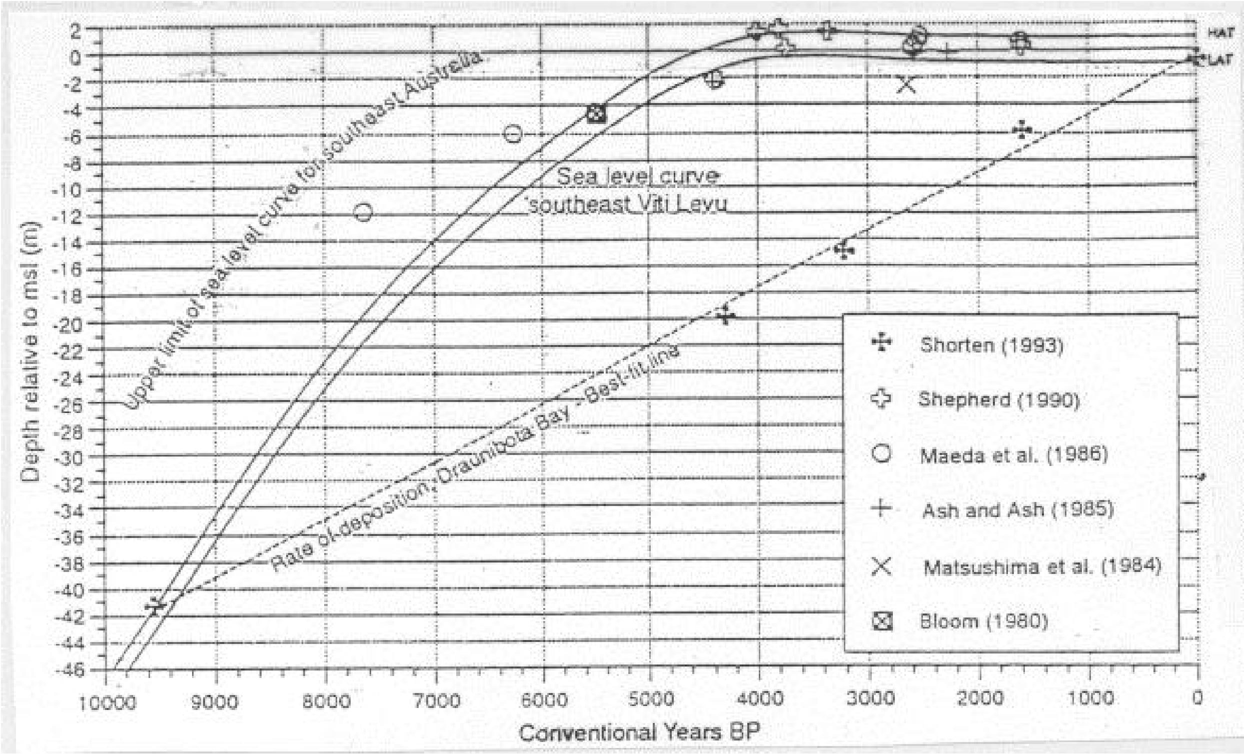

Figure 20. Sea-level curves for southeast Viti Levu (from Shorten 1993)

Figure 21. Part of the bank of coral rubble deposited during Cyclone Ofa on the reef edge close to Mulinu'u Point, Apia, Samoa. Note figure for scale.

CONCLUSIONS

Conclusions relevant to both lease areas

- The dredged areas of Nukubuco Reef represent only 4% of the total estimated reef area.
- The dredged areas are larger than the original lease areas prescribed.
- Dredging has occurred only in prograded sand deposits that have accumulated on the back reef slope of the Nukubuco Reef complex.
- Most of the sand resource was considered to have been generated as a result of changes in sea level during the Holocene Period from 4500 to 2000 BP.
- Modelled estimates of volumes of sand dredged from Leases 5 and 6 are in good agreement with Fiji Industries' reported figures.
- Coral rubble is the dominant component of the sand.
- The lack of baseline data and of appropriate studies leaves a large degree of uncertainty in the assessment of primary sediment production rates on the Nukubuco barrier reef, and thus leaves largely unanswered the question of the sustainability or, more importantly, the recovery time of the resource.
- The current levels of sand extraction are, however, considered higher than the rates of replenishment implying that the resource use is not sustainable.
- Present dredging practice leaves in place a hummocky seabed morphology that is subject to natural reworking until a form of stability is reached.
- Natural reworking of sediments in old dredge workings is evident from bathymetric profile, with the seabed topography levelling out.
- The constant movement of sediments in the dredged areas may also prevent seagrass from re-establishing.
- The most significant impact of the dredging appears to be the removal of the seagrass beds.
- Dredging the deeper water sediments may result in an increase of turbidity.
- High Magnesium levels seen in assay results of the sands may be attributed to in part to the presence in the sand clasts of coralline algae.
- The MgO contents for both lease areas show similar trends, with increasing concentration south, towards the central reef platform.
- The results of the mapping provide a basis for guiding future dredging areas, ensuring greater environmental sensitivity and resource quality and quantity management.

Lease 5

- Sand resources were initially considered all but exhausted in Lease 5.
- Modelling the old dredge workings in Lease 5 for dredging depths of 8, 10, 12 and 14 m below LAT indicates that potential reserves as high as 1.4 million m^3 are present.
- Analysis of the samples indicates a sand resource with a poorly sorted texture and a negligible fines content.
- Sieve analyses of the 3 deep water samples show an increase in the fines content to 5 % but this is still considered by the definition criteria defined in this report, as a clean sand.
- Sand resources to 14 m below LAT are sufficient to meet current demand for 10 years.
- Both surface and jetprobe samples show the MgO content to increase southwards towards the reef crest.

Lease 6

- Estimated sand available in the resource area for a dredging depth to 10 m below LAT is 480,000 m^3.
- Both surface and jetprobe samples show the MgO content to increase southwards towards the reef crest.
- High MgO grades assayed for the sediments in the resource area may impact significantly to reduce the resources volume to 210,000 m^3.
- Much of this reserve lies in seagrass areas and it is estimated that dredging may impact on as much as 35% of the known seagrass meadows mapped in Lease 6.
- Analysis of the samples indicates a clean sand with a fines content under 0.5%.
- Sand dredging confined to the current area has sufficient quantities to meet current demand for 2-4 years .

RECOMMENDATIONS

- Proposed new dredge areas should have baseline mapping completed to evaluate the resources prior to exploitation.
- Detailed mapping and jetprobing in dredge areas 1, 2 and 3 in Lease 5 should be undertaken to confirm volume estimates and the distribution of fines in the resource.
- Dredging techniques should consider removal of the seagrass beds prior to dredging for transplanting to alternate or previously dredged areas.

- Studies should be undertaken to isolate the principal sources of high Mg-bearing carbonates and assess what percentage of the resource sediments they represent.
- A comprehensive study should be initiated to review sediment composition, and radiocarbon dating would facilitate better understanding of sediment production and sustainability.
- Ongoing studies to assess the carbonate production rates and influence of dredging for selected important carbonate-producing species be undertaken.
- Implementation of a GIS data base incorporating the digital data set from this survey would enable better monitoring and management of resources.
- Consideration be given to implementing positioning control of dredge operation using GPS (Global Positioning System) to monitor and manage resources.

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APPENDIX 1

Sample Log Lease 5, 6

Sample#	Easting (m)	Northing (m)	waterdepth (m)	holedepth (m)	Comments	Date	time
				LEASE 6 SAMPLES			
1	1973428	3869744	2.3	0.5	rocky	12/06/97	11:37
2	1973367	3869769	1.6	0.6	sea-grass,sandy,solid resistance	12/06/97	12:07
3	1973329	3869794	1.6	3	surface sample	12/06/97	12:15
3A	1973329	3869794	1.6	3	1st metre rubbly, sand after that, hard going	12/06/97	12:17
4A	1973284	3869812	2.2	3	surface sample	12/06/97	12:23
4B	1973284	3869812	2.2	3	2nd metre gravelly, sand afterwards	12/06/97	12:30
5A	1973239	3869832	2.7		Surface sample	12/06/97	12:38
5B	1973239	3869832	2.7	4	hole stands up after probe removed, medium sand	12/06/97	12:40
6A	1973203	3869852	2.2		surface sample	12/06/97	12:45
6B	1973203	3869852	2.2	4	Easy driling, medium sand, sea-grass	12/06/97	12:47
7A	1973144	3869851	2.4		Surface sample	12/06/97	12:53
7B	1973144	3869851	2.4	4	Easy drilling, medium sand	12/06/97	12:00
8A	1973081	3869855	1.8		SURFACE SAMPLE	12/06/97	13:01
8B	1973081	3869855	1.8	6.6	Easy drilling, medium sand, compact, hole stands u	12/06/97	13:04
9A	1973037	3869846	2.5		Surface sample	12/06/97	13:10
9B	1973037	3869846	2.5	7.9	Easy drilling, fine sand, sea-grass area	12/06/97	13:00
10A	1972982	3869835	2.2		Surface sample	12/06/97	13:20
10B	1972982	3869835	2.2	7.8	Easy drilling, sea-grass meadow	12/06/97	13:25
11A	1972905	3869850	2		Surface sample	12/06/97	13:31
11B	1972905	3869850	2	5	Easy drilling, sea-grass meadow	12/06/97	13:37
12A	1972840	3869856	4.4		Surface sample	12/06/97	13:40
12B	1972840	3869856	4.4	5	Easy drilling, sparse sea-grass	12/06/97	13:48
13A	1972810	3869873	1.5		Surface sample	12/06/97	13:52
13B	1972810	3869873	1.5	4.5	easy drilling, sea-grass, medium sand	12/06/97	13:59
14A	1972756	3869898	1.8		Surface sample	12/06/97	14:05
14B	1972756	3869898	1.8	3	Relatively easy drilling, fine to medium sand	12/06/97	14:07
15A	1972773	3869827	2.2		Surface sample	12/06/97	14:15
15B	1972773	3869827	2.2	3	sea-grass meadow, firm, compact at bottom	12/06/97	14:17
16A	1972826	3869810	2.5		Surface sample	12/06/97	14:25
16B	1972826	3869810	2.5	5.5	Easy drilling, medium sand, sea-grass meadow	12/06/97	14:27
17A	1972877	3869786	2.2		surface sample	12/06/97	14:33
17B	1972877	3869786	2.2	7	easy drilling, medium sand	12/06/97	14:35
18A	1972920	3869784	2.2		Surface sample	12/06/97	14:48
18B	1972920	3869784	2.2	6	easy drilling, medium sand, sea-grass meadow	12/06/97	14:50
19A	1972966	3869765	2.3		Surface sample	12/06/97	14:56
19B	1972966	3869765	2.3	5.5	Easy drilling, medium sand, sea-grass meadow	12/06/97	14:57
20A	1973029	3869742	2.2		Surface sample	12/06/97	15:02
20B	1973029	3869742	2.2	4.5+	Easy drilling, medium sand, sea-grass meadow	12/06/97	15:05
21A	1973061	3869724	1.6		Surface sample	12/06/97	15:10
21B	1973061	3869724	1.6	3	sticky hole, fine sand, sea-grass meadow	12/06/97	15:11
22A	1973110	3869958	2.5		Surface sample	12/06/97	15:20

22B	1973110	3869958	2.5	4	medium sand, old dredge site, shelly surface, evider	12/06/97	15:22
23A	1973010	3869969	6.2		Surface sample	12/06/97	15:34
23B	1973010	3869969	6.2	3	last metre resistive, surface muddy, consolidated sa	12/06/97	15:38
24A	1972975	3869947	11		Surface sample	12/06/97	15:50
24B	1972975	3869947	11	3.0+	Easy drilling, fine -medium sand, cleaner sand, no v	12/06/97	15:55
25A	1972932	3869934	1.7		Surface sample	12/06/97	16:04
25B	1972932	3869934	1.7	1	1M after 4 attempts, rocky substrate	12/06/97	16:05
26A	1973272	3869984	2.4		Surface sample	12/06/97	16:17
26B	1973272	3869984	2.4	5	Easy drilling, very loose, clay in sand	12/06/97	16:20
27A	1973302	3870019	3.1		Surface sample	12/06/97	16:28
27B	1973302	3870019	3.1	5	sea-grass meadow with occasional rock, medium sa	12/06/97	16:30
28A	1973325	3870047	1.8		Surface sample	12/06/97	16:41
28B	1973325	3870047	1.8	4+	easy 4M, 1st 4cm- organic stuff, medium sand	12/06/97	16:43
29A	1973377	3870092	2.6		Surface sample	12/06/97	16:44
29B	1973377	3870092	2.6	5	Easy drilling, sea-grass , medium sand, rocky locati	12/06/97	16:46
30A	1973416	3870188	1.7		Surface sample	12/06/97	16:54
30B	1973416	3870188	1.7	2	Hard drilling, rocky substrate	12/06/97	16:55
31A	1973106	3869801	2.5		surface sample	13/06/97	10:45
31B	1973106	3869801	2.5	3	easy 3M, loose sand, sea-grass meadow	13/06/97	10:46
32A	1973146	3869778	1.8		Surface sample	13/06/97	11:00
32B	1973146	3869778	1.8	4+	Easy 4M, did not bind, sea-grass	13/06/97	11:02
33A	1973193	3869754	2.2		Surface sample	13/06/97	11:06
33B	1973193	3869754	2.2	0.3	Rocky, hard drilling, sea-grass	13/06/97	11:07
34A	1973231	3869722	2.1		surface sample	13/06/97	11:10
34B	1973231	3869722	2.1	3	1st 2M relatively coarse, sea-grass with some coral	13/06/97	11:18
35A	1973273	3869700	1.8		Surface sample	13/06/97	11:22
35B	1973273	3869700	1.8	3.5	1st 1.5M gravelly, fine after that, sea-grass	13/06/97	11:24
36A	1973321	3869673	2		Surface sample	13/06/97	11:28
36B	1973321	3869673	2	2.6	Very gravelly, sea-grass,	13/06/97	11:29
37A	1973346	3869648	1.8		Surface sample	13/06/97	11:35
37B	1973346	3869648	1.8	2	Very coarse, surface very rubbly	13/06/97	11:37
38A	1973400	3869936	1.8		Surface sample	13/06/97	11:57
38B	1973400	3869936	1.8	1.5	1st 0.5M very gravelly, hit bedrock	13/06/97	11:59
39A	1973413	3869992	2.6		Surface sample	13/06/97	12:14
39B	1973413	3869992	2.6	2.6	Veryy coarse and gravelly	13/06/97	12:16
40A	1973328	3869914	2.4		Surface sample	13/06/97	12:44
40B	1973328	3869914	2.4	2.8	hard going medium to coarse sand, sea grass, hard	13/06/97	12:49
41A	1973390	3869887	1.8		surface sample	13/06/97	12:54
41B	1973390	3869988	1.8	0.05	rocky substrate	13/06/97	12:55
42A	1973461	3870096	1.6		Surface sample	13/06/97	13:06
42B	1973461	3870096	1.6	2.6	sticky at 2.3M, then bedrock	13/06/97	13:07
43A	1972650	3869858	1.5		Surface sample	13/06/97	13:20
43B	1972650	3869858	1.5	2.4	Hard going, very gravelly, surface sandy with sea-gr	13/06/97	13:22

			LEASE 5 SAMPLES				
44A	1972232	3869903	2		Surface sample	13/06/97	13:34
44B	1972232	3869903	2	0.7	Hard drilling, very coarse aggregate	13/06/97	13:35
45A	1972150	3869889	2		Surface sample	13/06/97	13:42
45B	1972150	3869889	2	3	Neither easy nor hard drilling, gravelly 1st 2M then e	13/06/97	13:44
46A	1972131	3869851	2.5		Surface sample	13/06/97	13:51
46B	1972131	3869851	2.5	0.1	Very rocky, scattered coral	13/06/97	13:52
47A	1972052	3869846	1.9		Surface sample	13/06/97	13:53
47B	1972052	3869846	1.9	2.7	Hard going, gravelly, probe stuck	13/06/97	13:55
48A	1971972	3869828	1.5			13/06/97	13:58
48B	1971972	3869828	1.5	0.1	Rocky substrate	13/06/97	13:59
49A	1971924	3869767	1.6		Surface sample	13/06/97	14:04
49B	1971924	3869767	1.6	0.1	Very rocky, coral rocks everywhere	13/06/97	14:05
50A	1971808	3869778	1.5		Surface sample	13/06/97	14:10
50B	1971808	3869778	1.5	3	Rocky substrate, very coarse, hole did not collapse	13/06/97	14:11
51A	1971672	3869798	4.7		surface sample	13/06/97	14:24
51B	1971672	3869798	4.7	1.5	Hit bedrock, very rocky, reef patches	13/06/97	14:28
52A	1971707	3869827	12.1		surface sample	13/06/97	14:35
52B	1971707	3869827	12.1	7	Muddy sand, hole stands up well,sandy surface	13/06/97	14:38
53A	1971604	3869862	5.4		Surface sample	13/06/97	14:47
53B	1971604	3869862	5.4	6	Easy drilling, fine sand, hole stands up well, grass bı	13/06/97	14:55
54A	1971513	3869881	7.6		Surface sample	13/06/97	14:52
54B	1971513	3869881	7.6	5	easy drilling, sandy bottom, lots of bio-turbidation on	13/06/97	15:02
55A	1971434	3869899	8.7		Surface sample	13/06/97	15:07
55B	1971434	3869899	8.7	7	Easy drilling, sand and surface same as last hole	13/06/97	15:09
56A	1971319	3869925	2.6		Surface sample - nil	13/06/97	15:16
56B	1971319	3869925	2.6	0	Very rocky, coral patch	13/06/97	15:20
57A	1971339	3869950	9.7		Surface sample	13/06/97	15:25
57B	1971339	3869950	9.7	7.5	easy drilling, lots of clay in sand, sandy surface, blac	13/06/97	15:27
58A	1971350	3869969	4		Surface sample	13/06/97	15:35
58B	1971350	3869969	4	0	Rocky substrate	13/06/97	15:37
59A	1971264	3869948	2.5		Surface sample	13/06/97	15:44
59B	1971264	3869948	2.5	1.6	Rubbly substrate, medium to coarse sand, barren sı	13/06/97	15:45
60A	1971189	3869982	4.5		Surface sample	13/06/97	15:52
60B	1971189	3869982	4.5	0	rocky substrate- zero penetration	13/06/97	

APPENDIX 2

Grain Size Analyses

APPENDIX 3

Sediment Geochemistry

CORAL SAND ASSAYS

Sample	SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	Na2O	K2O	TiO2	SrO	Cl	Mn2O3	P2O5	BaO	LOI	Total
189CS3G180697 1A	0.34	0.18	0.13	50.32	2.69	0.50	0.60	0.02	0.01	0.55	0.240	0.00	0.07	0.00	44.98	100.64
190CS3G180697 2A	0.79	0.35	0.21	48.64	2.71	0.52	0.86	0.05	0.02	0.52	0.491	0.01	0.07	0.01	45.01	100.25
191CS3G180697 3A	0.42	0.22	0.16	49.68	2.84	0.58	0.69	0.03	0.01	0.52	0.141	0.01	0.06	0.00	45.96	101.33
192CS3G180697 4A	0.28	0.15	0.13	50.38	2.46	0.55	0.68	0.02	0.01	0.57	0.148	0.00	0.06	0.01	45.02	100.46
193CS3G180697 5A	0.28	0.15	0.11	50.08	3.15	0.53	0.63	0.02	0.01	0.50	0.186	0.01	0.07	0.01	44.80	100.53
194CS3G180697 6A	0.39	0.20	0.14	49.15	2.74	0.53	0.74	0.03	0.01	0.52	0.349	0.00	0.06	0.00	44.98	99.84
195CS3G180697 7A	0.23	0.13	0.10	50.00	3.03	0.53	0.64	0.02	0.01	0.51	0.250	0.01	0.07	0.01	45.01	100.55
196CS3G180697 8A	0.23	0.13	0.10	50.05	3.04	0.53	0.64	0.02	0.01	0.51	0.249	0.00	0.07	0.00	44.98	100.56
197CS3G180697 9A	0.25	0.14	0.10	50.24	2.77	0.53	0.55	0.02	0.01	0.53	0.175	0.01	0.07	0.00	44.82	100.22
198CS3G180697 10A	0.25	0.12	0.10	49.96	3.40	0.51	0.54	0.02	0.01	0.44	0.050	0.01	0.08	0.00	44.98	100.47
199CS3G180697 11A	0.58	0.16	0.11	49.53	3.00	0.54	0.57	0.02	0.01	0.48	0.148	0.01	0.08	0.00	44.89	100.12
200CS3G180697 12A	0.46	0.12	0.08	49.43	3.00	0.52	0.57	0.02	0.01	0.52	0.136	0.01	0.07	0.00	44.96	99.90
201CS3G180697 13A	0.75	0.24	0.15	49.47	3.37	0.53	0.60	0.02	0.02	0.47	0.148	0.01	0.08	0.00	44.92	100.78
202CS3G180697 14A	0.49	0.21	0.14	49.77	3.36	0.53	0.66	0.03	0.01	0.47	0.092	0.01	0.08	0.01	44.88	100.74
203CS3G180697 15A	0.30	0.15	0.11	49.79	3.16	0.51	0.64	0.02	0.01	0.47	0.212	0.01	0.07	0.01	45.01	100.47
204CS3G180697 16A	0.30	0.15	0.10	49.87	3.03	0.53	0.61	0.02	0.01	0.50	0.130	0.01	0.07	0.00	44.98	100.31
205CS3G180697 17A	0.38	0.18	0.12	48.93	2.80	0.55	0.67	0.02	0.01	0.51	0.389	0.01	0.07	0.00	44.88	99.52
206CS3G180697 18A	0.41	0.17	0.11	50.06	2.84	0.55	0.68	0.02	0.01	0.54	0.369	0.01	0.06	0.00	44.87	100.70
207CS3G18069719A	0.38	0.15	0.11	49.73	2.76	0.55	0.64	0.02	0.01	0.54	0.284	0.01	0.06	0.00	44.98	100.22
208CS3G18069720A	0.35	0.13	0.09	50.36	2.68	0.54	0.67	0.02	0.01	0.55	0.318	0.00	0.07	0.00	45.01	100.80
209CS3G180697 21A	0.47	0.21	0.13	50.03	2.74	0.58	0.69	0.03	0.01	0.54	0.378	0.01	0.63	0.00	44.89	101.34
210CS3G180697 22A	0.29	0.15	0.12	49.94	2.80	0.53	0.53	0.01	0.01	0.52	0.186	0.01	0.06	0.00	44.92	100.08
211CS3G180697 23A	0.30	0.15	0.10	50.48	2.54	0.53	0.66	0.02	0.01	0.54	0.344	0.00	0.06	0.00	44.96	100.70
212CS3G180697 24A	0.15	0.08	0.05	50.37	2.59	0.56	0.76	0.02	0.01	0.59	0.266	0.00	0.06	0.00	44.88	100.39
213CS3G180697 25A	0.34	0.15	0.12	49.57	3.05	0.50	0.61	0.02	0.01	0.49	0.285	0.01	0.08	0.00	44.78	100.01
214CS3G180697 26A	0.32	0.17	0.13	50.03	2.85	0.55	0.55	0.02	0.01	0.54	0.167	0.01	0.07	0.00	44.88	100.30
215CS3G180697 27A	0.66	0.31	0.20	49.43	2.75	0.55	0.73	0.03	0.02	0.54	0.391	0.00	0.07	0.00	44.89	100.57
216CS3G180697 28A	0.66	0.31	0.20	49.43	2.75	0.55	0.73	0.03	0.02	0.54	0.391	0.00	0.07	0.00	44.95	100.63
217CS3G180697 29A	0.44	0.20	0.15	49.85	2.91	0.53	0.56	0.02	0.01	0.52	0.150	0.01	0.08	0.00	44.78	100.20
218CS3G180697 30A	0.74	0.32	0.27	50.26	2.29	0.54	0.71	0.03	0.02	0.56	0.249	0.01	0.07	0.00	44.78	100.85
218CS3G18069730A	0.74	0.32	0.27	50.26	2.29	0.54	0.71	0.03	0.02	0.56	0.249	0.01	0.07	0.00	44.78	100.85
219CS3G180697 31A	0.29	0.14	0.11	49.87	2.97	0.52	0.66	0.02	0.01	0.50	0.189	0.00	0.07	0.01	44.86	100.23
220CS3G180697 32A	0.36	0.17	0.13	49.95	2.73	0.55	0.70	0.02	0.01	0.54	0.246	0.01	0.07	0.00	44.96	100.45
221CS3G180697 33A	0.33	0.16	0.12	50.11	2.75	0.52	0.66	0.02	0.01	0.53	0.252	0.01	0.06	0.00	44.84	100.37
222CS3G180697 34A	0.33	0.16	0.12	50.02	2.62	0.53	0.66	0.02	0.01	0.55	0.177	0.00	0.06	0.00	44.88	100.14
223CS3G180697 35A	0.34	0.16	0.14	49.81	2.98	0.54	0.71	0.02	0.01	0.50	0.292	0.01	0.07	0.01	44.78	100.37
224CS3G180697 36A	0.38	0.18	0.12	49.72	2.66	0.57	0.76	0.03	0.01	0.55	0.374	0.01	0.07	0.00	44.98	100.41
225CS3G180697 37A	0.38	0.17	0.13	49.92	2.54	0.54	0.74	0.03	0.01	0.57	0.314	0.01	0.06	0.00	44.86	100.27
226CS3G180697 38A	0.80	0.37	0.22	49.39	2.53	0.56	0.75	0.04	0.02	0.55	0.375	0.01	0.07	0.00	44.89	100.57
227CS3G180697 39A	0.70	0.33	0.20	49.48	2.68	0.57	0.71	0.03	0.02	0.54	0.338	0.01	0.07	0.00	44.78	100.46
228CS3G180697 40A	0.42	0.21	0.14	49.77	2.60	0.58	0.74	0.03	0.01	0.54	0.299	0.00	0.06	0.00	44.82	100.22
556CS3G240697 41A	0.32	0.15	0.11	49.30	2.77	0.51	0.62	0.02	0.01	0.53	0.249	0.00	0.07	0.00	45.01	99.67
557CS3G240697 42A	0.46	0.24	0.18	49.59	2.91	0.50	0.65	0.03	0.01	0.52	0.258	0.01	0.07	0.00	44.80	100.23
558CS3G240697 43A	0.38	0.20	0.14	49.66	2.96	0.56	0.64	0.02	0.01	0.50	0.247	0.01	0.08	0.01	44.96	100.38
559CS3G240697 44A	0.37	0.19	0.13	49.10	2.85	0.53	0.69	0.03	0.01	0.50	0.290	0.00	0.07	0.00	45.02	99.78
560CS3G240697 45A	0.29	0.15	0.11	50.12	2.69	0.51	0.66	0.02	0.01	0.54	0.350	0.01	0.07	0.01	44.96	100.50
561CS3G240697 46A	0.27	0.13	0.10	50.40	2.54	0.53	0.67	0.02	0.01	0.58	0.317	0.01	0.06	0.00	44.98	100.62
562CS3G240697 47A	0.36	0.18	0.12	50.06	2.62	0.52	0.69	0.03	0.01	0.56	0.370	0.01	0.06	0.01	44.88	100.48
563CS3G240697 48A	0.28	0.13	0.11	50.16	2.65	0.54	0.68	0.02	0.01	0.56	0.304	0.01	0.07	0.00	44.93	100.45
564CS3G240697 49A	0.24	0.11	0.09	50.20	2.81	0.51	0.58	0.02	0.01	0.55	0.257	0.00	0.07	0.00	44.72	100.17
565CS3G240697 50A	0.27	0.13	0.10	50.21	2.70	0.49	0.57	0.02	0.01	0.55	0.231	0.01	0.06	0.00	44.70	100.05
566CS3G240697 51A	0.23	0.12	0.09	49.59	3.40	0.49	0.49	0.02	0.01	0.48	0.167	0.01	0.08	0.01	44.09	99.28
567CS3G240697 52A	0.31	0.15	0.12	49.75	2.86	0.51	0.73	0.03	0.01	0.54	0.439	0.01	0.07	0.01	45.04	100.58
568CS3G240697 53A	0.95	0.42	0.24	49.28	2.76	0.60	0.91	0.04	0.02	0.56	0.555	0.01	0.07	0.01	44.62	101.04
569CS3G240697 54A	0.32	0.14	0.09	49.90	2.89	0.53	0.67	0.02	0.01	0.54	0.265	0.00	0.06	0.00	44.67	100.11
570CS3G240697 55A	0.29	0.14	0.10	49.73	2.67	0.56	0.79	0.03	0.01	0.56	0.335	0.00	0.06	0.00	45.07	100.35
571CS3G240697 56A	0.30	0.14	0.11	49.76	3.05	0.48	0.54	0.02	0.01	0.50	0.226	0.01	0.08	0.00	44.89	100.12
572CS3G240697 57A	1.25	0.56	0.30	48.83	2.51	0.59	0.83	0.04	0.02	0.59	0.466	0.01	0.07	0.01	44.46	100.54
573CS3G240697 58A	1.10	0.47	0.54	49.04	2.23	0.57	0.74	0.04	0.02	0.54	0.327	0.02	0.07	0.00	44.29	100.00
574CS3G240697 59A	0.30	0.14	0.12	49.88	3.17	0.48	0.54	0.02	0.01	0.49	0.215	0.01	0.08	0.00	44.81	100.26
575CS3G240697 60A	0.54	0.23	0.20	50.06	2.75	0.46	0.52	0.02	0.01	0.52	0.114	0.01	0.08	0.01	44.57	55.51
576CS3G240697 3B	0.91	0.38	0.24	48.85	2.87	0.56	0.83	0.05	0.02	0.49	0.608	0.01	0.07	0.00	44.90	55.89
577CS3G240697 4B	0.47	0.23	0.16	49.38	2.83	0.58	0.76	0.03	0.01	0.51	0.419	0.01	0.07	0.00	44.96	55.46
578CS3G240697 5B	0.42	0.21	0.15	49.44	2.76	0.53	0.61	0.02	0.01	0.50	0.248	0.01	0.07	0.00	44.63	54.98
579CS3G240697 6B	0.35	0.18	0.14	49.69	2.87	0.55	0.63	0.02	0.01	0.50	0.274	0.01	0.07	0.00	44.73	55.29
580CS3G240697 7B	0.39	0.19	0.17	49.64	2.61	0.51	0.63	0.02	0.01	0.50	0.261	0.01	0.07	0.00	44.80	99.81
581CS3G240697 8B	0.36	0.15	0.10	49.52	3.03	0.53	0.57	0.02	0.01	0.49	0.252	0.01	0.07	0.00	44.82	99.93
582CS3G240697 9B	0.38	0.18	0.11	49.64	3.09	0.52	0.62	0.02	0.01	0.48	0.284	0.00	0.08	0.01	44.75	100.18
583CS3G240697 10B	0.32	0.16	0.11	49.64	3.21	0.55	0.58	0.02	0.01	0.50	0.238	0.01	0.07	0.00	44.75	100.16
584CS3G240697 11B	0.29	0.12	0.09	49.41	3.48	0.53	0.51	0.01	0.01	0.44	0.228	0.01	0.08	0.00	44.73	99.93
585CS3G240697 12B	0.20	0.09	0.07	49.89	3.26	0.48	0.51	0.01	0.01	0.49	0.159	0.00	0.07	0.00	44.66	99.91
586CS3G240697 13B	0.26	0.11	0.08	49.07	3.37	0.49	0.47	0.01	0.01	0.43	0.174	0.01	0.08	0.00	44.68	99.24
587CS3G240697 14B	0.64	0.27	0.16	49.43	2.98	0.57	0.62	0.03	0.02	0.48	0.279	0.01	0.07	0.01	44.61	100.18
588CS3G240697 15B	0.30	0.14	0.10	49.61	3.17	0.54	0.58	0.02	0.01	0.49	0.235	0.01	0.07	0.00	44.46	99.73
589CS3G240697 16B	0.27	0.11	0.08	50.14	3.23	0.54	0.56	0.01	0.01	0.49	0.238	0.01	0.08	0.01	44.80	100.57
590CS3G240697 17B	0.44	0.15	0.11	50.07	3.25	0.56	0.59	0.02	0.01	0.50	0.269	0.00	0.07	0.00	44.18	100.23
591CS3G240697 18B	0.38	0.16	0.12	49.99	2.93	0.57	0.72	0.02	0.01	0.55	0.374	0.01	0.07	0.00	44.70	100.60
592CS3G240697 19B	0.32	0.15	0.10	49.99	3.00	0.55	0.64	0.02	0.01	0.51	0.303	0.01	0.07	0.00	44.88	100.55
593CS3G240697 20B	0.20	0.10	0.08	48.72	3.38	0.51	0.55	0.01	0.01	0.44	0.240	0.00	0.07	0.01	44.96	99.28
594CS3G240697 21B	0.45	0.21	0.17	49.72	2.83	0.62	0.74	0.03	0.01	0.53	0.415	0.01	0.06	0.00	44.83	100.63
595CS3G240697 22B	0.34	0.15	0.11	50.19	2.88	0.50	0.61	0.02	0.01	0.48	0.266	0.00	0.06	0.00	44.82	100.44

596CS3G240697 23B	0.23	0.12	0.09	50.32	2.75	0.53	0.61	0.02	0.01	0.54	0.172	0.00	0.06	0.00	44.80	100.26
597CS3G240697 24B	0.18	0.08	0.06	50.11	3.01	0.54	0.66	0.02	0.01	0.53	0.362	0.00	0.07	0.01	45.18	100.82
598CS3G240697 25B	0.24	0.13	0.10	50.08	3.19	0.47	0.54	0.02	0.01	0.45	0.155	0.01	0.08	0.00	44.69	100.16
599CS3G240697 26B	0.15	0.09	0.07	50.22	3.11	0.49	0.52	0.01	0.01	0.48	0.188	0.01	0.08	0.01	44.86	100.29
600CS3G240697 27B	0.39	0.20	0.14	49.99	2.86	0.57	0.62	0.02	0.01	0.52	0.315	0.01	0.07	0.01	44.52	100.24
601CS3G240697 28B	0.26	0.14	0.10	50.01	3.01	0.54	0.56	0.02	0.01	0.50	0.227	0.01	0.08	0.01	45.58	101.06
602CS3G240697 29B	0.30	0.15	0.11	50.02	2.86	0.50	0.55	0.02	0.01	0.54	0.226	0.00	0.07	0.00	44.84	100.20
603CS3G240697 30B	0.77	0.36	0.32	49.63	2.45	0.70	0.77	0.03	0.02	0.55	0.460	0.01	0.06	0.00	44.52	100.66
604CS3G240697 31B	0.29	0.15	0.12	50.02	3.02	0.54	0.59	0.02	0.01	0.50	0.268	0.01	0.07	0.01	44.71	100.32
605CS3G240697 32B	0.21	0.12	0.09	49.59	3.17	0.50	0.50	0.01	0.01	0.47	0.162	0.01	0.07	0.01	44.84	99.76
606CS3G240697 34B	0.31	0.16	0.01	49.96	2.77	0.52	0.64	0.02	0.01	0.50	0.337	0.01	0.06	0.00	44.93	100.23
607CS3G240697 35B	0.27	0.13	0.11	49.80	2.94	0.53	0.52	0.02	0.01	0.51	0.164	0.01	0.07	0.01	44.70	99.80
608CS3G240697 36B	0.28	0.14	0.11	50.14	2.54	0.55	0.59	0.02	0.01	0.55	0.207	0.01	0.06	0.00	44.83	100.04
609CS3G240697 37B	0.30	0.15	0.12	49.97	2.62	0.56	0.57	0.02	0.01	0.56	0.188	0.01	0.06	0.01	44.64	99.79
610CS3G240697 38B	0.44	0.22	0.14	50.01	2.61	0.53	0.61	0.02	0.01	0.56	0.289	0.01	0.06	0.00	44.84	100.35
611CS3G240697 39B	0.31	0.16	0.12	49.98	2.60	0.55	0.61	0.02	0.01	0.57	0.252	0.00	0.06	0.00	44.81	100.06
612CS3G240697 40B	0.33	0.18	0.14	48.95	2.48	0.59	0.62	0.02	0.01	0.57	0.266	0.01	0.06	0.00	44.72	98.95
613CS3G240697 42B	0.47	0.24	0.21	48.92	2.91	0.59	0.54	0.02	0.01	0.49	0.214	0.01	0.07	0.00	44.62	99.32
614CS3G240697 43B	0.36	0.19	0.16	50.57	2.45	0.59	0.63	0.02	0.01	0.56	0.265	0.00	0.06	0.00	44.72	100.59
615CS3G240697 44B	0.41	0.20	0.14	49.98	2.69	0.54	0.66	0.02	0.01	0.50	0.288	0.00	0.06	0.00	44.93	100.43
616CS3G240697 45B	0.32	0.16	0.14	50.47	2.52	0.55	0.62	0.02	0.01	0.55	0.225	0.01	0.06	0.00	44.72	100.38
617CS3G240697 47B	0.32	0.17	0.14	50.15	2.76	0.57	0.63	0.02	0.01	0.54	0.248	0.01	0.06	0.00	44.87	100.50
618CS3G240697 50B	0.22	0.11	0.09	50.07	3.12	0.53	0.55	0.02	0.01	0.52	0.219	0.01	0.07	0.00	44.90	100.44
619CS3G240697 51B	0.15	0.08	0.07	49.70	3.50	0.52	0.46	0.01	0.01	0.47	0.128	0.01	0.08	0.00	44.85	100.04
620CS3G240697 52B	0.63	0.30	0.18	49.81	2.85	0.61	0.66	0.03	0.01	0.55	0.300	0.01	0.07	0.01	44.97	100.99
621CS3G240697 53B	0.34	0.16	0.11	49.59	3.16	0.56	0.61	0.02	0.01	0.51	0.314	0.01	0.07	0.00	44.56	100.02
622CS3G240697 54B	0.20	0.01	0.08	49.85	3.02	0.56	0.62	0.02	0.01	0.52	0.279	0.01	0.07	0.00	44.98	100.23
623CS3G240697 55B	0.35	0.16	0.12	49.90	2.90	0.60	0.70	0.02	0.01	0.54	0.405	0.00	0.07	0.01	45.06	100.85
624CS3G240697 57B	1.00	0.48	0.27	48.71	2.81	0.65	0.71	0.04	0.02	0.54	0.383	0.01	0.07	0.01	44.56	100.26
625CS3G240697 59B	0.26	0.15	0.10	50.13	2.96	0.51	0.53	0.02	0.01	0.52	0.207	0.00	0.07	0.01	44.90	100.38
Average	**0.40**	**0.18**	**0.13**	**49.79**	**2.86**	**0.54**	**0.64**	**0.02**	**0.01**	**0.52**	**0.27**	**0.01**	**0.07**	**0.00**	**44.84**	**98.27**
Std Dev	**0.20**	**0.09**	**0.06**	**0.42**	**0.26**	**0.04**	**0.08**	**0.01**	**0.00**	**0.03**	**0.10**	**0.00**	**0.05**	**0.00**	**0.22**	**9.36**
Maximum	**1.25**	**0.56**	**0.54**	**50.57**	**3.50**	**0.70**	**0.91**	**0.05**	**0.02**	**0.59**	**0.61**	**0.02**	**0.63**	**0.01**	**45.96**	**101.34**
Minimum	**0.15**	**0.01**	**0.01**	**48.64**	**2.23**	**0.46**	**0.46**	**0.01**	**0.01**	**0.43**	**0.05**	**0.00**	**0.06**	**0.00**	**44.09**	**54.98**
Count	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**	**111**