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Fiji: Viti Levu: Reconnaissance photographic evidence for earthquake and tsunami events on tropical reef margins

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Fiji: Viti Levu: Reconnaissance photographic evidence for earthquake and tsunami events on tropical reef margins

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Contents

Summary

Photographs have been taken from a helicopter at locations on the barrier and fringing reefs extending from east to west on the southern coast of Viti Levu, Fiji. The sites are systematically described with reference to UTM coordinates, local names and observations of typical subaerial to submarine features of reef, estuarine and reef-rentrant structure. Most of the photographs document expected reef and other coastal scenes but exceptional features such as very large boulders and cracks map to the nearest facing barrier reef to the deep epicentre for the 1953 earthquake and associated tsunami. The observations are used to suggest that exceptionally large boulders perched on barrier or fringing reefs may be used as a criterion for the recognition of historical sites sites of earthquake and tsunami generation.

1 INTRODUCTION

The colour slides described in this note were taken from a 'Sioux' Royal New Zealand Air Force [RNZAF] helicopter which was available to the Fiji Government for various applied projects vetted by a Fiji Ministry of Home Affairs steering committee. The slides are archived in a collection maintained by the Principal Geological Information Services at the Mineral Resources Department. Images from those slides have been digitised and incorporated into this report.

The objective of the flight time allocated to the Fiji Mineral Resources Department (MRD) was to reconnoitre the distribution of coral boulders on the reef south of Viti Levu (Figures 1, 2, 3) and to take photographs of the reef at a resolution and angle not available from sea-borne vessels or standard aerial photographs. Part of the project plan was to test the hypothesis that the distribution of large coral boulders could be related to tsunami waves. The aim of this note is to report on the data acquired as digital images and to fill in as much as possible other background geological and other environmental information from the slides.

The flight was done with MRD representatives R A Eden and I Everingham aboard on 24 July 1983. The flight commenced at 1110 hrs at Nausori and terminated at 1310 hrs at Nadi. Low tide on the day was at 1232 hrs to recede 0.3 m above lowest astronomical tide. The slides finish at around Yadu Point when the participants ran out of film. The reconnaissance mapping continues NW beyond the slide record to the south end of Nadi Bay and Yako where presumably the coastal flight terminated. Luckily the weather on the day was exceptionally calm. Normally the dominant wind direction for Fiji is from the SE Trade Winds, sea state 4 or 5 and the fine detail captured for this project would have been obscured by images of sea-surface shine and clutter.

Site loci covered by the slides in the foreground and middle distance only were assessed approximately within grid lattices using the 50,000 D.O.S. topographic maps in the series X 754, reprinted for D.O.S. by the UK Ordnance Survey in 1979 and using WSG 72 Universal Transverse Mercator Grid Zone 60 International Spheroid. Because of the angle of the photograph relative to grid lattices most slides will not cover the full extent of the grid lattice references in this note. Slides are referred to against each sheet number in the 1:50,000 DOS series omitting the full UTM grid reference but utilising the grid lattice and annotated data printed at 1000 m intervals on each sheet. E.g. for the first slide AH30 described in this note the reference given in the text for the approximate extent of near and middle distance coverage is 60 to 65 E, 89 to 98 N. In full for this sheet VITI LEVU 20 this would be reference as $^{6}60^{000m}$E to $^{6}65^{000m}$E, $^{7}89^{000m}$N to $^{7}98^{000m}$N. On the 1:250,000 sheet (Fig. 1) the area is gridded into the 10 km sections. Therefore at 1:250,000 scale only the first two significant figures of the eastings are referenced and the first three significant figures of the northings are referenced.

The author of this report (Holmes) was not on the flight (being in UK at the time) and the data and interpretations are from the participants' field records plus some of the author's background knowledge.

2 SLIDES

<u>Figures 1,2 3.</u>

2.1 SLIDE	**AH 30 P524660**
DOS SHEET NO.	Viti Levu 20, Edition 7-GSGS, 'SUVA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	60 TO 65 E, 89 TO 98 N
LOOKING TOWARDS	SW

COMMENT Rewa River and delta looking south, Lokia landing to the right. All the area is tidal and towards the middle and far distance on the delta the vegetation is largely mangroves.

Laucala Bay is on the right, Nukulau island in the distance on the left. The delta ground area tends to flood in heavy rains and/or storm surges and people and stock are then moved out.

The river bed has clean lithic sand, parts of the river levees after flood almost pure magnetite and in the mangrove areas it is quite common to retrieve coral fragments (eg on fishing gear) from the channel beds – a sign of higher sea level covering these areas during the Pleistocene and Holocene? The Holocene geology of the delta has been mapped on a reconnaissance basis by CCOP/SOPAC (Roy, 1986) but the photo-geological interpretation has not been thoroughly ground verified.

AI30

2.2 SLIDE **AH 31 P524661**

DOS SHEET NO.	Viti Levu 20, Edition 7-GSGS, 'SUVA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	60 to 64 E, 87 to 91.5 N
LOOKING TOWARDS	SW

COMMENT Nukulau right, Makaluva left. Tip of Laucala Point (Rewa River 'birds foot' delta lobe) seen on extreme right hand side.

In the main river channel bed inside this finger and on the outside of the bend at 61 to 62 E, 92.3 to 94 N (NE of Laucala Island) in 1986 an MRD snorkelling party recovered semi-lithified claystone blocks exposed adjacent to the soft river muds. The age of the partially lithified formation is not known and samples were not preserved.

AI 31

2.3 SLIDE **AH 32 P524662**

DOS SHEET NO.	Viti Levu 20, Edition 7-GSGS, 'SUVA'
APPROX. AREA COVERED (UTM GRID ON SHEET)	55 to 62.58 E, 89.5 to 91 N.
LOOKING TOWARDS	WSW

COMMENT Nukulau island. From seismic reflection records adjacent to Nukulau the coral sand island is interpreted to overlie consolidated pro-deltaic lithic clastic formations probably of Plio-Pleistocene age (Smith, pers comm, 1986).

One hand-dug well has been put down on Nukulau by the hydrogeology section MRD but no clastic formations were penetrated. The well site is situated approximately 145 m ESE of the jetty at elevation 2.32 m above MSL. Soil and sand were penetrated to 0.74m below round level, beachrock from 0.74 to 1.70 m, sand from 1.70m to 2.0m, beachrock 2.0 to 2.26m, and coral gravel and rotten wood from 2.26 m to 2.45 m at the deepest section of the well. Complete records of this 'Well no. 1' are with the Hydrogeology Section MRD.

Nukulau is closely associated with Fiji's earliest colonial history. A United States of America citizen John Brown Williams who had a house on Nukulau involved the US Government in a property and cash compensation dispute with Cakobau and other chiefs concerning property on Nukulau and other parts of Fiji. The dispute played a major role in Fiji being offered to various other powers as a colony. Eventually Britain accepted the offer and Fiji was ceded to Britain on 10 October 1874. Currently the island is a penitentiary centre for the traitor George Speight (sentence commuted from death to life) who led the 1998 Fiji coup that split the Fiji military.

AI 32

2.4 SLIDE	**AH33 P524663**
DOS SHEET NO.	Viti Levu, Edition 7-GSGS, 'SUVA'
APPROX AREA COVERED	60.0 TO 61.5, 87.5 TO 89.0 N
LOOKING TOWARDS	WSW

COMMENT Makuluva island with the NE and SE arm of its reef. Nukulau Passage to the right, behind the island.

AI 33

2.5 <u>SLIDE</u> **AH34 P524664**

DOS SHEET NO.	Viti Levu 20, Edition 7-GSGS, 'SUVA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	60.5 to 61 E, 88.5 to 91 N
LOOKING TOWARDS	NNW

COMMENT Makuluva Island. The Makuluva Light is in foreground, the square object in the distance is reputedly an old concrete water tank (left over from World War 2? – it could be much older, Peter Rodda pers. comm., 1986) which used to be in the centre of the island. The sea in the distance is Nukulau Passage.

Most of the reef away from the reef edge is dead reef flat, and after rains the whole area becomes discoloured from mud in suspension from the Rewa River. The load of mud distributed offshore by the Rewa River must have been greatly increased by cultivation and therefore within historical times has probably had a severely damaging effect on nearshore reefal areas such as those around the Suva Peninsular. The river mud also discolours the water several kilometres out into the ocean.

AI 34

2.6 <u>SLIDE</u> **AH 35 P524665**

DOS SHEET NO.	Viti Levu 20, Edition 7-GSGS, 'SUVA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	55 to 58 E, 88.5 to 90.5 N
LOOKING TOWARS	NW.

COMMENT Suva main barrier reef: 'Sandbank' sand cay– local name Nukubuco – is seen right top centre. Immediately beyond Sandbank, Nukubuco Passage extends away to the left, beyond that again dark blue water marks the main channel round Suva Point and into Suva Harbour to the west. Laucala Bay and the Suva peninsula can be seen in the background with the old RNZAF flying-boat base breakwater in the far distant shore.

Sandbank and the adjacent barrier reef appear to be built on a large-scale foreset-bedded south-prograding formation possibly of lithiclastics (R Smith, 1987). These are interpreted as relict and pro-deltaic from an abandoned outlet of the Rewa Delta

Boulders more than 2m diameter can be seen on the ocean reef coralgal crest. The crest is composed mainly of cemented reef rock topped by brown living algae (sea weed). The crest dries at most low tides. Behind the reef crest is the reef moat which contains shallow water and scattered colonies of living coral interspersed with coral sand: the moat always drains landwards due to washover from ocean waves but never completely drains.

In the far distance the inner reef edge is normally slightly elevated before merging with the lagoon which in Laucala Bay is up to 40m depth adjacent to the Nukubuco Passage and approximately 20m depth in the middle of the lagoon opposite Nukubuco Passage. Consolidated reef platform in and around this slightly elevated area (relative to the moat) is usually exposed at very low tide. On this part of the reef the exposed area and its margins is covered by a 'skin' of cemented reef platform the order of 20 cm thick that can be prised up and overlies pure carbonate sands up to 200m south from the boundary with the land-shoreward reef/lagoon grassflat margins. The thickness of these sands is at least 1m (Holmes, 1980) and reflection seismic over the reef suggests that in some areas soft formations between rockhead and reef surface may be more than 4m thick (R Smith, 1987).

It appears therefore that the Suva barrier reef extends lagoonwards (north) by carbonate sand transgression followed by cementation. Cementation may have occurred following eustatic sea level lowering during the late Holocene following the sea-level high in the late Holocene (eg. see Roy, 1986). The loose sand, presumably the main reef builder into the lagoon, is moved northwards over the reef to the lagoon edge traction by strong currents originating from waves spilling over the ocean reef crest. The current is active at most stages of the tide and strongest when the ocean waves are trapped by the reef crest. At these times clean ocean water flowing over the reef to the lagoon can move at speeds in excess of 3 knots depending on the state of the tide.

Where the ocean water from the reef meets the slightly less saline and much more turbid lagoon water there is a sharp boundary between the relatively muddy lagoon water and the cleaner ocean water. This boundary is marked at the surface usually by a line of floating mangrove leaves, bamboo, sea grass and other debris, including pumice (lately from eruptions on the Tonga forearc to the east and south-east of Fiji) and, occasionally, sleeping sea snakes The pumice sinks with time, but a lot is also forces up into the mangrove areas where it tends to accumulate. During some high tides and more particularly northerly cyclonic winds the pumice is floated offshore from the mangrove and other beachlines and again becomes prominent in the lagoons and a menace to the cooling sytems of boat engines.

At the reef/lagoon margin in the photo are sea grass flats which comprise poorly sorted fine to coarse pure carbonate reef sand which in section are interbedded with layers of broken staghorn coral (observations when SCUBA diving of dredged reef margins in 1981; Holmes). The staghorn coral has presumably been washed in over the reef during hurricanes or other times of exceptionally strong current and wave action.

The coral sand at the reef/lagoon margin is dredged to 10m below sea level just to the east (right) of the area in this photograph. The sand is used in cement manufacture at a factory in Lami (a town west- adjacent to Suva). The sand is dredged by a road crane and bucket mounted on a barge on shifting moorings and is carried to Lami on relays of other barges pushed or pulled by tugs. Output is approximately 200k tonnes per year. Some of the cement is exported to other Pacific Islands.

AI 35

2.7 <u>SLIDE</u> **AI36 P524666**

DOS SHEET NO.	Viti Levu 20, Edition 7-GSGS, 'SUVA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	52 to 55.8, 88 to 89.5 N
LOOKING TOWARDS	SSW.

COMMENT Suva Main Reef with approaches to Suva Harbour is in the middle distance to the right. Foreground, and off the picture is Sandbank Passage in excess of 70m water depth. Rockhead contours interpreted from 'sparker' seismic reflection records suggests that the Rewa River delta may have run through this area at times of lowest Pleistocene sea level (R Smith, 1987).

Other seismic reflection records across lagoonal margins of Mukulau and Sandbank Passages (eg. MRD cruise 84/3, respectively line 18, line 21) demonstrate that passage channels reach back from the reef passages several tends of metres back into the lagoon itself. It is speculative whether such channels occur because of passage restricted tidal and wind swept water movements preventing settling of fine sediments or if incursion of the passages into lagoons may have a partially catastrophic origin from erosion linked to short period sea level changes related to tsunamis. For example eyewitness accounts on file at MRD Seismology Section suggest that prior to the 1953 Suva tsunami (which occurred at about low tide) sea-level dropped by approximately 2m in the whole of Suva Harbour, (some vessels including sizeable ocean yachts moored at the Royal Suva Yacht Club were temporarily stranded), there was yellow water reported in the Suva Passage, and that the wall along Queen Elizabeth Drive in Suva Harbour was hit by the succeeding 2m high wave. It is suggested that large vertical movements of sea level with periods in the order of a few minutes affecting the whole harbour could only be accommodated by strong currents at the restricted reef passages, and that the reports of yellow water may be linked therefore to erosion of the sea bed in the passages.

AI 36

2.8 SLIDE **AI 1** **P524623**

DOS SHEET NO.	Viti Levu 20, Edition 7-GSGS, 'SUVA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	50.5 to 51 E, 88 to 89.5 N
LOOKING TOWARDS	SSE.

COMMENT Suva main reef. The wreck is a Korean fishing vessel which went on the reef in 1979. Note the large boulders adjacent to the crest and which are scaled by the people on the reef. The boulders were reputedly thrown up on the reef as a result of the 1953 tsunami which affected the Suva area.

Striations on the reef are algal and sand ridges striking at right angles to sea water draining into the shallow depression to the left of the vessel. On barrier and fringing reefs such ridges commonly form cascades or small waterfalls at low tide which are fed by water draining off the reef, this water being continuously replenished by waves which break over the reef crest except at the lowest tides.

AI 1

2.9 SLIDE **AI 2** **P524624**

DOS SHEET NO.	Vitu Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	48 to 49.5, 90.5 to 95 N
LOOKING TOWARDS	N.

COMMENT Suva Harbour entrance, east side. Note large boulders, by repute thrown up by the 1953 tsunami (Houz, 1962).

AI 2

2.10 <u>SLIDE</u> **AI 3 P524625**

DOS SHEET NO. Vitu Levu 19, Edition 6-GSGS, 'MAU'

APPROX. AREA COVERED

(UTM GRID ON SHEET) 44 to 48 E, 93 to 94.5 N

LOOKING TOWARDS W

COMMENT Rat-tail reef looking W and towards Muaivuso Point. Passage marker lights are those at the Suva Harbour entrance, west side. Cracks at the reef edge (not ground verified) are seen on this image on the bottom right hand corner.

AI 3

2.11 <u>SLIDE</u> AI 4 P524626

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	Area 47 to 48E, 93 to 94 N, but precise location has not been ground verified
LOOKING TOWARDS	NW

COMMENT The cracks are reputed to have originated from the 1953 Suva earthquake. Almost all of the cracks around the Suva Reef are parallel to the reef edge and shortly after the earthquake some of the cracks were reported to extend for approximately 200m (Fiji Times, Wednesday October 7, 1953).

During the earthquake the sea-floor dropped by slumping by several metres, (by repute several hundred metres although the accuracy of navigation cannot be verified) a sea floor drop being the cause of the 1953 Suva tsunami. 3 or 4 cables extending out of Suva were broken by submarine landslides while at least 60km south and west from Suva cables were heavily damaged by turbidity currents generated from the movement of the sea bed between Beqa and Suva (Houtz, 1962).

AI 4

2.12 <u>SLIDE</u> **AI 5** **P524627**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	As for AI 4 (Area 47 to 48E, 93 to 94N, but precise location has not been ground verified)
LOOKING TOWARDS	N

COMMENT As for AI 4 P524626

AI 5

2.13 <u>SLIDE</u>	**AI 6 P524628**
DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED (UTM GRID ON SHEET)	As for AI 4 (Area 47 to 48E, 93 to 94N, but precise location has not been ground verified)
LOOKING TOWARDS	probably almost due N.

COMMENT As for AI 4

AI 6

2.14 <u>SLIDE</u> **AI 7** **P524629**

DOS SHEET NO.	Vitu Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	41.5 TO 43.5 E, 91 TO 93 N
LOOKING TOWARDS	NW

COMMENT Namuka island. The wreck in the foreground is on the main barrier reef. Namuka is privately owned (freehold) island which sits on gentle south dipping Suva Marl (Pliocene) not observed on this photo.

There is a flat platform cut into Suva Marl all around Namuka. The wave-cut platform is dissected by channels which at their tops are filled with cemented coral and sand layers, the succession interspersed with large voids (Holmes, 1980). It is presumed that the channels are former creek beds cut through the wave platform at times of lower sea level.

The blue water channel seen to the fore of Namuka island is more than 30m deep, and is flanked by steep or overhanging and largely dead coral to a steeply dipping sea bed of loose sand and rubble leading off to the channel axis. The channel leads off to open water in Namuka Passage to the left (west) and is presumably relict from former low sea-level stands. To the east of Namuka there are various E-W orientated 'blue holes' in the reef which apparently now have no subterranean connection to the ocean. It is speculative whether these blue holes may have originated from collapsed caves (massive cave development is very common in elevated marine limestones found on land in Vitu Levu) or perhaps from overhanging coral growth choking off formerly continuous narrow lagoons behind the barrier reefs.

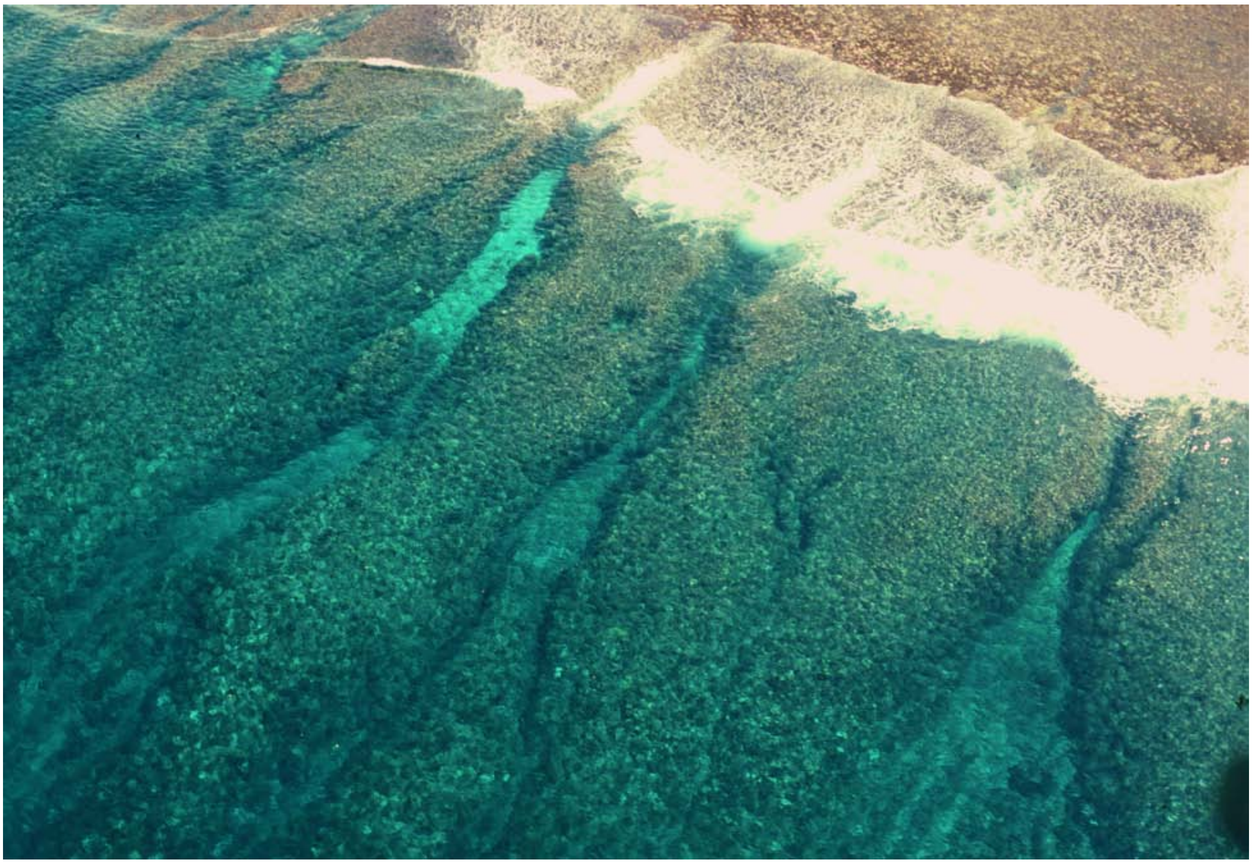
There is a small boat passage from Suva Harbour to Serua which is supposed to obviate the need for such vessels to travel outside the reef. The channel between Suva Harbour and Namuka has been dredged and blasted through consolidated reef flat and sand between blue holes. However, in the compilers' experience this channel is almost impassable even to a small craft some 3 hrs after mean low water neaps, and is in very poor condition also in terms of channel markers. Natural infill of the channel has been greatly aided by some dredged material being deposited on the north adjacent margin of the channel. The passage from Namuka to Serua is natural and being deep water is easily navigable in good weather.

AI 7

2.15 <u>SLIDE</u> **AI 8 P524630**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	40 to 41 E, approx 90.85 N
LOOKING TOWARS	NW

COMMENT Spur and grooves sea ward of Joske's Reef.



AI 8

2.16 SLIDE **AI 9** **P524631**

DOS SHEET NO. Viti Levu 19, Edition 6-GSGS, 'MAU'

APPROX. AREA COVERED

(UTM GRID ON SHEET) 41 to 42 E, 90.5 to 92 N

LOOKING TOWARDS NW

COMMENT Entrance to Namuka Channel

AI 9

2.17 SLIDE **AI 10** **P524632**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX, AREA COVERED	
(UTM GRID ON SHEET)	35 to 37 E, 83 to 88 N
LOOKING TOWARDS	SW

COMMENT Naqara Passage looking SW over Mau Passage, Beqa in distance

AI 10

2.18 <u>SLIDE</u> **AI 11** **P524633**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	36 to 37.5 E, 88 to 92 N
LOOKING TOWARDS	ENE

COMMENT Naqara Passage, looking ENE towards Joske's Thumb (a volcanic plug) Vunidoi Point in foreground

AI 11

2.19 <u>SLIDE</u> **AI 12 P524634**

DOS SHEET NO.	Vitu Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	32.5 to 36 E, 83 to 86 N
LOOKING TOWARDS	SW

COMMENT Reef to SW of Mau Passage. Note reef crest, algal ridges, moat on reef. Beqa Passage in the distance before Beqa Island is major local sports fishing and diving area and is also commercially fished.

AI 12

2.20 **SLIDE** **AI 13** **P524635**

DOS SHEET NO. Viti Levu 19, Edition 6-GSGA,'MAU'

APPROX. AREA COVERED

(UTM GRID ON SHEET) 33 to 36 E, 84 to 85 N

LOOKING TOWARDS NW

COMMENT Spurs and grooves and coralgal ridges between Naqarra and Vatuloa passages.

AI 13

2.21

SLIDE **AI 14** **P524636**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	approximately between 33 to 36 E, 84 to 85 N
LOOKING TOWARDS	NW

COMMENT Deep pools along reef crests – are these developed along areas of former reef edge cracks initiated by earthquakes? Note that the coral is not compact and appears overhanging at the seaward edge.

AI 14

2.22 <u>SLIDE</u> **AI 15 P524637**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	30 to 32 E, 84.5 to 86 N
LOOKING TOWARDS	NNE

COMMENT Looking towards Joske's Thumb. Foreground in top 1/3 of photo is the W end of Vatuloa Passage. E end of Vatuloa Passage can be seen in the background. Note that judging by the surf at the reef edge the passage is somewhat more sheltered than areas to the east, the photo area now being in the lee of Beqa and its encircling reefs.

AI 15

2.23 <u>SLIDE</u> **AI 16 P524638**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	Approx 29 to 31 E, 82 to 84 W
LOOKING TOWARDS	NW

COMMENT Reef between Vatuloa and Togoru Passages, deep pools at reef edges – developed from former reef edge cracks? The item in the foreground is part of the helicopter undergear.

AI 16

2.24 <u>SLIDE</u>	**AI 17 P524639**
DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	29.5 E to 30.5 E, 81 to 83 N
LOOKING TOWARDS	S

COMMENT Reef between Vatuloa and Togoru Passages, Beqa in distance. Deep pools at reef edges.

AI 17

2.25 <u>SLIDE</u> **AI 18 P524640**

DOS SHEET NO.	Viti Levu 19, Edition 6-GSGS, 'MAU'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	approximately 30 to 32 E, 83 to 86 N
LOOKING TOWARDS	NE

COMMENT Looking NE to Vatuloa Passage

AI 18

2.26 <u>SLIDE</u> **AI 19 P524641**

DOS SHEET NO.	Viti Levu 18, Edition 6-GSGS, 'NAVUA RIVER'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	18 to 20 E, 79.5 to 81 N
LOOKING TOWARDS	approximately W.

COMMENT The slide was originally labelled Naitata Flats, south of Navua River. However, Rovodrau Bay is in the background and the foreground includes Drekeilobi Bay. Therefore the photo is probably sited at the E end of the Rovodrau Reefs which are in the nearest foreground, Drekeilobi Bay headland (W) in the middle distance.

AI 19

2.27 **<u>SLIDE</u>** **AI 20** **P524642**

DOS SHEET NO.	Viti Levu 18, Edition 6-GSGS, 'NAVAU RIVER'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	17 to 20 E, 77 to 79 N
LOOKING TOWARDS	SW

COMMENT Rovodrau Reefs, Yanuca island in the distance. The Rovodrau Reefs are SW of the Navau River mouth and extend some 4km length to the SW into Rovodrau Bay at its margin with the Beqa Passage. The Rovodrau Bay beach comprises mainly lithic sand from the Navua Delta forming part of the Pacific Island Holiday Resort. Far background is the Cobe patch reef.

AI 20

2.28 SLIDE **AI 21** **P524643**

DOS SHEET NO.	Viti Levu 18, Edition 6-GSGS, 'NAVUA RIVER'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	18 to 19 E, 78 to 79 N
LOOKING TOWARDS	NW

COMMENT Rovodrau Reef and Rovodrau Bay (far distance). Foreground view starts at the Rovodrau Reef crest.

Lithic sand from the Navau River and its W edge delta distributary the Deuba River extends west at least 8km from the river mouths, displaced by longshore drift by the SE trades. Relatively little river clastic material is fed into the reefal areas east of the mouths. The Deuba River distributary is on the right of this photo but cannot be clearly demonstrated.

The sand on Deuba Beach (Pacific Island Resort) which is on the W part of Rovodrau Bay beach has low percentages of magnetite (estimated by sight less than 3%) although MRD has not, to 1987, done any exploration around the Navua River delta. Unlike the beaches west of the Sigatoka River outlet the Rovodrau Bay (including Deuba) beaches are not normally exposed to ocean waves because of shelter from Beqa to the south and south east. It seems possible therefore that sand dunes are not built along the Deuba coast because of shelter from trade winds by the land offshore but also because the beaches are not exposed to constructive ocean waves driving sand onshore. It is possible that much of the lithic sand from the Navau River is fed into the Beqa Channel and winnowed by strong tidal currents in that channel. Some cognizance of possibility may be taken into consideration in the future for a placer exploration programme.

AI 21

2.29 SLIDE **AI 22** **P524644**

DOS SHEET NO.	Viti Levu 18, Edition 6-GSGS, 'NAVUA RIVER'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	UTM cover cannot be estimated
LOOKING TOWARDS	W

COMMENT Looking W to Sharp Reef with sand cay, and across Rovodrau Bay.

AI 22

2.30 <u>SLIDE</u> **AI 23 P524645**

DOS SHEET NO.	Viti Levu 18, Edition 6-GSGS, 'NAVUA RIVER'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	UK cover cannot be estimated
LOOKING TOWARDS	WNW

COMMENT Serua Reef. This is at the extreme west end of the Beqa Channel, and a wide barrier reef is developed at this extremity as the coastline once again becomes exposed to the ocean.

The barrier reef here is exceptionally broad (in the order of 2.5km max), and the inlets are very sheltered typically with good development of mangroves. At times of heavy rainfall the bays spectacularly change colour to red and orange as a result of discharge of heavily weathered topsoil into the sea. The Serua Hills in the background seem to provide excellent rain catchment areas compared to areas to the E & W. From the compilers casual observation while motoring along the coastal roads it seems that this area of coast is the one most often exhibiting soil discoloured water.

AI 23

2.31 <u>SLIDE</u> **AI 24 P524645**

DOS SHEET NO.	Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	91.5 to 93 E, 77 to 81 N
LOOKING TOWARDS	NW

COMMENT Looking towards Vunanui village in Vunanui Bay. Vunanui Bay is very muddy inshore.

The last time the first author landed in Vunanui Bay (from HMFS Latui in 1983 as a follow up to OTEC reconnaissance survey on the Coral Coast) the area was just recovering from major cyclone flooding and at low tide the bay was covered in at least 50cm of reddish slimy mud with innumerable tree trunks and brush fouling up the bay. Korovisilou Village inshore from Vunanui Bay had been devastated by flooding and mud and tree trunks which had some down the valley and knocked many of the houses down. Currently a tourist development plant for Vunanui is in state of limbo after the financing conglomerate became insolvent. The development area does not look a very inviting shore tourist development spot now. Presumably the sea scenery and coastal amenities would always be in threat from the consequences of future heavy rains.

AI 24

2.32 SLIDE **AI 25** **P524647**

DOS SHEET NO.	Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	90.5 to 93 E, 79 to 82 N
LOOKING TOWARDS	NE

COMMENT Looking into Vunanui Bay. Nabouwalu (or Dogowali) radio mast is on the right.

The first platform of this radio mast provides a breathtaking view and has been used successfully many times for a secure trisponder navigation control point for MRD offshore survey. Keys have to be obtained for the road barrier (the road requires 4WD in wet weather) and also for access into the secure compound around the base of the mast. Note the reddish brown mud discolouration in the middle distance.

AI 25

2.33 SLIDE **AI 26** **P524648**

DOS SHEET NO. Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'

APPROX. AREA COVERED

(UTM GRID ON SHEET) 88 to 89 E, 80.5 to 82 N

LOOKING TOWARDS N

COMMENT Man Friday Resort (west of Namaqumaqua village). The resort is not marked on the current edition DOS map and is situated on the coast on the south tip of the 100 ft contour.

Note that this area comprises the start of the narrow fringing reed at the E extremity of the 'Coral Coast'. The breaks in the reef are opposite river and creek mouths.

The area along the Coral Coast from Man Friday Resort to Korolevu Bay is the most prospective in Viti Levu for development of shore-based OTEC in terms of the shortest distance from the coast to a delta T of 20°C at approximately the 800m contour within a 2km distance off Silalevu Point and immediately adjacent areas. The area has been surveyed topographically in details (10m space contours) with French aid from approximately the 400m isobath to the 1100m isobath with 'seabeam' by RV J Charcot in 1985 and following the reconnaissance surveys done by Fiji Mineral Resources Department with HMFS Latui in 1982 and 1983. These surveys covered most of the southwest coast of Vitu Levu and extended to parts of Vanua Levu and Viti Levu. The area off Silavevu point has good access to roads and the power grid.

AI 26

2.34 <u>SLIDE</u> **AI 27** **P524649**

DOSS SHEET NO. Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'

APPROX. AREA COVERED

(UTM GRID ON SHEET) 83.5 to 84.5 E, 83.4 to 84 N

LOOKING TOWARDS N

COMMENT Borehole no 3 as one of 4 boreholes in section across the fringing reef proved that at approximately 325m south from the high water mark where rockhead cropped out rockhead (volcaniclastics) occurred no deeper than approximately 16m below mean sea level. The depth to rockhead at the last position in the section and on the reef crest adjacent to the ocean (and some 200m further south) could not be found as for expediency reasons only some 5m of cemented coral could be drilled before the site had to be abandoned. Rockhead is known to outcrop in submarine canyons off the ocean reef in this area in water depths in the range of 200m to less than 500m, and less than 800m south of the reef crest drilled from the reef (Holmes, 1983).

AI 27

2.35 SLIDE **AI 28** **P524650**

DOS SHEET NO. Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'

APPROX. AREA COVERED

(UTEM GRID ON SHEET) 82 to 83 E, 83.7 to 84.2 N

LOOKING TOWARDS N, almost vertically

COMMENT Reef south of Namatakula showing a large boulder. The ocean edge consisting of the algal crest is on the right corner foreground, and the transition zone to the reef moat is on the top left foreground.

The Reef adjacent to Namatakula has been reconnoitred by 5 boreholes, 3 of them in the moat or lagoon behind the reef crest, one approximately 75m back from the reed crest, and one on the algal ridges at the passage margins (Smith, 1983). The moat and passage margin boreholes were put down at distances up to approximately 300m from the shoreline at mean sea level. All these boreholes penetrated rockhead at approximately 15 to 20 metres below MSL, and penetrated poorly consolidated mixtures of coral sand and coral blocks. The borehole on the reef crest penetrated more than 5m consolidated carbonate, and further drilling had to be terminated due to technical reasons.

AI 28

2.36 <u>SLIDE</u> **AI 29 P524651**

DOS SHEET NO.	Viti Levu 17, Edition 6-GSGS
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	82.8 to 83.5 E, 83.6 to 84.4 N
LOOKING TOWARDS	NE

COMMENT Namatakula village. On the extreme right, to the right of the stream, is a typical margin for the river made passages through the fringing reefs. To the right and left of the river channel exposed at low tides are mud flats.

The fringing reefs overlooking the tidal mud flats in the river channel comprise a series of algal ridges which at low tide dam up water from the moat on the reef which then overflows and cascades down into the reef passage. At the southern end of the reef passage the channel is exposed to ocean and may be more than 70m deep. The lines of the algal ridges are therefore natural barriers to water originating from waves coming over the front of the reef and returning to the ocean by disgorging into the passage. In these conditions the algal ridges are crossed at right angles by very swift currents at mid to high tide when the fore reef crest is trapping ocean waves into the moat. However, at low tide the algal ridges are the safest foot paths from the beach to the reef ocean crest. Access otherwise is very difficult across the moat dammed by the algal ridges and which has patches of coral interspersed with deeper water coral sandy areas.

AI 29

2.37 <u>SLIDE</u> **AI 30 P524652**

DOS SHEET NO.	Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	80 to 81 E, 84.8 to 85.5 N
LOOKING TOWARDS	N

COMMENT Looking towards Komave. This is an exceptionally narrow channel from a very small creek outlet.

In smaller channels associated with coastal fresh-water incursion onto fringing reefs the typical expression is a slight depression in the moat rather than a passage. The depression leads to blind deep water narrow fingers extending perhaps only ½ into the fringing reef. Such places are extremely dangerous for swimming as surface and down-plunging currents are strong during some states of the tide and weather. When a strong onshore wind (SE Trades) brings in much water over the reef with large waves the water drains out through these narrow channels. The channels are characterised at their top edges by several metres of growth of live overhanging coral. One such fingered inlet into the reef to the east of the Reef Resort Hotel and the Sandy Point Holiday Cottages has been associated with at least 4 deaths by drowning in recent (1987) history. Strong currents are known to the writer to drain through caves in segments of the channels in this inlet. The British Sub Aqua Club have banned club divers there following a near-miss diving incident involving 3 experiences divers, one of whom as apparently nearly swept down into a cave. The Reef Resort inlet is also known to some locals and by BSAN as 'Gibbons Gulch' after the late Dr Gibbons who recovered an excellent variety and quality of shells from the base of coral cliffs in the complex of inlets. The main attraction of these passages is their very prolific coral and fish life, including reef sharks that commonly rest on the seabed but can still respire because of very strong near-bottom currents.

2.38 SLIDE **AI 31 P524653**

DOS SHEET NO. Viti Levu 17, Edition 6-GSGS. 'KOROLEVU BAY'

APPROX. AREA COVERED

(UTM GRID ON SHEET) 77 to 79.7 E, 84.5 to 86 N.

LOOKING TOWARDS WNW

COMMENT Ahyatt Regency Hotel on right situated between Komave and Korolevu

This is a typical view of a fringing reef on the Coral Coast: algal and coral crest, moat with live coral which decreases in life and colonisation away from the crest, then pure coral sand beach, perhaps with a small development of sea grass just below the low water mark.

AI 31

2.39 **<u>SLIDE</u>** **AI 32** **P524654**

DOS SHEET NO. Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'

APPROX. AREA COVERED

(UTM GRID ON SHEET) 75 to 76.5 E, 85.2 to 86.3 N

LOOKING TOWARDS NE

COMMENT Blocks on reef could in part be upturned from fishing (shelling) activities.

AI 32

2.40 <u>SLIDE</u> **AI 33 P524655**

DOS SHEET NO.	Viti Levu 17, Edition 6-GSGS, 'KOROLEVU BAY'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	NOT KNOWN
LOOKING TOWARDS	NW?

COMMENT Situated somewhere between Korolevu and Sigatoka. Looks as though foreground is a channel edge through the fringing reef, but which channel is not known

The picture illustrated the rugged ridge and spur development exposed at the reef edge by a low on wave surge. These edges are often overhanging even on exposed crests, and some will be levered off with exceptional waves and thrown up on the reef. Overhangs and the effects of connected reef porosity are seen best developed at the sheltered edges of open water channels through the reef, where sometimes at very low tides and in large wave swells spouts can be seen on the incoming surge, and small whirlpools on the outgoing swell.

AI 32

2.41 SLIDE AI 34 P524656

DOS SHEET NO.	Viti Levu 16, Edition 6-GSGS, 'SIGATOKA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	51 to 55.3 E, 90 to 92 N
LOOKING TOWARDS	W

COMMENT Sigatoka sand dunes are composed of lithics from the Sigatoka River brought onshore west of the river mouth by longshore drift and ocean waves from the SE Trades. The coastline here is very exposed to strong trade winds and in the central and west portions in dunes are advancing over the cane growing and poor grazing land to the north

There is evidence from an abandoned river channel (strip lake) behind the dunes and from reflection seismic across the bay that the river channel used to be towards the west end of Sigatoka Bay ie in the far distance on this photo.

The bay sediments comprise at least 50m thickness of lithic sands varying from approximately 5% magnetite 0.5 km from the high water mark increasing with depth offshore to more than 15% at distances 1km from high water mark in water depths of approximately 30m (Holmes, 1983). Beyond 35m water depth the sea bed drops off very steeply in a series of slumps to an ocean basin floor at more than 2000m depth. Debris flow from the Sigatoka River has impinged into the deep water basin in the form of a broad spur (Brocher and Holmes, 1985). Sediments prograde from the shore in large scale oblique foresets to the bathymetric break at 50m or so. No sub surface seismic reflection is available for sediments in water depths from approx 60m to 600m. Sampling shows that there is a mobile layer of well mixed top sediments approximately1m thick but below this there is a sharp transition to finely layered sediments with much higher concentrations of magnetite than the surface sediments. Because of the low resolution of the seismic available to MRD it is not known whether the oblique prograding beds on the seismic are the same formation as the fine grained layed sediments sampled in the lower part of the longer cores.

AI 34

2.42 <u>SLIDE</u> **AI 35 P524657**

DOS SHEET NO. Viti Levu 16, Edition 6-GSGS. 'SIGATOKA'

APPROX. ARE COVERED

(UTM GRID ON SHEET) 53 to 55 E, 90.8 to 91.5 E

LOOKING TOWARDS WNW

COMMENT This is the E end of the Sigatoka dunes adjacent to the river source: grades average up to 13% magnetite max this end to some 6% or less at the W end of the dunes. The dunes are partially mobile and exposed historical soil profiles can be seen in the seaward exposed sections with shrubbery.

AI 35

2.43 <u>SLIDE</u> **AI 36 P524658**

DOS SHEET NO.	Viti Levu 16, Edition 6-GSGS, 'SIGATOKA'
APPROX. AREA COVERED	
(UTM GRID ON SHEET)	questionable 49 to 51 E, 90.5 to 91.3 N
LOOKING TOWARDS	almost vertical

COMMENT Cracks in beach-rock at the west end of the Sigatoka beach (it has not been ground verified whether this is beach-rock or part of the Cuvu Sedimentary Group (Pliocene) which is exposed on coastal sections.

AI 36

2.44 <u>SLIDE</u> **AI 37 P524659**

DOS SHEET NO.	Viti Levu 16, Edition 6-GSGS, 'SIGATOKA'
APPROX, AREA COVERED	
(UTM GRID ON SHEET)	questionable 41 to 47 E, 91.8 to 94 N
LOOKING TOWARDS	NW?

COMMENT The photo is not well fixed. The view could be looking NW towards Naevuevu.

AI 36

3 DISCUSSION

Not all of the boulders thrown up on the reef have been examined in the field, but it is common knowledge that they are mostly composed of reef limestone and must have originated from the ocean front or passage edges of the reef. Large blocks of reefal limestone occur on barrier reefs off the north and south sides of Vatulele island west of Beqa and some 15 to 20 miles south of Viti Levu. Because they are adjacent to this reconnaissance survey area their origin should be considered. The blocks on the Vatulele reef are relict from elevated reef limestone, they are in linear form, rectangular slabs, interspersed with undercut and mushroom profile islets and are not related in any way to passages. Their origin is obviously quite different to the boulders mapped on the Viti Levu reefs.

Observations from ships in the Fiji EEZ demonstrate that wind and swell waves in the range of 0.5 to 2.5 metres height have a frequency of more than 75% (Krishna, 1983) and do not through up boulders onto the reefs. Larger waves and swell may fall into the following categories:

1.1 South easterly winds over 25 knots occur some days at a time and generate waves which may be 3 to 6m height: these waves have a frequency of 2 to 5%.

1.2 Slow moving, extensive and intensive cyclones producing SW waves and swell over a large fetch in the ocean area originate to the SW of Fiji or W of New Zealand (Tasman Sea). In this category swell heights between 3 to 6m affect Fiji at a frequency of 20%. The local name for the largest of these swells are 'Loka' and they can be very damaging to shore areas at high tide.

1.3 Annually rare swell and wind wave generated heights of over 6.5m may be expected only during the passage of local tropical cyclones. Storm surges in the order of 2 to 3m above predicted tide heights may be associated with close passage of such cyclones. When high tides, storm surges and large cyclone generated waves coincide to hit coastal areas extensive coastal flooding and wave damage can ensue.

Out with weather generated waves:

1.4 Historically very rare tsunamis generated from earthquakes, e.g. the height of the 1953 Suva tsunami wave hitting the Suva barrier reef ocean front was estimated by casual observers to be in the range from at least 3m up to 15m (Houtz, 1962).

It is local knowledge that boulders are not thrown up on to the reef with 'normal' weather-driven conditions and wave heights less than 3m height. However, no data are available to the authors to document which of the conditions 1 to 4 above may have generated the largest number of boulders now found perched on the reefs off S Viti Levu, or if the frequency and size of boulders there is statistically different from other parts of Viti Levu or on other islands. It is well documented that the three sets of the very large boulders on the Suva barrier reef east of Levu Passage were thrown up by the 1953 tsunami, and that since these are the largest boulders on the reefs on south Viti Levu they represent a local and historically unique event. According to photographs at MRD scales off against adults the largest of the boulders in the three areas on the Suva Reef are at least 2m height and 4 metres length. To the writers knowledge boulders of this size have never been lifted onto the reef by weather storm waves.

Once on the reef it is well documented on admiralty charts that ship-wrecks may be moved slowly or suddenly by any of the wave conditions described above, and it is presumed that boulders will also be dispersed with time from their first resting point. With cyclone storm surges there is considerable potential for the whole of the reef to be exposed to very high energy waves to shift boulders already on the reef or to break them up into small boulders.

Barrier reefs off S Viti Levu and east of Somosomo Bay exhibit a pattern where the highest concentration of boulders occur at and adjacent to the passages. Possible reasons for this distribution are:

2.1 Overhangs of coral are developed at the passage margins, and these overhangs are likely to provide source material to break off and be carried a short distance to the reef crest in exceptional wave climates (Figure 4). Overhangs are not normally found on ocean reef margins facing the SE Trades. However, from the observations reported in this text, it is possible that reef cracked as a result of earthquake activity could provide good source for boulders thrown up as a result of exceptional weather conditions or tsunami.

2.2 Some passages may focus waves coming from certain directions. This effect has never been seen by the authors in normal SE Trades conditions, but could occur in any of the anomalous wave height conditions described above.

The relationship of boulders to reef passages is not as consistently developed west of Somosomo Bay and along the fringing reef compared to the SE Viti Levu coast. Since overhanging coral growth in the passages between the two areas is comparable, the data suggests that the wave climate around the passages in SE Viti Levu is more severe than in the passages around SW Viti Levu. This hypothesis cannot be tested with published wave data. However, it is in agreement with Vatulele, Beqa and Kadavu island complexes barricading much of the SW coast from a long SE fetch, and suggests that large waves originating from exceptional SE Tradewind strengths (1.1. above) have been dominant in determining the distribution patterns of the smaller boulders on the SE Viti Levu barrier reefs.

To the authors knowledge the only coral boulder of comparable size to the largest on the Suva barrier reef and adjacent to the south coast of Viti Levu occurs at the south end of Frigate Passage as a solitary passage marker. Frigate Passage is situated at a break in the fringing reef south west of Beqa island. The block is approximately 4 metres diameter and 3 to 4 metres height and its base is firmly cemented onto the reef.

The boulder is situated at the passage edges where large blocks are currently overhanging the deep water, and other adjacent large blocks have broken off from the passage edges and are found in water depths 20 to 30m plus (Holmes: SCUBA diving observations, 1986). By the size of this boulder, its different geometry and setting to boulders generated from reef elevated in situ and the historically high frequency of very severe storms incapable of lifting such a size onto the reef the author is of the opinion that it has been lifted onto the reef by an ancient tsunami.

4 CONCLUSIONS

1) Exceptionally large boulders on the reef can be used as indicators of tsunamis impinging on Fiji coasts. There is no historical evidence that tsunami generated outside Fiji have lifted large boulders onto the reefs, although large reef perched boulders found anywhere within the Fiji EEZ would not be discriminatory of local or regionally generated tsunami activity.
2) More than 60% of the well defined reef passages are associated with boulder fields at the junction of the reef passages with the ocean reef front rather than at the main ocean front of the reef. The dominant factor in this distribution is though to be sourcing of boulders for these areas from overhanging coral blocks growing at the reef passages margins.
3) Exceptional waves and swell capable of lifting boulders onto the reefs have principle directions and highest frequencies of fetch from the SW and SE. Imposed on this pattern are storm surges and cyclonic wind generated waves from any direction, and historically rare but very high energy tsunami waves. It is though that the various wave directions and the potential for all waves to disperse boulders from their original resting site on the reef may be responsible for local inconsistencies in boulder distribution.

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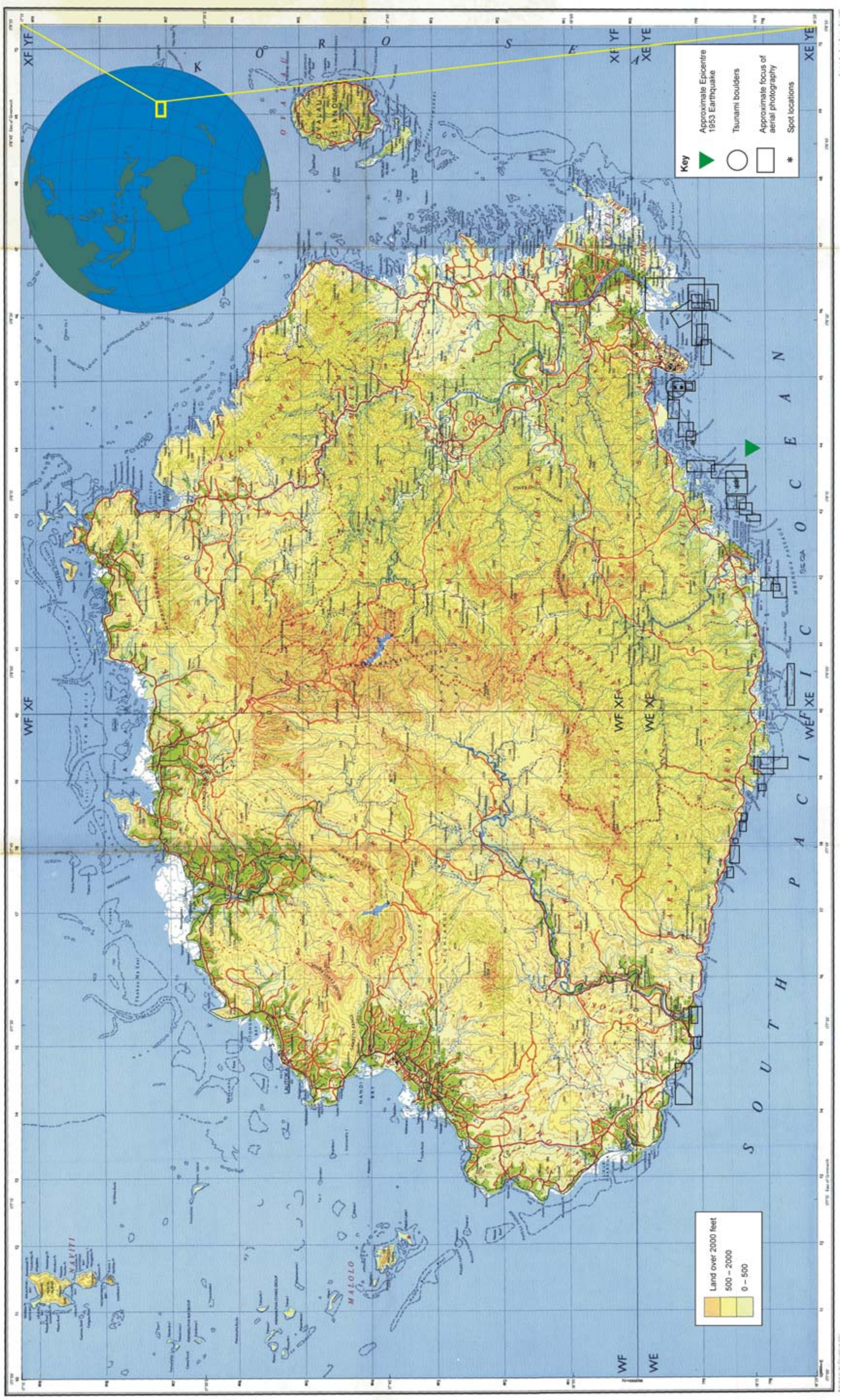

Figure 1. Geographical setting Viti Levu

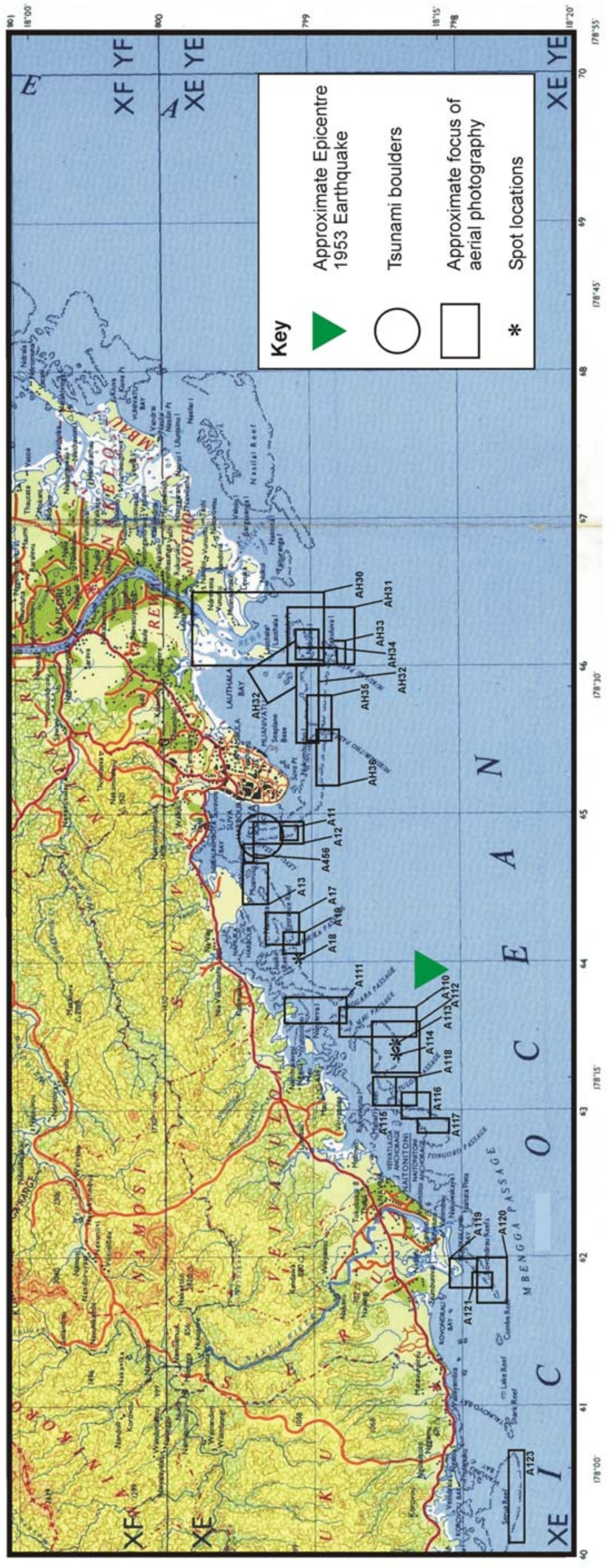

Figure 2. E. Viti Levu study

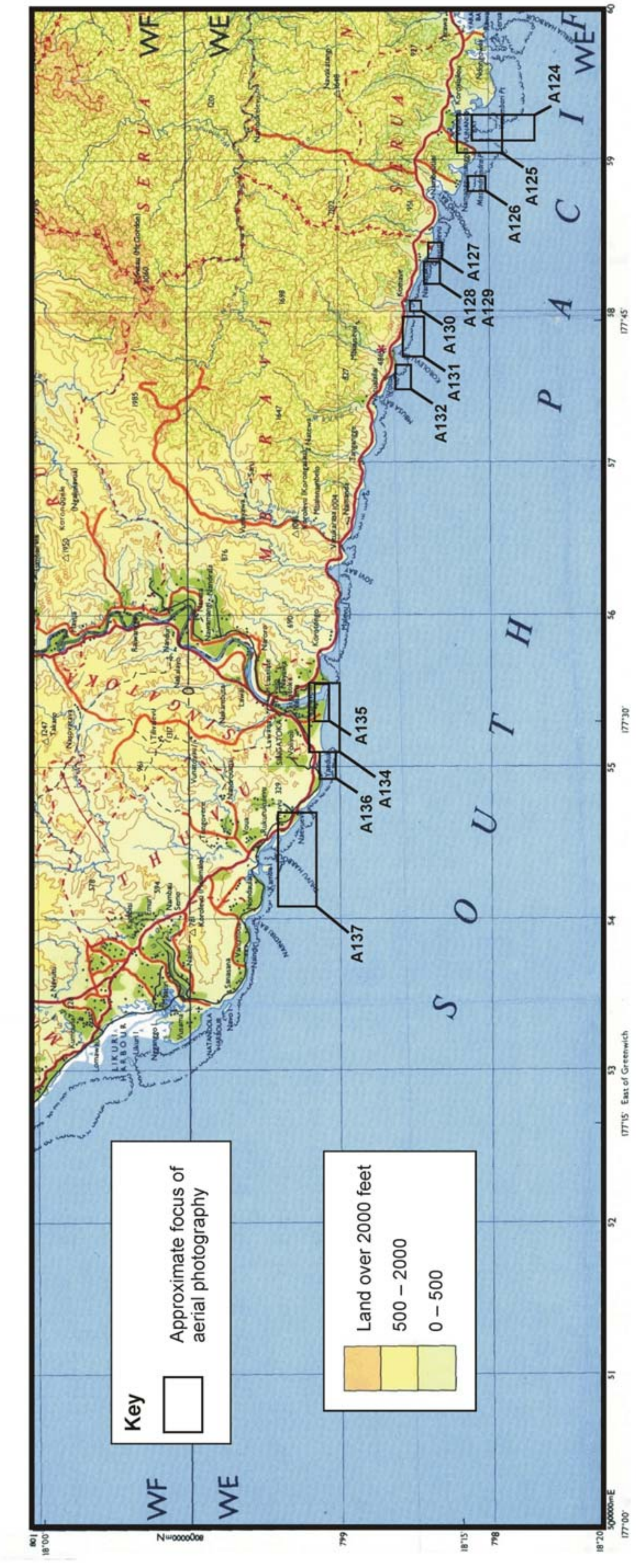

Figure 3. W. Viti Levu study

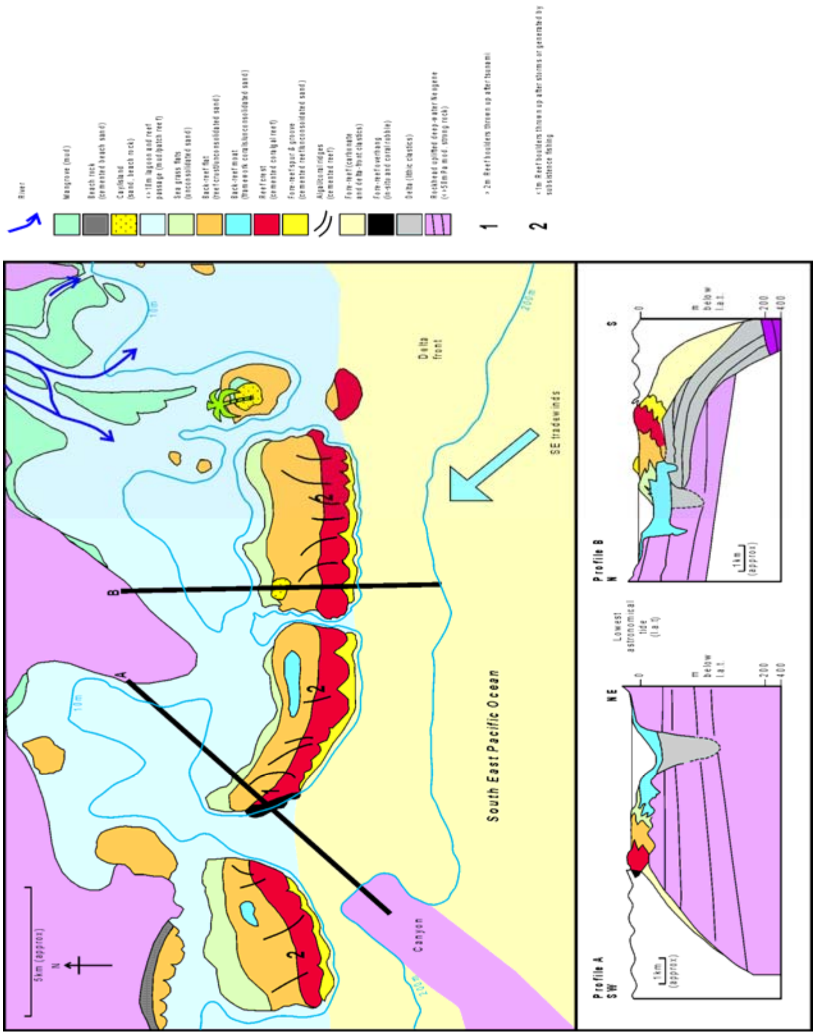

Figure 4.Summary geological /geomorphological setting reef boulders