Bull. Inst. Oceanic Res. & Develop., Tokai Univ. (2010), 31, 65 − 77

Global Sea Level in the Messinian Stage of the Late Miocene

Masaaki Hanada[1)]

Abstract

The Leg 13 voyage of the Deep-Sea Drilling Project was implemented in the Mediterranean Sea area and the evaporite deposits originating in the Messinian period that were discovered on the deep sea floor in the Mediterranean Sea as a result of the drilling became a focus of worldwide attention. Scientists aboard ship at the time concluded that the evaporite was formed by the lowering of the sea level by as much as 2,000 meters below the current sea level that occurred only in the Mediterranean Sea (Hsü *et al.*, 1977). In other words, they emphasized that the sea level in the Messinian period was 2,000 meters lower than the current sea level only in the Mediterranean Sea.

The author surveyed the initial report of the deep sea drilling results of the DSDP, IPOD and ODP and examined the rise in the sea level in the geological eras. Based on the distribution of shallow sea strata noted in the initial report as thought to have been formed at the site, I concluded that the old sea level at the very end of the Miocene period was about 2,000 meters lower than it is today (Hanada, 2000). The phenomenon of the low sea level in the Messinian period was not only limited to the Mediterranean Sea.

One proof evidencing this is indicated in the results of the deep sea drilling at two drilling sites implemented during the DSDP Leg 13 voyage. One of them is the drilling at site 120 on the Atlantic side across the Gibraltar Strait and the other is that at site 121 implemented in the Mediterranean Sea. The drilling at site 120 was carried out on the northern slope of the Gorringe Bank at the shallowest depth of about 50 m located about 260 miles into the Atlantic Ocean. Based on drilling record, an increase in the sea depth during the Pliocene period and later was evident at the drilling site. That is, site 120 had a sea depth of 1,711 m and Lower Pliocene deposits were found at a depth of about 55 m under the sea bottom. Similar increased sea depth is also seen in the record of drilling at site 121 implemented in the Western Alboran Basin in the Mediterranean Sea. Specifically, Trubian deposits overlapping unconformably on Messinian evaporite in the Mediterranean Sea are said to be abyssal based on the analysis of deep foraminifera and ostracodes contained in the deposits. It is consequently clear at the present time that the Mediterranean Sea was not isolated from the Atlantic Ocean.

1. Introduction

It is widely accepted that the sea-level in the Western Mediterranean in Late Miocene times (the Messinian Stage) was 2000 meters lower than that of the present Mediterranean Sea. This paper sets out to suggest that, in fact, the sea level in the Western Mediterranean was not a local phenomenon, but was part of a global picture.

Hoshino (1962) claimed in the past that the

1) Department of Marine Mineral Resources, School of Marine Science and Technology, Tokai University, 3-20-1 Orido, Shimizu-ku, Shizuoka 424-8610, Japan

(2009年11月11日受付／2009年12月15日受理)

sea-level of the Late Miocene was the uniformity of the water depth of the termination of deep sea canyons, water depth of the upper margins of deep sea terraces and the continental rise found on the seabed throughout the world.

A total of four deep sea drillings have been made in the Mediterranean Sea, the DSDP Leg 13 in 1970, DSDP Leg 42A of 1975, Leg 107 in 1987 and ODP Leg 161 in 1995. Among these, the discovery of evaporates of the Messinian Stage from the deep seabed in the Mediterranean Sea on Leg 13 Cruise, the first drilling cruise in the Mediterranean Sea, attracted worldwide attention.

The scientists on board at the time concluded that the evaporites were caused by a drop in the sea level by as much as 2000 meters due to seawater evaporation in the Mediterranean Sea (Hsü *et al.*, 1973). In other words, they emphasized that only the water level in the Mediterranean Sea was some 2000 meters lower in the Messinian than it is today. There is no explanation whatsoever, however, of the reason why the Mediterranean Sea evaporated to a level 2000 meters lower than today or what caused evaporations that were repeated eight times as Hsü *et al* (1973) estimated from the volume of the evaporite.

The authors has perused the initial report of the results of the global deep sea drillings by DSDP and ODP and examined the rise in the sea level in the Late Miocene era based on the distribution of shallow sea formations thought to have been formed locally. As a result, he concluded that the global paleo-depth in the late Miocene was approximately 2000 meters lower than it is today (Hanada, 2000). In other words, the *low sea level of the Messinian period was not limited to the Messinian Sea alone.*

In this study, I presents wide ranging geological evidence that the sea level around the world in the late Miocene was some 2000 meters lower than it is today.

2. Origin of the western Mediterranean basins

2.1 Geological origin

Comas *et al.* (1999) announced the pattern diagram based on an analysis of the records of seismic exploration conducted in the Alboran Basin area in the western part of the western Mediterranean Sea. According to this, it can be seen that the basement of the Alboran basin is about 6 km below present sea level. This is indicated in the basement depth contour map (Fig. 1). Watts *et al.* (1993) claimed that the sedimentary sequence of the

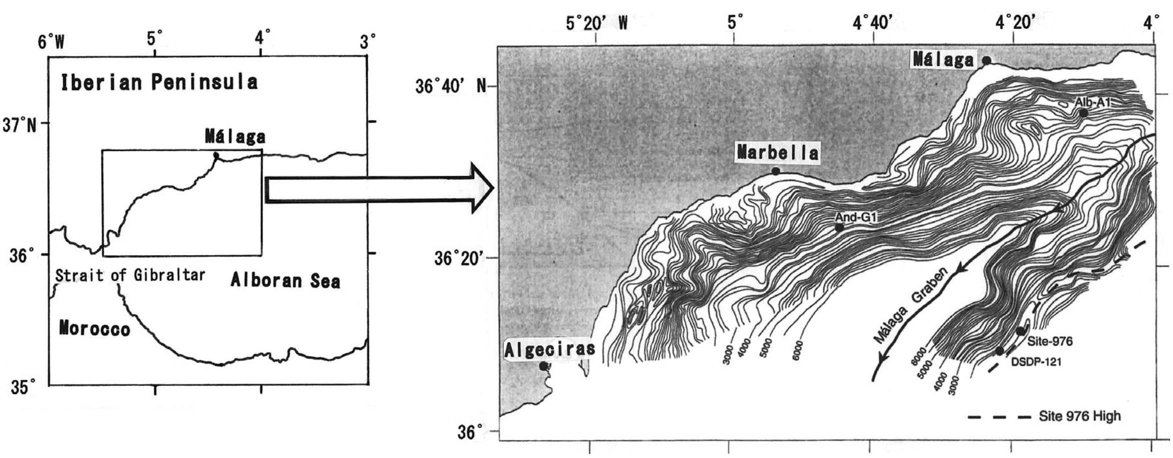

Fig. 1 Basement depth contour map of the Málaga Graben (de la Linde *et al.*, 1996). Contour lines every 100 ms (TWT), showing Andalucía-G1 (And-G1), Alborán-A1 (Alb-A1), DSDP 121 and Site 976 locations. Both flanks of the graben correspond to complex interference of formar dubmarine or formerly emerged surfaces and low- and high-angle faults, normal-oblique transfer faults, and tops of rollover structures affecting the basement (after Comas *et al.*, 1999).

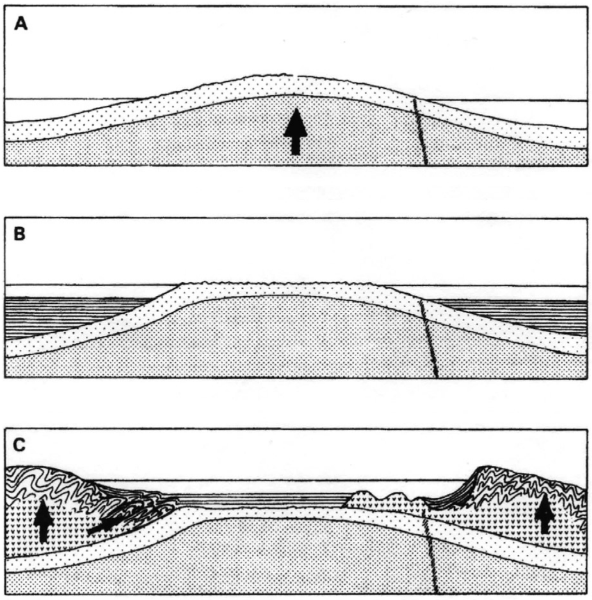

Fig. 2 Development of a central platform and its marginal geosyncline (after Hoshino, 1991).

Alboran Sea Basin has a thickness of 6-8 km and, furthermore, Chalovan *et al.* (1997) stated that the sedimentary column at the center of the Alboran sedimentary basin is at least 9 km thick. These results, however, were obtained using the seismic refraction method and it should pointed out that the bed of the sedimentary layer is not distinct.

Hoshino (1991) stated that the existence of a basement at some 6 km below the present sea level is also known in the Tyrrhenian Basin in the Mediterranean Sea as Well as in the Japan Sea Basin, North Sea Basin, Pannonian Basin, West Siberian Lowland, Song-Liao Basin in China and the Venazuelan Basin. He conclueded that the basins are remnant basins and furthermore advocated the mechanism as shown in Fig. 2 for the formation of remnant basins. He asserts that these sedimentary basins are the result of a large-scale rise of the sea level and surrounding mobile belts following A) unheaval og the central massif in the Hercynian, B) followed by erosion, peneplanation and sedimentation in the peripheral alpine geosyncline and C) sea level rise and uplift of gyosynclinal materials.

2-2 Origin of the Gibraltar Strait

The Gibraltar Strait is a strait linking the Atlantic Ocean and the Mediterranean Sea with a width of about 15 km with the shallowest depth of less than 300 meters.

Van Couvering *et al.* (1976) pointed to the structural upheaval prior to the Messinian period in the same area. It is thought, however, that the upheavals in this period took place no more than 2000 meters lower than the present sea level. That is, the beginning of the sill that was created by the upheavals at this time did not go so far as to totally isolate the Mediterranean Sea from the Atlantic Ocean. However, since an incomplete sill was created, the circulation of seawater in the Mediterranean Sea deteriorated markedly and it is thought that this promoted the evaporation of seawater. The current Gibraltar sill was not completed in the Messinian period, which is proven by the short-term exchange of terrestrial mammals between Spain and Africa at the end of the Pliocene period (DeBoajen, 1973).

There are many researchers who explain the origin of Mediterranean basins by means of plate tectonics (Calvert *et al.*, 2000, and Mejgs and Burbank, 1997). However, with regard to the evaporates of the late Miocene period, it is known that evaporite exists at a depth of 2000 meters below the current sea level in the Red Sea (Ross *et al.*, 1973). The explanation by the plate-tectonicists is the Mediterranean basin is due to the subduction of the Aflica plate under the Eurasia plate and that the Red Sea is due to the stretching of the Africa plate and Arabian plate. The two basins caused by differing mechanisms with the same sea level in the Messinian period is, the author believes, a reflection of the fact that the sea level at the time was globally 2000 meters lower than today. The Red Sea and Mediterranean Sea were connected during the Miocene period and the connection to the Indian Ocean occurred during the Pliocene period or later (Hoshino, 1998). In other words, the Red Sea and Mediterranean Sea were connected during the late

Miocene period, which indicates that evaporite was formed successively in this series of basins.

The unconformity that is occurs worldwide between the late Miocene and early Pliocene indicates that emergence in the Messinian and the rise of sea level in the early Pliocene were on a global scale.

2-3 Messinian period sedimentary stratum in the Gulf of Cadiz (Unit M3)

The Gulf of Cadiz is a part of the North Atlantic continental margin on the northwest side of the Strait of Gibraltar. The occurrence of the Messinian formation in the Gulf of Cadiz, in a drilling near shore (B3) (see Fig. 3) is at a depth of 1250 meters below present sea level (Maldonado *et al.*, 1997) and

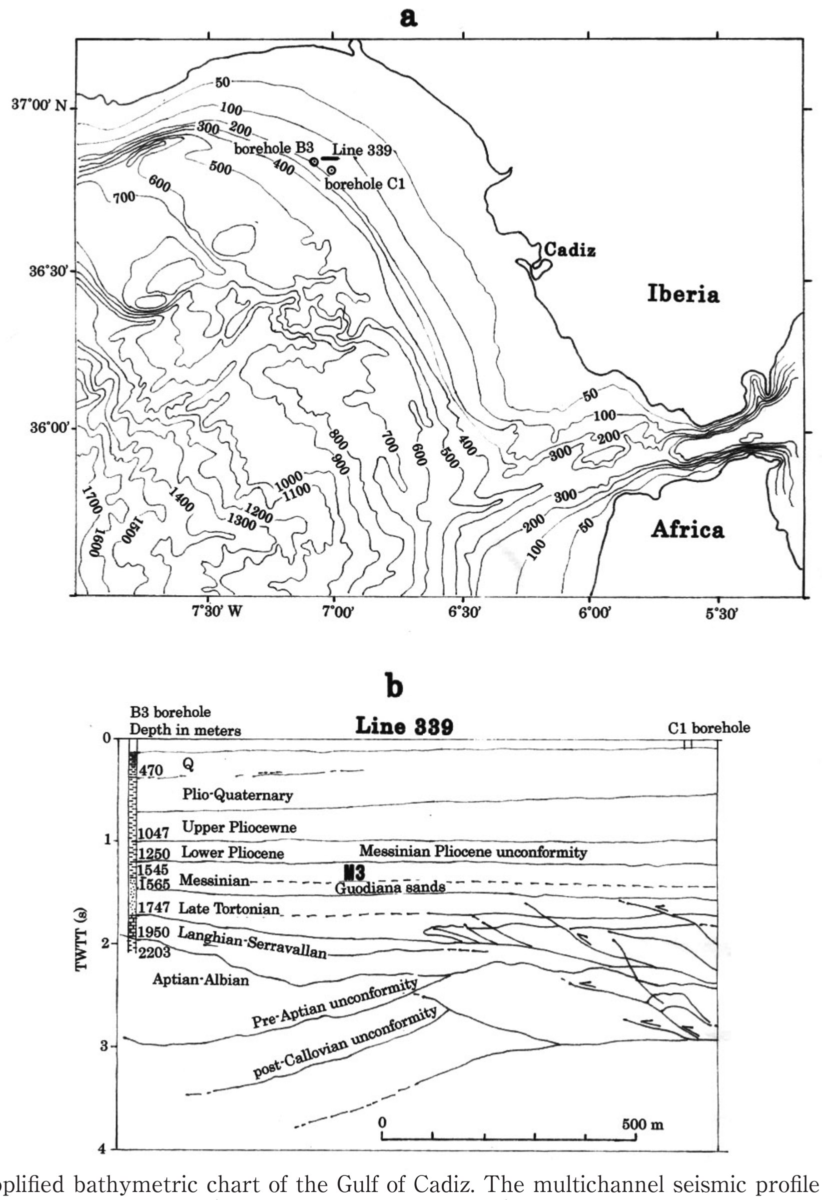

Fig. 3 a: Simpplified bathymetric chart of the Gulf of Cadiz. The multichannel seismic profile and location of commercial wells is shown (after Maldonado *et al.*, 1999). b: The interpretative line drawing showing representative cross-section of the northern Gulf of Cadiz (Line 339) (after Maldonado *et al.*, 1999).

Unit M3 (upper Messinian deltaic sediments) evident in the acoustic traverse through the vicinity has a water depth of about 0.8 sec (TWTT) and layer thickness of about 1.2 sec (TWTT) and, if the Vp in this formation is about 2.3 km / sec (TWTT) (Sartori *et al.*, 1994; refer to Fig., Line A), the upper portion of this Messinian stratum would be located at a depth of 2 km below sea level, equivalent to the depth of the contemporaneous evaporates in the Mediterranean Sea, thus indicating that sea level in the Mediterranean Sea during the Messinian period is the same as that of open ocean. Hoshino (1981) asserts that shallow autochthonous sediment and shallow sea fossils of the same period distributed in the deepest areas in the seabed indicate the sea level of the geological era with which these are affiliated. Maldonado *et al.* (1999) think that this area was exposed to rapid crustal subsidence in the early Pliocene; however, the depth of Unit M3 is the same as the Messinian evaporates in the western Mediterranean Sea and the evaporitic layer is thought to have been formed in response of the −2000 meters sea level occurring globally. The rapid crustal submergence of the early Pliocene refers to the large-scale rise in sea level as indicated by changes in the paleo-depth of benthic foraminifera referred to later.

3. Geological evidence indicating the sea level in the late Miocene period

3-1 Hypsographic curve

In the case of the Mediterranean Sea, Cita (1973) pointed out that the hypsographic curve in the Mediterranean Sea is similar to that in the open ocean, though the reason for that is not explained. The primary cause involved in this is the fact that the rise in the sea level after the Messinian period, during which the continental slope was formed, was global event.

Shepard (1963) notes that the terminal depth of continental slope is at −2000 meters. This is probably an indication of a major upheaval in the portion from the lower part of the continental slope to the

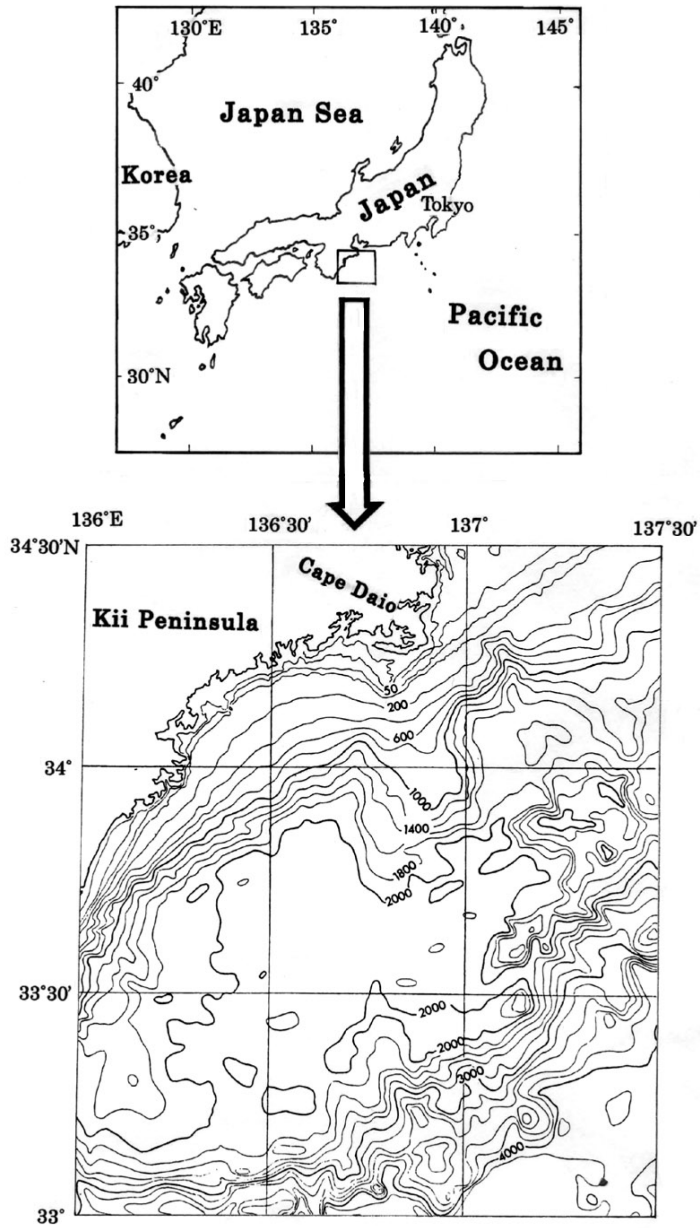

Fig. 4 Deep sea terrace in the Kumano-Nada Sea, off central Honshu, Japan.

continent in the Neotectonic Period taking the depth in the vicinity of −2000 meters as the standard, that is, with this major upheaval in the Neotectonic Period, there were conspicuous upheavals in the area from the continental margin to the inland area while the major part of the sea basin bed remained immobile. As evidence of this, the point can be cited that the Messinian evaporite widely distributed at the bottom of the basin in the Mediterranean Sea is hardly distributed at all. Meanwhile, the same evaporates are also distributed on the Island of Sicily and other locations on land along the Mediterranean Sea coast (Butler *et al.*, 1995; Hsü *et al.*, 1973).

Deep-sea terraces are evident in many locations in the vicinity of -2000 meters. In the case of Japan, the deep-sea terrace offshore in the Kumano Nada is well known (Fig. 4). Many of the deep-sea terraces are sedimentary basins that have a peripheral dam on the ocean side and sedimentary accumulation on the shore side, which form the terrace. Eroded bedrock was found in the peripheral dam on the outer side of the deep-sea terrace of offshore Shikoku

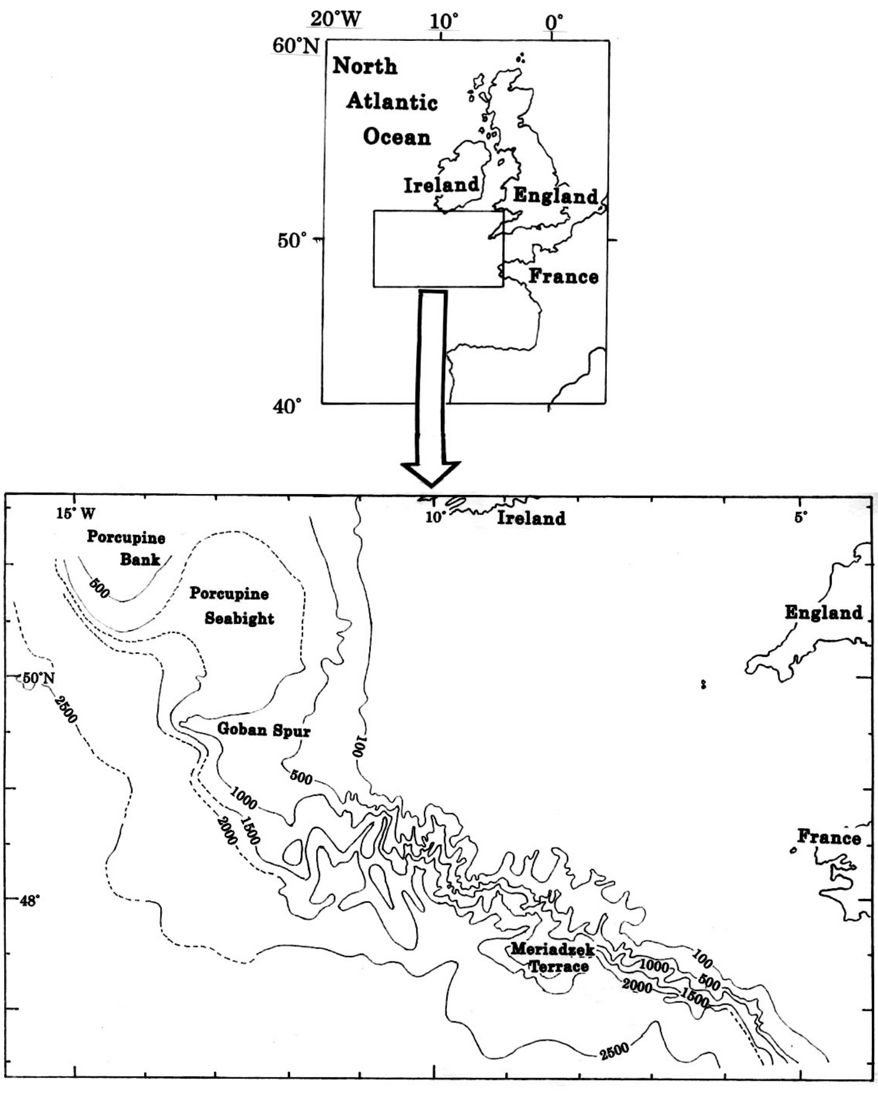

Fig. 5 Bathymetric chart of the continental margin between Britany and Ireland (after Day, 1959). Depths in fathoms.

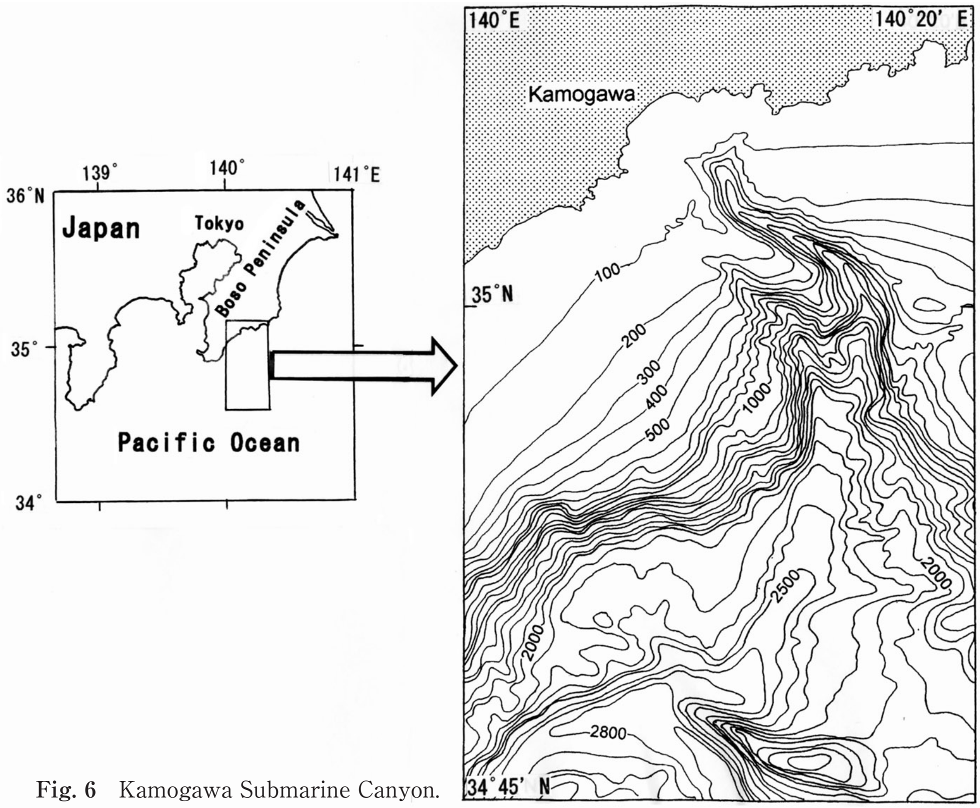

Fig. 6 Kamogawa Submarine Canyon.

in Japan through acoustic exploration, indicating the location of the sea level at the time (Hilde *et al.*, 1969). In addition, deep-sea terraces at a depth of 2000 meters dating from the Middle Miocene are partially developed from northern Honshu to Hokkaido on the Japan Sea side, in particular, a clearly-defined deep-sea late Miocene erosional terrace is distributed in the area from southwest offshore Okushiri Island to the Tsugaru Strait.

Among deep-sea terraces in the northern Atlantic Ocean, the Meriadgek Terrace (Day, 1959) in the western part of the English Channel, at a depth of about 2000 meters, is noteworthy (Fig. 5).

3-2 Submarine canyons

Submarine canyons which terminate at a depth of 2000 meters are found throughout the world.

There are numerous examples of submarine canyons with a terminal depth in the range of about 2000 meters. For example, it has been pointed out that Mississippi Canyon continues to a depth of about 2000 meters (Gealy, 1965), that the submarine canyon in the Bering Sea continues at depths from 165 meters to 2200 meters, the upper margin of the continental rise (Scholl *et al.*, 1968), that the Martaban Canyon in the Andaman Sea ends at a depth of 2000 m (Rodolfo, 1969), and that the gradient of the valley axis of the Black Mud Canyon in the western part of the English Channel moderates at a depth of 1800-2000 meters, which corresponds to the depth of the Meriadgek Terrace (Day, 1959). The same occurs off the eastern coast of the United States. In addition, the Kahana Canyon distributed on oceanic islands such as Oahu Island, Hawaii, also has a terminal depth of 2000 meters (Hamilton, 1957) and, moreover, according to Shepard and Dill (1966), many submarine canyons have a terminal depth of −2000 meters.

As in the case of the Kamogawa Submarine Canyon (Fig. 6), there are also submarine canyons with valley topography that extends even deeper than 2000 meters and, given the valley topography extending deeper than 2000 meters insuch cases, they are unusual valleys with a trough configuration and steeper valley axis gradients than at shallower depths, and we can see the submarine canyons with the same nature at the Korean continental slope of the Sea of Japan.

Submarine canyons are frequently explained to be created by turbidity currents; it would be difficult at present, however, to say that all submarine canyons are formed by such turbidity currents (Hoshino, 1998). It is evident from the deep-sea topography of Toyama Bay (Hanada, 1982) that the canyon loses form at the level surface of the bay at a depth of 1000 meters and that the canyon topography continues on to a depth of 2000 meters further out. In other words, turbidity currents originating near the coastline are not able to explain the origin of submarine canyons that cut into the lower part of the continental slope.

3-3 Examination of change in the sea level indicated by benthic foraminifera

Hanagata *et al.* (2001) claim that the disappearance of the benthic foraminifer *Spirosigmoinella compressa* from the Japan Sea and the appearance of *Miliammina echigoensis* into the Japan Sea indicate changes in maritime conditions in the Japan Sea at the boundary between the Miocene and Pliocene periods. Further, reporting on a large-scale rise in sea level after the Messinian based on an examination of paleo-depth from the benthic foraminifers, they claim that this phenomenon after the Messinian period is the result of a major rise in the sea level of global magnitude. That coincides with the assertion of Benson (1972), based on the paleoecology of ostracodes, that there was a rapid rise in sea level extending to 1000 meters after the formation of the Messinian evaporite.

In account of the continental margin of offshore Peru, Suess *et al.* (1988) concluded, based on an analysis of benthic foraminifera, that there was

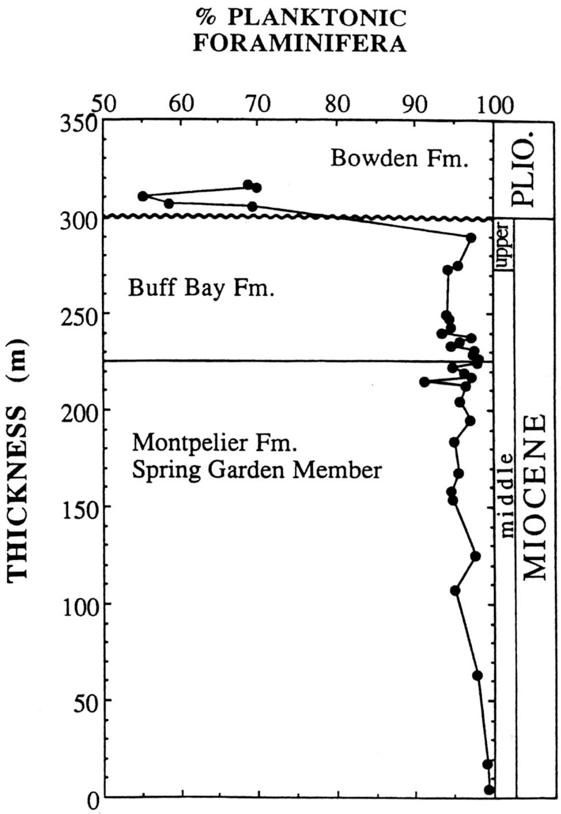

Fig. 7 Percent planktonic foraminifera at Buff Bay (after Katz and Miller, 1993).

a rapid increase in water depth of about 2 km after the Messinian period at both DSDP Sites 682 and 688. They considered the subsidence of the continental margin to be the cause of this increase in depth; however, this phenomenon should probably be seen as the result of a rise in sea level after the Messinian period.

As the result of research in benthic foraminifera in marine deposits of the Neogene and Quaternary periods along the coast of Jamaica, Katz and Miller (1993) released charts indicating that the paleo-depth in the Messinian period was shallower, that unconformities occurred and that, at the beginning of the Pliocene, the sea depth increased once again (Fig. 7), just as in the Mediterranean Sea. This indeed corresponds to eustatic changes in the sea level curve from the Miocene to the Pliocene in the Mediterranean Sea (Hoshino *et al.*, 2001) (Fig. 8).

The previously referenced Hanagata *et al.* and von Huene *et al.* also have much the same to say.

In Fig. 7, it is thought that the basin became shallower in depth in the Messinian period not as a result of the drop in the sea level but because the basin became shallower as it became filled in. This phenomenon represents the conclusion of stratigraphic geological research relating to oil in the Tertiary of the northeastern Japan Sea (Suzuki, 1989). Von Couvering *et al.* (1976) point out the increased shallowness prior to the Messinian period in the Guadalquivir Trough in Spain based on research in benthic foraminifera and this is also the result of fill, the same as in the case of the Tertiary Niigata oil fields.

There are results available of the deep sea drilling at two drilling points spanning the Strait of Gibraltar implemented during the DSDP Leg 13 cruise. These are the results of Site 120 on the Atlantic side across the Strait and Site 121 carried out in the Mediterranean Sea. Site 120 is located in the Atlantic Ocean about 260 miles west-northwest of the Strait of Gibraltar and the drilling was carried out on the north slope of the Gorringe Bank, which has a depth of about 50 meters at the shallowest point. Based on the record, it is clear from the results of the analysis of benthic foraminifera that the sea had increased in depth since the Pliocene at this drilling point (Shipboard Scientific Party, 1973). In other words, Site 120 had a depth of 1711 meters and Lower Pliocene was found at a depth of about 55 meters below the seabed. The same increase in depth is also seen in the drilling record of Site 121 in the Western Alboran Basin in the Mediterranean Sea (Shipboard Scientific Party, 1973). That is, the Trubian stratum that inconsistently overlaps the evaporite of the Messinian period in the Mediterranean Sea is said to be abyssal as the

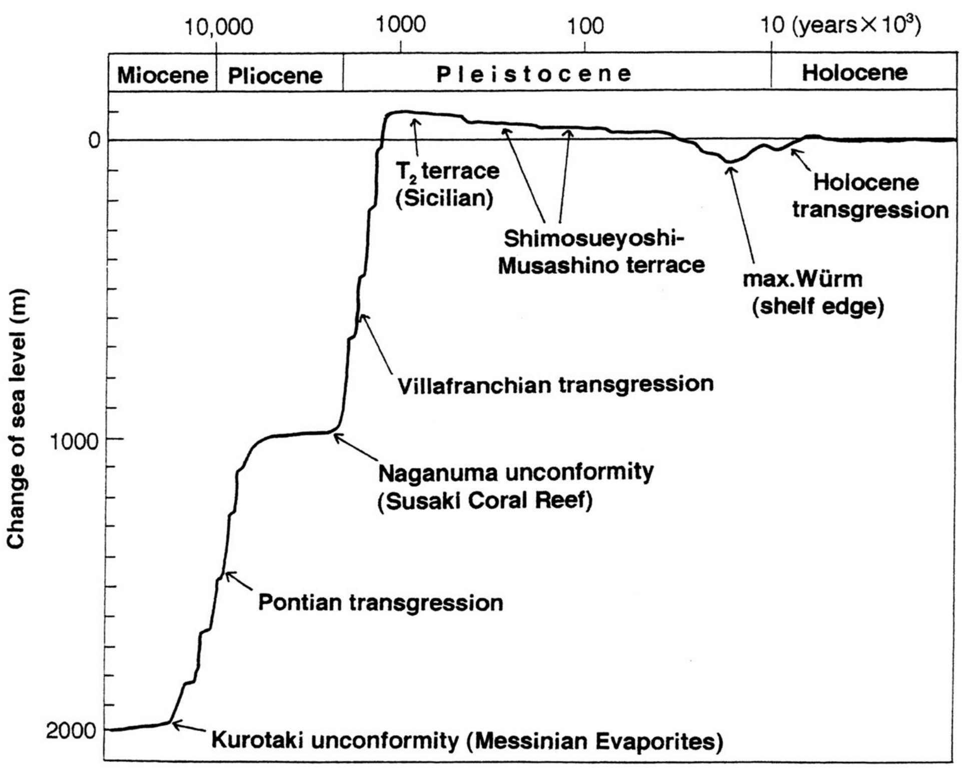

Fig. 8 Sea level change since the late Miocene (aftr Hoshino *et al.*, 2001).

result of analyses of the benthic foraminifera and ostracodes contained in it (Benson, 1972). Consequently, the Mediterranean Sea is not thought to have been isolated from the Atlantic Ocean at this time but that the Atlantic Ocean and Mediterranean Sea had the same sea level.

Here, the distribution depth of the Pliocene seabed at Site 120 has a current depth of 1766 meters, somewhat less than 2000 meters, which is due to the fact that this bank is an upheaval formation area and some upheaval is thought to have occurred after the accumulation of Pliocene sediment.

Thus, examples in marine areas of Lower Pliocene overlapping Miocene indicating abyssal environment do not only occur in the Mediterranean Sea but are also known to have occurred in other areas as well. For example, it is said that Lower Pliocene fauna indicates abyssal environment as the result of the analysis of the fossil of foraminifers, mollusks, sea urchins and other sea animals in the Los Angels sedimentary basin on the west coast of North America (Conery, 1967). Furthermore, in the Japan Sea, the increase in the depth of Japan Sea is said to have started in the early Pliocene (Ishiwada *et al.*, 1977).

4. Conclusion

It cannot be disputed that evaporates were formed in the western Mediterranean Sea at a depth of 2000 meters below the present sea level (Hsü *et al.*, 1977). The problem is the interpretation that this phenomenon occurred only in the Mediterranean Sea. Since the report of Hsü *et al.* (1977), many researchers have claimed that the Strait of Gibraltar sill was formed immediately prior to the Messinian period and, moreover, that the height of the sill was much the same as it is today (Fig. 10). They promote the idea that the sea level at the time when the sill of the Messinian period was formed is essentially the same as its current level.

However, the sea level in the end of the Miocene period was probably some 2000 meters lower than its current level.

Hoshino (1983) classified the magmatic history of the earth into the Granitic Stage (Archeozoic era), Transitional Stage (Proterozoic and Palaeozoic eras) and Basaltic Stage (Mesozoic and Cenozoic eras). What characterized the age since the Mesozoic era, that is, the Basaltic Stage, was basaltic activity and he points out that the ocean floor was rised by basaltic flooding and its underplating.

The Messinian evaporates are geologically important in that it indicates the level of sea surface immediately prior to the major global upheavals in the Neotectonic Stage Age that formed the entire topography of the present-day earth.

Acknowledgments

I would like to record here our thanks to Professor Michihei Hoshino, Professor Emeritus of Tokai University, for his encouragement to write this paper, for his valued discussion. I wish to express my gratitude to the conveners of the Session 164, Geology of the Mediterranean area of 32nd IGC in Florence, Italy. Our thanks are extended to the Professor A.J. Smith, Professor Emeritus of London University for his helpful advice on several subjects and his assistance in correcting our English manuscript.

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中新世最末期（Messinian 期）の地中海，および世界における－2000 m 海水準について

花 田 正 明

深海掘削計画のLeg 13航海が地中海海域で実施された．この深海掘削の結果，地中海の深海底からMessiniann期の蒸発岩が発見されたことが，世界中の注目を集めた．そして，当時の乗船科学者たちは，この蒸発岩の成因について，地中海だけに起こった現在の海水準にくらべて2000 m におよぶ海水準低下現象であった，と結論した（Hsü *et al.*, 1977）．すなわち，地中海においてのみMessiniann期の海水準は現在とくらべて，2000 m 低かったことを強調している．

筆者は，DSDP, IPOD, ODP による深海掘削結果のイニシャルレポートを通覧して，地質時代の海水準の上昇について検討した．イニシャルレポートで，現地で形成されたと考えられる記載がされている浅海層の分布から，中新世最末期の古海水準は現在とくらべて約2000 m 低い位置にあったと結論づけた（Hanada, 2000）．それは，Messinian 期の低海水準は，地中海だけではなかったということである．

このことを示す証拠の１つが，DSDP Leg13航海中におこなわれた２つの掘削地点の深海掘削の結果に示されている．ひとつは，ジブラルタル海峡をはさんだ大西洋側のsite 120であり，他のひとつは地中海で実施されたsite 121の掘削結果である．Site 120は，ジブラルタル海峡の西北西，約260マイルの大西洋に存在する，最浅部の水深が50 m ほどのゴリンゲ・バンクの北側斜面上で掘削がおこなわれた．掘削記録からは，本掘削地点では，鮮新世以降の深海化が明らかである．すなわち，site 120は，水深1711 m であり，海底下55 m 付近に下部鮮新統が発見されている．これと同様の深海化が地中海のWestern Alboran Basinにおいて実施されたsite 121の掘削記録にも見られる．すなわち，地中海のMessinian 期の蒸発岩の上に不整合に重なるTrubianの地層は，それにふくまれている底生有孔虫と介形虫の分析によって，深海相であるといわれている．したがって，この時点においては，地中海は大西洋から孤立した状態にはなかったことが明らかである．

このように，海成層において，中新統の上に重なる下部鮮新統が深海相を示すという例は，地中海だけのことでなく地中海以外の地域でも知られている．たとえば，北アメリカ大陸西岸のロサンゼルス堆積盆地では，下部鮮新統中にふくまれる有孔虫，軟体動物，ウニなどの化石の分析によって，下部鮮新統が深海相を示すことがいわれている（Conery, 1967）．さらに，日本海においては，日本海の深海化は鮮新世初期にはじまったといわれている（石和田ほか，1977）．また，筆者は，地形計測の結果と地質構造からみて，日本近海の上部大陸斜面の発達は，陸上の環境で形成された斜面が，その後に起こった海面上昇によって現在の海底に沈水したものであることを明らかにした（花田，1989）．

以上のようなことから，現在の海水準にくらべて，中新世最末期の海水準は2000 m 低い位置にあったのは地中海だけの現象ではなく，汎世界的なものであり，このことは，生物地理学的な考察からも裏づけられている（Hoshino, 1998）

（花田：東海大学海洋学部　〒424-8610　静岡県静岡市清水区折戸3-20-1）