Anatomy of methane-seep carbonate mounds in the lower Middle Miocene Bessho Formation, Nagano Prefecture, central Japan

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The lower Middle Miocene Bessho Formation consists of gray massive siltstone deposited on slope to trench in the northern Fossa Magna region during the back-arc opening of Japan Sea. The Bessho Formation is known to intercalate large limestone blocks (the Akanuda and Anazawa Limestones), which yields abundant fossils of chemosynthetic bivalves, such as vesicomyids, lucinids, thyasirids, and bathymodiolins. This study makes clear anatomy of the methane-seep carbonates on the basis of outcrop survey and boring cores, and reconstructs the underground 3-D seep systems of the fossil chemosynthetic community.

The limestone outcrops are in various scales (15 m in maximum length, 10 m in maximum height). Over 10 localities are distributed 350 m along the strike of the surrounding siltstone. The contact between the limestone and surrounding siltstone is gradational and irregular in shape, due to semi-concreted siltstone close to the contact. Semi-concreted siltstone patches are also intercalated in the limestone blocks. This lithological gradation and mosaic complex suggest that the limestone was formed in situ on the muddy slope.

The limestone blocks on outcrop surface are composed of the following three carbonate facies: 1) impure muddy micrite (mixture of dark-brown and bright-grey micrites); 2) veinlet-dominant micrite, composed of brecciated/corroded muddy micritic islands and their surrounding black microsparitic veinlets; and 3) white euhedral calcite veins, 20 cm in maximum width, composed of radiaxial calcite margins and blocky sparite core. The impure muddy micrite and veinlet-dominant micrite are gradational each other and distributed in complex mosaic in decimeter to meter scale, but the white euhedral calcite vein traverses the two lithofacies. Brittle and ductile deformation was observed in muddy micrite and veinlet-dominant micrite, whereas the euhedral calcite veins were not deformed.

In order to confirm the underground structure, a boring core was taken normal to the bedding in the Anazawa Limestone. The micritic limestone extends from the outcrop surface to about 18 m in core-depth, intermittently with intercalations of siltstone patches. The micrite is intensely brecciated and corroded, and their fractures were lined by radiaxial calcite and finally filled by blocky spar. The intercalated siltstone was autobrecciated or underwent ductile deformation. At about 20 m in core-depth, the micritic facies grades into brecciated siltsotne. Large bivalve shells, maybe vesicomyids, are intermittently confirmed from the subsurface micrite to the brecciated siltstone in the gradational zone. Beneath the gradational zone, siltstone continuously extends to the bottom (50 m in core-depth), but brecciation and ductile deformation are common between 20-30 m.

The outcrop and core observations show that the seep-carbonate rooted in underground brecciated siltstone, and grew upwards over 20 m in thickness, intercalating siltstone patches. Brittle and ductile deformation occurs in both micrite and the undergrownd siltstone during the seepage. The seepage was diffusive through high water-content silt, but frequently changed into focused or explosive through the interspaces between subsurface-crusts of lithified micrite, associated with brecciation. The interspaces of both micrite-breccias and underground siltstone-breccias were effective seep-conduits, and made contribution to the upward growth of seep-carbonate.

Abundant vesicomyid shells aggregate both in muddy micrite and the surrounding siltstone, but batymodiolin shell clusters are restricted in the micritic faicies associated with brecciation or network-veinlets. The fossil vesicomyids not only lived in the focused seep-flow between the carbonate crusts, but also used low fluid-flow discharge or relict sulfide in silt surrounding the carbonate mound. On the other hand, the fossil bathymodiolins needed the focused discharge between the carbonate crusts.