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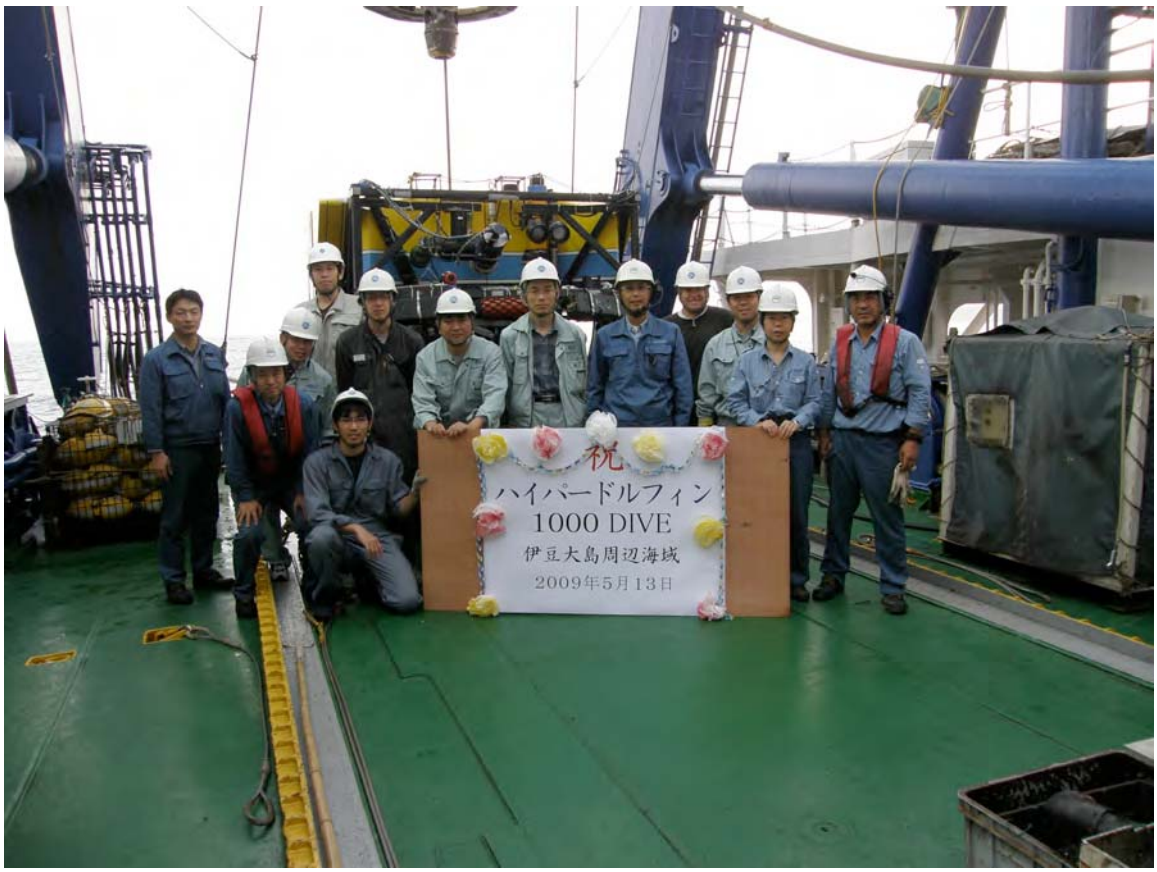
CRUISE REPORT
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
R/V Natsushima
Cruise NT09-06 Leg-2

Revealing long-distance lateral magma transport within oceanic island arc crust by investigating magma plumbing system of Izu Oshima volcano

May 6 to May 17, 2009

(JAMSTEC to JAMSTEC)



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1. Introduction

Long-distance lateral magma transport within the crust has been recognized in various geological settings. Giant dike swarms are one of the most spectacular examples [*Ernst and Buchan*, 1997]. Magma produced by upwelling mantle plumes may be transported within the crust for several hundreds to more than 1000 km [*Elliot et al.*, 1999; *Ernst and Baragar*, 1992; *Riley et al.*, 2006]. This long-distance transport appears to be mainly caused by topographic doming associated with magma emplacement and high magma supply rate[*Baragar et al.*, 1996; *Fialko and Rubin*, 1999]. Lateral magma transport is also recognized in volcanic rift zone of oceanic island volcanoes (Hawaii, Canary Islands, etc.:[*Ryan*, 1988]), mid oceanic ridges (e.g., [*Dziak et al.*, 1995; *Sinton et al.*, 2002; *Smith and Cann*, 1999]) and continental rift zones (e.g., [*Wright et al.*, 2006]). In these environments, magma transport is important for the growth of volcanic edifices, morphology of rift zones, and oceanic crust formation.

Compared to the above-mentioned tectonic settings for long-distance lateral magma transport, it is not clear if similar phenomena occur in island arc environments. Recent geophysical observations of basaltic composite volcanoes in the Izu-Bonin arc suggest that long-distance lateral magma transport may also occur within the shallow - lower crust of an oceanic island arc. Northwestward migration of earthquake swarms from Miyakejima volcano was observed when it erupted in 2000 [*Geshi et al.*, 2002; *Toda et al.*, 2002]. Seismic activity began beneath Miyakejima volcano and migrated about 30km northwestward for 6 days. This event was accompanied by ground deformation in the northern Izu arc area [*Nishimura et al.*, 2001]. A minor submarine eruption occurred off the west coast of Miyakejima. These events are interpreted to reflect northwestward dike injection from Miyakejima volcano, i.e., long-distance magma transport [*Geshi et al.*, 2002; *Nishimura et al.*, 2001; *Toda et al.*, 2002]. Earthquake swarms northwest of Miyakejima volcano continued for 1.5 months, implying continuous magma transport toward northwest at a depth range between 12 and 20km [*Kodaira et al.*, 2002; *Nishizawa et al.*, 2002].

This magma transport triggered caldera collapse (Miyakejima 2000: [*Geshi et al.*, 2002]). Similar migration of earthquake swarms was observed for Hachijojima volcano in 2002. Again earthquakes migrated about 20 km NNW from Hachijojima volcano (Nishiyama volcano). Associated with these earthquake swarms, very-long-period seismic signals were detected, which were interpreted to be resonances of dike filling with basaltic magma. This earthquake swarm was also associated with ground deformation, explained by 2 stages of dike injection and associated shrinkage of a subvolcanic magma reservoir [*Kimata et al.*, 2004].

These dike injection events in the Izu-Bonin suggest that long-distance magma transport could be common in the oceanic island arc setting and exert significant control on volcanism and arc crustal growth.

Long-distance magma transport has been inferred by geophysical observation. However no direct evidence of magma transport such as genetic linkage of magma of frontal arc volcano and transported magma has been petrologically demonstrated.

It is clear from the example of the Izu-Bonin system that arc volcanism is not restricted to a limited zone around each volcano. Large volumes of magma can be transported great distances in all directions. This magma dispersion is not just important in terms of volcanic hazards. It is also highly significant in estimates of the material transfer in subduction zones. The composition of the volcanoes and the crust they sit on is variable between the trench and the back-arc. So can we apportion how much of each type of volcano makes up the products of the subduction system? What is needed is a clear estimate of the relative volumes of each volcanic component. In the case of the main arc volcanoes it would seem likely that their contribution may be radically underestimated as much of their magma has been secreted in the crust. The research proposed in this joint project will lead to a more realistic estimate of the output from the subduction system by accounting for the hidden magma component. This information will be important in evaluating future deep drilling results from the Izu-Bonin back-arc region.

2. Scientific Objectives:

This study is the first attempt to investigate submarine edifices of Izu-Oshima volcano. Final goal of this study is 1) to obtain geological and petrological evidence of long-distance lateral magma transport, 2) to present a comprehensive model for the magma plumbing system of Izu-Oshima volcano incorporating lateral magma transport.

We recently demonstrated that long-distance lateral magma transport actually occurred at the Hachijo-Nishiyama volcano (Fig. 1: Ishizuka et al., 2008). At Hachijojima, 2 types of magma transport in the arc crust were recognized. Primitive magma was laterally transported NNW for at least 20km in the middle to lower crust (10-20km deep) from Nishiyama volcano with only minimal crustal-level modifications and formed Hachijo NW chain. On the other hand, magmas experienced crystal fractionation and accumulation at shallow magma chamber beneath Nishiyama volcano seems to have been transported in a short distance (<5km) and formed NE-trending edifices and subaerial satellite cones. The long-distance magma transport seems to be controlled by a regional extensional stress

regime, while short distance transport may be controlled by local stress regime affected by load of main volcanic edifice.

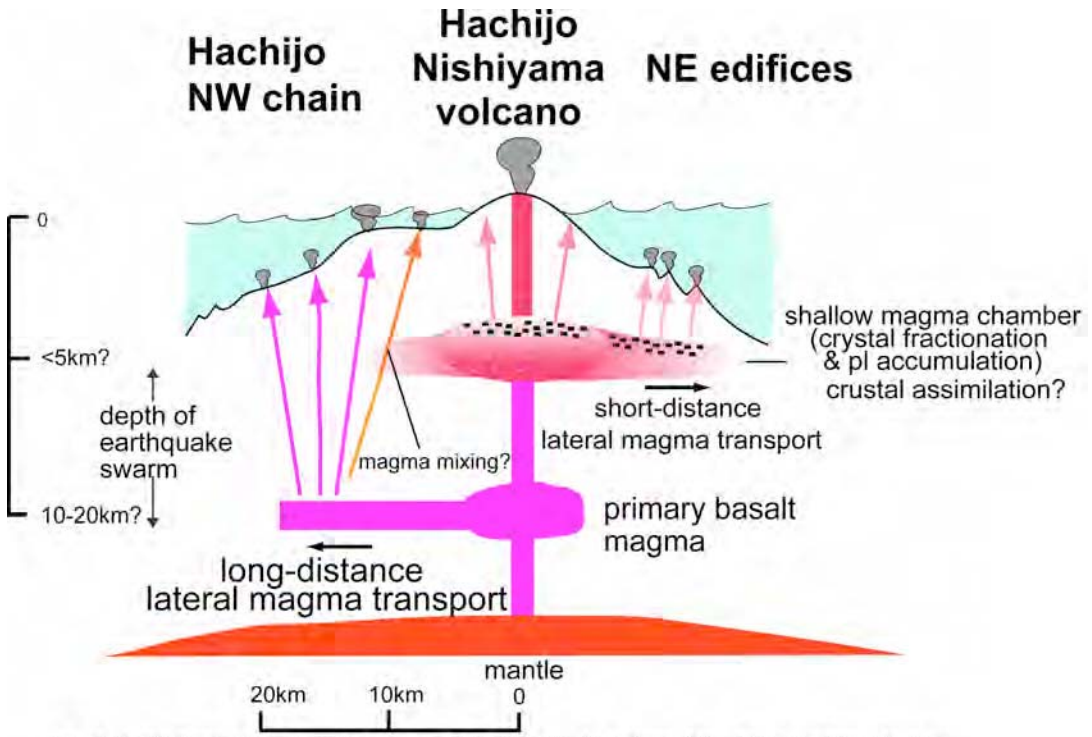

Fig. 1 Model for magma plumbing system of the Hachijo NW chain, NE edifices and the Hachijo Nishiyama volcano. The Hachijo NW chain magma is not transported from the shallow magma chamber of the Nishiyama Volcano, but transported in a long-distance in the middle to lower crust (at c.10-20km depth inferred by depth of hypocenters [Kimata et al., 2004]. The magma erupts without being affected by extensive crystal fractionation and accumulation in the crustal magma chamber.
The NE edifices magma could be supplied by the lateral magma transport from the shallow magma chamber, where crystal fractionation and plagioclase accumulation are taking place.

Then how about the other volcanoes in the Izu-Bonin arc such as Izu-Oshima? Izu-Oshima volcano has lines of vent of fissure eruptions. Recent bathymetric survey revealed that a number of NW-SE trending ridges and chains of knolls extend as long as 15km from NW and SE coasts of the Island. These bathymetric features might be chains of volcanic edifices formed as a consequence of long-distance lateral magma transport. We plan to investigate these possible submarine edifices around Izu-Oshima volcano as well as subaerial satellite cones.

Dives of ROV hyperdolphin were designed to:

1) conduct a systematic sampling of (in situ) volcanic effusives from submarine edifices.

2) observe the mode of occurrence of effusives, stratigraphic relationships among the edifices.

3) find structural features such as faults, fissures, dykes etc. that are indicative of ground deformation possibly caused by injection of magma into crust (i.e., magma transport).
4) determine parameters of structural features (dip, strike, offset etc….)

A bathymetric survey using SEABAT8160 was conducted during the night hours when Hyper Dolphin was not deployed. The survey was planned to complete the SEABAT coverage around Oshima, filling the major areas where data has not already been collected.

Main objectives of the dives are:
1) understand distribution of submarine edifices.
2) define major structural features around Oshima, enabling us to recognize the tectonic mechanisms which transport magma and create volcanic edifices..
3) Compile a backscattered image to identify the distribution of lava flows, scoria cones, etc. and also estimate age (stratigraphic relationship) of volcanic edifices and effusives.

3. Geological background

Izu-Oshima volcano

The Izu Oshima volcano is a basaltic stratovolcano located in the northern part of the Izu-Bonin arc system. The volcano is located at about 100km SSW of Tokyo and one of the most active volcanoes in Japan. It is an oval-shaped island elongated in NW-SE axis (15km x 9km). The elevation of the island is 764m a.s.l. but the volcanic edifice height s over 1000m from sea floor. The volcano has the high Bouguer anomaly type caldera in the summit. Inside the caldera, there is a central cone, Mt. Mihara.

Magmatic products of Izu Oshima volcano are low-K tholeiitic basalt to andesite. They normally contain plagioclase, clinopyroxene and orthopyroxene, and occasionally olivine as well. Mg values of the lavs generally decrease from older through younger. This may reflect a progressive fractional crystallization of basaltic magma in shallow, relatively homogeneous magma chamber.

The Izu-Oshima volcano began its activity at about 40000-50000 years ago. A pre-caldera Older Edifice is mainly composed of coarse pyroclastics derived from explosive eruptions in shallow water.

From about 20000 years ago, the eruptions have been relatively moderate and produced many scoria and ash fall deposits. These deposits form the Younger Edifice.

There are many flank volcanoes forming fissures, scoria cones, tuff cones and maar near shore. In particular there is a lineation of satellite cones extending in NNW-SSE directions.

About 1300-1500 years ago, following a scoria eruption from the summit and flank eruptions at several locations, a large phreatic eruption occurred in the summit area resulting in pyroclastic flow deposits (S2) covering almost all the island. The present shape of the caldera is thought to have been formed by this eruption. After the S2 eruption, eleven eruption cycles have been recognised. The mass of these eruptions is several hundred million tons and the average interval between events is 100 to 150 years.

In 1986, the latest eruption began with fire fountaining at Mt. Mihara on Nov. 15. On Nov. 21, after the short repose of activity, fissure eruptions occurred in the northwestern caldera floor. As the fissure extended outside the caldera, lava rushed down towards the largest city, Motomachi. Eruption ceased in the morning of Nov. 22.

No surface activity other than fumaroles has occurred after the small eruption of Oct. 4, 1990. However, earthquakes and volcanic tremors are sometimes recorded, and slow inflation of the volcano continues.

The submarine part of Izu-Oshima Island

Izu-Oshima extends to the NW and SE as a series of submarine ridges and chains of small knolls. To the NW of the island, at least 4-5 linear ridges can be recognised. These ridges appear to be composed of an aggregation of small knolls with heights of 50-100 m and basal diameter of around 300-1000m. These ridges extend up to 15km from the NW corner of the Oshima Island. Among these ridges is the Nishi-Chigasaki Knoll, which is exceptionally large, with a relative height of c. 450m and basal diameter of 3km. Three to four NW-SE trending ridges can be recognised on NW and SE slopes of this knoll.

To the SE of the Island, the Habu Spur extends southeastwards for about 10km. This spur is composed of 2 subparallel chains of knolls. Each of these knolls is has a relative height of 70-250m and basal diameters between 0.5-1.6km. In addition there are at least 3 short chains of knolls to the north of Habu Spur, on the eastern slope of the island.

West of Oshima, a NNW-SSE trending ridge called the Senba Spur is the most prominent bathymetric feature. It has a wide, shallow crest very gentle slopes on its flanks. The northernmost part of this spur is overlapped with by the NW-SE trending ridges , implying these ridges were formed after the Senba Spur.

Northern and eastern slopes of the island contrast with the other sides as they are characterized by well-developed gulleys and ridges related to submarine erosion. No volcanic cones or chains of vents have been recognized on these slopes.

This cruise aims to focus on the investigation of the volcanic ridges and knolls in NW and SE slopes of Izu-Oshima Island.

4. Cruise narrative and schedule of operations

NT09-06_Leg2 Cruise log

Date&Time (UTC+9:00)		Events	Area	Noon weather
2009.5.6	11:00	Scientists onboard	JAMSTEC	
	14:00-14:30	Briefing about safety and onboard life		
	16:00-17:00	Meeting		
2009.6.7	8:00	Departure from JAMSTEC	Stay in the Tokyo Bay	r/NE/5/3/1/7
	18:00-19:00	Meeting		
2009.5.8	14:00	Weigh anchor		o/calm/0/1/0/7
	18:00-19:00	Meeting		
	20:41	XBT		
	21:10	Start SEABAT bathymetric survey		
2009.5.9	4:07	Stop SEABAT bathymetric survey		bc/South/2/2/2/7
	5:55	XBT		
	8:15	HPD#991start diving	NW of Izu Oshima	
	8:59	Landing (811m)		
	13:55	Leave the bottom (693m)		
	14:23	Surface		
	15:34	HPD#992 start diving	NW of Izu Oshima	
	16:03	Landing (1,105m)		
	17:22	Leave the bottom (869m)		
	17:44	Surface		
	19:58	Start SEABAT bathymetric survey		
	20:00-20:30	Meeting		
2009.5.10	3:35	Stop SEABAT bathymetric survey		bc/South/5/4/2/7
	8:12	HPD#993 start diving	NW of Izu Oshima	
	8:45	Landing (771m)		
	13:13	Leave the bottom (505m)		
	13:33	Surface		
	14:54	HPD#994 start diving	NW of Izu Oshima	
	15:25	Landing (658m)		
	17:30	Leave the bottom (671m)		
	17:51	Surface		
	20:00-20:25	Meeting		
	20:02	Start SEABAT bathymetric survey		
2009.5.11	3:21	Stop SEABAT bathymetric survey		m/ESE/3/2/2/3
	8:29	HPD#995 start diving	NW of Izu Oshima	
	9:00	Landing (564m)		
	12:41	Leave the bottom (246m)		
	12:51	Surface		
	14:09	HPD#996 start diving	NW of Izu Oshima	
	14:43	Landing (884m)		
	17:18	Leave the bottom (768m)		
	17:40	Surface		
	20:00-20:20	Meeting		
	20:03	Start SEABAT bathymetric survey		
2009.5.12	5:21	Stop SEABAT bathymetric survey		c/SW/5/4/3/5
	6:07	XBT		
	9:45	HPD#997 start diving	SE of Izu Oshima	
	10:07	Landing (447m)		
	13:12	Leave the bottom (159m)		
	13:21	Surface		
	14:39	HPD#998 start diving	SE of Izu Oshima	
	15:08	Landing (562m)		
	17:16	Leave the bottom (317m)		
	17:28	Surface		
	18:22-18:31	SEABAT bathymetric survey		
	20:00-20:20	Meeting		

Date&Time (UTC+9:00)		Events	Area	Noon weather
2009.5.13	10:06	HPD#999 start diving	SE of Izu Oshima	c/SW/6/4/3/6
	10:45	Landing (534m)		
	13:34	Leave the bottom (267m)		
	13:44	Surface		
	15:12	HPD#1000 start diving	SE of Izu Oshima	
	15:33	Landing (503m)		
	17:18	Leave the bottom (351m)		
	17:33	Surface		
	19:51	Start SEABAT bathymetric survey		
	20:00-20:30	Meeting		
2009.5.14	5:20	Stop SEABAT bathymetric survey		bc/SSW/5/3/3/7
	8:14	HPD#1001 start diving	NW of Izu Oshima	
	8:49	Landing (802m)		
	13:04	Leave the bottom (690m)		
	13:25	Surface		
	14:44	HPD#1002 start diving	NW of Izu Oshima	
	15:11	Landing (599m)		
	17:25	Leave the bottom (465m)		
	17:40	Surface		
	20:00-20:15	Meeting		
	20:29	Start SEABAT bathymetric survey		
2009.5.15	6:02	Stop SEABAT bathymetric survey		bc/ESE/3/2/2/7
	8:14	HPD#1003 start diving	SE of Izu Oshima	
	8:31	Landing (357m)		
	12:00	Leave the bottom (173m)		
	12:15	Surface		
	13:50	HPD#1004 start diving	SE of Izu Oshima	
	14:12	Landing (358m)		
	17:57	Leave the bottom (203m)		
	18:00	Surface		
	20:00	Meeting		
	20:02	Start SEABAT bathymetric survey		
2009.5.16	4:40	Stop SEABAT bathymetric survey		o/SSE/4/2/2/7
		HPD#1005 start diving	SE of Izu Oshima	
		Landing (m)		
		Leave the bottom (m)		
		Surface		
		Stop SEABAT bathymetric survey		
		HPD#1006 start diving		
		Landing (m)		
		Leave the bottom (m)		
		Surface		
		Meeting		
2009.5.17	9:00	Arrive at JAMSTEC		
		End of cruise		

Weather

f= fine / bc=fine but cloudy / o=overcast / c=cloudy / r=rain / m=mist

Wind speed index

0 = 0 - 0.2 m/sec. / 1 = 0.3 - 1.5 / 2 = 1.6 - 3.3 / 3 = 3.4 - 5.4 / 4 = 5.5 - 7.9 / 5 = 8.0 - 10.7 / 6 = 10.8 - 13.8 / 7 = 13.9 - 17.1 / 8 = 17.2 - 20.7 / 9 = 20.8 - 24.4 / 10 = 24.5 - 28.4 / 11 = 28.5 - 32.6 / 12 = 32.7 –

weather /wind direction /wind speed index /wave /swell/visibility(n. mile)

5. Operations and data processing information

Hyper Dolphin usually dove with payloads that included six rock sampling basket, two MBARI-type cores and one M-type sampler, and one lidded box in the sample basket, as well as a temperature probe and water samplers mounted on the body of Hyper-Dolphin.

Data and samples from the dives were archived as customary. Half of all samples will be archived at JAMSTEC.

6. Dive results

Summaries of the results of each dive as well as all dive locations are included in this chapter.

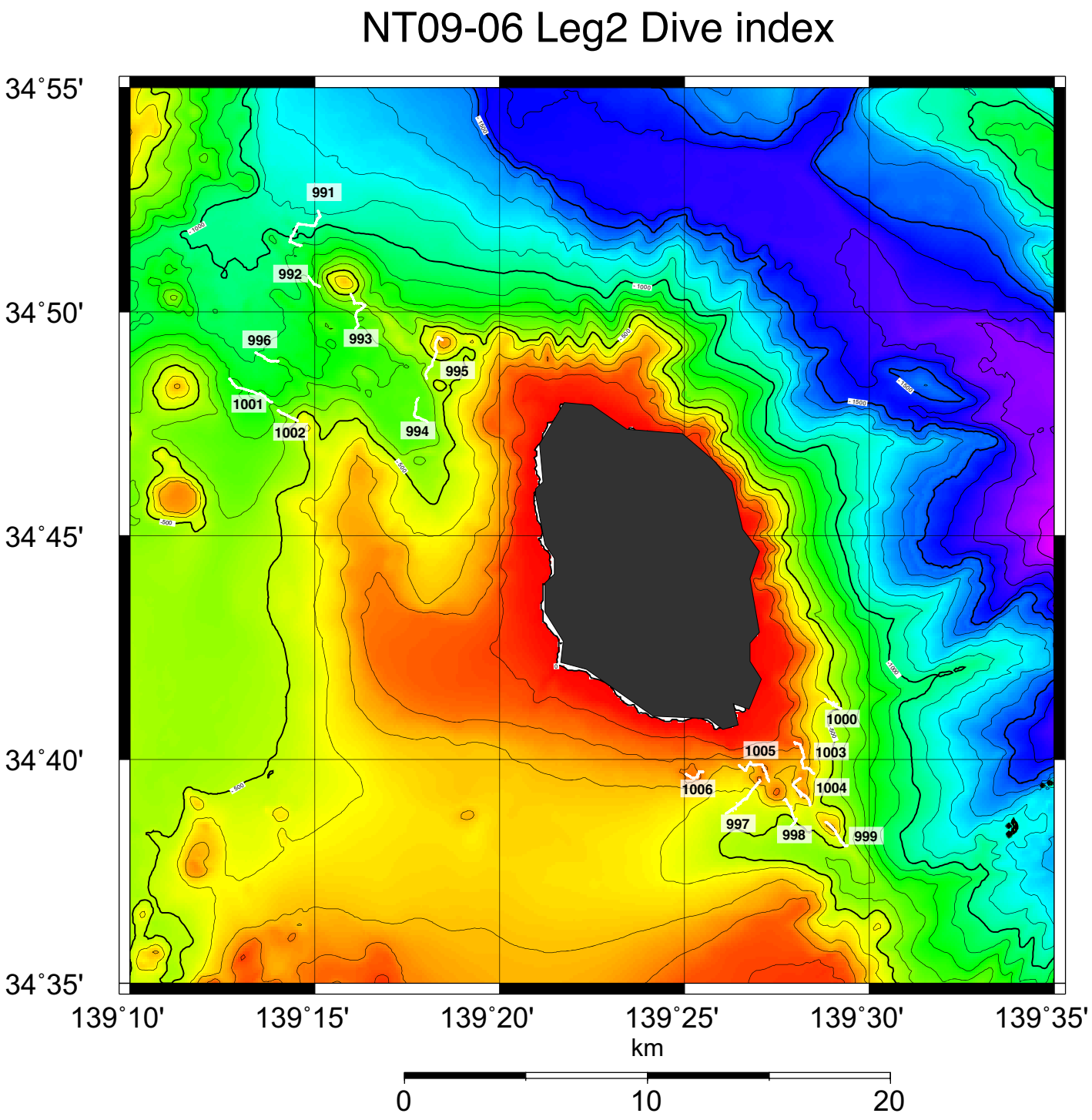

Fig.6-1 Dive locations during NT09-06 Leg2.

Dive 991

Technical information:

Location: NW off of Izu-Oshima, Northwestern rift of Izu-Oshima Volcano
Objective: Map and sampling along a lower part of NW rift

Dive 991	On bottom:	Off bottom:
Time(local)	08:59	13:55
Latitude:	34°52.248′ N	34°51.478′ N
Longitude:	139°15.086′ E	139°14.641′ E
Depth (m):	1105	869

Samples returned: 17 rocks

Scientific summary

The objective of this dive is geological observation and collection of petrologic samples from the far-side of the northwestern volcanic chains of Izu-Oshima, focusing the structural relationship between the NW-tending volcanic chains and Nishi-Chigasaki Knoll. The dive area is set in the northwestern foot of Nishi-Chigasaki Knoll, where at least four minor volcanic chains trending NW-SE are recognized. The dive track is divided into three sections to survey four ridges.

The first section of the dive track started on the northwestern slope of Nishi-Chigasaki Knoll, 1105 m deep, and crossed a minor ridge. The dive track passed through the slope consisting of lava blocks partly covered with fine-grained deposit. Some of the blocks show broken pillow-structure. The samples collected from this ridge are comprised of porphyritic basalt, containing olivine and plagioclase crystals as phenocryst. The crystals form clot. Typical size of phenocryst clot is 3 – 4 mm.

Then, the dive sifted to the foot of the second minor ridge, 0.6 km west of the first one, and climbed the northern slope of the ridge. The northern slope of this ridge is comprised of the outcrops of pillow lava and its breccia. Flow direction of pillow lobes are from south to north. Large plagioclase crystals ranging 6 mm characterize the samples from this ridge (R09-11).

The dive sifted to the northern foot of the third minor ridge, at 0.5 km south of the second ridge, and climbed the northern slope of the ridge. The slope of the third ridge also consists of pillow lavas and pillow breccia talus. The top of the ridge is covered with angular large lava block and possibly spatters, indicating the eruption vents. All the rocks collected from this ridge (R12-16) are plagioclase-phyric basalt. Plagioclase crystals max. 6 mm.

Finally, the vehicle traversed the slope to the foot of the fourth minor ridge sitting between the second and third ones. The slope of the fourth ridge consists of pillow lavas and pillow breccia. Plagioclase-phyric basalt is collected from this ridge (R17).

We conclude from this dive that all the ridges we visited are eruption fissure consisting of pile of pillow lava and breccia of plagioclase-phyric basalt. Thin sediment cover and fresh-looking of the samples without weathering and manganese coating indicate that these eruption fissures are recent products. Petrographycal character of the first ridge is distinguishable from other three ridges with the smaller size of phenocryst and presence of mafic phenocryst. We could not clarify the

relationship between these eruption fissures and Nishi-Chigasaki Knoll, because we could not reach the junction point between these two volcanic structures.

Dive 992

Technical information:

Location: NW off of Izu-Oshima, Northwestern rift of Izu-Oshima Volcano
Objective: Map and sample along a lower part of NW rift

Dive 992	On bottom:	Off bottom:
Time(local)	16:03	17:22
Latitude:	34°50.784′ N	34°50.562′ N
Longitude:	139°14.820′ E	139°15.124′ E
Depth (m):	811	693

Samples returned: 7 rocks

Scientific summary

The aim of this dive is to make geological observation, and collect petrologic samples from a NW-SE trending ridge on the western flank of Nishi-Chigasaki Knoll and the western slope of Nishi-Chigasaki Knoll itself. The dive track started at the northern foot of the ridge, 811 m deep, and climbed to the northern slope of the ridge. Then the track traversed along the northern side of the ridge toward the junction of the ridge and the knoll.

We could observe piles of pillow lava, pillow breccia and spatter blocks during the whole dive track on the ridge. Orientations of the elongated pillows in N-S direction indicate that these pillows flew down from the summit of the ridges. All the samples collected from the ridge consist of plagioclase-phyric basalt with 6-7 mm across crystals. These samples are very fragile owing to the development of cooling joints and high vesicularity. We crossed the boundary between the ridge consisting of pillow lavas and blocky slope partly covered with sediments, possibly the slope of Nishi-Chigasaki Knoll, around 700 m deep. The sample (R07) collected from the slope is plagioclase-phyric basalt with mafic phenocrysts, clearly different from the samples from the ridge.

The result of this dive indicates that the petrographycal difference between the NW trending ridges and Nishi-Chigasaki Knoll. As the result of Dive 991, NW trending ridge is an eruption fissure produced spatters and pillow lava in recent age. The dive observation suggests that the ridge is younger than the knoll.

Dive 993

Technical information:

Location: NW off of Izu-Oshima, Northwestern rift of Izu-Oshima Volcano
Objective: Map and sample along a NW rift and Nishi-Chigasaki Knoll.

Dive 993	On bottom:	Off bottom:
Time(local)	8:45	13:13
Latitude:	34°49.612′ N	34°50.390′ N
Longitude:	139°16.089′ E	139°15.973′ E
Depth (m):	771	505

Samples returned: 17 rocks (lost 3 samples)

Scientific summary

The objective of this dive is geological observation and collection of petrologic samples from the northwestern volcanic chains of Izu-Oshima, focusing the structural relationship between the NW-trending volcanic ridges and Nishi-Chigasaki Knoll. The dive began from about 1nm south of Nishi-Chigasaki Knoll, 771m deep, and climbed toward the north. The track first crossed or traced three NW-SE trending volcanic ridges and the junction of the ridge and the knoll, then climbed the southern slope of the knoll.

We could observe pillow breccias, polygonal lava blocks and spatters at the NW-SE trending ridges. We could observe several steep collapsed? wall and piles of pillow breccias or spatters are exposed. Very thin sediments cover these ridges. All samples from the NW-SE trending ridges are plagioclase-phryric basalt sometimes with very small amounts of olivine phenocryst.

As ascending from the ridge to Nishi-Chigasaki Knoll, the petrographical character changed dramatically. The samples collected from the upper southern slope of the knoll are plagioclase-phyric basalt with many (about 3 to 5 vol.%) mafic phenocrysts. The many mafic phenocrysts bearing basalt only found in the upper slope of the knoll and lower slope are covered by mafic phenocryst-poor basalt from the ridge. It suggests that the ridge is younger than the Nishi-Chigasaki Knoll.

Dive 994

Technical information:

Location: NW off of Izu-Oshima, Northwestern rift of Izu-Oshima Volcano
Objective: Map and sample along a NW rift.

Dive 994	On bottom:	Off bottom:
Time(local)	15:25	17:30
Latitude:	34°47.535′ N	34°48.035′ N
Longitude:	139°18.048′ E	139°17.771′ E
Depth (m):	658	671

Samples returned: 8 rocks

Scientific summary

The objective of this dive is geological observation and collection of petrologic samples from the northwestern volcanic ridges of Izu-Oshima. The dive began from the eastern end of small ridge, 658m deep, and traced NW-SE trending volcanic ridges. Then heading to the north, we tried to trace sea floor about 670m deep to survey another NW-SE trending ridge and small knoll but cancelled halfway.

We could observe pillow lava, pillow breccias, polygonal lava blocks and spatters at the NW-SE trending ridges. Thin sediments cover these ridges. All the samples from the NW-SE trending ridges are aphyric basalt with small amounts of plagioclase phenocryst.

The flat sea floor, north of the observed ridge, is sandy bottom with dunes. Some lava blocks are observed. The lava sample is a aphyric basalt.

Dive 995

Technical information:

Location: NW off of Izu-Oshima, Northwestern rift of Izu-Oshima Volcano
Objective: Geological observation and sampling of ridges and cones

Dive 995	On bottom:	Off bottom:
Time (local)	09:00	12:41
Latitude:	34°48.508′ N	34°49.369′ N
Longitude:	139°18.033′ E	139°18.452′ E
Depth (m):	564	246

Samples returned: 16 rocks

Scientific summary

The objective of this dive is geological observation and sampling of volcanic rocks from the NW-tending volcanic ridges and Chigasaki Knoll, northwest of Izu-Oshima, focusing on the structural and tectonic relationship among them.

This dive starts from about 1.5km south of Chigasaki Knoll. The vehicle cruised toward the north and traversed two ridges. After that, the vehicle climbed up the south and west slope of Chigasaki knoll. 16 rocks are recovered on this dive. Some of them are fresh spatters. Two samples recovered from first ridge are almost aphyric and contain a small amount of plagioclase. They are moderately vesiculated. Three samples from second ridge show almost the same features as the first ridge. Four samples from south slope of Chigasaki knoll (R06~09) are moderately-plagioclase phyric basalt. In these rocks, phenocrysts of plagioclase up to 1cm were recognized. Small amount olivine phenocrysts are also observed. The other samples recovered from south and west slope of Chigasaki knoll contain a small amount of plagioclase phenocrysts. There is no Higashi-Izu like feature volcanic rocks from this dive.

Dive 996

Technical information:

Location: East of Senba Spur, east off of Izu-Oshima
Objective: Geological observation and sampling of ridge

Dive 996	On bottom:	Off bottom:
Time (local)	14:43	17:18
Latitude:	34°49.088′ N	34°48.901′ N
Longitude:	139°13.401′ E	139°14.011′ E
Depth (m):	884	768

Samples returned: 9 rocks

Scientific summary

The objective of this dive is geological observation and petrologic sampling of volcanic rocks from the ridge extending from Senba Spur.

This dive starts from northwest of Senba Spur, east of Izu-Oshima. From the northwest end of ridge, the vehicle cruise along the ridge axis to the tip of the SenBa Spur. Relatively thick deposits covered the slopes. On this dive, nine volcanic rocks are recovered. Most of them are spatters. They are homogeneous in their petrographic features. They are nearly aphric with small amount of plagioclase and moderately vesiculated. Some of them rarely contain large plagioclase phenocrysts up to ~1cm in diameter. There is no Higashi-Izu like feature volcanic rocks in this dive.

Dive 997

Technical information:

Location: SE off of Izu-Oshima: Ridges to the southeast of Izu-Oshima Volcano
Objective: Map and take samples of one NW-SE ridge.

Dive 997	On bottom:	Off bottom:
Time(local)	10:07	13:13
Latitude:	34°38.797′ N	34°39.540′ N
Longitude:	139°26.123′ E	139°27.040′ E
Depth (m):	447	159

Samples returned: 9 rocks

Scientific summary

The objective of this dive is geological observation and collection of petrologic samples from the westernmost of the two NW-SE volcanic chains extending southeastwards from Izu-Oshima. The dive was initiated on the NW side of a ridge located 2km ESE of the prominent knoll at 34°39.25N 139°27.55E and was set to progress for ~3km to the NW, ending at the furthest of two small knolls at 34°39.57N 139°27.15E.

On reaching the bottom at the start of the dive track the sea floor was flat and covered with fine sand and lapilli. The dive track then passed over around 1km of similarly level, sandy sedimented bottom, with areas of ripple marks. Occasional rounded blocks are observed on the sandy bed. 100m after the start of the dive track, a group of 10 rounded boulders were observed on the bed. One of these was sampled, and found to be aphyric basalt cobble. Due to the smooth rounded form and the lack of any other similar rocks in this area, this sample could be interpreted as either a clast washed from Izu-Oshima, or a rock-weight from a fishing basket. Another round boulder was sampled after another ~100m (R02). This was found to be granite. Again, it was interpreted that this boulder was not in situ and may represent marine ballast offloaded from a ship.

As little exposed volcanic rock was observed, the ROV was flown to points 3, 4 then 5 on the dive plan. Each location revealed a rippled, sand and lapilli covered seabed. A sub-rounded boulder was collected at point 5, and found to be plagioclase porphyritic basalt with large vesicles. This may be a boulder that has rolled off the surrounding knolls into this basin. It is different from the other samples collected after this point in having plagioclase, olivine and pyroxene phenocrysts.

After this the dive track ascended a ridge composed of blocks and lapilli size scoria, which were collected as samples R04 to R06. These are highly vesicular (25-45%) and are around 2-5% plagioclase phyric. At water depth 280m, a large lava lobe was sampled from the ridge, with extrusion grooves on its contorted surface. This was of the same sparsely plagioclase phyric composition.

The dive track continued up the ridge, ascending to a water depth of 177m, collecting samples R07, R08 and R09 progressively up to the summit. All of these samples are sparsely plagioclase phyric basalt. The exposures are all 10-40cm blocks of scoriaceous basalt with a finer disaggregated lapilli size matrix. One of the exposures near the top of the ridge is shown below. The head-on current experienced

throughout the dive made progress slow and the original dive plan had to be curtailed due to time constraints.

Dive 998

Technical information:

Location: SE off of Izu-Oshima: Ridges to the southeast of Izu-Oshima Volcano
Objective: Map and take samples of one NW-SE ridge.

Dive 998	On bottom:	Off bottom:
Time(local)	15:08	17:16
Latitude:	34°38.506′ N	34°39.110′ N
Longitude:	139°27.888′ E	139°27.723′ E
Depth (m):	562	317

Samples returned: 5 rocks

Scientific summary

The objective of this dive is geological observation and collection of petrologic samples from the westernmost of the two NW-SE volcanic chains extending southeastwards from Izu-Oshima. The dive commenced on the edge of a ridge extending SE from the large knoll at 34°39.25N 139°27.55E.

Initially the dive track extended northeaswards directly up the ridge. This area is covered in a blanket of lapilli size fragments with occasional blocks exposed. A sample taken from the first significant exposure was a large block of vesicular, sparsely plagioclase phyric basalt (R01). Similar samples were collected further up slope and were of the same composition and form. Towards the top of the ridge crest, the dive track turned to move along the ridge axis. At this location, the nature of the exposure changed to a rugged bathymetry with a narrow spine of lava separated by 1-3m deep gullies to the sides. This may represent a fissure eruption centre along the axis of the ridge; perhaps much of the scoriaceous material observed and sampled on the flanks of the ridge may originate from this fissure.

Due to time constraints Hyper Dolphin was flown along the ridge axis – progress had been slow due to a head on current direction. Two more samples were collected (R06 and R07) close to the base of the large knoll. These were of a similar composition and character to the fissure basalts sampled in the earlier part of the dive. As time ran out, there was no opportunity to sample near the summit of the large knoll.

Dive 999

Technical information:

Location: SE off of Izu-Oshima, Northwestern rift of Izu-Oshima Volcano
Objective: Map and sample along a lower part of NW rift

Dive 999	On bottom:	Off bottom:
Time(local)	10:45	13:34
Latitude:	34°38.086′ N	34°38.602′ N
Longitude:	139°29.411′ E	139°28.829′ E
Depth (m):	534	267

Samples returned: 15 rocks

Scientific summary

The aim of this dive is to make geological observation, and collect petrologic samples from a NW-SE trending ridge and cone, which form Habu Spur in the SE off of Izu-Oshima. The track began at the side of minor but clear ridge and traced the ridge axis. Then HPD climbed up to a cone.

We found very fresh scoriaceous spatters and bombs entire the track except for the northern flank of the cone, at where the sandy deposit covers the bottom. Sizes of large spatters exceed 1 meter and very high vesicularity. The rocks collected during this dive are relatively aphyric except for R01 with plagioclase-phyric basalt which is collected at the foot of the ridge.

The result of this dive indicates that the ridges and cone is a series of a volcanic fissure with very young age. The pile of large spatters with very high vesicularity indicates the vigorous fountaining eruptions from the ridges.

Dive 1000

Technical information:

Location: Off of Fudeshima coast, SE off of Izu-Oshima
Objective: Map and sample along the satellite cones SE off of Izu-Oshima

Dive 1000	On bottom:	Off bottom:
Time(local)	15:33	17:18
Latitude:	34°41.143′ N	34°41.360′ N
Longitude:	139°29.411′ E	139°28.811′ E
Depth (m):	503	351

Samples returned: 15 rocks

Scientific summary

The aim of this dive is geological observation and collection of petrological sample from a small ridge at the off of Fudeshima coast, SE of Izu-Oshima. This ridge has two peaks aligning WNW-ESE. This memorable dive began at the eastern foot of the ridge and climbed up to along the ridge, and finally reached the western top of the hill.

We found very fresh scoriaceous spatters and bombs at the summit area of both hills. Size of the spatters reaches 0.5 – 1.0 m. These blocks have fresh-looking and are very fragile. Particularly at the summit of the western hill, we encountered thick pile of spatters and bombs. We found an outcrop of coarser-grained strata of volcaniclastic materials overlaid by a scoriaceous bed. We found that sandy sediment thickly covers the col between two hills. The rocks collected from these hills are almost aphyric, with small amount of plagioclase and olivine crystals as phenocrysts.

The observation during this dive indicates that these hills at the eastern slope of Izu-Oshima also satellite eruption fissures in recent age.

Dive 1001

Technical information:

Location: NW off of Izu-Oshima, NW tip of Senba Spur.
Objective: Map and sample along a NW-SE trending ridge

Dive 1001	On bottom:	Off bottom:
Time(local)	8:49	13:04
Latitude:	34°48.505′ N	34°47.986′ N
Longitude:	139°12.698′ E	139°13.833′ E
Depth (m):	802	690

Samples returned: 11 rocks

Scientific summary

The aim of this dive is to make geological observation, and collect petrologic samples from a NW-SE trending ridge and knoll on the NW of Senba Spur. The dive track started at the northern foot of the small NW-SE elongated knoll, 802 m deep, then the track traversed along the NW-SE trending ridge.

We could observe piles of pillow lava, pillow breccia blocks during the whole dive track on the ridge. All these pillow lavas are covered with thin sediments and without alteration. Orientations of the elongated pillows and flow striations on the surface of pillow lobes indicate that these pillows flew down from the summit of the ridges. All the samples collected from the ridge consist of plagioclase-phyric (10 to 20 vol.% of plagioclase phenocrysts) basalt with small amounts (< 1 vol.%) of olivine phenocrysts.

Dive 1002

Technical information:

Location: NW off of Izu-Oshima, NW tip of Senba Spur.
Objective: Map and sample along a NW-SE trending ridge and at knolls

Dive 1002	On bottom:	Off bottom:
Time(local)	15:11	13:04
Latitude:	34°47.802′ N	34°47.570′ N
Longitude:	139°14.005′ E	139°14.532′ E
Depth (m):	599	465

Samples returned: 8 rocks

Scientific summary

The aim of this dive is, as a continuation of the dive #1001, to make geological observation, and collect petrologic samples from a NW-SE trending ridge and knoll on the NW of Senba Spur. The dive track started from the middle of the small NW-SE trending ridge, 599 m deep, then the track traversed along the ridge toward SE and climbed the slope of knoll.

We could observe piles of chilled lava blocks, spatters and bombs during dive track on the ridge. Most lava blocks have ropy and/or cauliflower-like surface, chilled but have rougher surface than common pillow lava. Size of the blocks are smaller than those of the dive 1001, and few large lobate pillow lava. The R01 to R04 samples collected from the ridge consist of plagioclase-phyric (10 to 15 vol.% of plagioclase phenocryst) basalt with small amounts (< 1 vol.%) of olivine phenocryst. They resemble to the samples collected from dive #1001.

At the lower slope of knoll, we could observe piles of relatively massive angular lava blocks (R05 and R06). As the HPD ascend, we observed piles of more vesicular lava blocks or spatters (R07 and R08). Both massive and vesicular samples are pyroxene – plagioclase phyric basalt with small amount of olivine. They are different from the samples from ridge.

The result of the dive #1001 and #1002 indicates that the ridge is made of plagioclase-phyric basalt, and knoll is made of pyroxene-plagioclase phyric basalt. There are no cover of the pyroxene-plagioclase phyric basalt on the ridge, thus the ridge is younger than the knoll.

Dive 1003

Technical information:

Location: northwest of Habu spur, Southwest of Izu-Oshima,
Objective: Geological observation and sampling of ridge

Dive 1003	On bottom:	Off bottom:
Time (local)	08:31	12:00
Latitude:	34°39.687′ N	34°40.388′ N
Longitude:	139°28.513′ E	139°27.988′ E
Depth (m):	357	173

Samples returned: 10 rocks

Scientific summary

The objective of this dive is geological observation and sampling of volcanic rocks from the northwest trending ridge, north-south trending volcanic chain, and knoll located at the southwest of Habu bay.

This dive starts from the few km southeast of Habu bay. The northwest trending minor ridge was firstly surveyed. Vehicle cruised from southeast to Northwest along the axis of the ridge. Bottom surface was covered with relatively thick deposit. From the first ridge, three fresh spatters are recovered. They are nearly aphyric and contain sparse plagioclase. The north-south trending volcanic chains were secondly surveyed. Three peaks were observed and 4 samples were collected including fresh spatters. They have few % of plagioclase and moderately vesiculated. From the south slope of the knoll located north of north-south trending volcanic chains, some altered samples are recovered. Some of them are altered lapilli aggregate. The survey of the northwest trending ridge extending from the knoll was cancelled, because of the strong current.

Dive 1004

Technical information:

Location: Northeast of Habu spur, Southwest of Izu-Oshima,
Objective: Geological observation and sampling of ridge

Dive 1004	On bottom:	Off bottom:
Time (local)	14:12	17:44
Latitude:	34°38.984′ N	34°39.583′ N
Longitude:	139°28.403′ E	139°28.134′ E
Depth (m):	358	203

Samples returned: 13 rocks

Scientific summary

The objective of this dive is geological observation and sampling of volcanic rocks from the knolls located at northwest of Habu spur. The dive starts from few km southeast of the Habu bay. The vehicle climbed up southwest slope of the first knoll. The slope was covered with lapilli size scoria. Five samples, mainly fresh spatters, are recovered from the southwest slope of the knoll. They contain a small amount of plagioclase phenocrysts and some of them contain spare olivine. The small ridge existing on the northwest extension of knoll was secondary surveyed. They show almost the same features as first knoll. We have collected four fresh spatters from this ridge. These samples are almost aphyric containing only sparse plagioclase. The knoll located the north was surveyed from southwest. The southwest slope was covered with sandy lapilli and some spatters were recovered. At the final landing point, huge jointed lava (~140kg) was recovered.

Dive 1005

Technical information:

Location: SE off of Izu-Oshima: Ridges and knolls to the southeast of Izu-Oshima Volcano
Objective: Map and take samples of knolls and a NW-SE ridge.

Dive 1005	On bottom:	Off bottom:
Time(local)	08:39	12:39
Latitude:	34°39.518′ N	34°39.876′ N
Longitude:	139°27.298′ E	139°26.486′ E
Depth (m):	281	229

Samples returned: 17 rocks

Scientific summary

The objective of this dive is geological observation and collection of petrologic samples from three tentatively identified ridges extending southeastwards from Izu-Oshima. The dive commenced at the base of the easternmost ridge extending roughly N-S to the north of the landing point at 34°39.7N 139°26.9E. At this point the ridge was covered with sub-rounded ~30cm blocks and lapilli-sized clasts. The second ridge contrasts in having what appears to be large rounded blocks of lava. Steep-sided exposures of this lava are draped by dark lapilli sized scoria. The final westernmost ridge is similar in appearance, again having a blocky appearance with exposures surrounded by lapilli. The areas between the ridges were overflown to save time, but it was noted that between the eastern and the central ridges there was no visible exposed lava; just a ripple-marked lapilli covered floor.

The majority of the samples from the first section of the dive (the easternmost ridge) are 2-6% plagioclase phyric with vesiculation between 10-40%. Some samples towards the top of this ridge are highly vesicular, up to 70%. Samples from the westernmost ridge (R15 and R16) are similarly plagioclase phyric, but also have subordinate amounts of clinopyroxene. These later lavas are more coherent and could represent a different intrusive/extrusive episode relative to the more easterly ridges.

Dive 1006

Technical information:

Location: SE off of Izu-Oshima: Small knoll and ridge to the south of Izu-Oshima Volcano
Objective: Map and take samples of knoll and ridge.

Dive 1006	On bottom:	Off bottom:
Time(local)	14:24	17:27
Latitude:	34°39.736′ N	34°39.672′ N
Longitude:	139°25.503′ E	139°25.058′ E
Depth (m):	214	116

Samples returned: 11 rocks

Scientific summary

The objective of this dive is geological observation and collection of petrologic samples from a small knoll with a bathymetric outline of a breached cone. Further samples were to be taken from a ridge extending to the NW from this cone.

The dive commenced at the base of the cone. Here the seabed was ~70% covered with dark, scoria lapilli, which appeared to bury large blocks of lava. The dive path extended up the cone to the west where the proportion of blocks increases until a sheer 10m exposure of massive coherent lava is exposed. This appears to be part of a fissure/ridge eruption sequence extending to the NW. These fissures are a common feature of this dive section, breaking up the sequence of coherent lava exposures.

In the later part of the dive, the dive path extends around the cone along a ridge to the NW. A notable feature of this section of the cone is that the lava appears to have a greater covering of coral and other materials. This implies that the western sector of the cone is older than the east. The final section of the dive (waypoint 7-8) consists of large blocks, >50cm, but are similarly adorned with large amounts of slimy biology and coral.

Petrologically, all of the lavas sampled in this dive are 5-10% phyric, with plagioclase the dominant phase and olivine subordinate. No significant difference was observed between the ridges through the course of the dive. The phase ratios are on average plagioclase:olivine = 0.95:0.05. Vesiculation is around 15-20% in most of the lavas.

7. Bathymetric survey

During the NT09-06 Leg 2 cruise, bathymetric data were collected using a SeaBat 8160 multi-narrow beam echo-sounder system, which has frequency of 50 kHz beams and a swath width of 150°. The survey was conducted in nighttime during 5/8/2009 5/16/2009. Mean ship's speed during the survey was 8 kt (14.8 km/h). These data fill gaps of swath coverage of previous cruises (e.g. NT04-ENG) in NW of Izu-Oshima and provide new coverage for other areas around the island (Fig. 7-1). A complete data set of swath bathymetry in the study area was obtained.

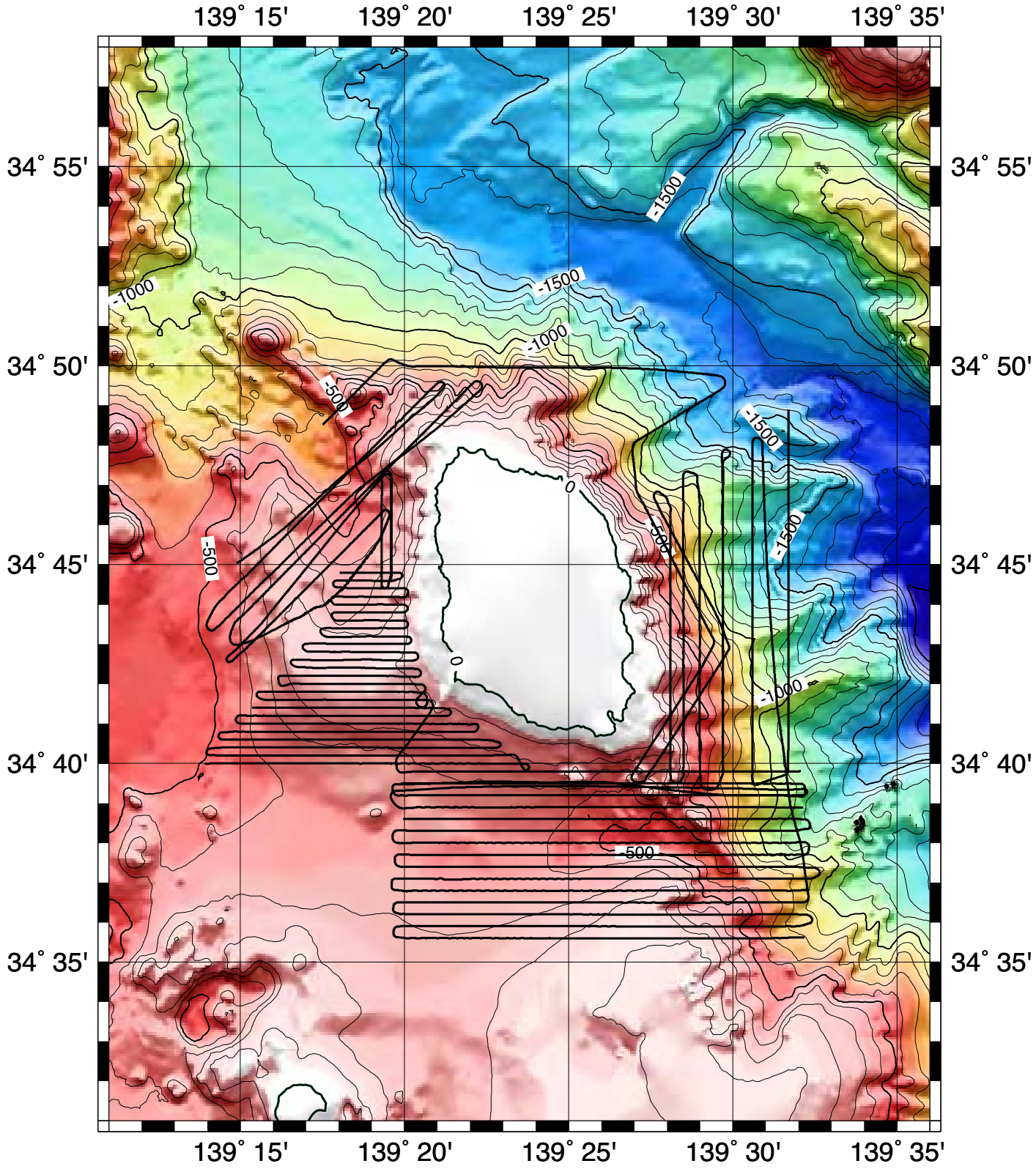

Fig.7-1 Survey line for bathymetric survey conducted during NT0906 Leg2.

8. Future studies

A comprehensive work plan for the rock samples was developed by the shipboard scientific party. This work will include major element analyses, trace element analyses, geochronology studies, mineral analyses, petrographic characterization, and radiogenic isotope characterization. The work will be completed at the Geological Survey of Japan/AIST, National Oceanography Centre, Southampton (NOCS), Tokai University, and other possible collaborators. Analytical responsibilities include:

•Whole rock chemical composition (XRF, ICP-MS): GSJ
•Mineral chemistry (major elements: EPMA,LA-ICP-MS): GSJ
•Ar/Ar dating and some radiogenic isotopes (Sr, Nd, Pb): GSJ, NOCS
•Hf isotopes (possibly at NOCS)
•melt inclusion studies (including chemical composition, water content): GSJ?

Other shore-based studies include:
•Bathymetric and seismic reflection data will be merged with existing databases and synthesized at GSJ.
•Backscattering image will be generated and synthesized at GSJ.
•Volcanic and geologic synthesis will be done at GSJ and Tokai University.
•Links between crustal structure and characteristics of volcanism will be extensively investigated.

9. Summary

This study is the first attempt to investigate submarine edifices of Izu-Oshima volcano. Final goal of this study is 1) to obtain geological and petrological evidence of long-distance lateral magma transport, 2) to present a comprehensive model for the magma plumbing system of Izu-Oshima volcano incorporating lateral magma transport.

Dives of ROV hyperdolphin were designed to:1) conduct a systematic sampling of (in situ) volcanic effusives from submarine edifices.2) observe the mode of occurrence of effusives, stratigraphic relationships among the edifices. 3) find structural features such as faults, fissures, dykes etc. that are indicative of ground deformation possibly caused by injection of magma into crust (i.e., magma transport). 4) determine parameters of structural features (dip, strike, offset etc….).

NT0906 Cruise Leg2 accomplished 16 dives from May 9 to May 16, 2009. Dive areas are 1) NW of Izu-Oshima Island where NW-SE trending ridges and chains of volcanic edifices are distributed. “Higashi-Izu-Oki” monogenetic volcanoes are also present in this area. 2) SE of Izu-Oshima Island where chains of volcanic edifices extending in SE direction from SE termination of the island.

Major findings of diving survey include:

1) NW-SE trending ridges are eruption fissures, which erupted basaltic spatter and lava flows.

2) Basaltic effusives are petrographically similar among each ridge, while there are some noticeable difference among the chains.

3) Basalts from NW-SE trending ridges and chains of volcanoes are petrographically distinct from those from “Higashi-Izu-Oki” monogenetic volcanoes distributed in the same area (i.e., NW of Izu-Oshima).

4) Most of the NW-SE trending ridge has almost no sediment cover, implying that these eruption fissures are very recent. On the other hand, “Higashi-Izu-Oki” monogenetic volcanoes and some of the cones belonging to the Habu Spur have thicker sediment (mainly volcanic sand), implying older age of these edifices.

A bathymetric survey using SEABAT8160 was conducted during the night hours when Hyper Dolphin was not deployed. The survey was planned to complete the SEABAT coverage around Izu-Oshima, filling the major areas where data has not already been collected.

Some of the major findings of this survey are:

1)There are several volcanic ridges extending in NW-SE direction in NW of Izu-Oshima. These are subparallel. Volcanic chains extend as far as 20km from Miharayama volcano of Izu-Oshima.

2) Trend of volcanic ridges in NW of Izu-Oshima is different from that of those in SE of the island.

3) NW-SE trending ridge overlaps with Higashi-Izu-Oki monogenetic volcanoes. The ridges appear to be younger than the monogenetic cones. The size of Higashi-Izu-Oki volcanoes are generally larger than that of those belonging to NW-SE trending ridges.

4) In SE of Izu-Oshima, there are also several volcanic ridges and chains of cones extending in NW-SE direction.

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