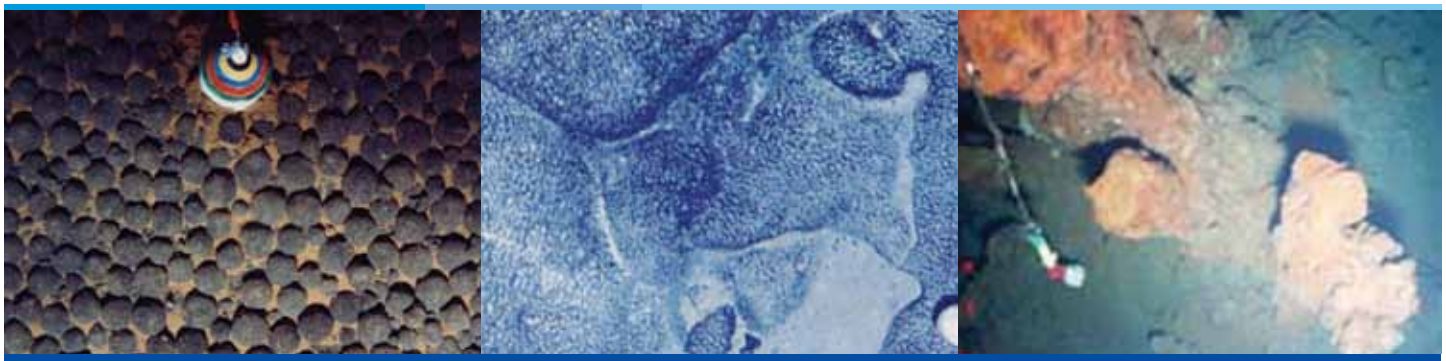
SPC
Secretariat of the Pacific Community
Applied Geoscience and Technology Division (SOPAC)

SPC-EU EDF10 Deep Sea Minerals (DSM) Project



Information Brochure 10
Fiji Deep-sea Mineral Potential

The Fiji Islands group is bounded by the North Fiji Basin (NFB) to the west, the Lau Basin to the east, and the North Fiji Fracture Zone (NFFZ) to the north (Figure 1). Studies have confirmed that the NFB is a back-arc basin created by oceanic back-arc spreading behind the Vanuatu Arc. It is characterized by a Triple Junction that connects a north-south aligned central spreading centre, a north-northwest trending spreading centre and the east-northeast NFFZ (Figure 1). Out of the four back-arc basins (Manus, Woodlark, NFB and Lau) that lie within the boundary of the Indo-Australian Plate and the Pacific Plate, the 2,500m–3,000m deep NFB is the largest.

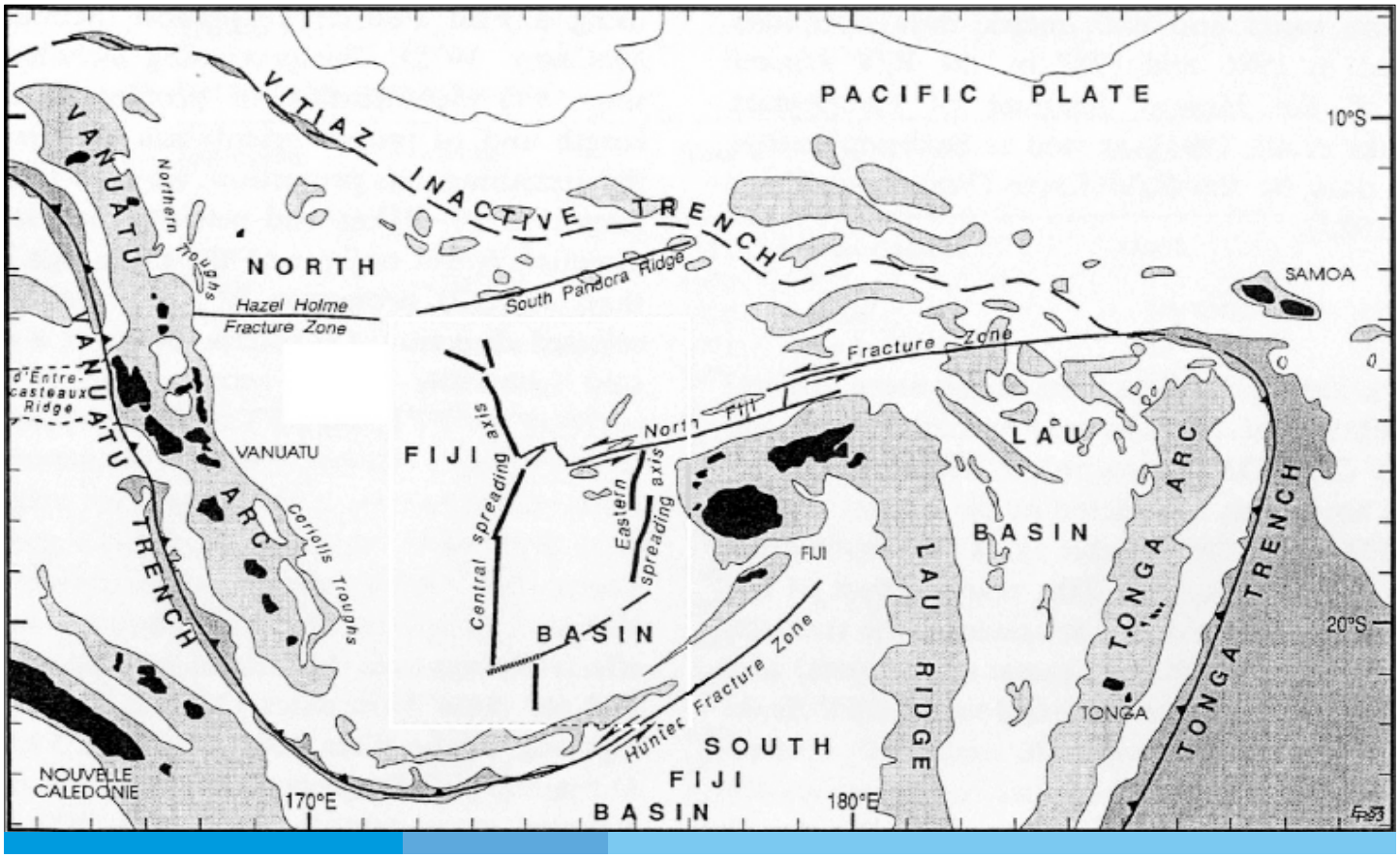


Figure 1. Main Tectonics of the North Fiji Basin (from MMAJ and JICA, 2000).

Early marine scientific researches conducted from the early 1970s to early 1980s were concentrated on studying tectonic behaviour as well as investigating the potential for petroleum, metalliferous sediments, phosphates and precious corals in various offshore areas of Fiji.

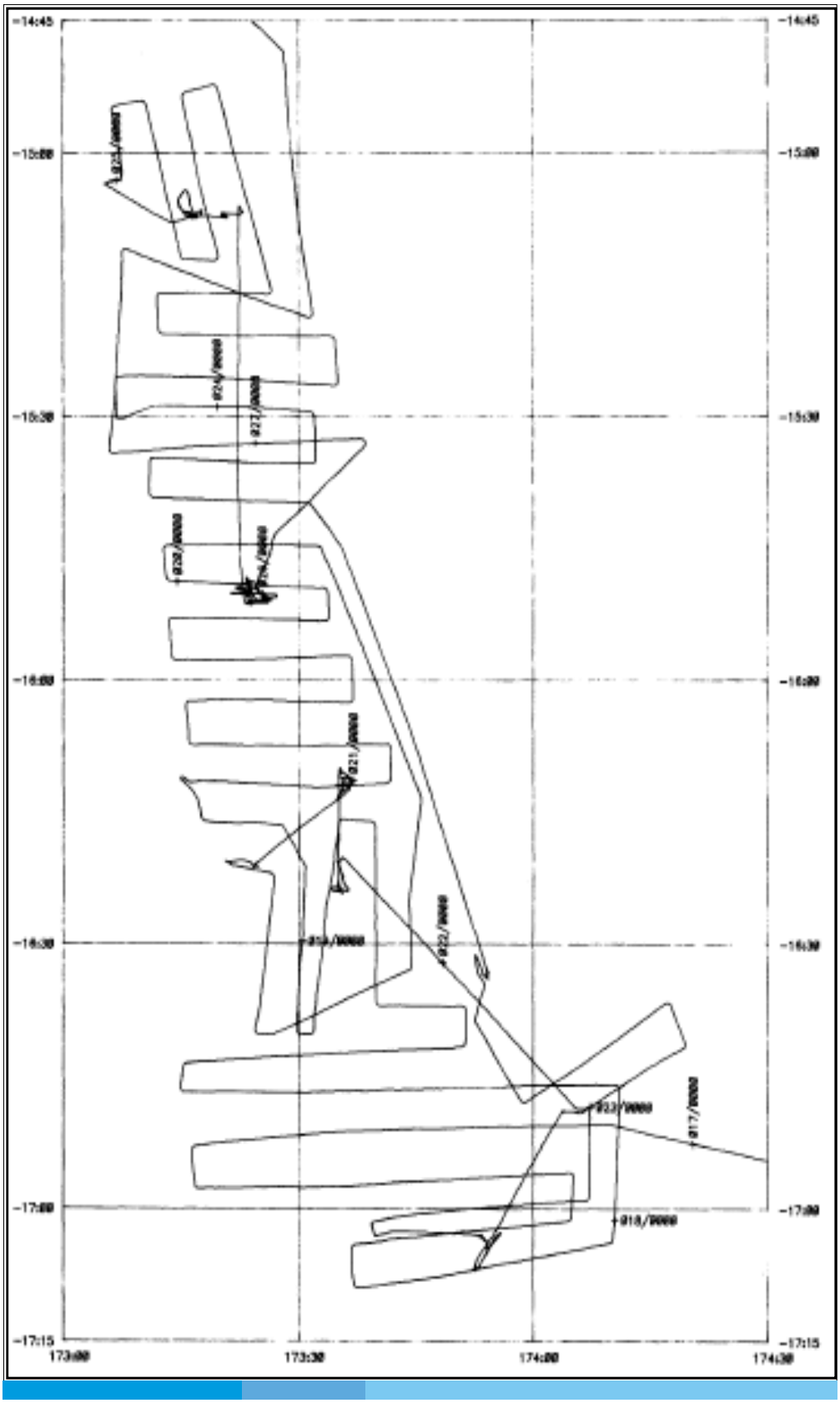


Figure 2. The 1987 RV Moana Wave survey tracklines over the Central North Fiji Basin Ridge.

Following the discovery of hydrothermal vents in the Lau Basin in 1982, the NFB has been an area of significant interest in the search for hydrothermal vents and associated Seafloor Massive Sulphide (SMS) deposits. In the last two and half decades, the NFB had been the target of many deep sea minerals prospecting.

Under the Tripartite II program that was jointly funded by Australia, New Zealand and the United States, the Central North Fiji Basin was surveyed in early 1987, exploring for evidence of hydrothermal mineralisation along the ridge system. The survey tracklines over the Central North Fiji Basin Ridge are shown in Figure 2. This was followed by several joint Japan-French cruises under the 1987–1992 study of the central North Fiji Basin.

Prior to the commencement of the Japan-SOPAC survey program in Fiji in 1999, the occurrence of hydrothermal deposits in the Central Spreading Ridge of the NFB has been established from previous scientific studies. Reasonably detailed investigations were carried out during the 1999, 2001 and 2004 Japan-SOPAC studies in the NFB, targeting potential sites for SMS deposits along the spreading centres and other areas.

This information brochure highlights the results of previous exploration results and the mineral potential of Fiji's Exclusive Economic Zone (EEZ), in particular the NFB.

Exploration History

Previous seabed mineral investigations on SOPAC record that took place within the EEZ of Fiji are shown in Table 1 below.

Table 1. Summary of previous offshore minerals exploration in Fiji.

Research Vessel and Year of Survey	Survey Area	Target Minerals
HMFS Kiro (1977)	Koro Sea and Bligh Water, Fiji	Petroleum
RV Acheron (1977)	Yasawa Trough, Fiji	Metalliferous sediments
RV Machias (1978)	Southern Lau Group and Lau Ridge	Phosphorites
RV Machias (1980)	Beqa Channel, Northern coast of Kadavu Island	Precious coral
RV Kana Keoki (1982)	An area west of Samoa, North Fiji Basin, Baravi Basin (southwest of Viti Levu)	Tectonic behaviour, metalliferous sediment, phosphate
RV Kana Keoki (1982a)	Central North Fiji Basin	Geologically define the Triple Junction, metalliferous sediments
RV S. P. Lee (1984)	Baravi Basin (Southwest of Viti Levu), Fiji-Vanuatu transit route	Hydrocarbon, marine minerals, bathymetry mapping
RV Jean-Charcot (1985)	North Fiji Basin (French SEAPSO Program)	Tectonics and bathymetry mapping
RV Moana Wave (1987)	North Fiji Basin (Fiji Fracture Zone and Ridge System, Pandore Ridge (near Rotuma)	Hydrothermal mineralisation, tectonic behaviour
RV Kaiyo (1987–1992)	North Fiji Basin (Japan-France cooperative project)	Tectonic processes, hydrothermal vents
FNS Babale (1988)	Lau Group	Precious coral
German Hyfiflux Project (1995)	North Fiji Basin	Hydrothermal vents, SMS deposits
RV Hakurei Maru 2 (1999)	North Fiji Fracture Zone (NFFZ) including the Central Hill and Extensional Relay Zone A (ERZ A)	SMS deposits
RV Hakurei Maru 2 (2001)	The Triple Junction area of the Central Spreading Ridge in the North Fiji Basin	SMS deposits
RV Hakurei Maru 2 (2004)	North Fiji Basin	SMS deposits

Previous Survey Results

Summary Findings of the pre-Japan-SOPAC Cooperative Study

- During the 1977 metalliferous sediment survey in the Yasawa Trough, eleven core samples were collected and sent to Imperial College London for metallic ion content determination of each core. A very crude indication of the metalliferous content of the sediment is provided by the colour of the sediment samples collected. Analysis results are not available.
- In 1978 echo sounding data were collected north and south of Vatoa Island and the tracks were designed to supplement existing data collected by the RV Tangaroa, RV Kana Keoki and HMFS Ruve. Fe/Mn deposits and associated phosphatised limestone occur on the highest parts of the Lau Ridge between Ongea Driki and Vatoa at depths less than 800m.
- During selective dredging and coring in the NFB and adjacent areas during the 1982 cruise, Holocene foraminifera's rich mud was recovered; however, there was no evidence of metalliferous rich mud in the few samples collected.

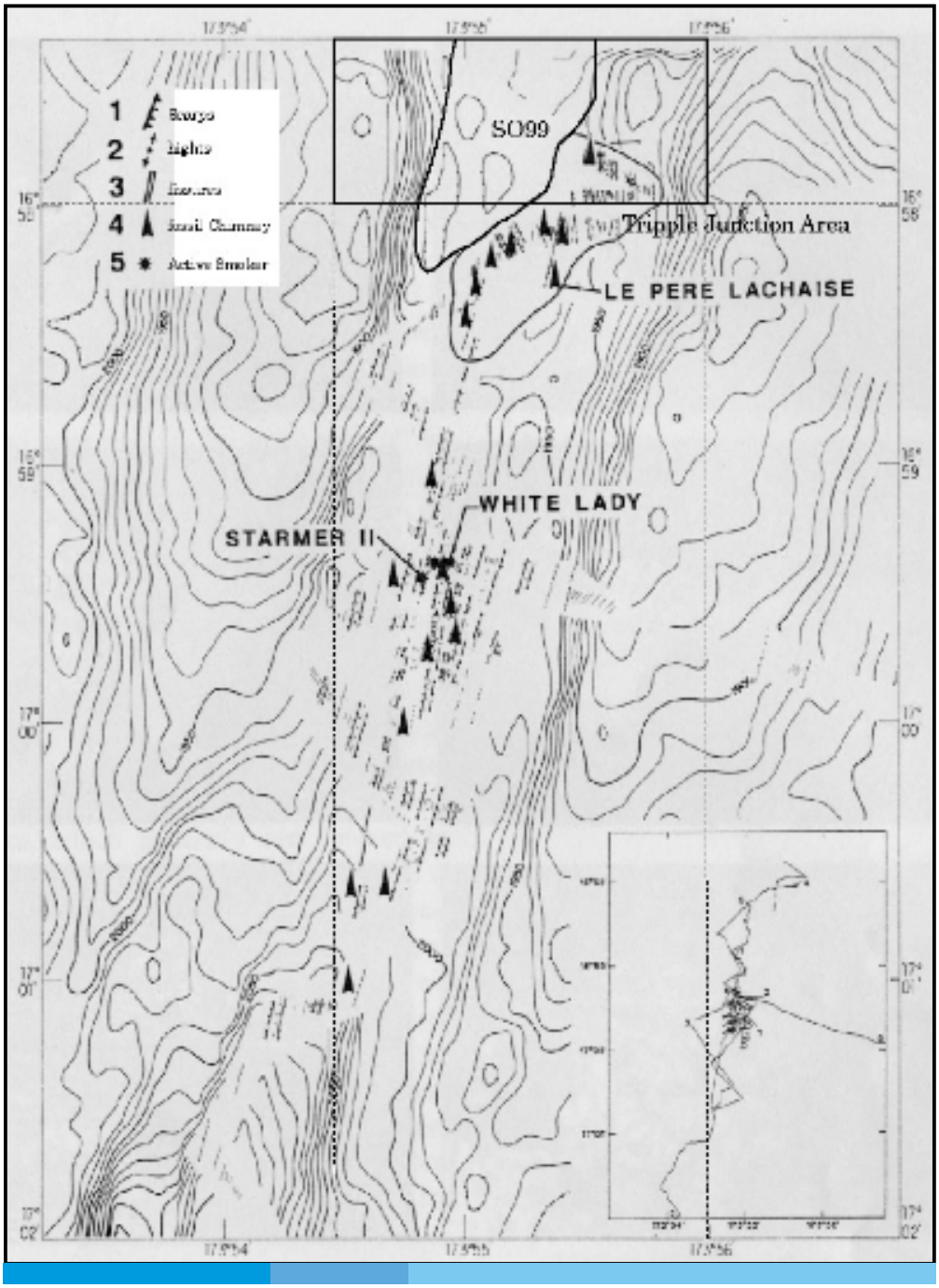


Figure 3. Hydrothermal activity along the Central Spreading Ridge of the NFB.

- The sediment analysis results of the 1982 survey revealed that iron, manganese, copper and zinc concentrations are well in excess of the regional values. This may indicate the potential for the presence of more highly enriched polymetallic massive sulphide deposits. While the presence of Mn-rich encrustations are possible evidence of hydrothermal activity and metallogenic enrichment of recent sediments across the NFB, there is no sign of polymetallic sulphide deposits in the dredged sedimentary rocks studied.
- The 1987 CCOP/SOPAC[1] -ANZUS[2] survey concluded that the Central Ridge of the North Fiji Basin has three elements: a southern arm, a northern arm, and an eastern arm that comprise the Triple Junction.
- Active volcanism and methane anomalies along the central ridge system indicate that prospective areas lie to the south even though hydrothermal mineralisation was not pinpointed during the survey. The Pandora Ridge (Figure 1) is an east-west trending linear belt dominated by active rifts and seamounts.
- During the RV Kaiyo Cruise in 1987, a temperature anomaly (i.e. an abnormal temperature high of 0.02°C) was recorded just above the sea bottom of the rift valley at one of the CTD[3] stations. This suggests the presence of hydrothermal activity and may indicate that the NFB is prospective for massive sulphides.
- The deep-tow television and photography performed around 17°S on sample station ST04 provides direct evidence of hydrothermal activity: living animal colonies, temperature anomalies, and sulphide deposits.
- Chimney-mount groups such as STARMER II, White Lady and Père Lachaise sites were discovered during the 1987–1992 STARME[4] Project (Figure 3).
- The SO99 mineralisation site was discovered during the 1995 German Hyfiflux Project (Figure 3).

1 CCOP/SOPAC – Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas
2 ANZUS – Australia-New Zealand-United States Tripartite Survey Programme
3 CTD – Conductivity-Temperature-Depth
4 STARMER – a joint international inter-disciplinary Project of France and Japan in association with SOPAC in the North Fiji Basin.

- The centre of the Triple Junction is occupied by the volcanic hill with approximately 18km across dome shape, rising 500 to 600m above the surrounding sea bottom, and it is called the Central Dome.
- Inside the graben of the Central Dome, three sites of hydrothermal mineralisation, White Lady, Père Lachaise and SO99 sites, have been found (Figure 3).
- At White Lady site, located on the fault scarps in the 2km wide and 100 to 150m deep graben, anhydrite chimneys expelling shimmering 285°C water were found on the mound consisting of sulphides and oxides.
- The Père Lachaise site, located closer to the Triple Junction, north of the White Lady site, is characterised by the disappearance of the axial graben and increasing width of the domain. The site consists of several tens of inactive individual spires growing directly on basalt scattered over 2km × 2km surface.
- The SO99 site, located northwest of the Père Lachaise site, consists of hydrothermal mounds with inactive chimney scattered over an area of 500m × 600m. The seafloor observation of the site suggests chimney and basalt of younger generation compared with those of the Père Lachaise site.

Japan-SOPAC Cooperative Study

1999 Survey

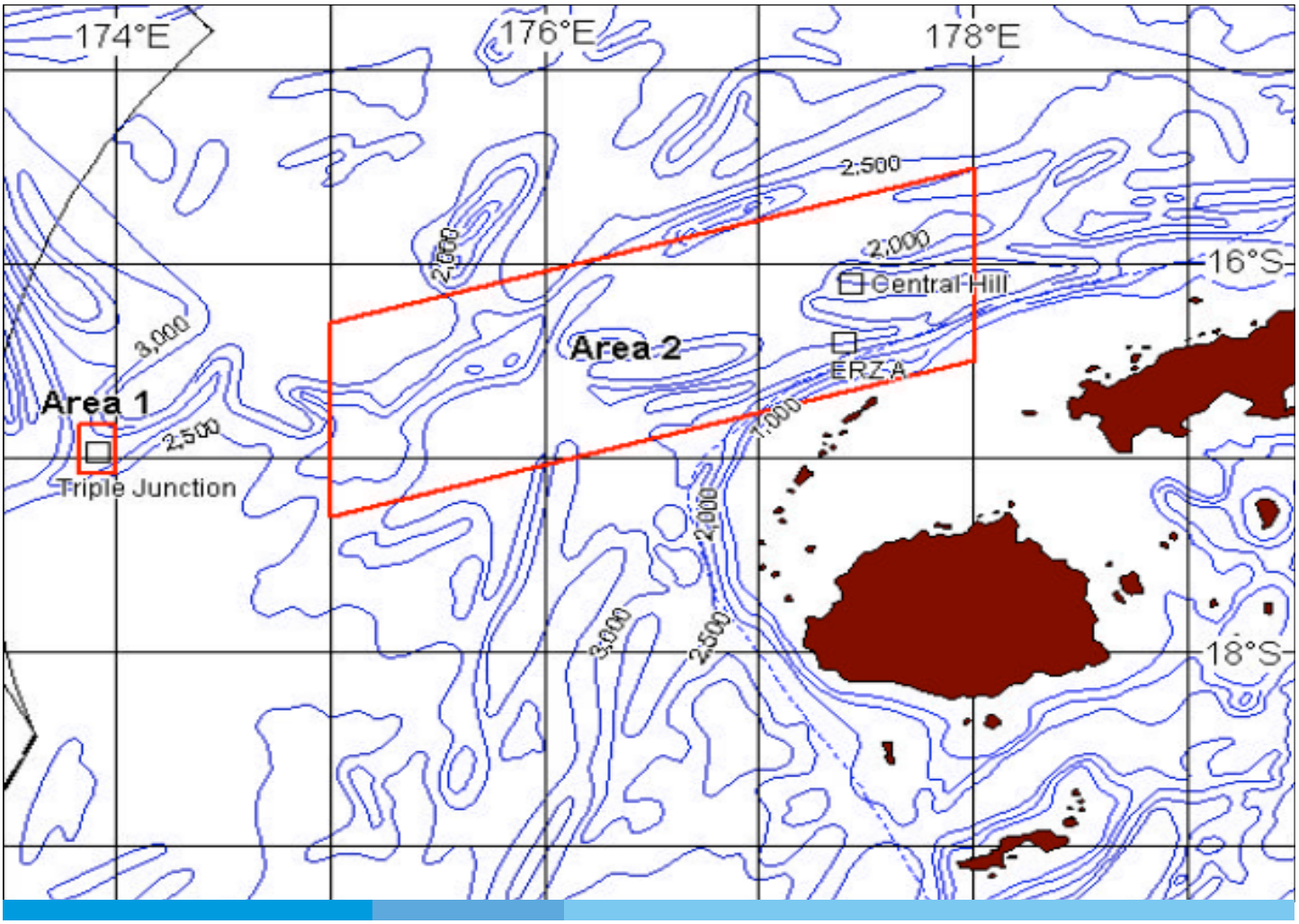


Figure 4. 1999 survey area within Fiji's EEZ.

he purpose of the 1999 survey was to assess the potential for resources of hydrothermal deposits within Fiji's EEZ. For the study of known mineralised zones, the topographic highs near the Triple Junction of the Central Spreading Ridge were chosen and designated as "Area 1 (Figure 4)." The area from north of the Triple Junction to around the Fiji Islands was designated as "Area 2" (Figure 4) for topographic survey and study of mineralisation in unexplored areas.

Area 1 Survey

Seafloor topographic mapping, Side Scan Sonar (SSS) survey, Deep-sea Camera with Finder (FDC) observations were carried out in areas around the Triple Junction, where mineralised zones including SO99 site, White Lady, and Père Lachaise had been discovered. Due to adverse weather conditions, no Benthic Multi-coring System (BMS) operation was carried out in 1999.

Area 2 Survey

A regional survey of topographical and magnetic surveys was conducted during the first leg in order to study the geological structure in Area 2. Seafloor observations by FDC and sampling by Chain Bucket Dredge (CB) were also conducted in "Extensional Relay Zone A" (ERZ A) and "Central Hill" (Figure 8) during the first leg. Five drilling operations were carried out during the second leg, two in the ERZ A and three in the Central Hill.

Results of the 1999 Survey

Area 1 Survey Results

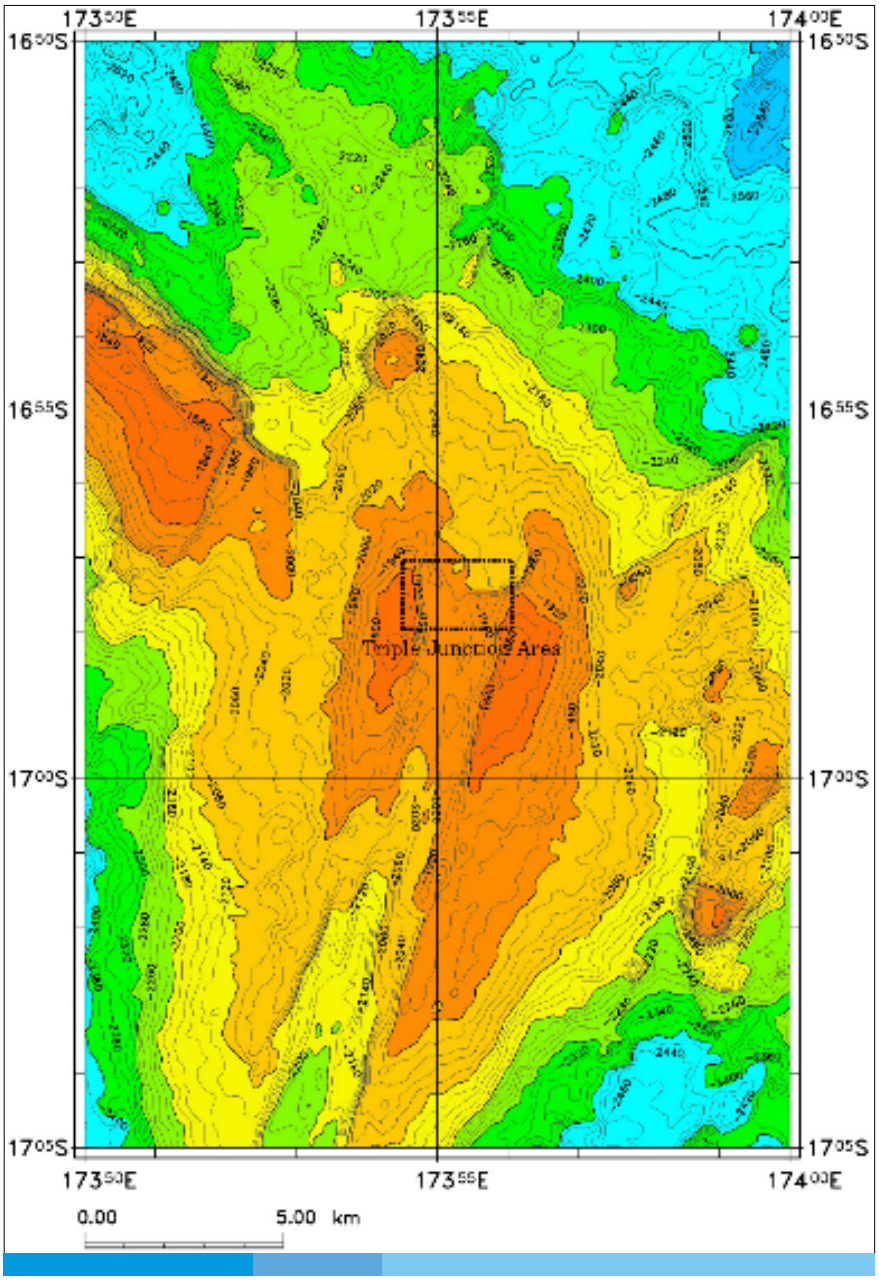


Figure 5. Bathymetry map of Area 1.

A detailed topographical survey of Area 1 reveals that the hill covers an area of about 20km x 12km and forms an egg-shape (Figure 5). The shallowest part is 1860 m deep, and the northern slope is relatively steep while the southern slope is gentle. A 2-km-wide valley extends in the NNE-SSW direction cutting through the central part of the topographic high. Thus the knoll is divided into two parallel ridges by the central valley (Figure 5).

Side Scan Sonar (SSS) Survey – SSS Survey was carried out to clarify the seafloor conditions of the Central Graben and to detect hydrothermal mounds. SSS images clearly show linear structures reflecting fractures or stairstep structures parallel to the trough. Protrusions which may correspond to chimneys and mounds were observed in these linear structures. Judging from the reflection intensity, the western part of the survey area has less sediment than the eastern part.

Deep sea Camera with Finder (FDC) Survey – FDC observations were carried out in the area around SO99 site where the known mineralised zones are said to occur most densely. Apart from the different rock types observed, the mineralised zones and indications of hydrothermal activity detected by FDC observations are:

1) fumaroles and pinnacles discoloured to reddish brown, dark red, green, and yellowish brown with probable chimneys;

2) mounds discoloured to reddish brown, dark brown, green and yellowish brown;

3) yellow discolouration considered to be effusion of sulphur;

4) discolouration to iron-rust colour.

Chimneys and mound groups were found in more than ten localities on the track lines (Figure 6). Mounds of which diameters extended close to 100m were found in nine localities associated with chimneys.

Mounds with strong discolouration without confirmed chimneys were observed in several localities. Possible chimneys were detected in more than 50 localities through the observations (Figures 6 & 7). The chimneys were pale brown to brown in general, though some are grey to greyish green. Most of the chimneys were 1m to 2m high, but some exceeding 3m high were observed in several localities (Figure 7).

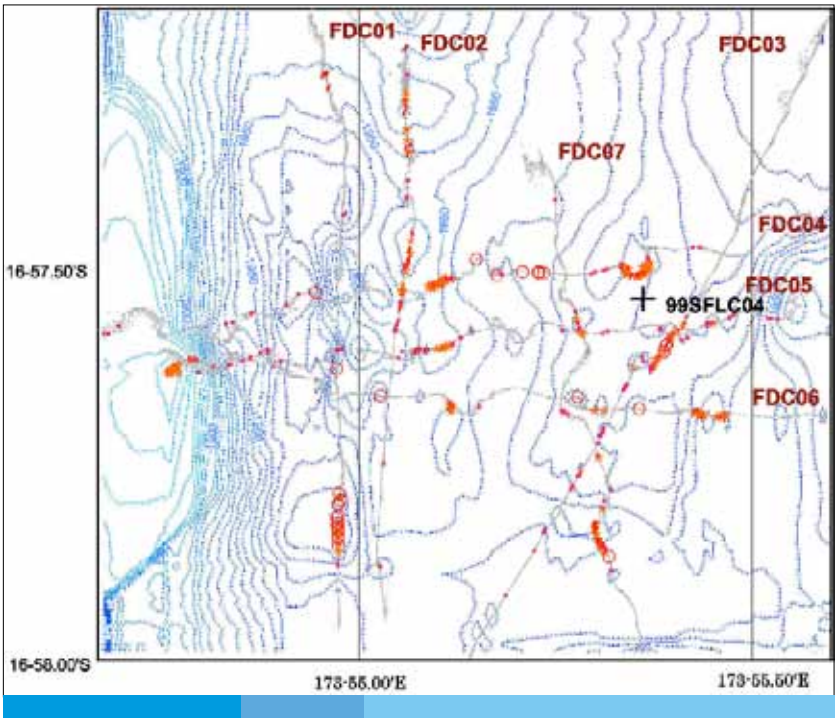


Figure 6. Mineral showing distribution map of Area 1 as observed by FDC.

These mineralised zones occurred aligning in the N-S direction around the topographic high at 173°55.1'E and also in the depression from 173°55.3'E to 173°55.4'E.

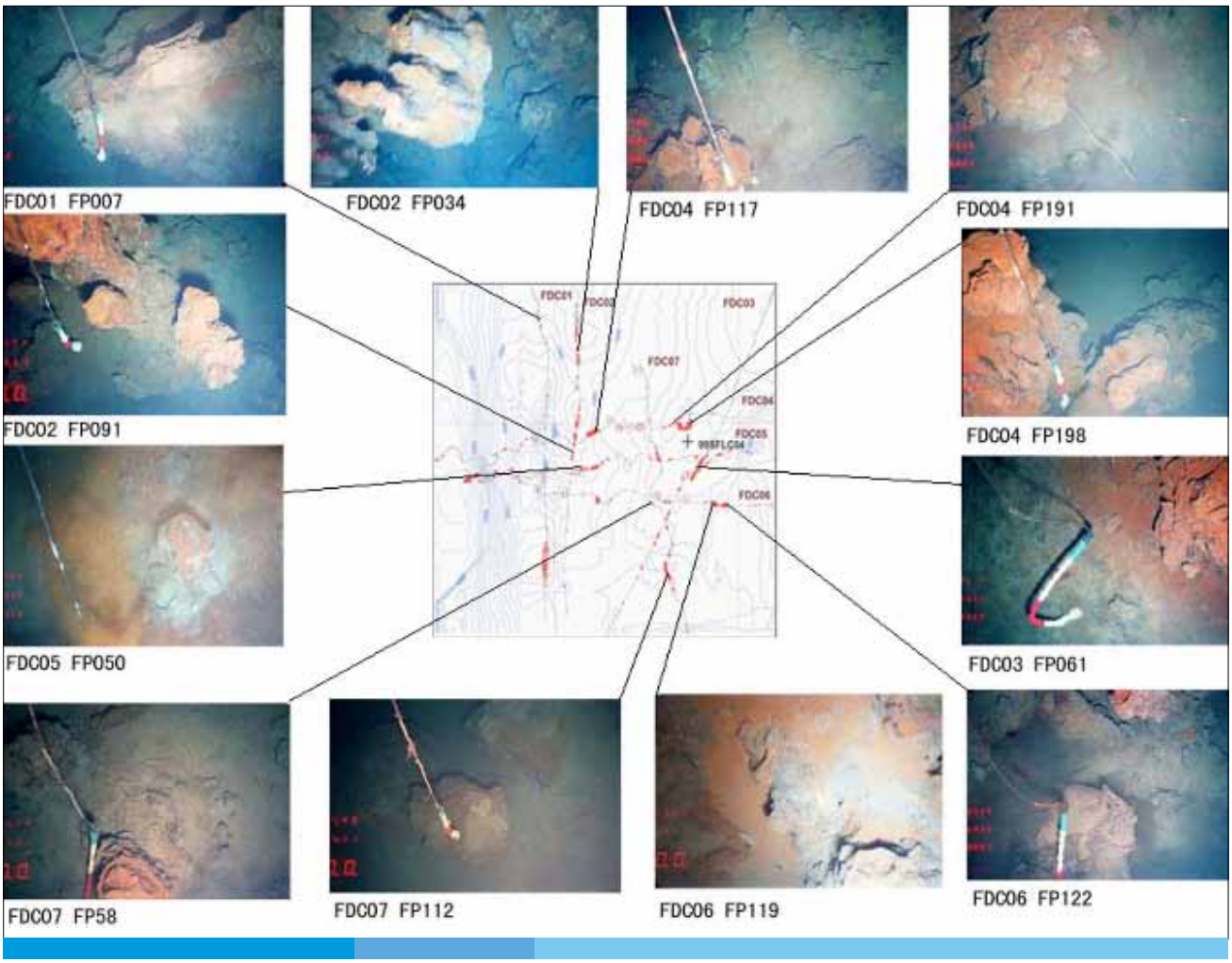


Figure 7. Chimneys and mounds observed by FDC in various areas of Area 1.

Area 2 Survey Results

Topographic Survey – This area has a conspicuous E-trending topography consisting of troughs such as Yasawa and Yadua, and oceanic ridges. In addition, N-trending valley topography consisting of Viwa Rift and ERZ A was recognised.

Hydrothermal Activity – Results of the topographic survey in Area 2 indicated that occurrence of hydrothermal activity was highly probable in the following three areas: 1) Viwa Rift with rifting topography; 2) ERZ A; and 3) Central Hill.

It was suggested from the acoustic reflection intensity images that the sediments were thinnest on ERZ A, followed by Central Hill and then Viwa Rift. Consequently, prospecting for hydrothermal deposits prospecting was carried out in ERZ A and Central Hill.

Prospecting in ERZ A

The ERZ A is located at 16°24'S and 177°25'E, 35km south of the Central Hill (Figure 8), and it shows topographic feature of north-south trending ridges of approximately 1,800m deep with a valley in the middle of the ridges.

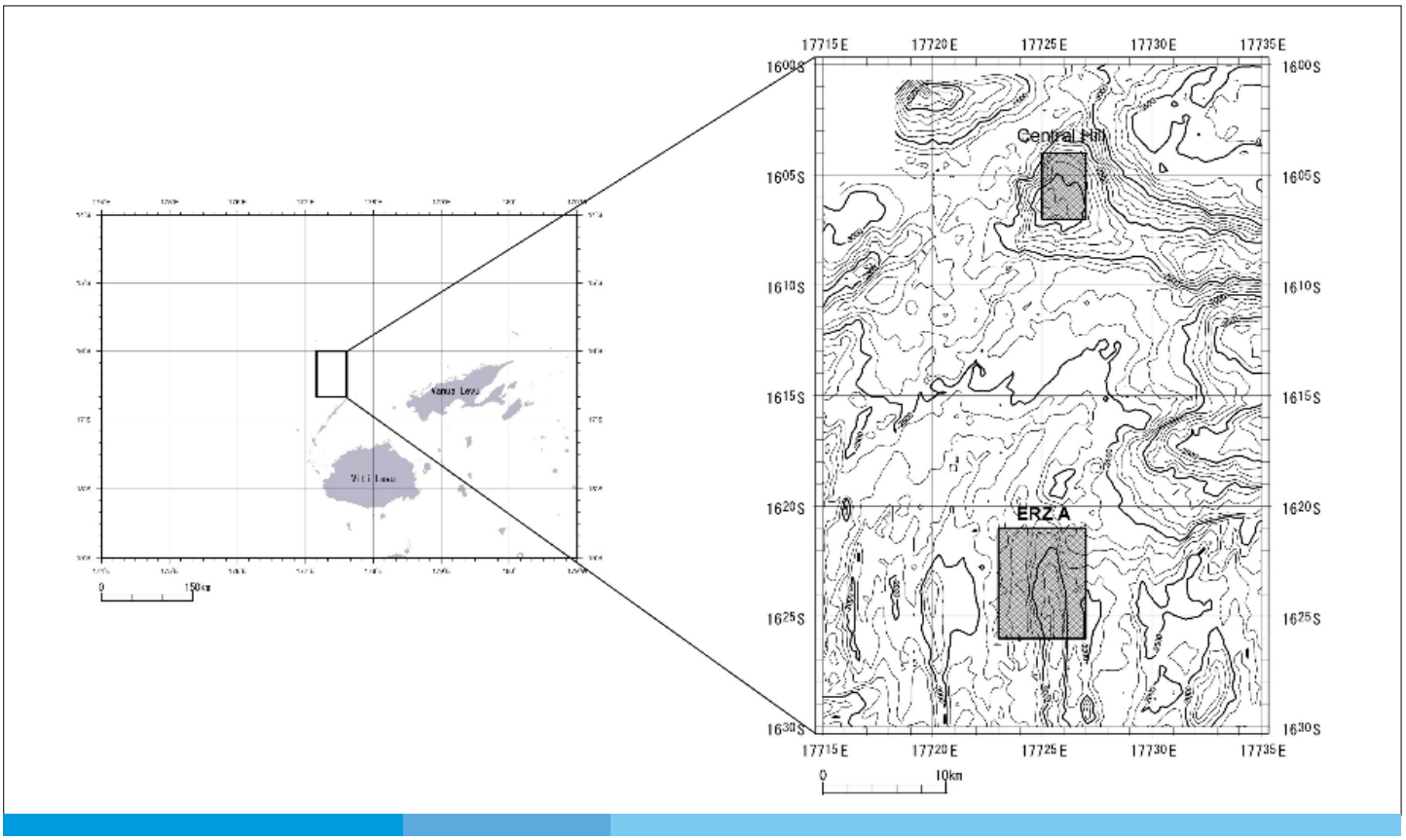


Figure 8. Location map of ERZ A and Central Hill.

The FDC survey suggested that sheet lava predominated in the area and pillow lava was locally distributed. Although no significant hydrothermal activity was recognised, reddish-brown altered rocks were identified in the eastern area. A dredge recovered an altered rock that contained fine-grained pyrite. A drilling operation obtained a 70-cm core, which was mainly composed of basalt, but no altered rock was recovered by drilling.

Prospecting in Central Hill

The Central Hill (Figure 8) is a knoll with summit depth of 1,800m, located at 16°06'S and 177°26'E, 35km north of ERZ A. The hill is approximately 700m high with gentle slopes. The FDC survey suggested that sheet lava was widely distributed in the area and was generally covered with muddy unconsolidated sediment.

The FDC survey revealed that huge quantities of shell fragments, which were considered to have belonged to a hydrothermal vent community, have accumulated in an area of 0.5km^2. A drilling operation collected black silt that contained pyrite and smelt of sulphur. Dredged samples include altered rocks and manganese oxide coatings were recognised on shell fragments and rocks.

2001 Survey

Based on the information obtained in 1999, the 2001 survey was concentrated on drilling program by Benthic Multi-coring System (BMS) and sampling by Large Corer (LC) and Multi Corer (MC) (Figure 9) in the area covering the SO99 Site and the western part of the Père Lachaise site, aiming at understanding the potential of hydrothermal mineralisation of the area. However, the topographic and magnetic surveys were conducted over the 1999 Area 1 survey site at the center of the NFB including the Triple Junction of the Central Spreading Ridge.

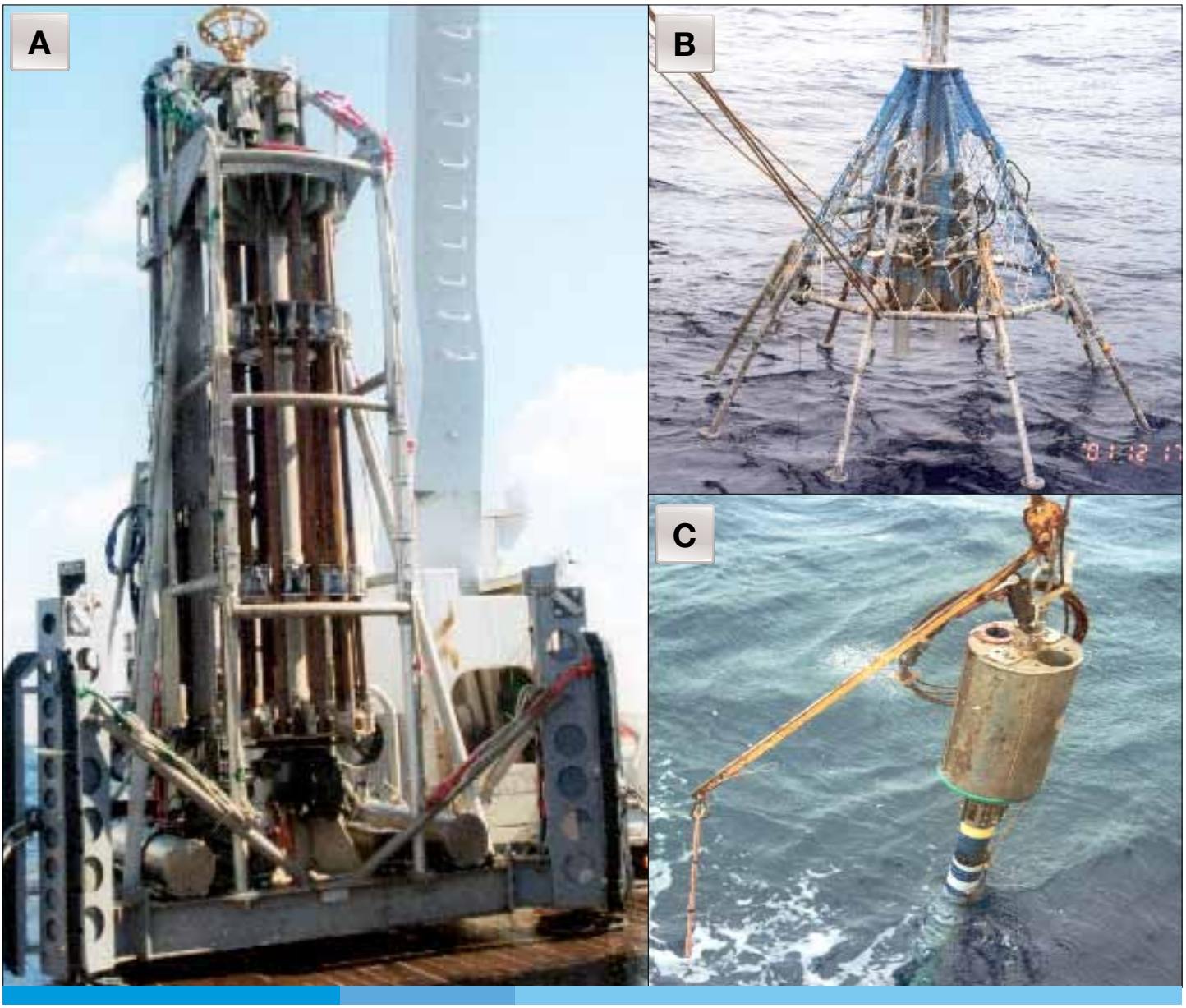


Figure 9. Main survey equipments: (A) Benthic Multi-coring System (BMS); (B) Multi Corer (MC); and (C) Large Corer (LC).

During the towing of BMS before and after the drilling of each hole, the seafloor observation was conducted by the high-resolution camera installed to the BMS. Based on the results of this observation together with 1999 FDC results, the search of new ore showings and the interpretation work of ore showings and geology of the area were conducted. Whenever drilling operations were hampered by bad weather, LC sampling obtaining the surface materials was conducted to understand the distribution of ore showings.

Results of the 2001 Survey

The distribution of the ore showings is shown in the geology map (Figure 10). The ore showing in the Triple Junction Area, typically, forms a hydrothermal mound rising 5m–10m high from the surrounding sea floor, and inactive chimneys are found standing on the mound (Figure 11). It was relatively easy to identify the hydrothermal mound by seafloor observation due to the reddish brown discoloring of the fragments of chimney and sulphide ore accumulated on the mound.

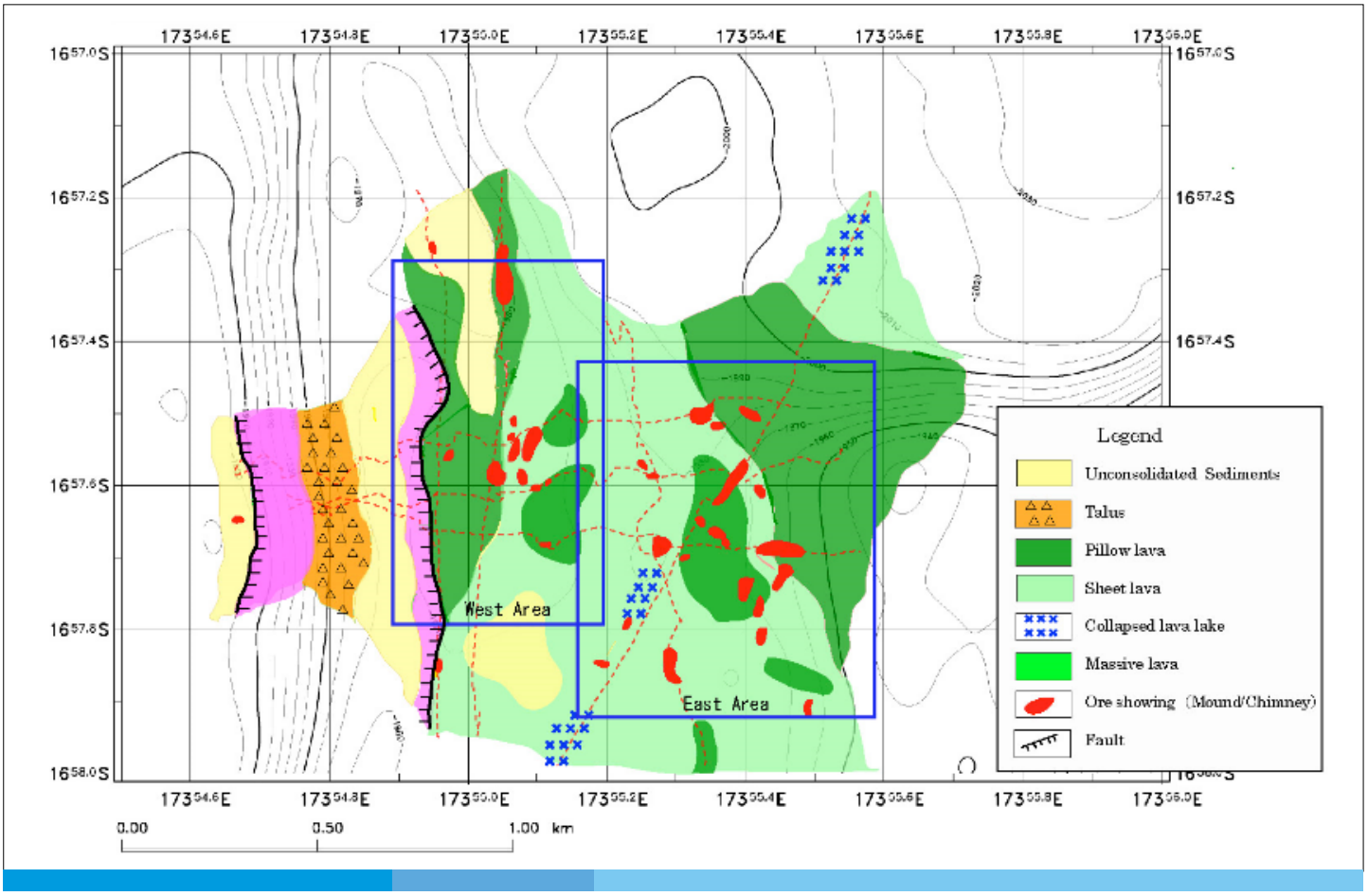


Figure 10. Geology map with ore showings of the Triple Junction Area.

The massive sulphides of the mound collected from the West Area show high variability in Copper (Cu) grade even at the same location. On the other hand, the East Area has recorded lower Copper values. Zinc (Zn), Gold (Au) and Silver (Ag) grades are high in the East Area samples. The mineral grades from each study area are tabulated below:

Study Area	Grade				
	Cu (%)	Pb (%)	Zn (%)	Au (g/t)	Ag (g/t)
West Area	1.0 – 17.1	0.01 – 0.14	0.16 – 1.69	0.15 – 4.53	4.6 – 90.8
East Area	1.16 – 5.38	–	0.22 – 8.17	1.00 – 2.93	37.0 – 210.0

These variations in assay results between the two areas are considered to be due to the fact that only mound samples were collected in the West Area whereas samples of the East Area consist mainly of chimney samples with some mound samples collected at shallow level.

The schematic model of the ore showing in the Triple Junction Area is shown in Figure 11. The relatively large mounds extending over an area approximately 100m in length, and rising 10m high from the surrounding seafloor occur in the Triple Junction Area. Chimneys of 3m–5m high stand on the mound and they are surrounded by fragments of chimney and sulphide ore.

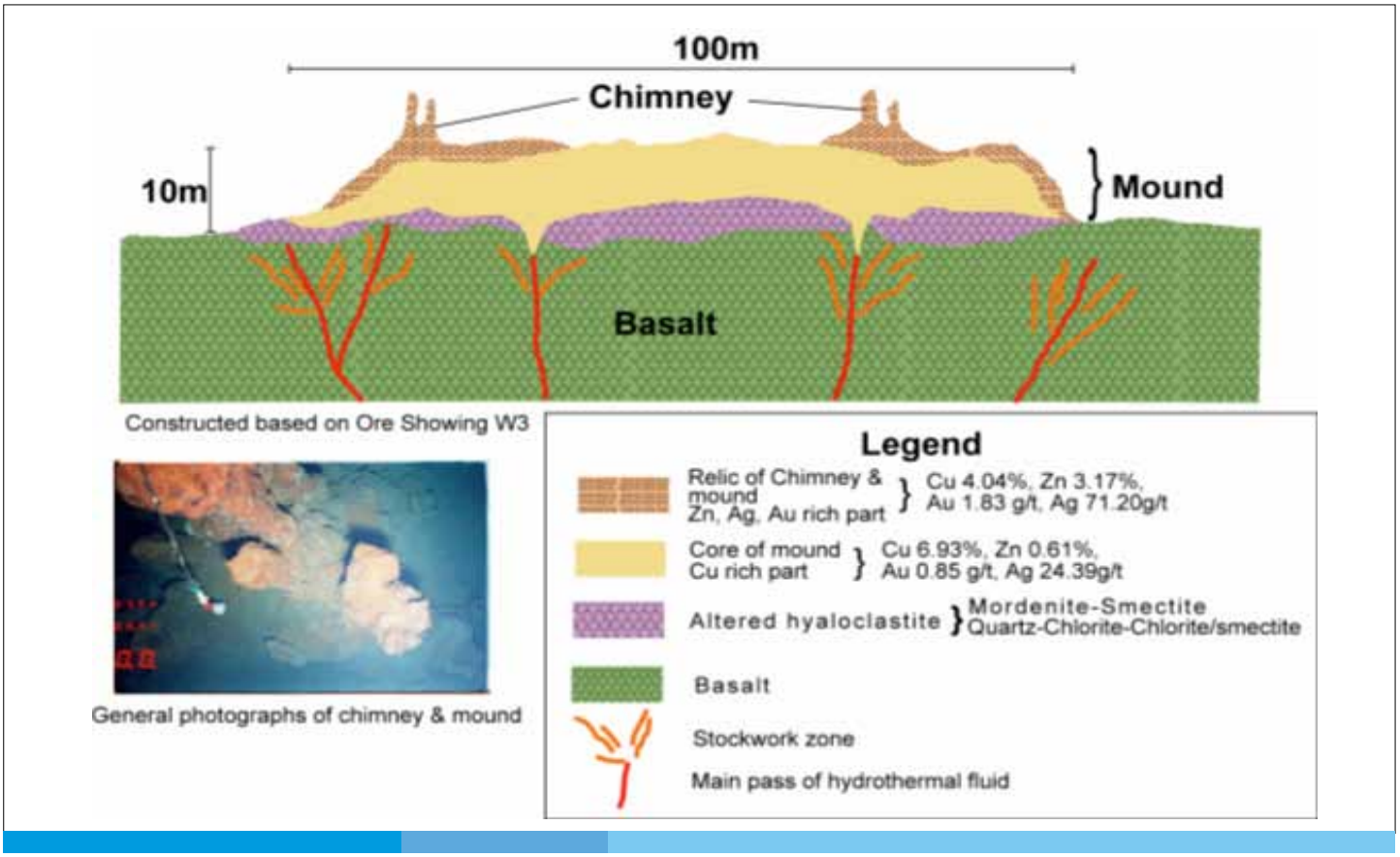


Figure 11. Schematic cross section of the ore showing with a photo of chimney and mound in the Triple Junction Area (MMAJ and JICA, 2002).

As observed from BMS camera and the results of drilling, it has an aerial extent of 100m x 30m and a thickness of 7m at Ore Showing W3. The observations of the seafloor by BMS and FDC suggest that there are at least seven mounds of similar size to ore showing W3 in the Triple Junction Area. The mineral grades of the chimney and the mound are also shown in the legend of Figure 11.

The survey suggests that more than seven ore showings, with mineral resource estimates of 70,000t at the grade of Cu 6.93%, Zn 0.61%, Au 0.85% and Ag 24.39%, are expected to exist in the Triple Junction Area. The average specific gravity of the mineralised materials is 3.5g/cm^3.

2004 Survey

The purposes of the 2004 survey were to assess the potential of seafloor hydrothermal mineralisation based on the results of the 1999 survey, and to understand environmental characteristics in Central Hill and ERZ A (Figure 12).

Results of the 2004 Survey

The survey of Central Hill resulted in the discovery of an active hydrothermal zone, consisting of bluish green and yellow discoloured zone accompanied by organisms characterising hydrothermal activity, distributed over the top of the host rocks. The active hydrothermal zone, north-south extension of 180m and 30m wide, occurs on the west facing slope of the north declining ridge (Figure 12).

Thin coatings of ferro-oxides were observed on the surface of rock samples, however, mounds and chimneys formed by sulphide mineralisation were not found. Temperature anomaly of seawater and distribution of hydrothermal activity related shell fragments were observed in the area surrounding the active hydrothermal zone, suggesting that the zone of hydrothermal activity was centered in the ridge and the hydrothermal fluids were distributed in a much wider area.

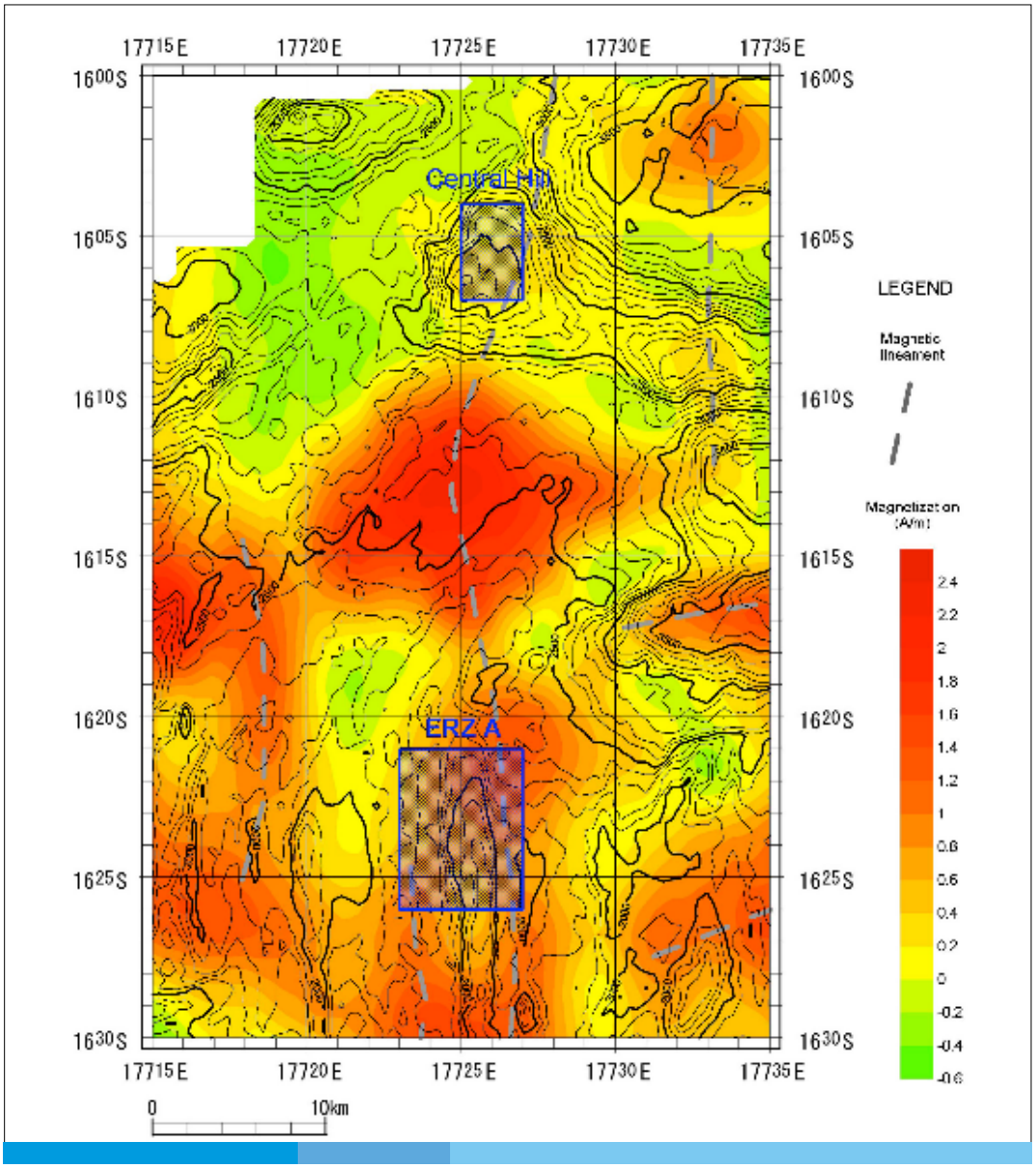


Figure 12. Bathymetry and magnetic structure of the 2004 survey area.

The ERZ A is overlain by basaltic lavas erupted along the north-south trending extensional relay zone of the NFFZ. Although yellow and light brown discoloured zone with north-south extension of approximately 250m was identified overlapped by temperature anomaly of seawater along the boundary of steep slop and flat terrace, neither organisms characterising hydrothermal activity nor sulphide mineralisation was found.

Altered and discoloured rocks of Central Hill were selected for chemical analyses to characterise the alteration and possible mineralisation of the area. The analysis results were not encouraging as most grades of Cu, Zn, Pb, Au and Ag were below detection limits.

Although the geology and tectonics of Central Hill and ERZ A appear to be different, the north-south trending magnetic lineament suggests the existence of high magnetic body connecting these two areas that are 35km apart.

Prospectivity

The prospecting results of the North Fiji Basin to date suggest that the areas surrounding the Triple Junction have significant potential for economic SMS deposits. Although the scale of the ore body is small compared to on-land copper deposits, Cu grade is higher compared to the Cu grade of on-land mines. Further, the NFB has the potential for additional discoveries of ore showings particularly in the areas surrounding the Triple Junction, hence detailed and systematic investigations should be encouraged.