SEAFLOOR HYDROTHERMAL MINERALIZATION IN ARC-BACKARC ENVIRONMENT

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Summary

About 31 seafloor hydrothermal mineralization sites (20 active and 11 inactive) are known in arc-backarc settings of western Pacific margin. They exclusively occur at or above volcanic centers either on backarc spreading axes (n=12), backarc rifts (n=9), or volcanic front (n=10) (Table 1 & Fig. 1). Active sites are classified into black smoker chimney sites (n=8, Temp.=268-400°C), white (clear) smoker sites (n=6; Temp.=119-290°C), and low temperature diffuse flow sites (n=6; Temp.=30-40°C), respectively. We do not yet know the tonnage of these deposits, but large sulfide deposits tend to occur at sites where there is acidic volcanism (3, 4, 12, 18, 19, and 20: the numbers refer to those in Table 1). Acidic magma chambers are likely to be much larger than that of basalt and can sustain high-temperature convection system for a long period of time. They also act as a source of constituent sulfur and metals. Therefore, arc-backarc environment is more favorable for the genesis of economic VMS deposits rather than mid-ocean ridge systems.

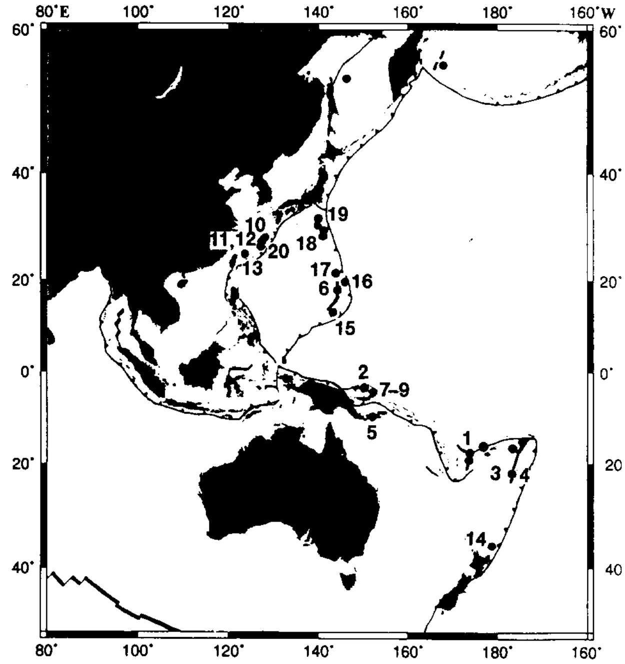

Fig. 1. Active and inactive hydrothermal mineralization sites on the seafloor of the western Pacific rim (modified after Ishibashi and Urabe, 1995). Closed circles with numbers are active sites and are listed in Table 1.

Introduction

About 31 seafloor hydrothermal mineralization sites have been discovered since 1985 when exploration for the hydrothermal activity started in the arc-backarc systems of the western Pacific basin (e.g., Ishibashi and Urabe, 1995). The successful results confirmed a speculation from land-based geology (e.g. Mitchell and Bell, 1973) that arc-backarc environment is a fertile tectonic setting for base- and precious-metal mineralization. Of course, vast majority of the potential sites remain unexplored but present-day equivalents of Kuroko- and Besshi-type volcanogenic massive sulfide (VMS), high- and low-sulfidation-type epithermal gold, and porphyry-copper type deposits are known on the seafloor of the western Pacific.

Variation in magma composition give rise to the variety of mineralization style (e.g., Sawkins, 1990). MORB-like basalt in matured backarc spreading center hosts Cyprus-type mineralization in North Fiji Basin (1, in Table 1) and Manus Basin (2, *ibid*). Barite-sphalerite chimney in Mariana Trough (6) may have chemical influence from deep fluid from subduction zone and is transient from Cyprus- to Besshi-type. Besshi-type deposits

Table 1. Observed Active Hydrothermal Sites in Arc-Backarc Setting of the Western Pacific. Modified and updated from Ishibashi and Urabe (1995).

Backarc Basin or Arc Area (geology) Site Name	Water Depth Latitude Longitude	Assoc. Volcan- ism	Fluid. Temp* (°C)	Mineralogy & Remarks
(Backarc Spreading Centers)				
1. North Fiji Basin Central Spreading Center White Lady Site	1,980m 16°59'S 173°55'E	Basalt	290	Anhy-silica chimney on dead sulfide mound (py, mc, cp, sph, wurz)
2. Manus Basin Manus Spreading Center Viena Woods Site	2,500m 3°10'S 150°17'E	Basalt	302	Many tall chimneys (sph, wurz, py, mc, cp, gn, barite, anhy, silica)
3. Lau Basin Val Fa Ridge Vai Lili Site	1,650m 22°18'S 176°35'W	Basalt -rhyolite	400	Massive ore, chimneys (py, cp, mc, sph, bar) tenn, gn, native gold)
4. Lau Basin Val Fa Ridge Hine Hina Site	1,900m 22°33'S 176°32'W	Andesite- dacite	40	Mn-Fe-oxide coating on fossil sulfide ore (sph, py, cp, bar)
5. Woodlark Basin Franklin Seamount	2,143m 9°55'S 151°50'E	Basaltic andesite	30	Inactive barite-silica chimneys
6. Mariana Trough Central Mariana Trough Alice Spring	3,600m 18°12'N 143°30'E	Basaltic andesite	287	Barite-silica chimneys (sph >> gn, cp, py)
(Backarc Rifting Centers)				
7. Eastern Manus Basin Pual Ridge seamount PACMANUS Site	1,650m 3°42'S 151°43'E	Dacite domes on basalt	268	Several chimneys (cp, bn, tenn, sph, anhy)
8. Eastern Manus Basin DESMOS Caldera Onsen Site	1,980 3°42'S 151°52'E	Basaltic andesite	119	Milky fluid (pH=2) venting from fissures (nativeS, py, mc,anhy)
9. Eastern Manus Basin SuSu Knoll Suzette Site	1,460m 3°48'S 152°08'E	Andesite- dacite	?	cp, py, ba (active venting is ob- served by camera-tow)
10. Okinawa Trough Minami-Ensei Knoll	700m 28°23'N 127°38'E	unknown (acidic?)	278	Anhydrite chimney (anh, sph, wurz) (sedimented rift)
11. Okinawa Trough Iheya Ridge CLAM Site	1,400m 27°33'N 126°58'E	Basalt	220	Calcite crust (anhyd, wurz, po, gn, cp, iso-cubanite)
12. Okinawa Trough North Iheya Ridge	1,000m 27°47'N 126°54'E	Rhyolite- dacite	311	Endeavour-type big sulfide structure (py, bar, native S)
13. Okinawa Trough (southern end) Hatoma Knoll	1,400m 24°51'N 123°50'E	Basalt?	293	Active chimneys on caldera rim (no mineral data)
(Volcanic Front)				
14. Havre Trough Brothers Seamount North Wall	1,650m 34°52'S 179°04'E	Dacite, basalt	?	cp, sph, py, barite (active venting is inferred from plume)
15. South Mariana Arc "B" Seamount Forecast Site	1,470m 13°24'N 143°55'E	Basalt (Island-arc)	202	Anhydrite-barite chimneys (sporadic sulfides)
16. North Mariana Arc No.2 Kasuga Seamount	402m 21°35'N 143°37'E	Basalt & basaltic andesite	39	CO2-SO2-rich diffuse flow (native S, Fe-Mn-oxides)
17. Izu-Bonin Arc Kaikata Seamount Kaikata Caldera	930m 26°42'N 141°05'E	Andesite, basalt	30	Diffuse flow (py, mc). Disseminated veinlets (filling temp=290°C)
18. Izu-Bonin Arc Suiyo Seamount Suiyo Caldera	1,370m 28°34'N 140°39'E	Dacite (low-K ser.)	311	Numerous short (<1m) chimneys (cp, sph, anhy, bar, gold-rich)
19. Izu-Bonin Arc Myojin Knoll Caldera Sunrise deposit	1,360m 32°06'N 139°52'E	Rhyolite (pumice cone)	278	Numerous chimneys (cp, sph, gn, py, mc, barite, gold-rich)
20. Okinawa Trough Izena Caldera JADE Site	1,350m 27°16'N 127°05'E	Dacite	320	Chimneys and crusts (sph, tetrah, gn, bar, cp, py, wurz, anhy, S)

Abbr.: anhy:anhydrite, py:pyrite, mc:marcasite, sph:sphalerite, wurz:wurtzite, cp:chalcopyrite, bar:barite, tenn:tennantite, tetrah:tetrahedrite, gn:galena) are known in association with basalt and/or andesite on backarc rifting centers of Okinawa Trough (11, 13?) and volcanic front of Izu-Bonin Arc (15). Acidic or bimodal volcanism which is characteristic to active backarc rifting or early stage of backarc spreading causes present-day Kuroko-type mineralization in Okinawa Trough (10, 12), Valu Fa Ridge (3,4), and Manus Basin (7, 9) (Ishibashi and Urabe, 1995). Acidic volcanism on volcanic front tends to generate gold-silver-rich ore in Izu-Bonin Arc (18, 19) and Okinawa Trough (20).

High-sulfidation epithermal deposits are found at DESMOS caldera (7 in Table 1) and No. 2 Kasuga Seamount (16, *ibid.*) where end-member fluid contain sulfuric acid (Gamo et al., 1997) which is never observed in mid-ocean ridge (MOR) hydrothermal systems. No gold is observed from these sites but the chemical environment and the alteration mineralogy are quite similar to those of the subaerial high-sulfidation epithermal gold deposits (Gena et al., 1997) which develop above shallow intrusive stocks. Low-sulfidation epithermal example is known at Kaikata seamount (17, *ibid*) where enrichment of gold (0.14 g/t) and silver (1.8 g/t) is observed in quartz-sphalerite veinlets in altered andesite (Urabe et al., 1987).

Fragments of porphyry-copper ore were found from a seamount of dacitic to andesitic composition in backarc knoll zone of the northern Izu-Bonin Arc. The ore is related to tonalitic magmatism (7 Ma) at Manji Seamount (31°52'N, 138°56'E) and is exposed due to later collapse of the volcanic edifice (Ishizuka et al., 1997). Submersible dive observation failed to locate the outcrops on the seafloor, but the example indicates that porphyry-copper deposits occur not only under subaerial condition but also those within seamounts of oceanic island-arcs. Sub-seafloor mineralization such as epithermal gold and porphyry-copper deposits is more difficult to find than VMS and the number will increase as we continue exploration.

It is natural to expect to find sediment-hosted massive sulfide deposits (SEDEX type) which is another common type of seafloor mineralization. The deposits may not be visible from submersible due to sediment cover. However, we have chance to identify its surface expression, because low-temperature seepage sites are usually modified by biological colonies which include giant clams (*Calyptogena*) or tube worms (*Vestimentifera*). There are several tens of such colonies found along faults or cliffs especially in fore-arc region of the western Pacific, but none of them are more than a few degree higher in temperature than ambient seawater if they exist in non-volcanic area. It is too low to expect SEDEX-forming fluid (say, T >100 °C) circulating beneath the seafloor and the deposit might be formed under different tectonic setting such as rifted continental margins. Volcanism is the easiest and only one known way to generate high-temperature fluid convection within the oceanic crust in arc-backarc environment.

Volcanism and mineralization

The high-temperature hydrothermal activity in western Pacific exclusively occurs at volcanic centers either on backarc spreading- or rifting-centers, or on volcanic fronts, regardless of the chemical composition of the magma (Table 1). Discovery of submarine epithermal gold and porphyry-copper deposits indicate that the seafloor hydrothermal system has a potential to form porphyry-copper deposit above magma chambers at depth, epithermal vein deposits during the ascent of the fluid to the seafloor, and VMS deposit on or near the seafloor. This is the unique transition of the mineralization styles in arc-backarc environment which do not exist in MOR systems.

Submarine caldera is the most favorable geologic structure for mineralization as more than 1/3 of known sites have such structure. They include Izu-Bonin Arc (17, 18, 19), Manus Basin (8), Okinawa Trough (13, 20), and Havre Trough (14). Circular fault of the caldera wall provides fracture permeability to focus high-temperature fluid discharge. It also indicates close genetic link between mineralization and post-caldera magmatism. Such a close time-spatial relationship between characteristic volcanism and hydrothermal activity strongly suggests that both present-day and ancient deposits have volcanogenic origin (e.g., Sawkins, 1990).

Comparison with MOR system

The fluxes of mass and heat per unit length of the MOR are proportional to the spreading rate (Baker and Urabe, 1996). However, the tonnage of sulfide ore of the MOR hydrothermal systems show inverse relationship with spreading rate of the ridge (e.g., Fouquet, 1999) and large deposits (>10^6 ton) are found only on slow-spreading or sedimented MORs (e.g., Rona, 1988). The reason for the small sulfide structure at fast- to superfast-spreading MOR is explained by three main reasons: That is, shallow brittle/ductile boundary which limits the size of circulation cell, small axial magma chamber (AMC) which rapidly cools by heat loss from black smokers, and frequent magmatic activity to seal the flow path of fluid circulation. The combination between large acidic magma and caldera structure in arc-backarc environment will be the reason why large VMS deposits on land are associated with acidic volcanism (Rona, 1998; Barrie and Hannington, 1999). Comparison in isotopic composition such as sulfur, carbon, and between fluids, ore minerals and associated magma in well-studied area in western Pacific (e.g., Okinawa Trough, Izu-Bonin Arc) strongly suggests the magmatic origin of these volatile elements. On the other hand, magmatic contribution is not evident in MORs where AMC is under-saturated in terms of H_2O throughout the process of differentiation.

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