Chapter 4 Geology

4 - 1 General Geology

The Federation of Micronesia (FMS) is located to the north of the equator in the West Pacific. Most of the islands belong to the Caroline Islands which are widely distributed in the east-west direction, and the westernmost islands belong to the Yap Islands. The surveyed area is in the vicinity of the Caroline Islands. These islands is contiguous to the Yap Islands to the west across the Yap Trench, and to the Mariana Islands on the northwestern side across the Mariana Trench. The Marshall Islands lie to the northeast to east across the East Mariana Trough, and the Solomon, Bismark, New Guinea and other islands are separated by Ontong Java Plateau on the southeastern side and East and West Caroline Basin on the south to southwestern side.

The term "Caroline Island waters" in this report will indicate the marine area in the vicinity of the islands existing in the east-west direction from the Kosrae Island in the east to the Ulithi Atoll in the west. The geologic structure expressed in the seafloor topography differs significantly to the east and west of approximately 150° E.

Caroline Ridge and Sorol Trough occur with a WNW-ESE trending axis from 140° to 145° E in western Caroline Island waters, and some seamounts occur over them. On the eastern side from 145° to 150° E, the extension of the Sorol Trough becomes obscure, but the Caroline Ridge extends in the east-west direction with many atolls on its summit.

On the other hand to the east of 150° E, the oceanic islands and seamounts of the eastern Carolines are arranged independently in the NW-SE～WNW-ESE direction as seen in the island chains of Namonuito Atoll-Truk Islands-Nomoi Islands, Minto Reef-Oroluk Atoll-Ngatik Atoll, and Phonpei-Kusi.

Keating et al., (1984) suggested that these islands are aligned in the order of age with 13Ma for Truk Islands in the west, through 6Ma of Phonpei to 1.2Ma of Kusi in the east and that there is a hot spot to the east of Kusi. Also the results of our survey carried out last year show that the age of the basalt of the seamounts in the zone from the eastern Caroline Islands to the eastern part of the Caroline Ridge is all younger than 13Ma with the exception of MC08 and MC10 in the northern side. These facts indicate that the age of the several island chains aligned in the WNW-ESE or NW-SE direction in the zone from eastern Caroline Ridge to eastern Caroline Islands have ages 13～1Ma and they become younger towards the ESE or SE direction. The older Cretaceous seamounts, on the other hand, are located to the north of the Caroline Ridge and eastern Caroline Islands.

The volcanic rocks which constitute the seamounts are generally different from the mid-oceanic ridge basalt (MORB) and are called oceanic island basalt (OIB). In the present survey area, the chemical composition of basalt varies with area similar to the age because of various geologic structure and seamount morphology.

The seamounts are comprised of basalt and clastic basalt, and are sometimes accompanied by limestone and sedimentary rocks. The surface of the rocks exposed on the seafloor, with the exception of parts in shallow waters, are almost always covered by ferromanganese oxides, and these are called manganese crusts. The flat summit of guyots are covered by thick unconsolidated foraminiferal sand with the exception of the peripheral parts, small hills, and slopes. On the slopes of these seamounts, secondary sediments are considered to be predominant due to denudation and water flow, while foraminiferal sand is deposited on terraces and gentle slopes.

During the present year survey, four areas; namely two areas near the northeastern end of the eastern EEZ of the Caroline Islands and two areas to the north of the Caroline Ridge were investigated.

The target of the survey is the manganese crusts which cover the bedrock and are exposed on the seafloor. These crusts are ferromanganese oxides similar in nature to the manganese nodules which occur on the deep ocean floor. The significant characteristics of the manganese crusts are that they contain 0.5～1.5wt% of cobalt which is considerably higher than the average 0.2wt% content of the nodules. Thus they are sometimes called cobalt-rich manganese crusts. The relatively high content of platinum (0.1～0.3ppm) is also a notable feature of these crusts. The thickness of these crusts varies significantly by the topography, geology, water depth, morphology and location of the seamounts, and other factors. Their average thickness in the study area is about 2cm with a maximum exceeding 10cm. The results of the investigation on the geology, petrology and manganese crusts will be presented in the appropriate sections of this report.

4 - 2 Results of Sampling

Sampling of cobalt-rich crusts, rocks, and unconsolidated sediments was carried out in each area using; chain bag dredge (CB), arm dredge (AD), and large corer (LC). Sampling was carried out at 49 sites in the four areas of MC11～13 and MS13. Dredging was done at 41 sites and large corer was used at eight sites. Also in MC02 area dredging was done at four sites and large coring at four, a total of eight sites. But the survey of MC02 was directed at hydrothermal deposits and will not be included in this section.

In this chapter, description of rocks and unconsolidated sediments collected by dredging and coring will be reported together with the outline of the collected samples of each area.

Sampling point map are shown in Fig.4-2-1(1)～(4) and summary of geology of each area are shown Table 4-2-1(1),(2). Also, rock summary of sampling results are shown in Appendix Table 1(1),(2).

4 - 3 Collected Samples

(1) Rocks

The rock samples collected during the present cruise are; basalt, limestones including phosphatized rocks, tuffaceous rocks, hyaloclastite, mudstone, chert, and pumice. The outline of geology of each area and seamount is laid out in Table 4-2-1(1),(2). Rock samples' lists from eac area are shown in Appendix Table 2(1) ～(4). Nine basalt samples, one each of hyaloclastite and tuff breccia were studied by thin section microscopy. and photographs of representative rock samples ond their microscopic phtographs are laid out in Figure 4-3-1(1)～(5). The Result of microscopic obsevation is shown in Table 4-3-1 and the notes of microscopic observation of thin section are shown in Appendix Table 3. The results of microscopic study together with microphotographs are appended. The characteristics of these rocks are described below.

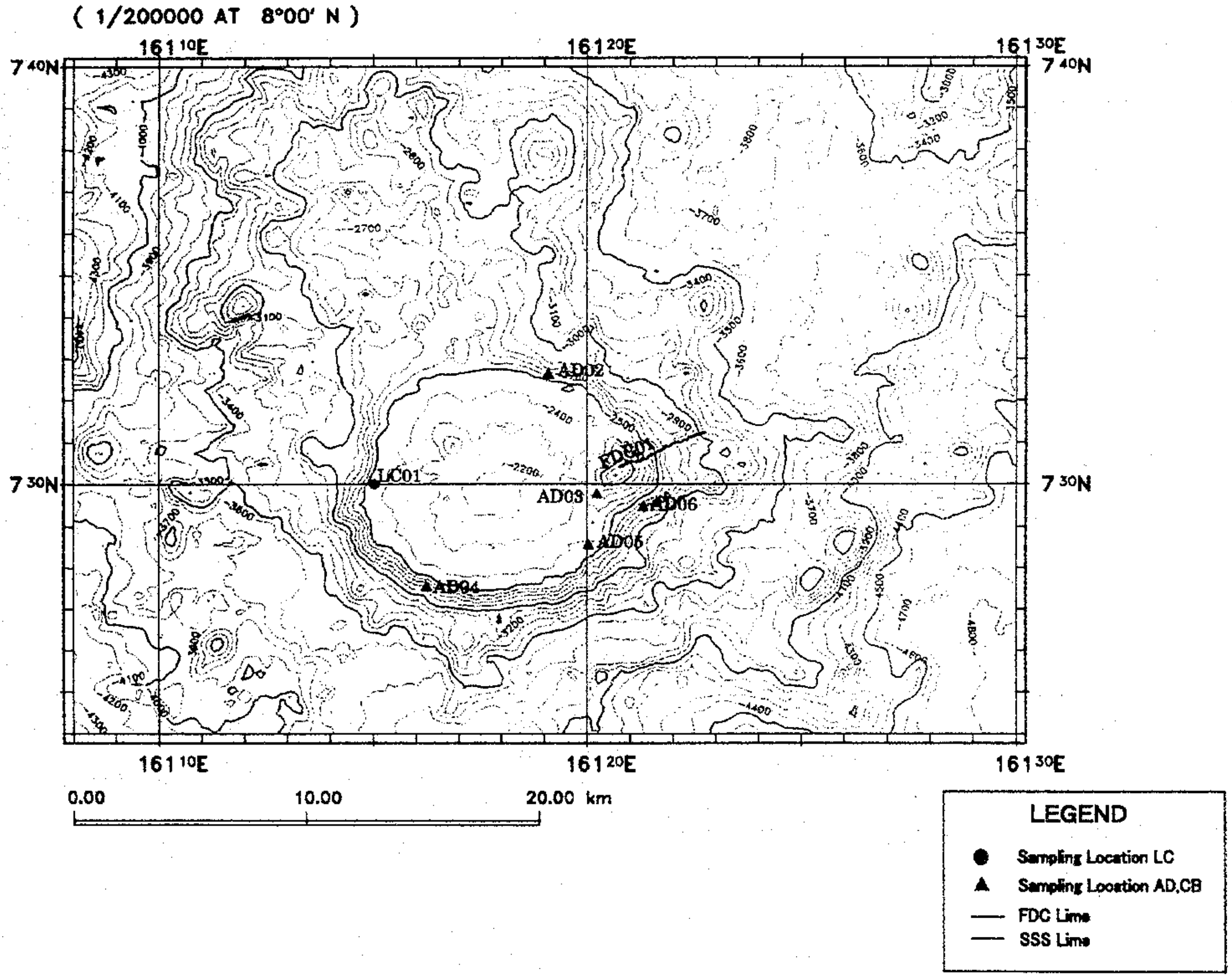
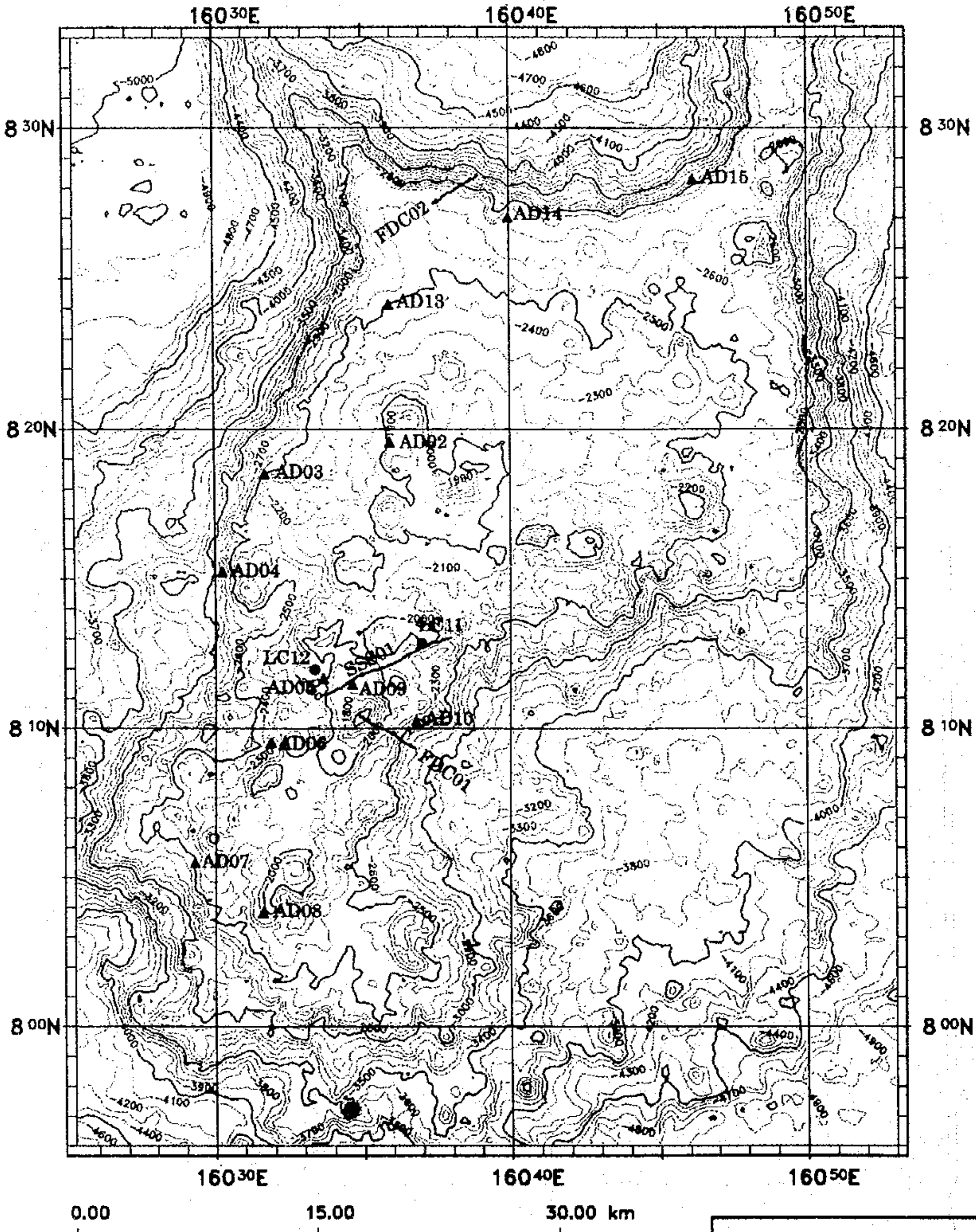


Fig. 4-2-1(1) Location map of sampling sites (MC11 area)

(1/300000 AT 8°00′ N)



LEGEND

- ● Sampling Location LC
- ▲ Sampling Location AD,CB
- —— FDC Lime
- —— SSS Lime

Fig. 4-2-1(2) Location map of esites (MS13 area)

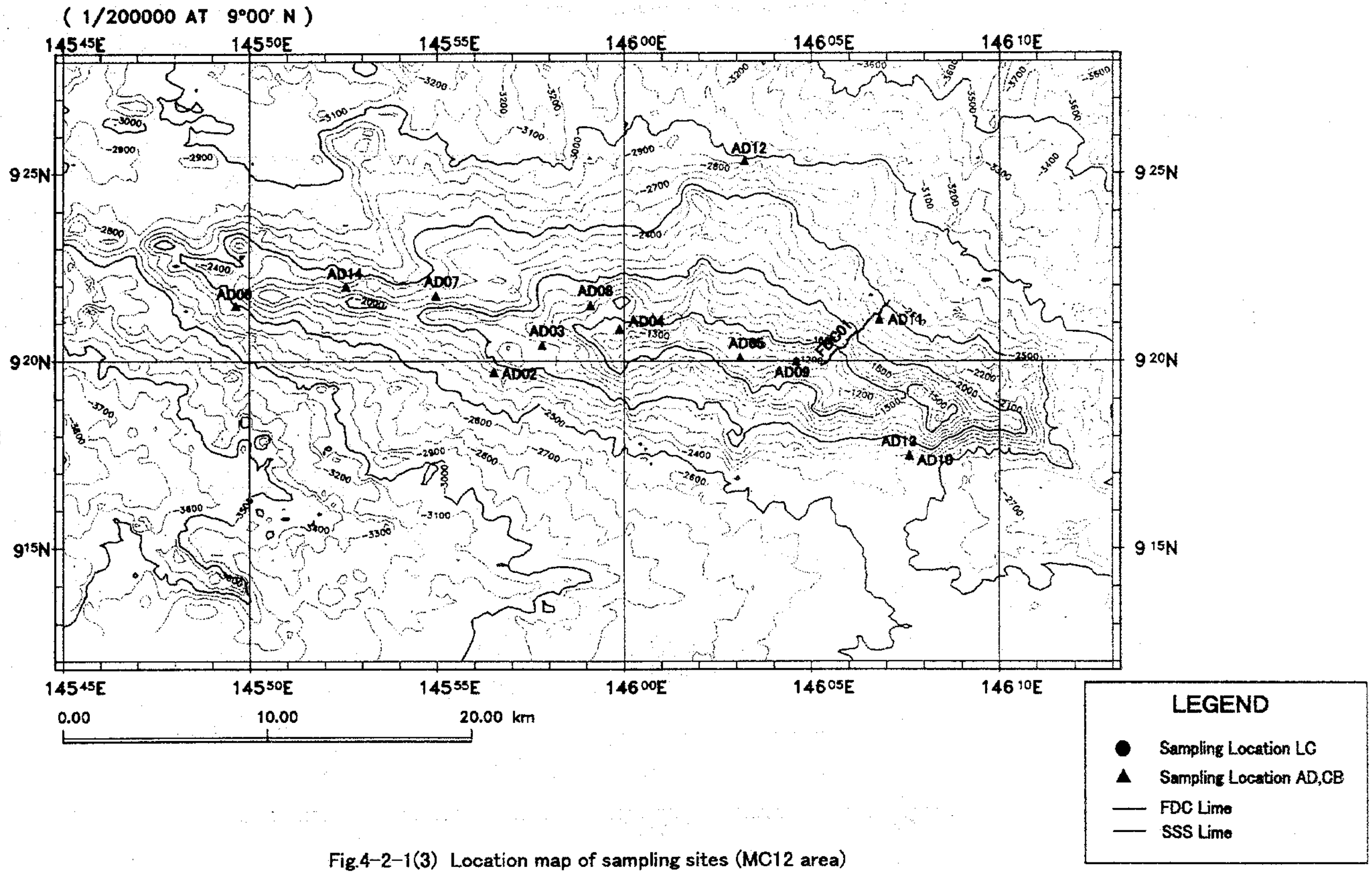


Fig.4-2-1(3) Location map of sampling sites (MC12 area)

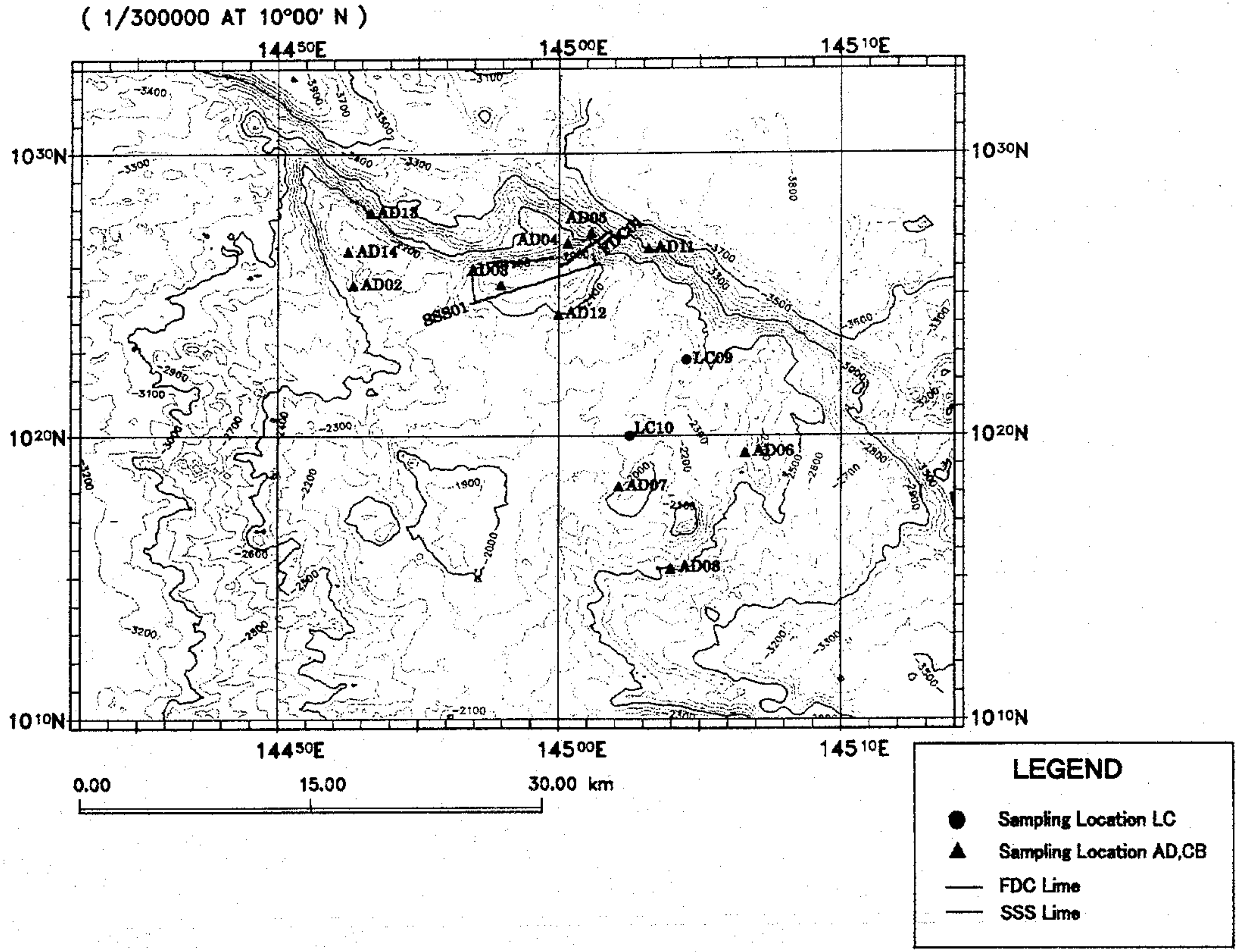


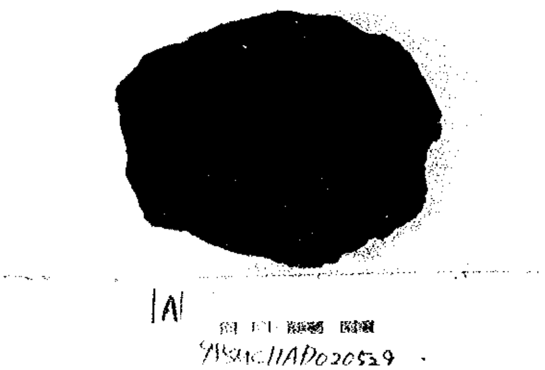
Fig. 4-2-1 (4) Location map of sampling sites (MC13 area)

Table 4-2-1(1) Summary of Geology of Each Area

Area	Seamount topography (water depth)	Topographic division	Basement geology	Basalts	Limestones	Tuffs	Sediments & exposures	Crust summary
(Eastern Sea)								
MC11	Guyot (dome summit) Small guyot, oval shaped about 23km long axis, 13km short axis. Covered by sediments except pinnacles, gentle dome rising from periphery to center. N slope gentle, terrace topography developed from middle slope. S slope steep from upper to middle part. (Shallowest : 1,777m) (Summit : <2,500m)	Summit.	Basalt and foraminiferal limestone	Coarse grained, compact, pyroxene phenocrysts clearly observed.	Pelitic, compact, but fragile. No pebbles.		Summit generally covered by thick sediments, but bedrock exposures near pinnacles and in parts of periphery.	Crusts exceeding 20mm collected near pinnacles in E. Maximum 55mm.
		Upper slope.	Basalt and foraminiferal limestone	Two types ; fine grained, compact and porous. Parts of vesicles filled by opal and zeolite. Clear pyroxene and plagioclase phenocrysts generally observed.	Contain subangular basalt pebbles. Matrix fine grained, compact, but fragile.		Generally covered by unconsolidated sediments, but thin and bedrock exposures on uppermost E slope.	Thick crusts on uppermost E slope, several tens of mm crusts collected, maximum 55mm.
(Eastern Sea)								
MC13	Guyot (ragged seamount) Pinnacles scattered, topography rugged on summit. Summit somewhat rectangular with NNE-SSW long axis about 50km, short axis about 25km. Topography changes in complex manner from N to S. Inclination of summit somewhat steeper than normal guyots. Slope gentle, except ridges on NE and NW end, particularly thick unconsolidated sediments cover terraces on NE side forming gentle slope. (Shallowest : 1,387m) (Summit : <2,700m)	Summit.	Basalt, foraminiferal calcareous conglomerate, tuff.	Mixture of fine-grained, compact and porous rocks. Aphyric, phenocrysts, if any, minute and not clear. Acicular plagioclase collected rarely.	Foraminiferal calcareous conglomerate. Subrounded~subangular basalt pebbles. Same samples without pebbles. Matrix contains micronodules, pelitic, fragile, generally not phosphatized.	Collected at foot of pinnacles somewhat N of summit center. Fine grained, compact, strongly weathered, fragile.	Pinnacles sporadic on summit exposed. Sediments thin on depressions between pinnacles.	Crusts exceeding 100m collected near pinnacles. Thick cobble crusts scattered on depressions between pinnacles. Maximum 160mm thick.
		Upper slope.	Basalt, foraminiferal limestone, tuff breccia.	Mixture of fine -grained, compact and porous rocks. Almost all aphyric, acicular plagioclase phenocrysts occur rarely.	Foraminiferal limestone. Pelitic fragile. Contain micronodules. Phosphatization almost nil.	Collected W slope. Contain basalt granules. Matrix fine grained, compact, weathering notable, partly argillized.	Generally covered by thick sediments.	Crust distribution in exposures confirmed by FDC. 35mm crust collected at W uppermost slope (correspond to summit periphery).
(Western Sea)								
MC13	Oceanic plateau seamount Topographic high on oceanic plateau. Western and southern slope extensive and gentle. Morphologic axis NW-SE, steep slope parallel to this axis in NE. Topographic high observed in central part of summit, relatively smooth seafloor despite undulation because of thick sediments. (Shallowest : 1,656m) (Summit : <2,500m)	Summit	Basalt, limestones, mudstone, chert, tuff	Mainly fine grained, aphyric. Some with minute vesicles filled by nephrite. Some below 2,100m depth have minute pyroxene phenocrysts.	Two types of foraminiferal limestone, coarse grained but compact and hard, and pelitic and soft merely cementing pebbles. Basalt pebbles flat above 1,750m depth and angular below. Nodules cemented around basalt nuclei were collected. Unexpectedly extremely fine-grained limestone with clear bedding, white, very compact samples were collected from pinnacles on summit.	Relatively fresh, compact hard samples collected near summit pinnacles. Porous. Somewhat coarse-grained tuff containing onion-structured weathered tuff granules collected from summit away from pinnacles.	Summit covered by sediments on the whale, but bedrock exposed near pinnacles at northern end and from northern to eastern periphery (corresponding to uppermost slope).	Crusts several tens of mm collected mainly from eastern periphery, 8mm crusts from foot of eastern pinnacles. Thick cobble crusts collected from eastern and northern periphery. 140mm crust collected from foot of northern pinnacle and 105mm from foot of eastern pinnacle.
		Upper slope.	Basalt, mudstone, tuff.	Fine grained, compact. 2~7mm irregular phenocrysts. Fresh minute augite observed.		Porous somewhat coarse-grained tuff containing green onion-type weathered tuff granules collected.	Seamount, as a whole, covered by sediments, bedrock exposures observed on steep N and E slope.	30mm thick crust collected from N slope.

Table 4-2-1(2) Summary of Geology of Each Area

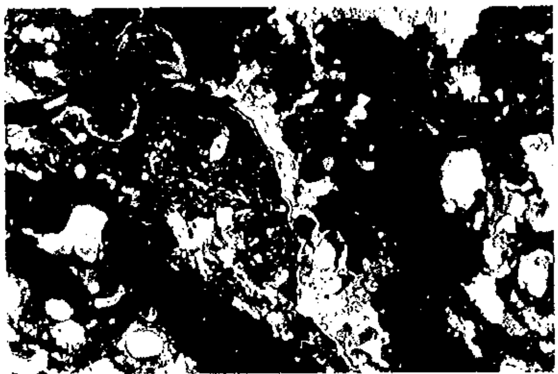
(Western Sea) MC12	Ridge seamount. Oceanic ridge topography without flat summit. 60km axis in approximately E-W direction, widest base about 20km. Summit about 18km long, 2km wide coral reef. Summit upper slope continuously steep, becomes gentle from middle slope downward. Seafloor very smooth from W to S side of seamount. (Shallowest : 1,141m) Summit : <1,500m)	Summit.	Reefal limestone and foraminiferal limestone.		Reefal limestone coarse grained and fragile. Contain biological fragments (corals, shells). Foraminiferal limestone somewhat coarse grained and soft.		Generally bedrock exposed, sediments observed only in parts of valleys.	15～20mm crusts and cobble crusts collected.
		Upper slope.	basalt and tuff.	Aphyric, porous.		Porous tuff. Subrounded basalt pebbles observed. Matrix strongly weathered and fragile.	Generally bedrock exposed, sediments observed only in parts of southern slope of valleys.	Crusts exceeding 30mm collected. 70mm, 150mm cobble crust collected from W ridge. 40mm cobble crust collected from E ridge.
		Middle slope	Basalt, foraminiferal calcareous conglomerate, tuff, and mudstone.	Mixture of fine-grained, compact, and porous rocks. All aphyric. Porous dominant above 2,250m water depth, fine grained compact below.	Foraminiferal calcareous conglomerate, Angular basalt pebbles. Matrix pelitic, soft, barely cementing pebbles. Reefal limestone pebbles collected.	Pumiceous tuff. Some samples contain basalt granules. Generally weathered, fragile. Hyaloclast-like pyroclastic rocks collected.	Bedrock generally exposed, sediments observed only on valleys in the S slope and parts of gentle slope.	Crusts thick on W ridge. 180mm and 19mm collected. Also 190mm crust collected at boundary with lower slope. 20～30mm crust collected at E ridge.
		Lower slope	Basalt, tuff, mudstone.	Aphyric, mixture of porous and fine-grained, compact rocks.		Porous, abundant pumice contained.	Generally covered by unconsolidated sediments, but thickness uneven, partly thin and bedrock exposed.	190mm crust collected at boundary of W ridge and middle slope.
(Western Sea) MC13	Oceanic plateau seamount Topographic high on oceanic plateau. Western and southern slope extensive and gentle. Morphologic axis NW-SE, steep slope parallel to this axis in NE. Topographic high observed in central part of summit, relatively smooth seafloor despite undulation because of thick sediments. (Shallowest : 1,656m) (Summit : <2,500m)	Summit	Basalt, limestones, mudstone, chert, tuff.	Mainly fine grained, aphyric. Some with minute vesicles filled by nephrite. Some below 2,100m depth have minute pyroxene phenocrysts.	Two types of foraminiferal limestone, coarse grained but compact and hard, and pelitic and soft merely cementing pebbles. Basalt pebbles flat above 1,750m depth and angular below. Nodules cemented around basalt nuclei were collected. Unexpectedly extremely fine-grained limestone with clear bedding, white, very compact samples were collected from pinnacles on summit.	Relatively fresh, compact hard samples collected near summit pinnacles. Porous, Somewhat coarse-grained tuff containing onion-structured weathered tuff granules collected from summit away from pinnacles.	Summit covered by sediments on the whale, but bedrock exposed near pinnacles at northern end and from northern to eastern periphery (corresponding to uppermost slope).	Crusts several tens of mm collected mainly from eastern periphery. 8mm crusts from foot of eastern pinnacles. Thick cobble crusts collected from eastern and northern periphery. 140mm crust collected from foot of northern pinnacle and 105mm from foot of eastern pinnacle.
		Upper slope.	Basalt, mudstone, tuff.	Fine grained, compact. 2～7mm irregular phenocrysts. Fresh minute augite observed.		Porous somewhat coarse-grained tuff containing green onion-type weathered tuff granules collected.	Seamount, as a whole, covered by sediments, bedrock exposures observed on steep N and E slope.	30mm thick crust collected from N slope.



Open Nicol

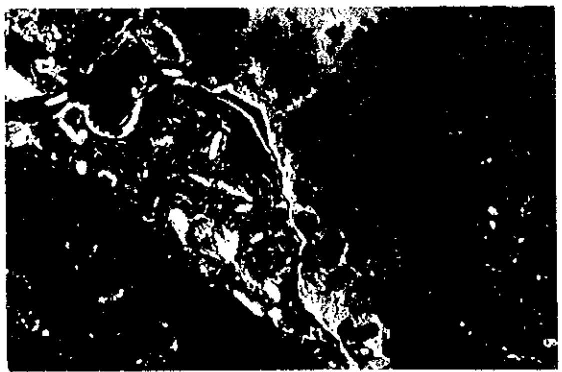
A. 98SMC11AD02-A
Altered pyroxene olivine basalt
Phyric texture, phenocryst plagioclasw show strong flow structure.

Crossed Nicols



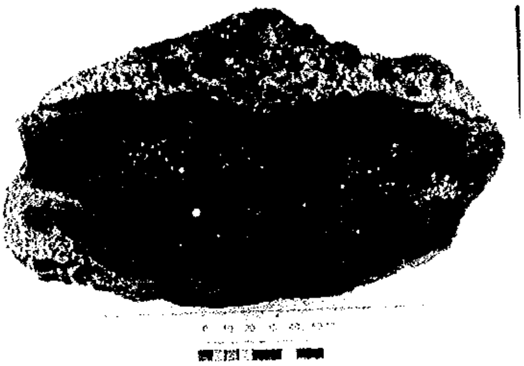
Open Nicol

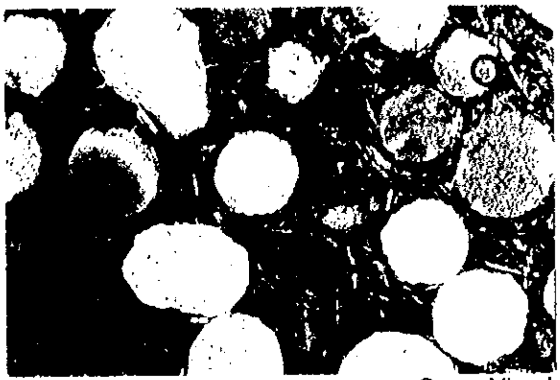
B. 98SMC11AD06-E
Vitreous porou basalt
Phyric, porous matrix., plagioclace and olivine micro-phyric texture



Crossed Nicols

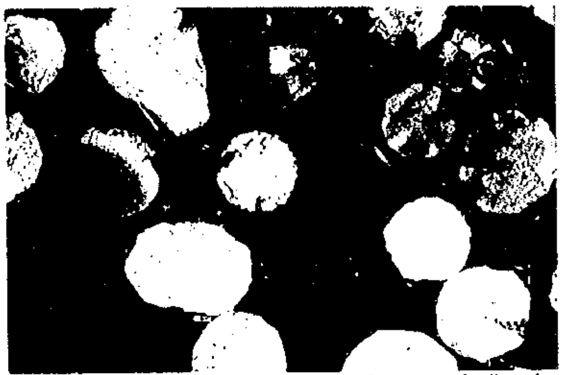
Fig. 4-3-1 (1) Photographs of typical rock samples



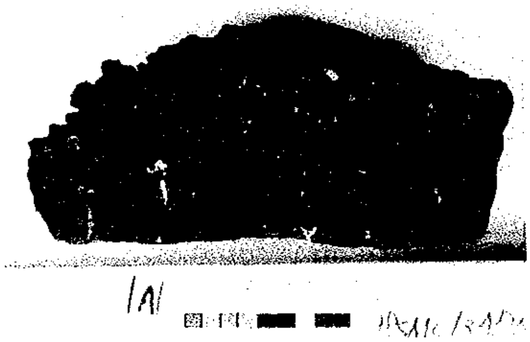


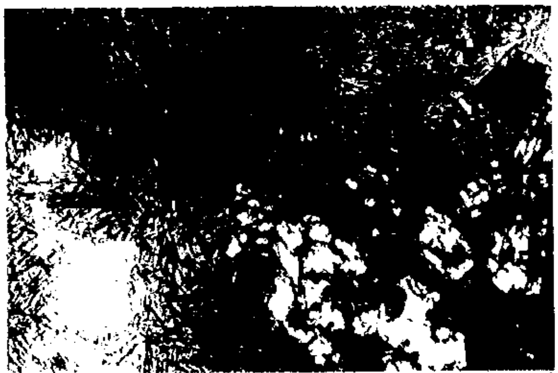
Open Nicol

C. 98SMC12AD13-E
Porous aphyric basalt
Calcite-brown carbonate minerals fills voids and show spherulitic ～ amygdaloidal texture.



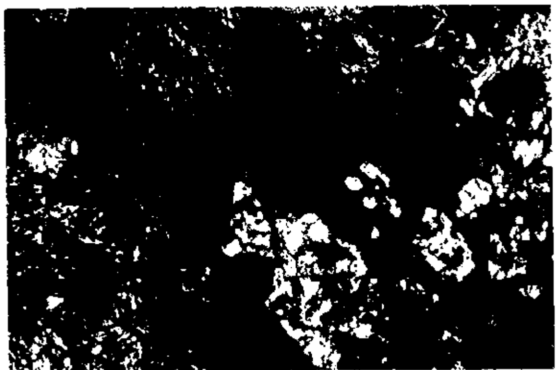
Crossed Nicols





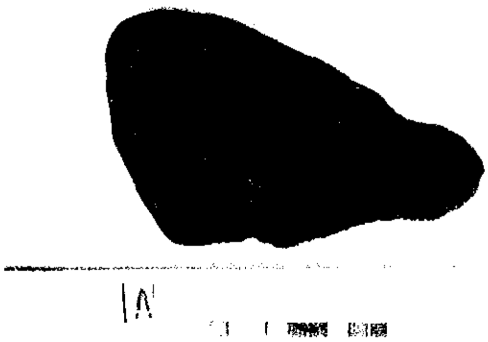
Open Nicol

D. 98SMC13AD02-A
Vitreous microphyric altered basalt
Divitrification and argillization observed in volcanic grass matrix.

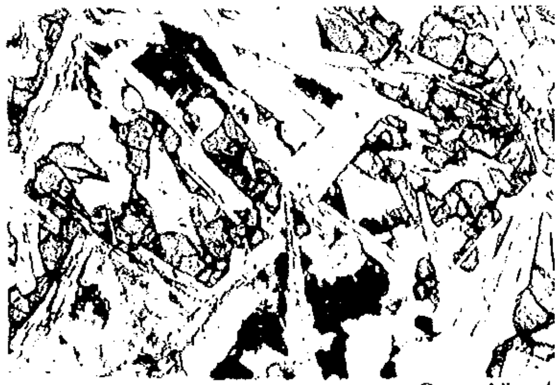


Crossed Nicols

Fig. 4-3-1 (2) Photographs of typical rock samples



E. 98SMC13AD04-A
Dolerite
Coarse grained, ophitic texture characteristic of dolerite.



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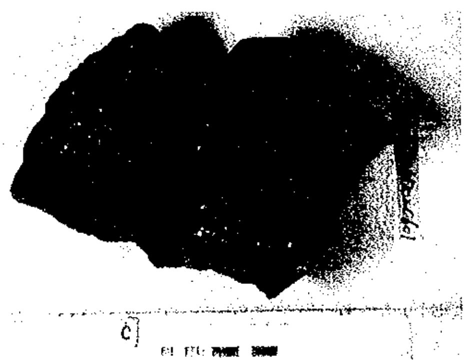
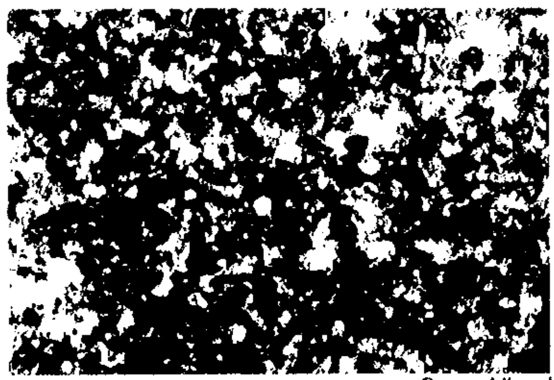
Crossed Nicols



F. 98SMS13AD02-C
Hyaloclastite
Coarse grained ~ pisolitic.
Calcite vein developed network -like appearance.



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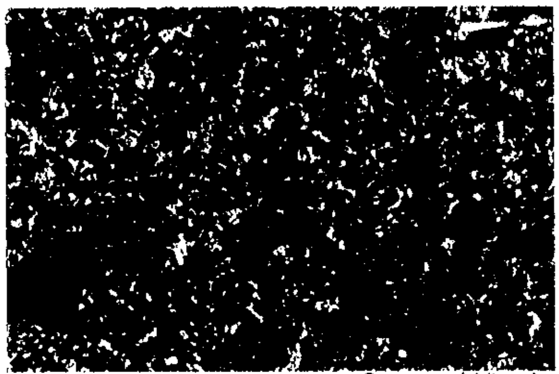
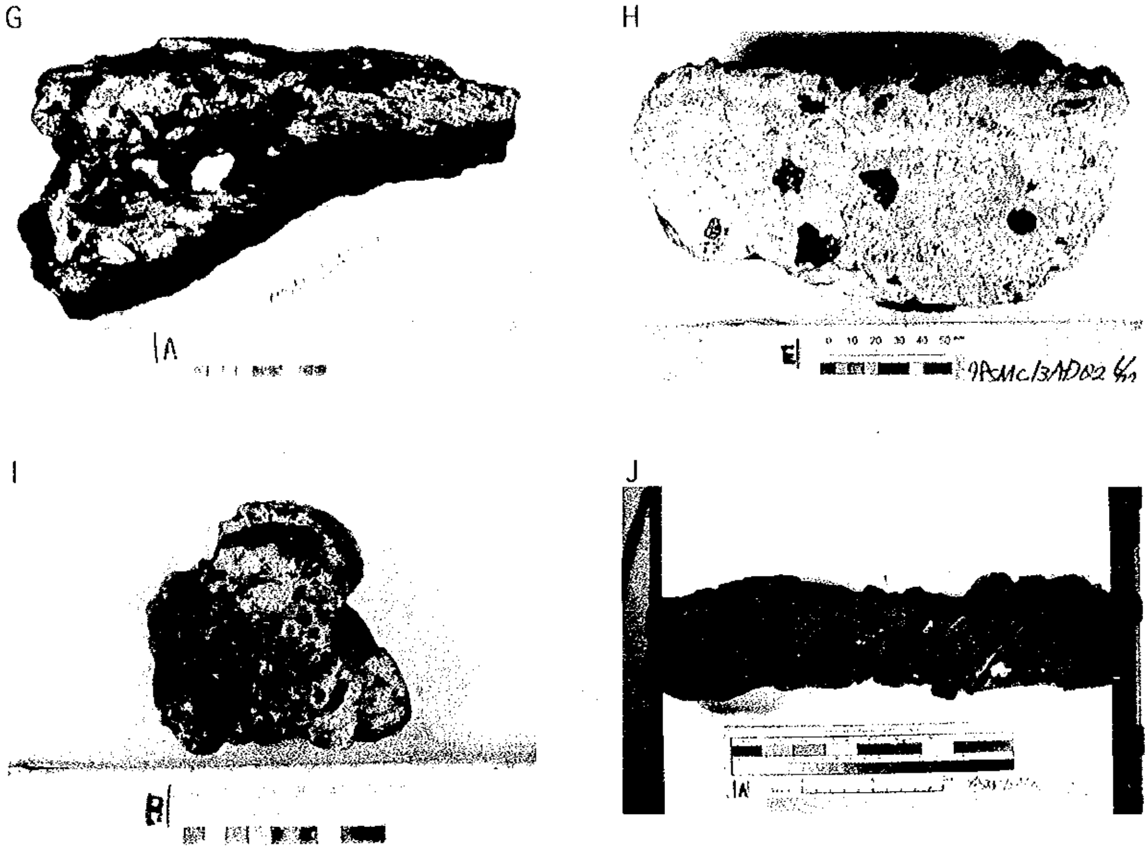


Crossed Nicols

Fig. 4-3-1 (3) Photographs of typical rock samples



G. 98SMC12AD09-A
Coral limestone
Porous, cotains fragments of coral and shallow sea lives.

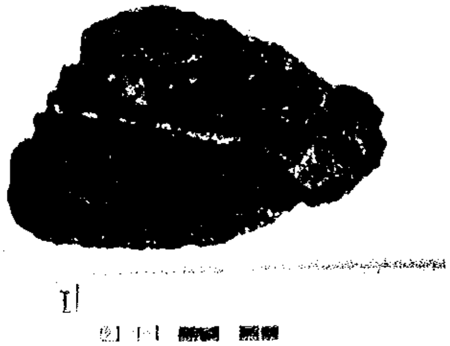
H. 98SMC13AD02-E
Globigerina carbonate conglomerate
Contains basalt gravel coated with mamganees crust.

I. 98SMS13AD14-B
Globigerina limestome
Sand pipes (φ some mm) observed.

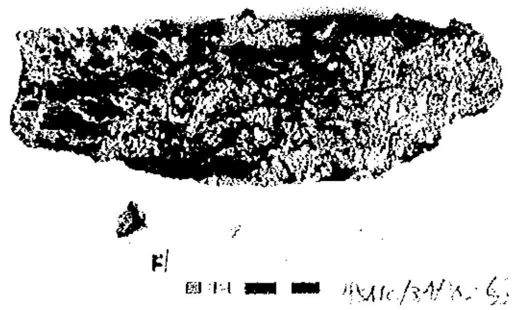
J. 98SMC12AD06-A
Mudstone
Hard, including calcaleaous ooze.

Fig. 4-3-1(4) Photographs of typical rock samples

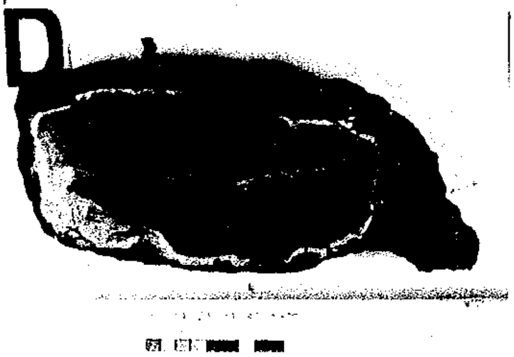
K



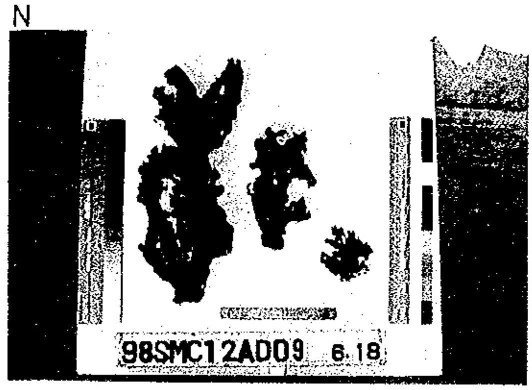
L



M



N



K. 98SMC13AD06-I
Taff
Weathered and frangile.

L. 98SMC13AD04-B
Tuff breccia
Contains basalt breccia and pamice.

M. 98SMC13AD12-D
Chart
Chart lamina observed distinctly.

N. 98SMC12AD09-C
Coral
coated with mamganees crust.

Fig. 4-3-1 (5) Photographs of typical rock samples

Table 4-3-1 Results of microscopic observation for rock thin sections

Sampling location No.	Sample code	Sampl e No.	Rock	Structure	Penocryst content	Alteration	Phenocryst minerals							Matrix					Altered minerals					Note	Description (unaided eyes)
							Plagioclase	Olivinee	Augite	Orthopyroxene	Clinopyroxene	Opaque mineral	Spinel	Plagioclase	Olivinee	Clinopyroxene	Opaque mineral	Volcanic glass	Smectite	Iddingsite	Silica minerals	Zeolite	Chporite		
98S MC11AD02	A	T01	Altered pyroxene olivine basalt	Phyric texture Phenocryst plagioclasw show strong flow structure. Vitreous matrix.	30～35%	intermediate	◎	○			○							◎	◎	○				Volcanic grass of matrix and phrnocryst olivine altered to smectite and iddingsite.	Raddish brown. Phyric texture.
98S MC11AD06	E	T01	Vitreous porou basalt	Phyric, porous matrix. Matrix plagioclace show weak flow structure.	40%	little weak	◎	×				◎		+				○		+				Mostly devitrification of matrix and iddingsitization of olivine (pseudomorph). Plagioclase phenocrysts corroded vermicularly.	Brown, porous basalt with blackish brown crust on surface. Spherulitic~ amygdaloidal phenocrysts
98S MC12AD13	E	T02	Porous aphyric basalt	Cryptocrysalline. Calcite-brown carbonate minerals fills voids and show spherulitic~ amygdaloidal texture.	45%	little weak								◎				◎						Alteration not significant except devitrification of matrix. Alteration minor.	Greenishi-brown gray, porous, spherulitic ~ amygdaloidal texture developed. Spherulites are white ~ brown material filling voids.
98S MC13AD02	A	T01	Vitreous microphyric altered basalt	Microphyric texture, vitreous matrix, crystallites notable.	5%	intermediate	×		+								○	◎	+					Alteration weak. Weak divitrification observed in volcanic grass matrix.	Yellow brown basalt. Clayey, fragile, microphyric, contain vein-pipe white clayey parts.
98S MC13AD04	A	T01	Dolerite	Holocrystalline, coarse grained,ophitic texture characteristic of dolerite	65%	little weak	◎			◎				○				×						Devitrification of volcanic grass observed.	Yellowish green brown.Fine grained,compact, aphyric. Weak altered.
98S MC13AD08	A	T01	Pyroxene basalt	Macrophyric texture, amygdaloidal texture. Phenocryst/matrix plagioclase show weak flow structure.	30～50%	little weak	◎				◎			◎			×	○	×					Veins, alteration of volcanic glass. Partly plagioclase altered.	Green brown, porous, weakly altered. Phyric with fine plagioclase phenocrysts(~8mm)
98S MC13AD13	E	T01	Dolerite	Holocrystalline, semi-equigranular. Ophitic texture characteristic of dolerite	65%	little weak	◎				◎	×						○	×					Semictite-like mineral observed as a product of matrix volcanic glass devinification.	Yellowish green brown, fine grained, weak altered. Microdolerite(?).
98S MS13AD02	C	T02	Hyaloclastite	Clastic, network veins developed. Pockets of calcite.		intermediate						◎					×	◎	◎		○			In matrix, smectite and silica minerals formed as cementing matter (colloform, void filling).	Brown hyaloclastite. Do not pebbles. Coarse grained ~ pisolitic. Voids (milky white incrustation inside) observed locally.
98S MS13AD03	A	T01	Aphyric porous basalt	Aphyric porous. Matrix phyric. Plagioclase shows weak flow structure.	few	strong	+	+	+					◎					○					In phenocrysts, cllinopyroxene is argillized (smectite), alteration significant. Matrix partly argillized (smectite), but alteration generally weak.	Brown, compact, porous(brick-like appearance). Grayish white filling observed locally.

Regend ◎: many ○: intermediate ×: few +: rare

1) Basalt (Fig. 4-3-1(1), Photos A～F)

Basalt was collected from the summit peripheries and slopes of all seamounts. From the MC11 and MS13 area seamounts in the eastern sea, many of the basalt samples were collected as substrates of thick crusts, cobble crusts which are more than 20mm, and pebble in foraminiferal limestone, whereas from the seamounts of the MC12, MC13 areas in the western sea, many of them occurred as pebbles with merely manganese oxide coating. Substrate basalt of crusts and cobble crusts collected from the eastern sea are almost all weathered and altered, even basalt pebbles with manganese oxide coating are weakly altered. On the other hand, regarding basalt from the western sea, relatively large amount of coated basalt pebbles or substrates of thin crusts were observed to be fresh or very weakly weathered. Several samples of cobble crust with basalt substrate were collected from MC13 area in the western sea, and many of these substrates were much strongly weathered than those of the eastern sea and resulted in mudstone-like appearance.

In the eastern sea, basalt occurs widely from the summits to the slopes of the seamounts in all areas. In the western sea, basalt occurrence is diverse; from the MC13 area seamount, basalt was collected evenly from the summit to the slope, while regarding the MC12 seamount, the summit is composed of reefal limestone and basalt was recovered from only below 1,950m of water depth. Lithology of the rock in both eastern and western seas is mostly vitreous or compact and the phenocrysts appear aphyric to the unaided eyes or are very minute. Large phenocrysts or glomerophyric texture basalt was collected only from the eastern slope of the MC13 seamount in the western sea. The sampling of basalt in individual seamounts is reported below.

At the MC11 seamount, basalt was collected as substrate of thick crusts from summit periphery and upper slope. Matrix is compact fine grained, and many have pyroxene and minute acicular plagioclase phenocrysts.

At the MS13 seamount, basalt was collected as substrate of 10～30mm-thick crusts from the su mmit periphery to the slope on the northern side. The samples are a mixture of fine-grained and compact rocks and porous rocks, both are aphyric or have acicular plagioclase phenocrysts. Also basaltic hyaloclastite sample was recovered as substrate of thick cobble crust from depressions between the pinnacles of the summit.

At MC12 seamount, basalt was recovered as pebbles and not as substrates of crusts and cobble crusts. Some were, however, collected as nuclei of nodules from lower slope. These samples were recovered from the slope and its occurrence on the summit has not been confirmed. Most of the basalt is fine grained and aphyric, with some having minute acicular plagioclase phenocryst. Also those with very fine voids are predominant below 2,250m water depth.

At MC13 seamount, basalt was collected almost all as pebbles with coating level of mineralization from near the summit pinnacles and the northern and eastern upper slope. Only several samples forming crust substrates were recovered from the summit exposure in the northwestern and peninsula-type protrusion on the eastern side. They are cobble crust substrates and nuclei of nodules and are strongly weathered. The rock is generally aphyric and fine grained or vitreous, some have fresh pyroxene or plagioclase phenocrysts. Phenocrysts are 0.5～2mm, but some are glomerophyric with over 10mm in size. Aphyric rocks were collected at various localities from the summit to the slope, and phyric ones from the steep slope on the northern side and from the eastern periphery of the summit.

Microscopy revealed that major part of the basalt samples from all seamounts have volcanic glass and plagioclase matrix. Olivine basalt with olivine phenocrysts was found from MC11 seamount. Almost all the basalt samples recovered from MC12 area appeared aphyric by unaided eyes, and microscopically it was shown to consist only of volcanic glass and minute plagioclase matrix.

At MC13 area, parts of basalt was confirmed to be dolerite. Phyric and aphyric dolerite occur on the northern slope. Also a phyric basalt sample from the eastern periphery of the summit contain quartz and opaque minerals in the matrix and is a pyroxene basalt with possibly different origin from dolerite. The strongly weathered basalt sample with massive mud appearance, collected from the northwestern periphery, was shown to contain many crystallites indicating quenched basalt lava with mineral composition similar to dolerite.

2) Limestone(Fig. 4-3-1(4) G～J)

Limestone occur as foraminiferal calcareous conglomerate containing basalt pebbles and as reefal limestone, and were collected as substrate of crusts and cobble crusts and as pebbles.

Foraminiferal calcareous conglomerate was recovered from all seamounts of areas MC11～MC13 and MS13. In the eastern sea, it was collected from various localities of the seamount summit and slope, while in the western sea, the occurrence was limited to the seamount slope on the MC12 area and in seamount summit in the MC13 area. With the exception of the MC12 area, limestone is the substrate of crusts and cobble crusts and not many occur as pebbles. In MC12 area, one sample was recovered as a substrate of a thick crust, but others were pebbles of coating grade. The lithology is all white and pelitic, and the matrix of the calcareous conglomerate show relatively good consolidation in the seamounts of MC11 and MS13 areas in the eastern sea, while in the western sea, except for the strongly phosphatized rocks of MC12 and MC13 areas, matrix is mainly soft merely cementing the pebbles.
Reefal limestone was recovered on the summit of the seamount in MC12 area. They form the substrates of crusts and cobble crusts. These contain shell fragments and are accompanied by Nummlites and have clear remnants of coral structure. They are generally coarse grained and porous, phosphatization is almost nil. Also coral branches coated by crust were also collected.

Aside from the above, white, very fine-grained, hard, stratified, micritic, and crust substrate limestone was collected from the seamount summit of MC13 area.

3) Tuffaceous rocks(Fig. 4-3-1(5) K,L)

Tuffaceous rocks were collected from all survey areas of western sea and MS13 seamount including the past survey. Tuff occurs widely from the summits to the slopes of the seamounts in MC11 and MC13, while in MC12 seamount, it was not recovered from the summit. With the exception of rare nodule nuclei occurrence, almost all tuff were collected as pebbles, and none were recovered as crust or cobble crust substrates. Those collected during the present survey in the seamounts of MC12, MC13, and MS13 areas were coarse-grained, porous, pumiceous tuff and tuff breccia containing angular basalt pebbles. Weathering is observed in all the samples.

Thin section microscopy of the tuff breccia from MC12 showed the content of microfossils such as foraminifera and radiolaria. It is believed that volcanic ashes deposited near the CCD and subsequently solidified because it has oolitic texture of volcanic glass coated by carbonate minerals. This tuff would be mudstone～sandstone in strict classification.

4) Hyaloclastite (Fig. 4-3-1(3) F)

Hyaloclastite was collected as substrates of cobble crusts scattered between the summit pinnacles of the seamount in MS13 area. Several samples were recovered as nodule nuclei from the slope of MC12 seamount. It is brown, vitreous and minute voids occur locally.

5) Mudstone

Brown mudstone was collected in the western sea as crust substrates and as pebbles. In MC12 area it was recovered as crust substrate from seamount slope, and in MC13 area it was crust substrate and pebbles on the seamount summit. It was formed by consolidation of bottom sediment ooze, and it is soft but the consolidation is good. Many have platy form and are bedded.

6) Chert(Fig. 4-3-1(5) M)

Chert was recovered from seamount upper slope of MC13 area as coated pebbles. Fresh ones are brown, translucent, and vitreous. Banded pattern due to inner cleavage is seen on the surface.
It was not collected during the previous survey.

7) Pumice

Pumice is highly foamed and is pale gray.

Pumice was recovered from almost all seamounts during the present survey as pebbles.

(2) Unconsolidated sediments

Large corer sampling was carried out at 12 sites in five areas of; MC11~13, MC02, and MC13. The results of LC sampling at eight sites of four seamounts, excluding the four sites of MC02 for hydrothermal investigation, are summarized below.
LC sampling is carried out with dual objective of collecting manganese crust and bottom sediment samples, and of observing the seafloor conditions by seafloor photography. Thus in some cases it was done in sites where bedrocks were inferred to be exposed and bottom sediments were not collected. During the present survey, bottom sediments were collected from five sites out of eight. The nature of the samples collected by LC and the results of the seafloor photography are summarized in Table 4-3-2 and Figure 4-3-2(1),(2). And the column of the recovered cores in Appended Figure 4.

The five sites where bottom sediments were recovered are; three in the piedmont to the base of the seamounts (MC12LC01, MC13LC01, MS13LC01) and two (MC11LC01, MC13LC10) in the summit peripheral parts.

The samples from the piedmont and the base are brown clay. Although the clay locally contains minor amount of foraminiferal sand or spots or thin layers of grayish white to pale grayish brown clay, it is generally homogeneous with pale brown to brown color. Aside from the surface, the water content percentage is somewhat low and some parts are half-consolidated. Pipe-shaped trace fossils are observed from the surface to about 1m depth.

Unconsolidated sediments consisting mainly of grayish white foraminiferal sand was collected at summit periphery (MC11LC01, 2,422m water depth). The foraminifera are spherical with 0.5~1.0mm diameter.

Table 4-3-2 LC samples and seafloor photographs

Area	Sampling	Sampling site water depth	Samples (cm)	Bit deformation	Crust exposure ratio	Crust type	Seafloor surface, crust surface
MC11	LC01	2,432m	Foraminiferal sand (66) Strongly weathered basalt (5)	Deformed	Photo quality poor	-	-
MC12	LC01	3,798m	Ooze (98)	None	1%	Nodule	Several cm crust occur sporadically.
MC13	LC01	3,441m	Ooze (140), Nodule.	None	1%	Nodule	Several cm crust occur sporadically.
	LC09	2,247m	Ooze stuck on bit.	Deformed	95%	Crust	Botryoidal. Ooze in depressions.
	LC10	2,149m	Foraminiferal sand (129)	None	0%	-	Foraminiferal sand cover.
MS13	LC01	4,069m	Ooze (215), Nodule.	None	20%	Nodule	Nodules smaller than 5cm occur sporadically.
	LC11	2,029m	Ooze stuck on bit.	Deformed	Photo quality poor	-	-
	LC12	2,079m	Foraminiferal sand stuck on bit.	Deformed	Photo quality poor	-	-

Water content percentage is high and consolidation weak.

Foraminiferal sand and calcareous clay were collected at MC13LC10 (2,141m water depth). The surface consists of white to brown 0.5～1mm foraminiferal sand and grayish white calcareous clay mixes downward, and becomes almost completely homogeneous calcareous clay below 90cm from the surface. The water content percentage is high and is soft.

4 - 4 Chemical composition of rocks

(1) Analytical methods

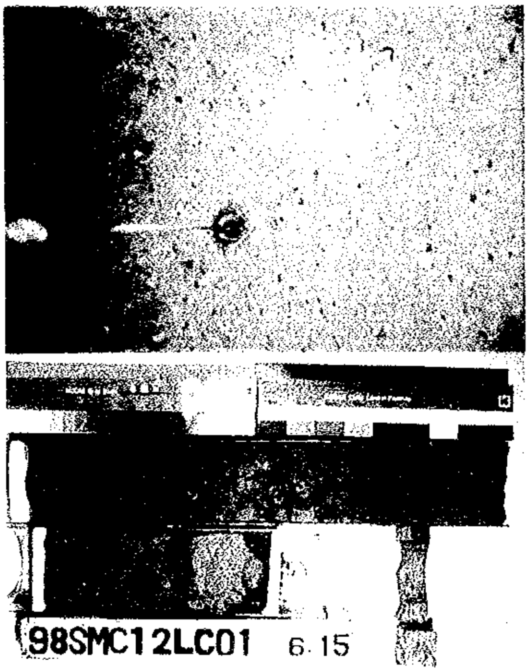
Analytical methods and the components analyzed are laid out in Table 4--4-1, and the analysed componentw and the limit of detection in Table 4-4-2. Before analysis, samples were washed and dried to constant weight and prepared.

Table 4-4-1 Analytical methods and elements

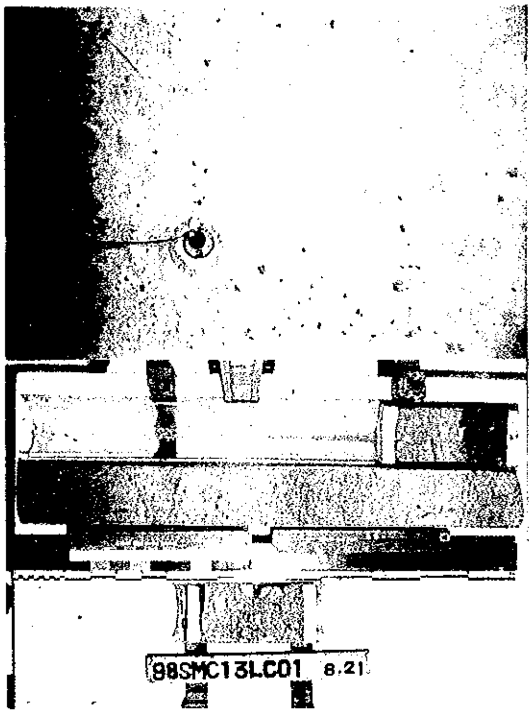
Elements	Methods
SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5	ICP emission spectroscopy
FeO	Neutralization titration
CO_2	Combusion and infrated absorption spectroscopy(LECO)
H_2O^+, H_2O^-, LOI	Gravimetry
Rb, Sr, Ba, Zr, V, Nb, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu	ICP mass spectroscopy

Table 4-4-2 Analyzed elements and limit of detection

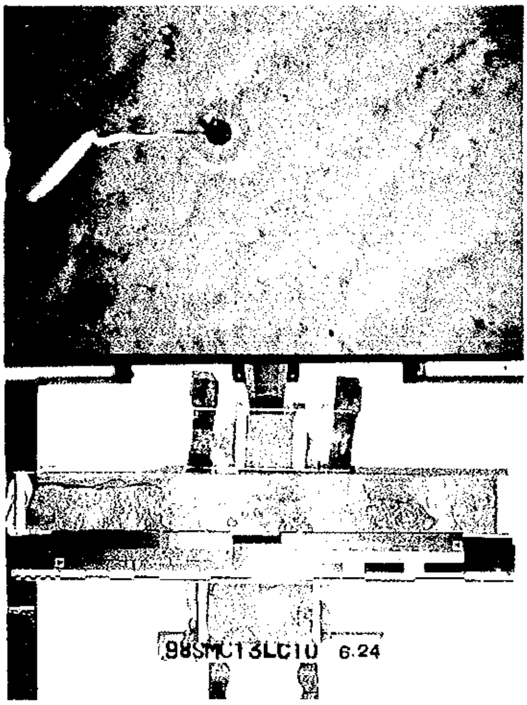
35 Elements	14 major elements	SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, CO_2, H_2O^+, H_2O^-, LOI	limit of detection; 0.01%
	21 minor elements	Sr, Ba, Zr, V, Y	limit of detection; 1ppm
		Rb, Nb, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho,Er, Tm, Yb, Lu	limit of detection; 0.1ppm



98SMC12LC01
Seafloor:Nodules scattering on ooze surface.
Core:Ooze (98cm).solidified partially.

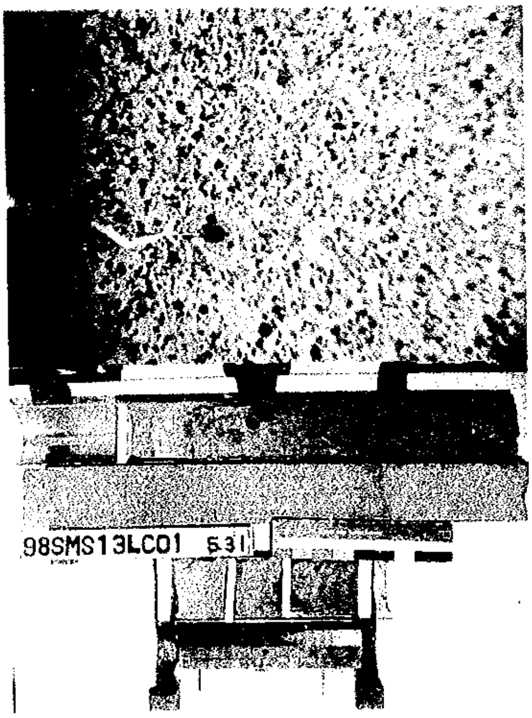


98SMC13LC01
Seafloor:Nodules scattering on ooze surface.
Core:Ooze(140cm),including 1-2cm nodule.

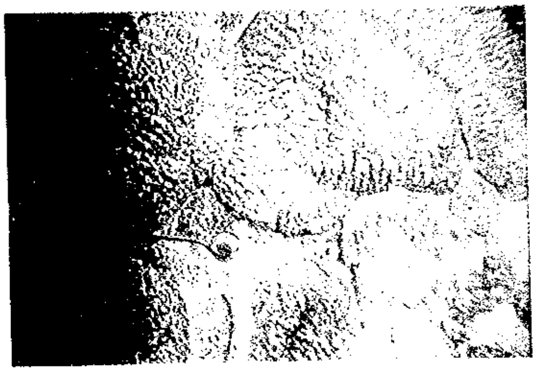


98SMC13LC10
Seefloor:Forminiferal sand and ripple marks.
Core:Forminiferal sand (136cm),
argillite partially alternated.

Fig. 4-3-2(1) Photographs of seafloor and sediments(LC sampling)



98SMS13LC01
Seafloor:Nodule scatter on calcareous ooze.
Core:Calcareous ooze (215cm), including
micro-nodulu on the whole.



98SMC13LC09
Seafloor:botryoidal surface of crust.
Core:Not collected.

Fig. 4-3-2(2) Photographs of seafloor and sediments(LC sampling)

(2) Results of analysis

The analytical results are shown in Table 4-4-3 (1), (2). Various diagrams based on the analytical results were prepared. The results of analysis are as follows.

1) Norm calculation

The results of norm calculation is shown in Table 4-4-4. Triangular diagram of normative; nepheline, olivine, diopside, hypersthene, and quartz is shown in Figure 4-4-1.

All samples are in the tholeiite area where normative quartz, normative hyperthene, and normtive diopside are calculated. The basalt samples from MC12 contain high normative calcite value and this is believed to be the effect of calcareous clay filling the cracks and voids in the samples.

2) AFM diagram

AFM diagram is shown in Figure 4-4-2.

In the AFM diagram, basalt samples collected from MC11 and MC12 areas are FeO rich and MgO poor, and are plotted in tholeiite area. Samples colected from MC13 area are Na2O+K2O poor but rich in MgO and are plotted in calc-alkali basalt area. Basalt samples from MS13 area have MgO, Na2O+K2O values intermediate between the above two groups, and the FeO value is somewhat small and these samples are plotted in the calc-alkali basalt area.

3) Spider diagram of MORB normalized incompatible elements

Spider diagrams of MORB normalized HFS and LIL elements of the samples are shown in Figure 4-4-3. Mile ORB balues of Benvins et al., (1984) was used for normalization.

Basalt samples from MS13 and MC11 areas show pattern of increase from Sr to Ba of LIL elements, and decrease from Nb to Y of HFS.

Basalt from MC12 has a peak at Rb for LIL, takes high values at P and Y, and low at Zr for HFS elements.

Basalt from MC13 has low values for six elements from Sr to P, and although there is a peak at Rb, it shows a general gentle pattern.

Comparing these data with typical spider diagrams of HFS and LIL elements of basalt in tectonic environment, it is seen that basalt from MS13 and MC11 show patterns similar to those of oceanic island alkali basalt, while that of MC12 area is similar to the island-arc tholeiite. The pattern of basalt from MC13 has different peak, but it is close to that of P-type MORB.

4) Chondrite normalized spider diagrams of rare earth elements

Spider diagrms of chondrite normalized REE of each sample are shown in Figure 4-4-4. Chondrite values of Wakita et al., (1971) were used for normalization.

Basalt from MS13, MC11, and MC12 show linear and steep pattern while the basalt from MC13 show

Table 4-4-3(1) Results of chemical analysis for rocks (main elements)

Sample No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O-	CO_2	LOI	TOTAL	FeO*	Mg#
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	tatal	tatal
98SMC02AD11CA01	48.58	1.81	14.30	7.34	4.76	0.16	7.29	11.61	2.55	0.16	0.18	2.05	0.66	0.06	1.85	100.61	11.38	0.390
98SMC11AD02CA01	38.94	2.40	17.01	8.93	1.90	0.13	1.30	8.93	3.57	1.16	3.47	6.04	2.74	0.44	9.94	97.65	9.94	0.116
98SMC12AD13CA01	30.93	2.75	11.29	6.94	0.90	0.09	1.56	21.04	2.16	1.75	3.21	3.96	1.56	10.70	16.52	99.14	7.14	0.179
98SMC13AD04CA01	48.97	1.72	15.56	4.56	4.10	0.14	5.95	12.23	3.03	0.40	0.18	1.76	0.79	0.34	2.84	99.70	8.20	0.420
98SMS13AD03CA01	47.11	2.56	15.69	7.91	0.70	0.05	2.73	5.25	3.57	1.77	1.12	6.87	2.51	0.13	10.43	98.92	7.82	0.259

Table 4-4-3(2) Results of chemical analysis for rocks (rare elements)

Sample No.	V	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
98SMC02AD11CA01	335	3	150	34	108	5	24	6	16	2.67	14.0	4.3	1.48	5.1	1.0	5.7	1.2	3.6	0.51	3.1
98SMC11AD02CA01	182	11	1070	84	244	121	652	126	218	25.70	99.0	17.0	4.91	13.0	2.2	12.0	2.3	6.7	0.89	5.4
98SMC12AD13CA01	133	34	437	38	69	43	154	40	97	10.80	47.0	9.8	2.93	8.4	1.3	6.7	1.2	3.2	0.42	2.5
98SMC13AD04CA01	266	8	208	30	112	6	46	7	17	2.59	13.0	3.9	1.36	4.3	0.8	5.1	1.0	3.0	0.45	2.7
98SMS13AD03CA01	80	24	530	26	381	25	342	27	72	8.06	38.0	9.2	3.09	7.9	1.1	5.4	0.9	2.1	0.22	1.2

Table 4-4-4 Results of normative calculation

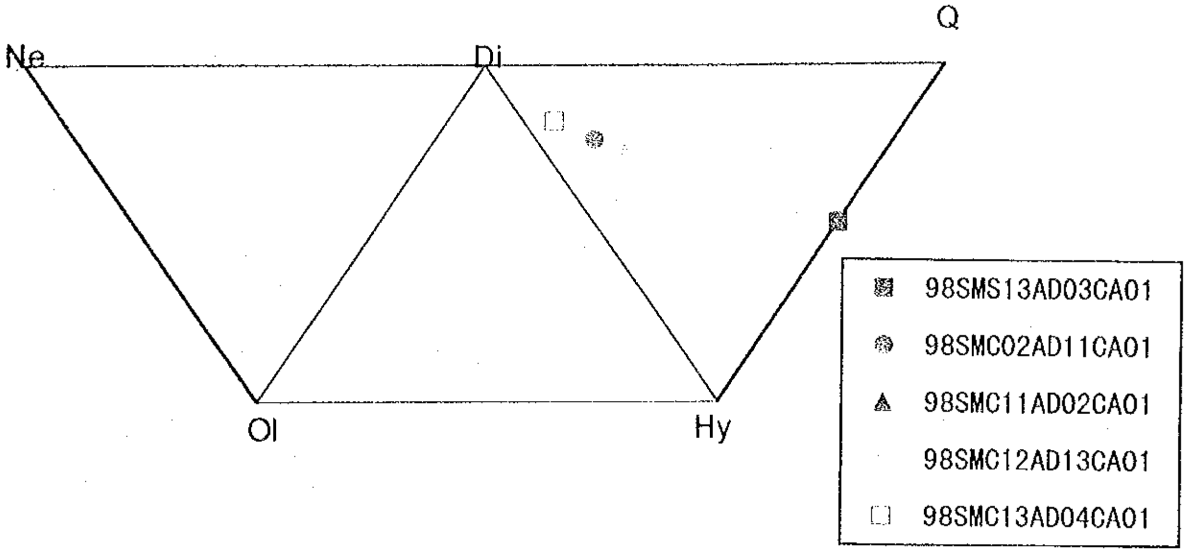
Sample No.	Q	C	or	ab	an	wo-di	en-di	fs-di	en-hy	fs-hy	fo-ol	cs	mt	hm	il	tn	pf	ru	ap	cc
98SMC02AD11CA01	4.30		0.95	21.58	27.10	12.08	10.43	0.01	7.72	0.01			10.64		3.44				0.42	0.14
98SMC11AD02CA01	3.65	2.97	6.86	30.21	18.85				3.24					8.93	4.29			0.14	8.04	1.00
98SMC12AD13CA01	2.50	0.03	10.34	18.28	15.85	4.50	3.89		3.89			0.76		6.94	2.09		2.81	1.65	7.44	24.32
98SMC13AD04CA01	2.04		2.36	25.64	27.67	12.39	10.10	0.80	4.72	0.38			6.61		3.27				0.42	0.77
98SMS13AD03CA01	7.77	1.34	10.46	30.21	17.91				6.80					7.91	1.58			1.73	2.59	0.30

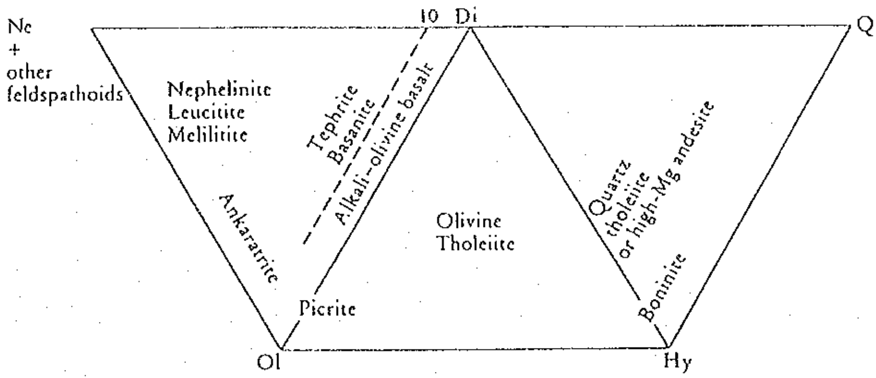
Q: Quartz
C: Corundum
or: Orthoclase
ab: Albite
an: Anorthite

wo-di: Wollastonite-diopside
en-di: Enstatite-diopside
fs-di: Ferroselite-diopside
en-hy: Enstatite-hypersthene
fs-hy: Ferroselite-hypersthene

fo-ol: Fayalite
cs: Cyclosilicate calcium
mt: magnetite
hm: Hematite
il: Illmenite

tn: Titanite
pf: Perovskite
ru: Rutile
ap: Apatite
cc: Calcite





The classification of basalts and related basic and ultrabasic magmatic rocks according to their CIPW normative composition expressed as Ne–Ol–Di, Ol–Di–Hy or Di–Hy–Q (after Thompson, 1984).

Fig4-4-1 Normative composition diagram.

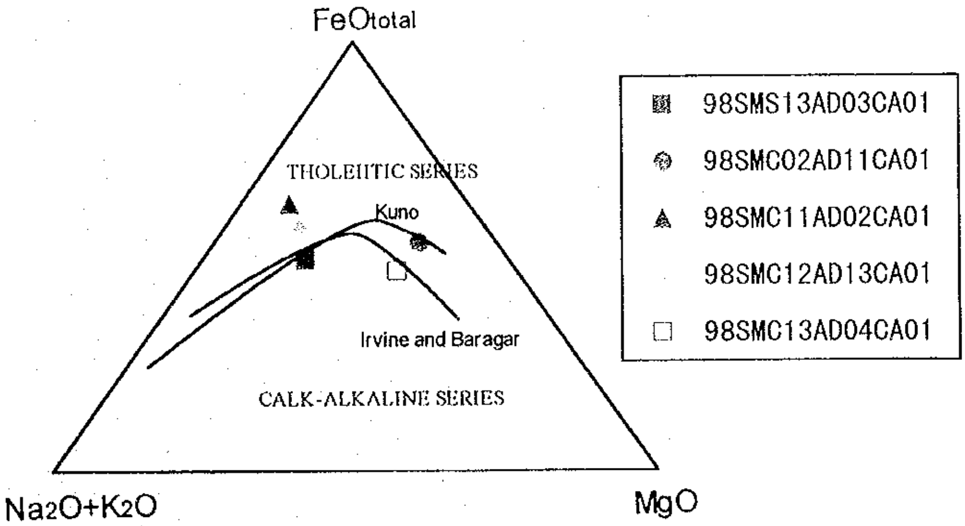


Fig4-4-2 AFM diagram

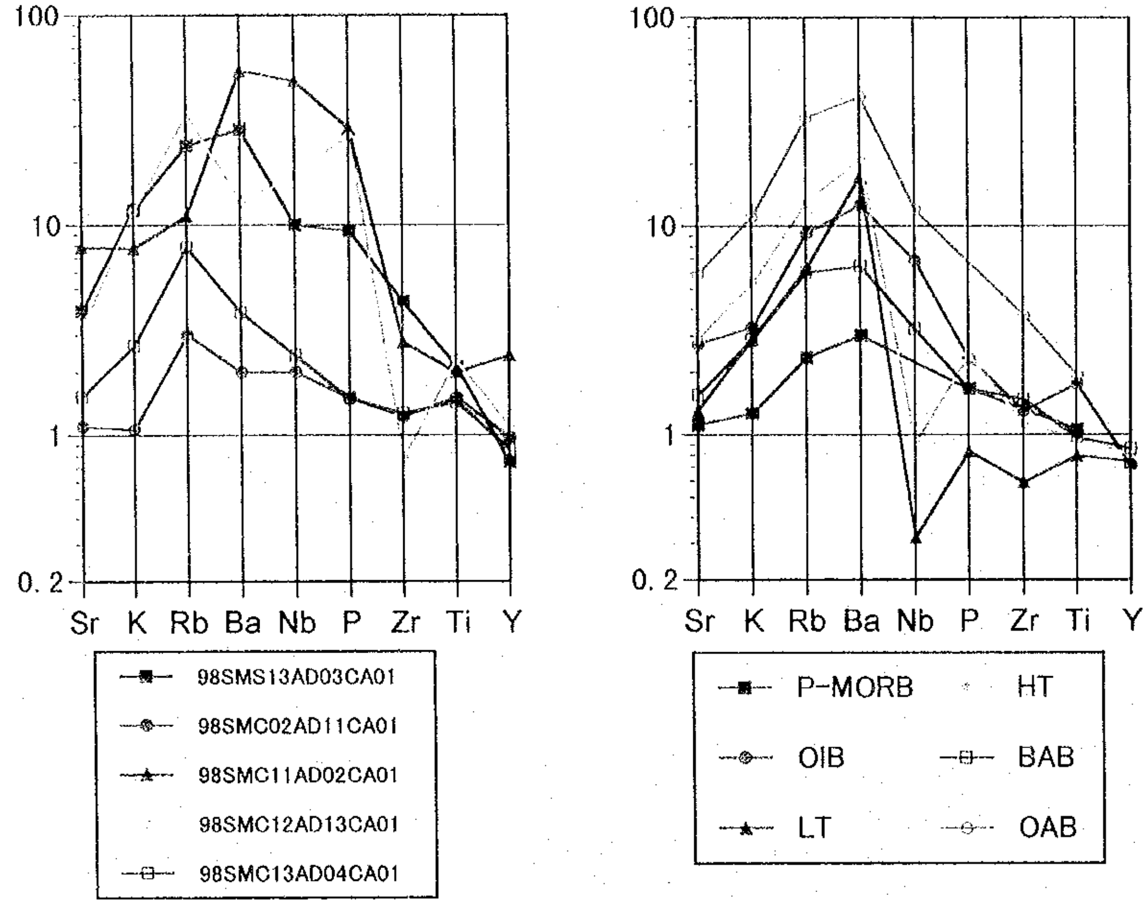
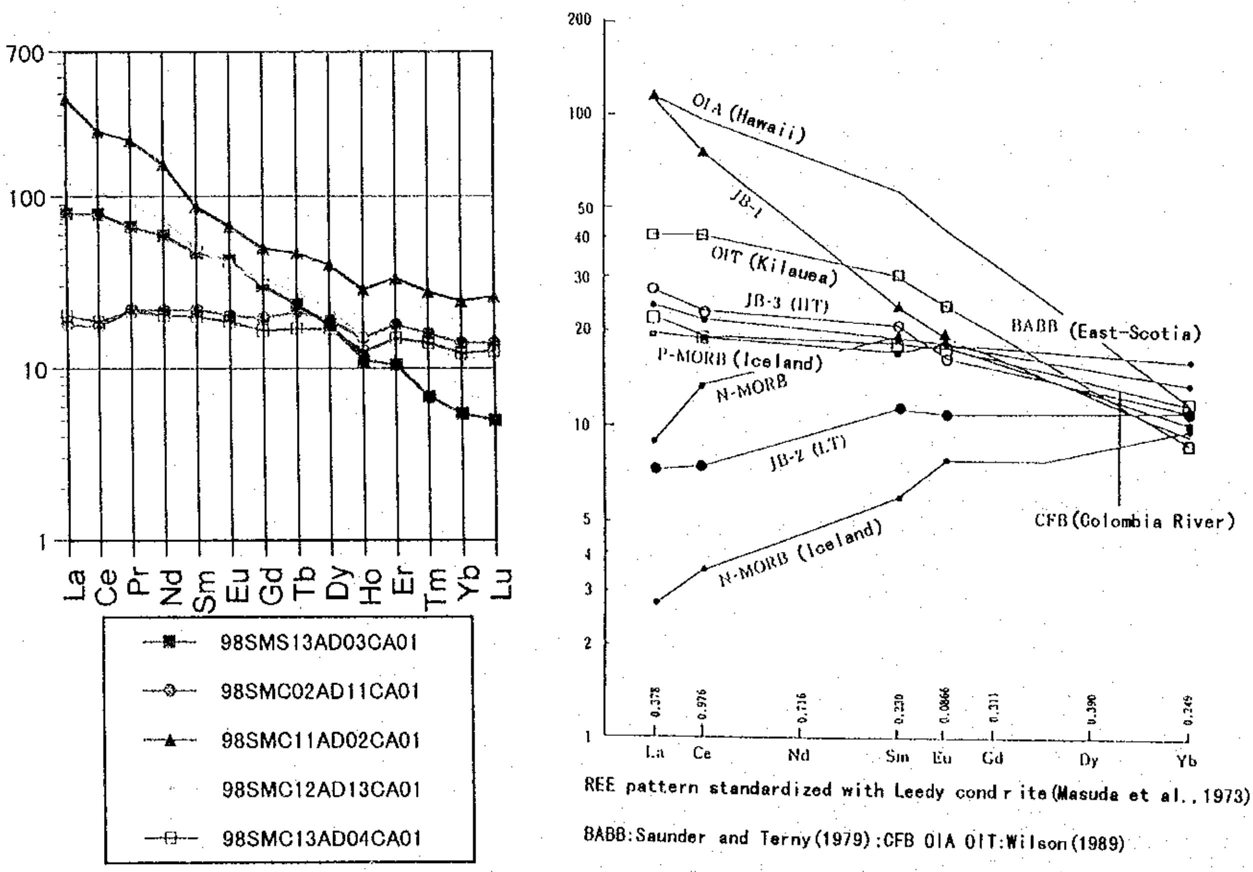


Fig. 4-4-3 Spidergram of incompatible elements



REE pattern standardized with Leedy condrite (Masuda et al., 1973)

BABB: Saunder and Terny (1979); CFB OIA OIT: Wilson (1989)

JB-1〜3 : Ando et al. (1987) N-MORB P-MORB: Schilling et al. (1983)

Fig. 4-4-4 Spidergram of REE elements

almost flat pattern.

Comparing these patterns with REE spider diagrams of basalt in tectonic environment (Fig. 4-4-4), the basalt from MS13, MC11, MC12 show pattern close to those of oceanic island alkali basalt (OIA), while the spider diagram pattern of basalt from MC13 is close to that of P-type MORB.

5) Characteristics and division

Division of basalt using various diagrams is as follows.

① TiO2-MnO-P2 O5 diagram (Fig. 4-4-5)

The MC13 area basalt is plotted in the MORB area. The other three samples in the oceanic island alkali basalt area.

② Ti-V diagram (Fig. 4-4-6)

The MC13 basalt has Ti/V ratio of 48 and is i8ncluded in the MORB area. The other three samples are plotted in a position somewhat lower in V than oceanic island and alkali basalt area.

③ Zn-Nb-Y diagram (Fig. 4-4-7)

The MC13 basalt is plotted in the MORB area. The other three samples are off the basalt plate, but near the alkali basalt area.

The division considering; norm calculation, AFM diagram, HFS and LIL elements spider diagram, REE spider diagram, and various diagrams; is shown in Table 4-4-5. The division of basalt from each locality is considered from the above results.

MS13 area (98SMS13AD03CA01)

The basalt collected from MS13 area is inferred to be oceanic alkali basalt from the study of; HFS, LILelement spider diagram, REE spider diagram, and various diagrams. Also the high NaO+K2O content is in agreement with the above. The high H2 O+ value is due to the argillization confirmed by microscopy. Also 3-valent iron and clay and apatite filling the voids result in normative hypersthene and diopside and thus this rock was classified as tholeiite by norm values and AMF diagram.

MC11 area (98SMC11AD02CA01)

This sample is inferred to be oceanic alkali basalt from the study of; HFS,LIL element spider diagram, REE spider diagram, and various diagrams. The high H2 O+ value is also due to the argillization. This sample is also filled the voids with clay and apatite like one of MS13 area, thus this rock was also classified as tholeiite by norm values and AMF diagram.

MC12 area (98SMC12AD13CA01)

This sample is inferred to be oceanic alkali basalt from the study of; HFS,LIL element spider diagram, REE spider diagram, and various diagrams. The calcite content was calculated to be 24% by norm calculation and was classified as tholeiite, but this calcite is filling the vesicles.

MC13 area (98SMC13AD04CA01)

This sample is inferred to belong to P-type MORB from HFS,LIL element spider diagram, REE spider diagram, and various diagrams.

The basalt samples collected during the previous and present surveys are classified as follows.
Oceanic island alkali basalt: MC05, MC07, MC09, MC10, MC11, MC12, MS13 areas
Oceanic island alkali basalt～tholeiite: MC08 area
Oceanic island alkali basalt～oceanic island tholeiite: MC03 area
P-type MORB: MC02, MC13 areas.

Seamounts composed of oceanic island basalt are widely distributed in the seas of Micronesia. The origin of these seamounts is hotspot and the seamounts are aligned from the west to the east indicating the movement of the plate. But from the present survey, it was confirmed that the seamounts in MS13 area and other four seamounts are composed of tholeiite or MORB. The geology of these seamounts reflect the complex geologic structure of the area. And these seamounts are not common guyots, but they are oceanic ridge-type or oceanic plateau-type with clear lineaments.

4 - 5 Ages of rocks

K-Ar age determination was carried out on fresh basalt samples from MC12 and MC13 areas. As the reliability of age determination is dependent on the degree of alteration of the rock, chemical analysis and thin section microscopy were carried out for the samples in order to confirmed the degree of alteration. The measured basalt samples were determined to be either fresh or very weakly altered. Thus the results of age determination are believed to be reliable and the margin of error to be small. Content of potassium was determined by flame spectroscopy, and rare gas mass spectrometer was used for the determination of argon content. Disintegration constants of Steeper and Jaguar (1977) were used.

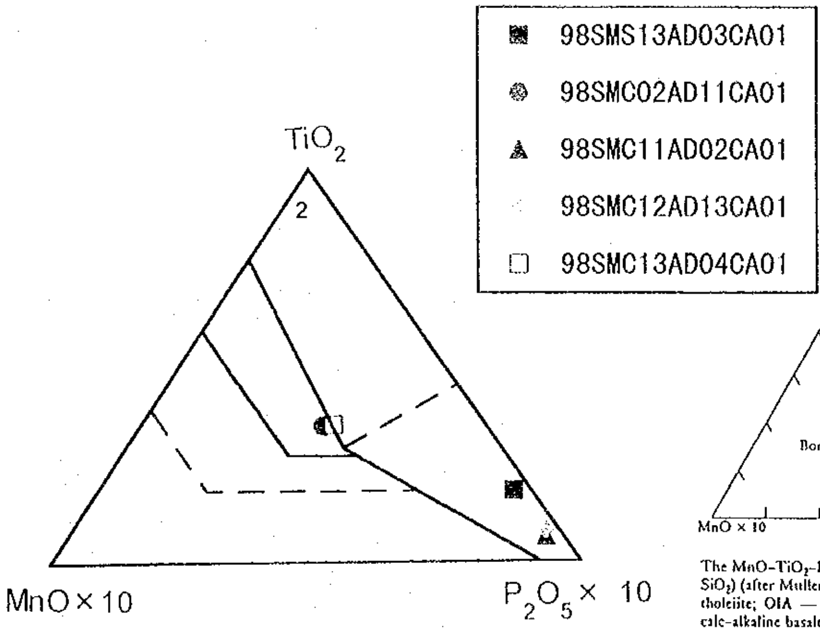
The measured results are shown in Table 4-5-1.

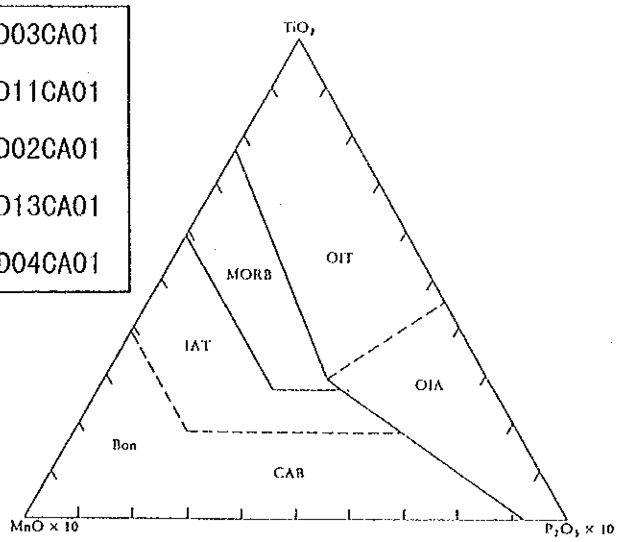
Table 4-5-1 Results of dating rocks

Area	Sampling point	Sample code	Sample No.	Sampling depth(m)	potassium (wt%)	Rad.40Ar (nL/g)	K-Ar Age (Ma)	Geological	Alteration Microscopic description
MC12	AD14	A	K02	2,326	1.83	0.411	71.1±3.6	Late Cretaceous～ Early Paleogene	Porous aphyric basalt. Altered mineral cannot be found under microscope.
MC13	AD04	A	K01	2,069	0.64	0.181	56.8±2.8	Early Paleogene	Dolerite. Few of mayrix volcanic glass were altered to smectote. but almost fresh.

The age of basalt from MC12 area was determined to be 71.1± 3.6Ma, and that of the basalt from MC13 area to be 56.8±2.8Ma. The geologic age of the rocks correspond to; Late Cretaceous to Eocene for MC12 basalt, and Eocene for MC13 basalt. Even in fresh rocks, leaching of potassium with time is unavoidable, and generally the measured age tends to shift to the smaller side. Therefore, it is believed that the rocks were formed earlier than the geologic time obtained.

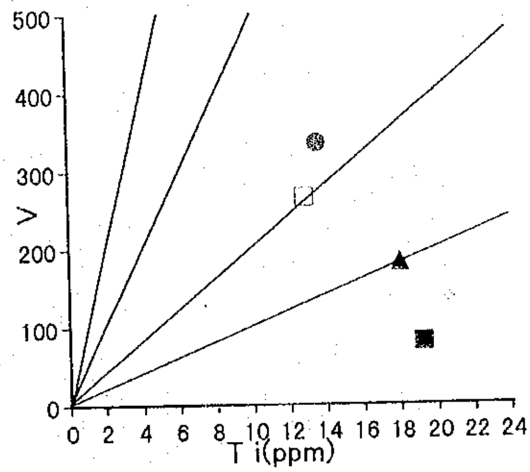
The result of the survey in 1997 indicate the possibility that the seamounts in the eastern sea including MC12 and MC13 areas can be divided into the following three seamount groups. Namely; the seamount chain on the northern side of the survey area extending in the east-west direction and formed by

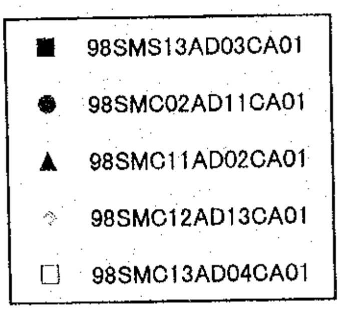


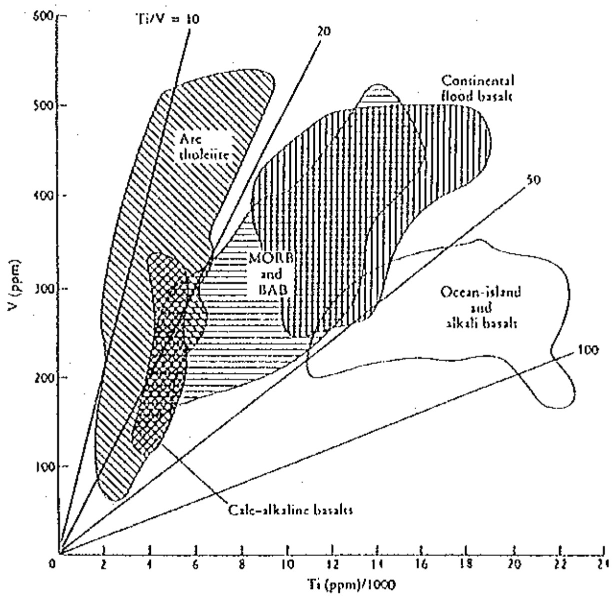


The MnO–TiO_2–P_2O_5 discrimination diagram for basalts and basaltic andesites (45–54 wt % SiO_2) (after Mullen, 1983). The fields are MORB; OIT — ocean-island tholeiite or seamount tholeiite; OIA — ocean-island alkali basalt or seamount alkali basalt; CAB — island-arc calc-alkaline basalt; IAT — island-arc tholeiite; Bon — boninite. The boninite field occupies the MnO-rich sector of the CAB field.

Fig. 4-4-5 TiO_2–MnO_2–P_2O_5 diagram

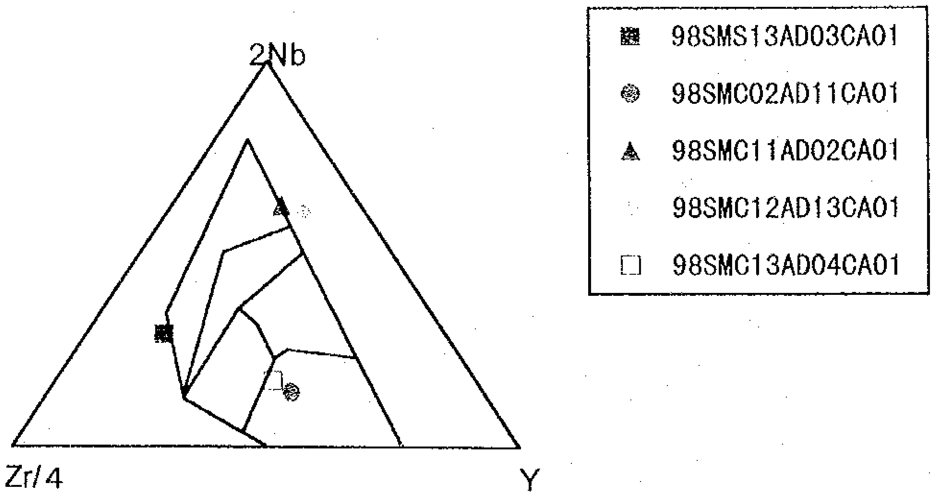


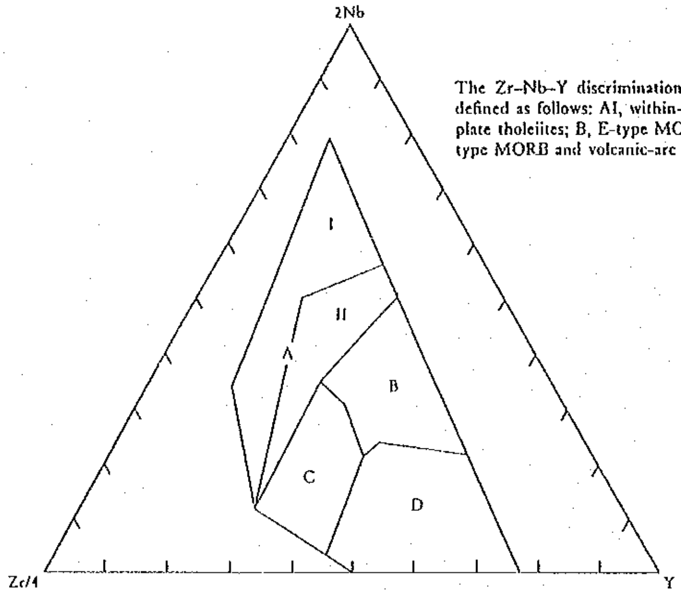




The Ti–V discrimination diagram for basalts (compiled from Shervais, 1982). The fields of arc tholeiite (diagonal hatching), MORB and back-arc basin basalts (BAB) (horizontal hatching), continental flood basalts (vertical hatching) and ocean-island and alkali basalt (unshaded) are recognized by their Ti/V ratio as shown. Calc-alkaline basalts (shaded) plot with low Ti concentrations with a wide range of Ti/V ratios.

Fig. 4-4-6 Ti–V diagram





The Zr-Nb-Y discrimination diagram for basalts (after Meschede, 1986). The fields are defined as follows: AI, within-plate alkali basalts; AII, within-plate alkali basalts and within-plate tholeiites; B, E-type MORB; C, within-plate tholeiites and volcanic-arc basalts; D, N-type MORB and volcanic-arc basalts.

Fig. 4-4-7 Zn-Nb-Y diagram

Table 4-4-5 Classification of Basalt based on each diagram

area	Microscopic description	Normative composition diagram	AMF diagram	Spidergram of incompative elements	Spidergram of REE elements	TiO_2-Mn-P_2O_5 diagram	Ti-V diagram	Zn-Nb-Y diagram
MC11	Altered olivin basalt	Tholeiite	Tholeiite	OIB	OIA	out of domain	out of domain	out of domain
MC12	Porous aphyric basalt	Tholeiite	Calc-alkali basalt	IAT	OIA	out of domain	out of domain	out of domain
MC13	Dolerite	Tholeiite	Calc-alkali basalt	P-MORB	P-MORB	MORB	MORB	MORB
MS13	Porous aphyric basalt	Tholeiite	Tholeiite	OIA	OIA	out of domain	out of domain	out of domain

pre-Paleogene volcanic activity, the seamount group distributed to the west of the Caroline Ridge formed during Miocene, and the seamount group extending in east west direction from the central part of the survey area parallel to the pre-Paleogene seamount chain and was formed after Oligocene.

The fact that the ages of the basalt samples from MC12 and MC13 located on the northern side of the eastern sea are 71.1Ma and 56.8Ma is harmonious with the above grouping of the seamounts. The ages of the basalt samples recovered during the 1997 survey are 69Ma and 46.5Ma for MC10 and MC8 areas respectively. Thus the seamounts in these four areas can be characterized as been formed before Paleogene. The thickness of the crusts generally increases with the age of the seamounts, and it is seen that the crusts of the above four areas formed before Paleogene have maximum thickness of 90～190mm, which is 2～3 times greater than those of the seamounts formed after Neogene.

The location of the seamounts and the ages of the basalt are shown in Table 4-5-2. It seen from these figures that:

Table 4-5-2 Results of basalt dating of 4 areas

Area	Seamount -type	K-Ar age (Ma)	Geological age	Rock	Alteration	Latitude	Longitude
MC08	Table seamount	46.5±1.5	Early Paleogene	Augite olovine basalt	weak	10° 20′ N	156° 41′ E
MC10	Ridge-shaped seamount	69±2	Late Cretaceaous	Aphyric basalt	very weak	9° 45′ N	148° 16′ E
MC12	Ridge-shaped seamount	71.1±3.6	Late Cretaceaous-Early Paleogene	Porous aphyric basalt	fresh	9° 20′ N	146° 05′ E
MC13	Plateau-shaped seamount	56.8±2.8	Early Paleogene	Dolerite	very weak	10° 20′ N	145° 00′ E

- The seamounts of the neighboring MC10 and MC12 areas have different morphology, namely guyot and horst-shaped oceanic ridge type seamount respectively. They, however, consists of basalt which are the products of volcanic activity of similar time.
- The basalt of MC13 has younger age than those of MC10 and MC12 areas. Other samples from the MC08 and MC10 areas show 25±2 for MC08 and 24±1 for MC10 areas. Both samples are weathered and the reliability is low, but they indicate volcanic activity in late Paleogene to early Neogene time.

From the above, it is inferred that the seamount group aligned in the east-west direction on the northern side of the eastern sea were formed by volcanic activities either before Late Cretaceous or before Paleogene and subsequently there were volcanic activities in conjunction with the westward crustal movement in late Paleogene. Although evidence is insufficient for definitive argument due to the small number of samples, if the basalt recovered from the MC13 area is considered to be formed by the later volcanic activity, the formation of the seamount could be earlier than 56.8Ma.

4 - 6 Identification of Fossils in Rocks and Bottom Sediments

Fossil identification was carried out for foraminifera, radiolaria, coral, and other biologic fragments in; seven limestone and one chert samples dredged from MC12 and MC13 areas, and one foraminiferal sand and one clay samples collected by LC sampling from MC11 and MC12 areas. The results of identification are shown in Tables 4-6-1 and 4-6-2(1),(2), and microphotograph of representative fossils in Figure 4-6-1, 4-6-2 and 4-6-3. In MC11 and MC13 areas, foraminiferal limestone was recovered as matrix of conglomerate but the amount was insufficient for fossil identification.

Late Pliocene (2.0～3.12 Ma) planktonic foraminifera assemblage occurred in the bottom sediments from the northern summit periphery of the seamount in MC11 area.

In the MC12 area, it was confirmed that the reefal limestone from the summit and upper slope of the seamount contain massive reef-building coral. Cretaceous reef-building coral was identified in three samples recovered from zones shallower than 1,173m water depth, and Middle Jurassic to Middle Cretaceous reef-building coral was confirmed from one sample recovered from 1,424m water depth. Also planktonic foraminifera was identified from the void-filling material of this reefal limestone. Oligocene (33.8～28.5Ma) planktonic foraminifera fossils occur in reefal limestone collected from 1,173m water depth, and late Eocene～early Oligocene (35.3～28.5Ma) planktonic foraminifera fossils occur in the reefal limestone from water depth of 1,424m. Early Miocene (23.8～16.4Ma) foraminifera fossils were confirmed from consolidated clay rich in manganese oxides from the seamount base.

In the MC13 area, radiolaria assemblage and some foraminifera fossils were confirmed in chert sample recovered from the seamount summit. As the co-existence period of the radiolaria assemblage is limited to Valanginian stage, these are believed to have deposited during 135～141 Ma. Also Late Cretaceous (102～91Ma) foraminifera was identified in the foraminiferal limestone from the summit.

The above results are interpreted as follows.

In the MC13 area, radiolarian assemblage considered to have deposited in Early Cretaceous Valanginian (135～141Ma) stage was confirmed in the chert from the seamount summit, and thus the seamount is believed to have formed before Early Cretaceous. And as Late Cretaceous planktonic foraminifera fossils were confirmed in the foraminiferal calcareous conglomerate, the summit is inferred to have been subsided to deep seafloor in Late Cretaceous. Although the K-Ar age determination of rocks indicate early Paleogene formation of basalt, there are indications as to the pre-Paleogene formation of the seamount itself. Thus the younger age of the rocks by K-Ar method is not necessarily contradictory to the results of fossil identification.

In MC12 area, Jurassic to Middle Cretaceous reef-building coral fossils have been identified. This indicates that the seamount was formed before Middle Cretaceous. This is in agreement with the pre-Late Cretaceous age of the rocks obtained by K-Ar method. Other reef-building corals from this area is limited to Cretaceous age, and the foraminifera fossils range in age from late Eocene to early Oligocene (35.3～28.5Ma), and thus the seamount summit is believed to have subsided to deep seafloor in late Eocene.

From the above fossil identification results and age determination of rocks of the seamounts in the vicinity, the following history of the seamounts of the survey area is inferred.

Table 4-6-1 Results of fossil observation for rocks and seafoor sediments

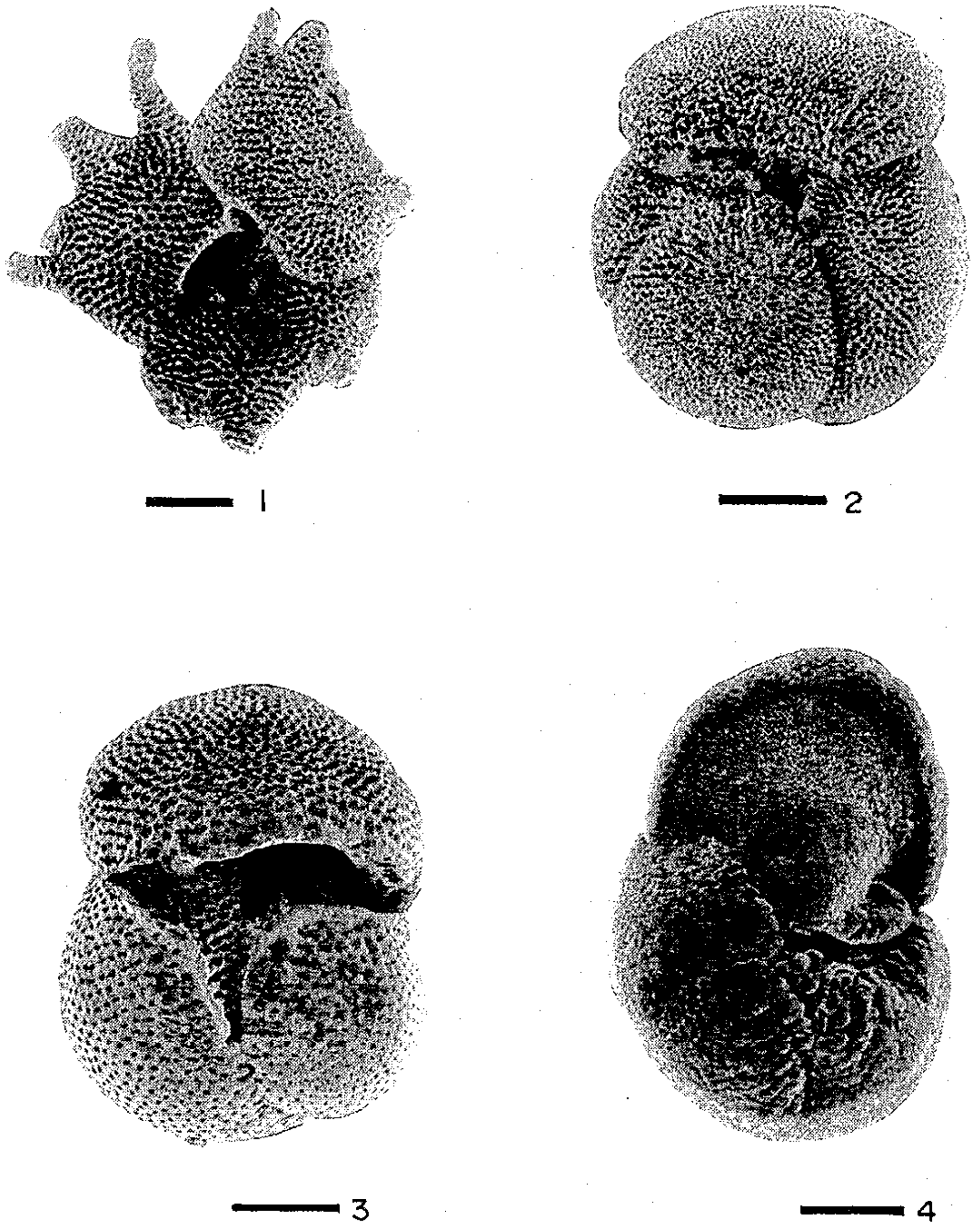
Area	Sampling No.	Sample code	Sample No.	Sampling depth(m)	Sample classification	Foraminifera		Geological age	Radiolaria	Geological age	Coral	Geological age	others	Geological age
						Planctonic	Benthonic							
MC11	LC01		Fm02	2,432	Foraminifera sand	many	rare	Late Pliocene	few					
MC12	LC01		T01	3,798	Mud-stone	few		Early Miocene						
	AD04	A	Fr01	1,424	Reefal limestone	many		Late Eocene～Early Oligocene			Reef	Middle Jurassic ～Middle		
	AD05	B	Fr01	1,260	Reefal limestone	rare					Reef	Cretaceaous		
		A	Fr02	1,260	Reefal limestone	rare					Unknown			
	AD09	A	Fr01	1,150	Reefal limestone	little many	few	Early Oligocene			Reef	Cretaceaous		
		B	Fr02	1,150	Foraminifera limestone	many		Early Oligocene			Reef			
	AD13	D	Fr01	2,308	Reefal limestone	little many	few	Early Oligocene						
MC13	AD02	A	Fr01	2,319	Foraminifera limestone	many	few	Late Albian～Cenomanian						
	AD12	D	Fr01	2,007	Chart	medium		Late Eocene	many	Late Valanginian				

Table 4-6-2(1) Results of Fossil Identification in Rocks and Bottom Sediments

No.	Sampled	Sampling	Sample number	Water depth (m)	Unaided eye observation	Identified fossils	Remarks
1	SMC11	LC01	Fm02	2422	Contain colorless, transparent, polygonally irregular material probably volcanic glass and colorless, transparent, opaque, minerals stained black.	Planktonic foraminifera assemblage in these sediments is ; *Globigerinoides conglobatus, G.ruber, G.sacculifer, Globerigerinita glutinatee, Globorotalia menardii, G.tumida, Neoglobaquadrina dutertrei, Pulleniatina obliquiloculata* (Table 3). The occurrence of *Globigerinoides obliquus extremus* in this sample, and the lack of species which occur in Pleistocene sediments of the equatorial Pacific region, such as *Globorotalia trancatulinoides* and *Sphaeroidinellopsis seminulina* indicate late Pliocene (2.0～3.13Ma) age.	
2	SMC12	LC01	T01	3798	Small amount of probable foraminifera fragments observed. Colorless transparent quartz grains contained in small amounts.	Planktonic foraminifera in these sediments are ; *Globigerinoides altiaperura, G.succulifer, Globoquadrina venezuelana, Galtispira globosa, Sphaeroidinellopsis semimulina* (Table-3). The occurrence of *G.altiaperteira* indicate early miocene (23.8～16.4Ma) age. The range zone of other species span early Miocene to Pliocene and is harmonious with the above age.	Ad04(1,424m), AD05(1,128m), AD09(1,173m) are located near the summit of this seamount. Therefore, these samples, pelagic limestone is deposited filling the roids of coral fossils and shallow sea fossils. The age of the corals is all Cretaceous and the formation of the seamount is concluded to be Cretaceous. Therefore, the seamount which was formed in Cretaceous, gradually subsided after the formation of limestone cap and with the cessation of coral formation and deposition of shallow sea sediments, foraminifera ooze began to deposit. It is inferred that the rapid subsidence began in late Eocene to early Oligocene.
3		AD04	Fr01	1424	Coral rudstone, blocky calcite fills the voids in coral fossils.	Coral fossils include reef-building coral *Amphiastrea* SP. Thus the depositional environment of limestone is inferred to be reef flat or reef slope of shallow sea reef. The age of deposition probably was Middle Jurassic to Middle Cretaceous. In the void-filling material, planktonic foraminifera fossils occur scattered and neritic benthic forminifera are also observed rarely. In parts of the coral voids, blocky calcite cement is observed. This indicates exporure on land. The following 3 groups are recognized in the planktonic foraminifera assemblage. ①Small with trochoid rotating thin shell (genus Globigerina), ②with biserial form (genus Chiloguembelina), ③thick shell and large specimen (genus Subbotina or Globigerinatheka). All of these groups, however, have simple form and species cannot be determined. Groups indicating middle Eocene were not found in the thin section, thus it is believed that the assemblage indicate late Eocene to early Oligocene (35.3～28.5 Ma) age. Therefore, this sample is believed to have been exposed on land after formation of coral reef in shallow sea in Middle Jurassic to Middle Cretaceous, and then subsided in late Eocene～early Oligocene to deep sea but above CCD where pelagic sediments deposited.	
4		AD05	Fr01	1128	Coral rudstone, blocky calcite fills the voids in coral fossils.	Coral fossils include reef-building coral (*Placocoenia* ? SP.). Thus the depositional environment of limestone is inferred to be reef flat or reef slope of shallow sea reef. If the determination of genus Placocoenia is correct, the deposition took place in Cretaceous. In the void-filling material, planktonic foraminifera fossils occur scattered and neritic benthic foraminifera are also observed rarely. The following 3 groups are recognized in the planktonic assemblage. ①Small with trochoid rotating thin shell (genus *Globigerina*), ②with biserial form (genus *Chiloguembelina*), ③thick shell and large (genus *Subbotina* or *Globigerinathka*). All of these groups however, have simple form and species cannot be determined. Groups indicating middle Eocene were not found in the thin section, thus it is believed that the assemblage indicate late Eocene to early Oligocene age (35.3～28.5Ma). Blocky calcite cement is observed in the coral voids as in the case of SMC12AD04Fr01, and this sample is believed to have formed in shallow waters in Cretaceous, and after the formation of coral reef it was exposed on land. The study of foraminifera shows that it was in deep sea but above CCD during late Eocene～early Oligocene.	
5			Fr02	1128	Reefal limestone, voids are hardly filled, but Mn crusts are formed around the voids.	Reefal limestone. Voids in the reefal limestone are hardly filled, but Mn crusts are formed around the voids. Fragmented planktonic foraminifera are found in the coral voids in rare cases, and there may be parts filled by calcareous sediments. Coral are of Cretaceous age, but the age of the microfossils are not known.	
6		AD09	Fr01	1173	Coral rudstone. Blocky calcite cement and calcareous sediments containing large amount of foraminifera fills the coral voids.	Contain massive reef-building coral (Multicolumnastrea SP.). This sample also is considered to have formed in the reef flat or reef slope from being a reef, building coral. Genus Multicolumnastrea indicate Cretaceous Period formation. The voids in coral fossils are filled by pelagic calcareous sediments. Planktonic foraminifera occur sporadically in these fills and also neritic benthic foraminifera are included. The planktonic foraminifera fossil assemblage include the following 3 groups as in the case of SMC12AD04Fr01. ①Small with torchoid rotating thin shell (genus *Globigerina*), ②with biserial form (genus *Chiloguembelina*), ③thick shell and large (genus *Subbotina* or *Glogigerinatheka*). Here, again, determination of species is difficult. Species belonging to middle Eocene are not found in this section and the age is believed to be early Oligocene (33.8～28.5Ma). Blocky calcite cement is found in the coral voids. Thus, this sample is also inferred to have formed in shallow sea as coral reef during Cretaceous exposed on land and subsided into deep sea in early Oligocene.	
7			Fr02	1173	Wackestone containing coral and shell fragments. Reefal limestone was brecciated and pelagic limestone filled the interstices forming matrix.	Fragments of reef-building coral branches are contained, but they are too small for identification. Reefal limestone was brecciated and pelagic limestone filled the matrix. Parts where pebbles are concentrated and where matrix dominate are observed in thin section. A large part of planktonic foraminifera occurs in matrix with rare occurrence of neritic benthic fossils. The major constituent of planktonic assemblage in the matrix dominant part is genus *Globigerina* with small and somewhat thin trochoid rotating shell. It is considered to be *Globigerina. praebulloides* and *G. ouachitaensis*. On the other hand, in parts with pebble concentration, many fossils have somewhat shell crust and are large. They are considered to belong to genus *Subbotina*, but the form is simple and identification of species is difficult. Fossils indicating middle Eocene were not found in thin sections and this assemblage is believed to be of early Oligocene age (33.8～28.5Ma). The depositional environment is inferred to be above CCD off coral reef. It is inferred that pelagic limestone containing reef-building corals was brecciated through same process, their surface covered by Mn, and then pelagic calcareous sediments containing planktonic foraminifera deposited in early Oligocene.	
8		AD13	Fr01	2308	Wackestone. Consists of limestone pebbles obtaining neritic fossils. The boundary between pebbles and matrix is not clear.	This sample is limestone conglomerate containing shallow sea fossils. The boundary between pebbles and matrix is not very clear. Planktonic and neritic benthic foraminifera occur sporadically and these are believed to be in matrix. Planktonic assemblage has large amounts of specimens with biserial form (genus *Chiloguembelina*) and large specimens with rather thick shell (genus *Subbotina*), and rarely planispiral specimen (genus *Pseudohastigerina*) is observed. *Nummulite* spp. was confirmed in benthic foraminifera. In this thin section, fossils indicating geologic age earlier than middle Eocene were not found. Thus this assemblage is also believed to indicate early Oligocene age (33.8～28.5Ma).	

Table 4-6-2(2) Results of Fossil Identification in Rocks and Bottom Sediments

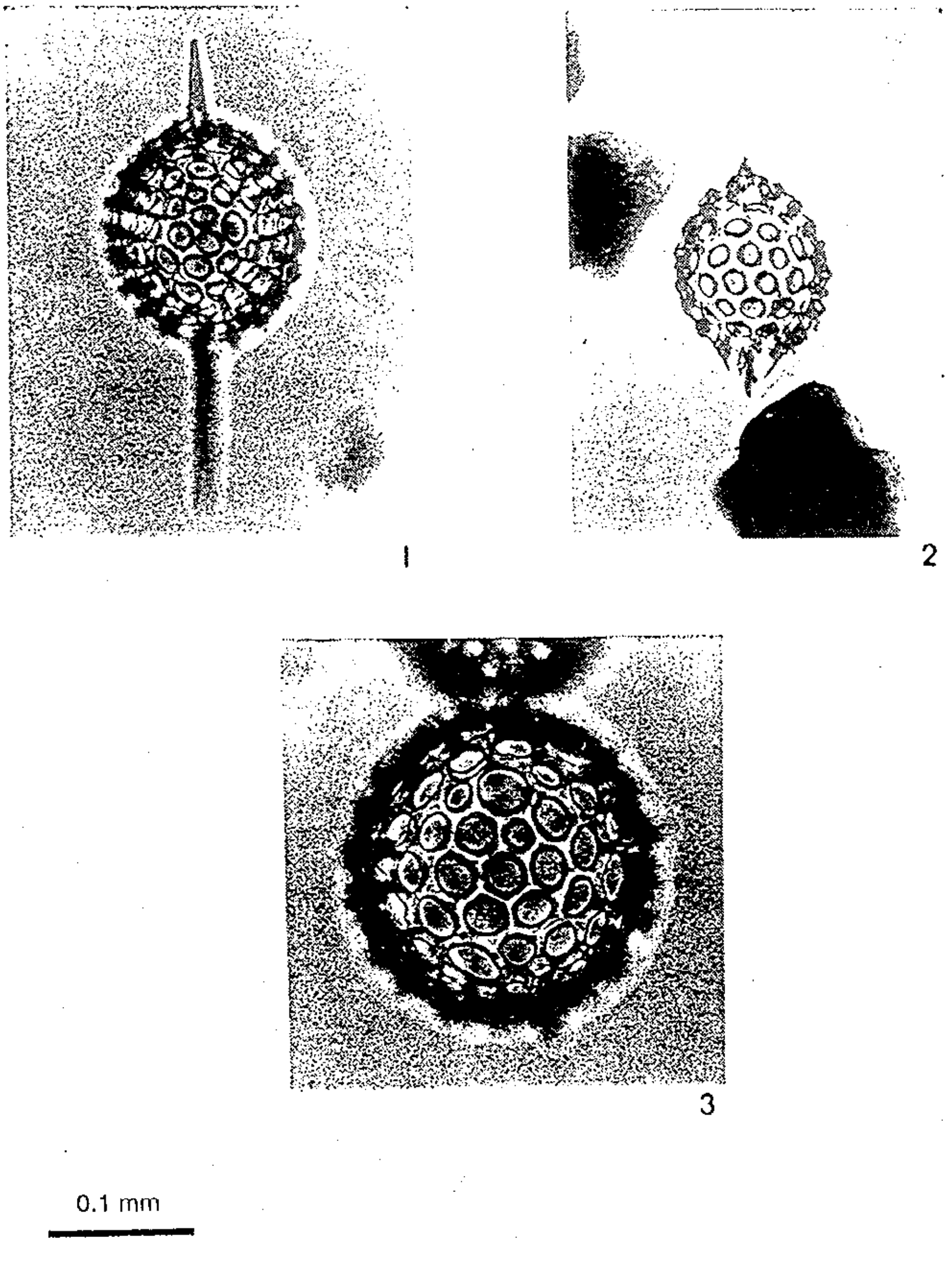
No.	Sampled locality	Sampling	Sample number	Water depth (m)	Unaided eye observation	Identified fossils	Remarks
9	SMC13	AD02	Fr01	1795	Pelagic limestone. Volcanic pebbles of 1cm size occur rarely.	This sample consists of pelagic limestone, but rarely contains 1cm pebbles of volcanic rocks. Planktonic foraminifera are abundant, but benthic ones occur only rarely. The planktonic fossils are believed to be genus *Rotalipora* because many have keel, but species cannot be determined. *Hodbergella* and *Globigerinelloides* are also found, but they are not abundant. *Rotalipora* has a range zone from Albian to Cenomanian (102～91Ma) (Caron, 1985; Grandstein et al., 1995; Braloower,1995) and the age of this sample is Late Cretaceous.	Of the rocks dredged near this seamount, pelagic limestone (AD02, 1,795m) is early Late Cretaceous (Albian～Cenomanian), but chert (AD12, 2,007m) is Early Cretaceous (late Valanginian). Thus the ages of the volcanoes which form the basement of the above rocks could be different. On the other hand, the age indicated by foraminifera fossils in Mn crusts and limestone (late Eocene) is the time of either brecciation or of deposition of calcareous sediments over bedrock. Thus this seamount is inferred to have formed during Cretaceous as in the case of SMC12 and began subsidence simultaneously (late Eocene).
10		AD12	Fr01	2007	Chert containing calcareous components. Weak laminated generally developed.	Most of the fossils in the thin section are radiolaria with rare occurrence of shell judged to be foraminifera. Grains interpreted to be terrigenous clastics occur only rarely. These facts indicate pelagic sedimentation of the rock. The preservation of calcareous shells such as foraminifera show that deposition took place near CCD or shallower sea. Separated radiolaria assemblage is shown in Table 5. From the Co-existing period of these radiolaria, the geologic age is judged to be late Berriasian to early late Valanginian in Cretaceous of the 16 taxa inculuded, the range of 6 taxa has relatively high accuracy. The Co-existing period of these 6 taxa is from middle Berriasian to early late Valanginian, but as *Pantanellium: berriasianum* Baumgartner does not occur, the period can be limited to late Berriasian to end of middle Valanginian. Further, *Pantanellium corriganeusis* Pessagno is said to have a range limited to late Valanginian (Pessagno, 1997). This type of range has not been verified later and the reliability is unknown, but if this range is correct, the age of the radiolaria in the sample can be limited to early late Valanginian. This age is not contradictory to the age of species unrelated to the age determination. The site of deposition is believed to be pelagic and at or shallow than CCD. That site probably was located at low latitude. The lack of 2 genuses *Eucyrtidiellum* and *Solenotryma* (matsuoka, 1998) which did not exist in low latitude are as in late Jurassic to early Cretaceous also strongly suggest deposition at low altitude, 2～3cm thick Mn crust and limestone covers the chert mass. Chert itself consists of early Cretaceous (late Valanginian) radiolaria, but the remnant sand after chemical treatment contain fair amount of planktonic and benthic foraminifera. Planktonic fossils include *Catapsydrax unicavus, "Globigerina" ampliapertura, Subbotina corpulenta, Globoquadrina venezuelana, Turborotalia cerroazulensis*. of these, *T. cerroazulensis* become extinct near the Eocene/Oligocene boundary (33.8Ma). The occurrence of this species and the complete lack of middle Eocene Eocene. Therefore, the age of the planktonic foraminifera is not that of the chert itself, but the age of the limestone which attached to the chert after brecciation. On the other hand, regarding benthic foraminifera, *Bathysiphon* spp. with tube form was discovered. This suggests the existence of environment exceeding CCD, and it indicates the mixture of material both deeper and shallower than CCD in the crust and limestone.	



Scale bars: 100 μ m

1. Globigerinoides fistulosus (Schubert). Umbilical view, Sample from 98SMC11LC01Fm02.
2. Globigerinoides conglobatus (Brady). Umbilical view, Sample from 98SMC11LC01Fm02.
3. Sphaeroidinella dehiscens (Parker and Jones). Umbilical view, Sample from 98SMC11LC01Fm02.
4. Globorotalia tumida (Brady). Umbilical view, Sample from 98SMC11LC01Fm02.

Fig. 4-6-1 Species of the Typical Foraminifera Fossils



Scale bars: 100 μ m

1	*Axoprunum stauraxonium* Haeckel	98SMC11 LC01 Fm02
2	*Ellipsoxiphus atractus* Haeckel	98SMC11 LC01 Fm02
3	Actinommidae *sp.*	98SMC11 LC01 Fm02

Fig. 4-6-2 Species of the Typical Radiolarian Fossils

The seamounts in MC12 and MC13 areas are believed to have formed before Late Cretaceous, but MC13 seamount is inferred to have formed earlier. Also the subsidence of MC13 seamount is believed to have taken place before that of the MC12 seamount.

Regarding MC11 seamount, bedrocks of the summit periphery is inferred to have been exposed before Pliocene because late Pliocene (2.0～3.12Ma) foraminifera fossils occur in the bottom sediments from immediately above the bedrock 65cm below the depositional plane of the summit periphery. Although this fact does not necessarily mean that the bedrock was exposed from the cessation of subsidence to Pliocene, it does show that rocks were exposed for a certain period of time. Thus there is a possibility of crust occurrence below the sediments. The sedimentation rate of unconsolidated sediments such as foraminiferal sand is slow at 0.3mm per 1,000 years, and the environment was favorable for crust formation.

In MC12 area, early Miocene (23.8 ～ 16.4Ma) foraminifera fossils were confirmed from consolidated clay rich in manganese oxides from the seamount base. If cobalt-rich crusts were formed by precipitation from sea water, the precipitation was greater during this period than in normal times.

4 - 7 Summary of Each Area

MC11 area

Basalt and foraminiferal calcareous conglomerate are generally distributed on this seamount.

Basalt is olivine basalt and is classified as oceanic island alkali basalt. It is fine-grained, compact with plagioclase, olivine, and clinopyroxene phenocrysts. Weathering is generally strong, and argillization is observed in both phenocrysts and matrix. Also vesicles and voids are filled by clay and other material.

Foraminiferal calcareous conglomerate have different lithology from those on the summit and those on the slope. Those from the summit contain very little pebbles and are compact and hard, while those from the slope contain many basalt angular fragments and the matrix is fragile merely cementing the pebbles.

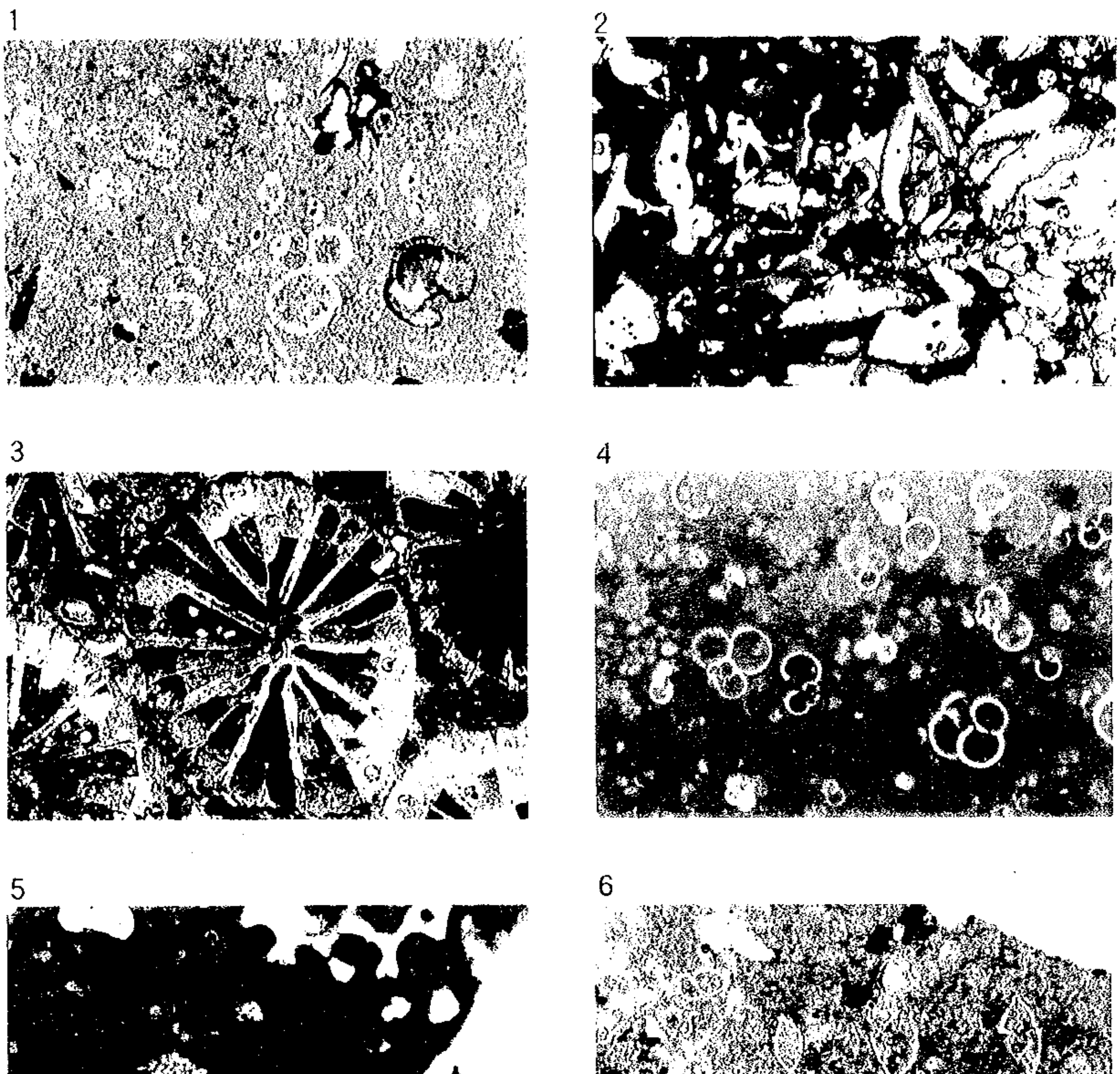
The seamounts of this area are considered to have been formed by hot spot volcanism and subsequently subsided to the present water depth. Fresh basalt for age determination and limestone useable for fossil identification were not collected from this area and thus age determination could not be carried out. However, the seamount age is inferred to be older than early Paleogene, from comparison with the age and chemical composition of basalt samples collected from the vicinity.

Regarding unconsolidated sediments, foraminiferal sand covers the whole seamount. The deposit on the central part of the summit is particularly thick and attains 60m. But exposures are observed near the pinnacles on the summit and in parts of the periphery of the summit.

MS13 area

Basalt and foraminiferal calcareous conglomerate are generally distributed on this seamount. Also tuff breccia is observed on the western upper slope.

Basalt is mostly aphyric, and is classified as oceanic island alkali basalt. Some minute plagioclase,



1. Planktonic foraminifera (generic name unknown)(98SMC12AD04)
2. Coral (generic name unknown)(98SMC12AD05)
3. Coral (Multicolumnastrea sp.) Cretaceous (98SMC12AD09)
4. Planktonic foraminifera (Globigerina) Early Pleistocene (98SMC12AD09)
5. Benthonic foraminifera (Nummulites spp) Early Pliocene(98SMC12AD13)
6. Radiolarite (Rotalipora) Late Cretaceous (98SMC12AD02)

Fig.4-6-3 Photographs of microfossils in limestone and chart

olivine, augite phenocrysts are observed microscopically. Weathering is generally strong and both matrix and phenocrysts are argillized. Also basaltic hyaloclastite is observed in the depressions between the pinnacles.
Foraminiferal calcareous conglomerate contains large amount of angular basalt fragments, and the matrix is fragile merely cementing the pebbles.

This seamount is considered to have formed by hot spot volcanism, and subsequently subsided to the present water depth. As in the case of MC11 area, it was not possible to obtain rock samples for age determination, and the age of these rocks are not known. But the REE pattern of the basalt is similar to the basalt samples from the nearby seamounts, and if the origin of the basalt of these seamounts is similar, the age is believed to be before Paleogene.

Regarding unconsolidated sediments, clay containing foraminiferal sand is distributed over the whole seamount, but exposed rocks are observed near the pinnacles on the summit. The sediments in the depressions between the pinnacles are relatively thin.

MC12 area

Reefal limestone occur above 1,900m water depth and basalt is distributed below this depth. Basalt occurs throughout the seamount. Foraminiferal calcareous conglomerate is confirmed in the summit and middle slope, and tuff breccia in various parts of the slope, but both of these rocks are considered to have limited distribution.

Most of the basalt is aphyric with rare occurrence of the rock with minute plagioclase phenocrysts. This rock is chemically classified as oceanic island alkali basalt. Microscopically major part is volcanic glass. Fresh grayish black samples were collected from various parts of the slope. The K-Ar age is 71.1± 3.6Ma.

Reefal limestone is coarse-grained, porous, and contains many biological fragments such as shells. Middle Jurassic to Cretaceous fossils are confirmed in the reef-building corals. And late Eocene～early Oligocene planktonic foraminifera are found in the fillings of the voids.

The seamount of this area is considered to have been formed by hot spot volcanism which is inferred to be before Middle Cretaceous from age determination and fossil identification. At its formation, the summit was at a depth favorable for coral reef formation, and the seamount probably subsided slowly during Cretaceous allowing the reef to develop. Then rapid subsidence took place, and the present water depth was attained in late Eocene (38.6～35.4Ma).

Reflecting the oceanic ridge-type seamount topography, unconsolidated sediments consisting of foraminiferal sand and calcareous clay occur only locally.

MC13 area

Basalt occurs throughout the seamount, and foraminiferal calcareous conglomerate occur widely on the summit. Mudstone, chert, and tuff were collected, but the occurrence is believed to be local.

Basalt is largely divided into dolerite and pyroxene basalt. Dolerite is distributed from the northern slope to the summit, while pyroxene basalt occurs in the eastern slope. Dolerite samples were measured for K-Ar age determination and chemically analyzed. It is classified as P-type MORB and the age is 56.8 ± 2.8Ma.

There are two types of foraminiferal calcareous conglomerate, that with compact and hard matrix and that with soft matrix merely capable of cementing the pebbles. The pebbles are basalt, and those from the summit are mainly subrounded while those from the slope are mainly angular. Late Cretaceous foraminifera fossils are obtained from the compact, hard rock. Chert from the summit contain Early Cretaceous radiolaria fossils. Late Eocene planktonic foraminifera fossils have been confirmed from the foraminiferal calcareous conglomerate containing chert pebbles.

The results of microfossil identification indicate that there are two volcanoes which form the bed rock of the seamount. One volcano was formed before Early Cretaceous, and the other in Late Cretaceous. The age of the dolerite is believed to correspond to the latter volcano. Basalt considered to be of the earlier volcano, however, has not been collected.

The present survey area, is considered to be the product of the movement of the Pacific Plate after the formation of the seamounts by hot spot volcanism before Early Cretaceous. During this process, new volcanism occurred in Late Cretaceous and dolerite formed by this activity occur in various part of the seamount. The Late Cretaceous volcanism is of P-type MORB and thus is not a hot spot activity. It is probable that the volcanism accompanied the formation of faults which correspond to the northern steep slope. The fact that the fossil age of the matrix of the foraminiferal calcareous conglomerate and that of the chert differ, is considered to be the evidence of rapid subsidence of the seamount after late Eocene.

Unconsolidated sediments are thick on the seamount summit, but exposed rocks are observed on the ridge topography on the northern side of the summit and the continuing steep northern slope.