論文内容の要旨

論文題目**: An integrated study on the gas hydrate area of Joetsu Basin, eastern margin of Japan Sea using geophysical, geological and geochemical data**

（日本海東縁上越海盆ガスハイドレート地域における地球物理・地質・地球化学データを用いた総合的研究）

氏名**: アントニオ　フェルナンド　メネゼス　フレイレ**

Gas hydrate is an ice-like solid compound composed of methane and water molecules. Since the gas hydrate, often called “methane hydrate”, was found in deep sea sediments in late 1980’s during the Deep Sea Drilling Project, marine gas hydrate has been attracting growing interests from the viewpoint of future natural gas resources as well as environmental mediators as enormous carbon sink. Exploration of marine gas hydrate has rapidly increased our knowledge as to the occurrence, origin and significance both in resources and environmental changes, but, we know little of the mechanism of accumulation and major controlling factors of the emplacement and evolution of gas hydrate system in marine sediments. As a matter of fact, gas hydrate has been often identified by means of anomalous reflectors called BSR’s in seismic profiles, and believed to develop as strata-bound type deposits at around few hundred meters below seafloor. However, recent development of ocean floor observation and marine geochemical studies have revealed various occurrence of gas hydrate in shallow subsurface. Massive gas hydrates sometime expose on the seafloor are concentrate in shallow sediments < 5 meters. Seismic surveys have also identified chimney structures below gas hydrate bearing unit. These findings strongly suggest a formation of gas hydrate deposits in shallow sediments, totally different from strata-bound type deposits of gas hydrate associated with BSRs.

Integrated geological, geochemical, and geophysical exploration since 2004 has identified massive accumulation of gas hydrate associated with active methane seeps on two ridges called Umitaka Spur and Joetsu Knoll in Joetsu Basin, eastern margin of Japan Sea. The ridge structures are asymmetric anticlines formed along an incipient subduction that extends throughout the western side of the Japanese island-arc system, suggesting that the accumulation of gas and gas hydrate in Joetsu Basin is closely, and perhaps genetically related with the tectonics of Japan Sea Basin.

This study has two approaches: one is a tectono-stratigraphy to investigate the geologic background of the formation of shallow gas hydrates. The other is a geochemical aspect to constrain the mechanism of gas migration and accumulation of gas to form gas hydrate in shallow horizons. Discussion on the tectono-stratigraphic control on the gas hydrates of Umitaka Spur is based on 2D single channel seismic profiles. The study recognized chimney structures which seem to be strongly controlled by a complex anticlinal axial fault system. Seismic profiles exhibit high amplitude events with pull-up structures, probably due to massive and dense accumulation of gas hydrate above. BSR's are widely developed, in particular, within gas chimneys and in the gently dipping eastern flank of the anticline of the Umitaka Spur. The spur sediments are largely composed of clayey hemipelagic, while SCS identified several sharp horizons to indicate debris-flow deposits. BSR's are often strengthened within debris-flow units as well as in gas chimneys. Debris flow deposits are expected to contain high concentration of gas hydrate due to high permo-porosity characteristics, and are considered to be a possible target of shallow gas reservoirs.

Methane of gas hydrate has been observed to be of thermogenic with relatively heavy carbon isotopic composition. For comparison, deep subsurface marine gas hydrates as those of Nankai Trough and Blake Ridge, are entirely microbial, no indication of thermogenic. However, the shallow subsurface and even ocean-floor gas hydrate of the Joetsu Basin is mostly derived from deep-seated thermogenic methane. The unique feature of the Joetsu Basin gas hydrate is related with the evolution and tectonics of the eastern margin of Japan Sea.

The axial fault system, the anticline shape, and the permeable horizons as conduits induce gas migration to the top of the Umitaka Spur, providing strong seepages and giant plumes in the sea water column. Well developed conduit system carries large amount of thermogenic methane and forms massive gas hydrate buildup within the shallow part of gas chimney structures. Gas hydrates are also observed associated to debris within the gas hydrate stability zone in the eastern flank of Umitaka Spur, and may represent a potential natural gas resource in the future.

Migration of deep-seated methane has been well documented by organic and inorganic geochemistry of the Quaternary sediments of the Umitaka Spur, which was strongly suffered from sea-level change during the glacio-interglacial cycles.

Geochemical analyses and lithological description were used to understand the late Quaternary depositional history of Joetsu Basin. Geochemistry of sediment samples enabled the characterization of the background signatures and the origin of the organic matter of the Holocene and late Pleistocene sediments, on the basis of $\delta^{13}C_{org}$, TOC/TN and TS/TOC ratios coupled with palynofacies analysis. Based on this study the paleoenvironmental settings of the study area were reconstructed.

The Holocene sediments are characterized by high TOC and TN contents, low TOC/TN and TS/TOC ratios, and heavier $\delta^{13}C_{org}$ values, which indicate a predominant marine organic matter origin, probably due to the warming and inflow of warm ocean and coastal currents along the East China Sea. These currents carried abundant phytoplankton from the Pacific Ocean as a result of the sea level rise. Occurrence of particulate organic matter shows abundant primary productivity during the Holocene under marine conditions. On the other hand, LGM sediments are characterized by low TOC and TN contents, high TOC/TN and TS/TOC ratios, and lighter $\delta^{13}C_{org}$ signatures, which are characteristic of terrestrial organic matter, probably due to seaward migration of shorelines and strong input of freshwater carrying terrestrial materials. This terrestrial influence decreased gradually from the LGM to the Holocene because of the sea level rise and consequent increase in the marine organic matter productivity.

Shallow to surface sediments at seep sites should be identical to the equivalent shallow sediments a bit far from seep sites, however, seep site sediments are greatly depleted in $\delta^{13}C_{org}$ values, followed by high TOC/TN and TS/TOC ratios. These signatures are different from background surface sediments, but quite similar to the geochemical signatures of LGM sediments. Sulfate-methane transition promotes the anaerobic oxidation of methane and the consequent precipitation of carbonates and sulfides, which can explain the elevated TS/TOC ratio observed near seafloor sediments. Moreover it cannot explain the anomalous depleted values of $\delta^{13}C_{org}$ and the high TOC/TN ratio signature, in an opposite trend of the neighboring Holocene sediments.

Anomalous features of seep sites sediments seem to imply migration of sediments as well as water and gas. Deep-seated sediments were migrated upward from deeper horizons to the top of mound-seep sites, showing appearance older and deeper LGM sediments on the seafloor. This mechanism is consistent with the findings of strong “pull-up” structures on seismic profiles. Migration of deeper sediments and gas must have occurred even in deeper and older sequences, which will be confirmed by finding of anomalous geochemical features in deeper horizons.

Keywords: $\delta^{13}C_{org;}$; gas chimneys; gas hydrates; Joetsu Basin; Japan Sea; methane seeps; organic matter; single channel seismic; tephrostratigraphy; TOC/TN; TS/TOC.