Final report about the study of bottom material at the west of Western Mariana Ridge

U2014-028

Dr. Prof. Ai-jun Wang

Third Institute of Oceanography, State Oceanic Administration

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Content

1. Information of investigation cruise

The investigation of marine sedimentary environment research in the West Mariana Ridge under the national jurisdiction of the America was applied by the Third Institute of Oceanography, State Oceanic Administration, using R/V “Xiangyanghong 06”. The application (U2014-028) was approved by the United States Government from October 15, 2014 to December 31, 2014. Due to the weather condition, the previous task was adjusted, and according to the weather conditions at that time, the project team decided to carry out the project. The in situ survey in the application area was began to conduct from October 11, 2014 (4 days earlier than the approved entry time) by Third Institute of Oceanography, State Oceanic Administration, using R/V “Xiangyanghong 06” , and finished at October. 27, 2014. The in situ survey lasted for about 17 days.

2. Oceanographic settings

The Parece Vela Basin-West Mariana Ridge is located in the east of the Philippine Sea, and is one of the largest backarc basins in the world (Ren and Li, 2000). More specifically, it is a nearly closed marginal basin lying to the Mariana Trrench, south of the Shikoku Basin, east of the Palau Ridge and north of a complex system of island arc-trench-fault zones, with an average water depth of 4800 m. The main ocean current flowing through the Parece Vela Basin is the North Equatorial Current, and the bottom current is a branch of the Antarctic Intermediate Water that travels counterclockwise around the Parece Vela Basin and Shikoku (Lee and Ogawa, 1998). The North Equatorial Current is formed under northeast trade winds, and travels from east to west. After meeting the Philippine islands, the North Equatorial Current splits into two branches, with the Kuroshio towards the north and the Equatorial Counter Current turning eastward.

3. Scientific objectives

This project would be collect marine sediment sample and suspended matter at the west of Western Mariana Ridge. As an important component of marine sediment can be used to indicate the provenance of marine sediment; in addition, it shows a good response to the change of the East Asian monsoon and ocean current. The aim of the project is to determine the sediment source of the marine sediment and palaeoenvironment evolution in deep water environment.

4. Investigation content

Because of the slow speed of the geological winch of Xiangyang Hong06 (average 28 m/min) and the lack of sounding data, it is difficult to judge the bottom touching of the sampler during the investigation period, and the box sampler is always damaged during the investigation process in the previous section. Therefore, grab sampler is used to collect surface sediment during the investigation process, and each station need to collect several times. In addition, due to the influence of sea conditions, there are many empty stations in columnar sampling. After 17 days of survey, 16 stations were surveyed in this area, including 16 stations for surface sediments, 3 stations for sediment cores, and 8 stations for CT and LISST profiles. The detail information of the survey site is as follow Table1 and Figure 1. A set of sediment trap system was planned to be put into this area, but this work was not carried out in the actual implementation process considering the subsequent recovery of the system.

Table 1. The detail information about the sample station

Station	Longitude (°E)	Latitude (°N)	Depth (m)	Survey parameters	Sediment type
2014PAC-01	141.6883	15.0260	4621	Surface sediment, CTD, LISST	Deep brown deep-sea clay
2014PAC-02	142.8519	15.0667	3200	Surface sediment, sediment core, CTD, LISST	Brown deep-sea clay
2014PAC-03	142.0968	15.4345	4260	Surface sediment	Brown deep-sea clay
2014PAC-04	142.9030	16.2195	2962	Surface sediment, CTD, LISST	Brown deep-sea clay
2014PAC-05	142.4593	16.9592	4100	Surface sediment	Brown deep-sea clay
2014PAC-06	142.8862	17.3480	2670	Surface sediment	Sandy gravel
2014PAC-07	142.0367	18.4637	4484	Surface sediment	Brown deep-sea clay
2014PAC-08	142.8668	18.4962	3000	Surface sediment, sediment core, CTD, LISST	Brown deep-sea clay
2014PAC-09	142.4805	19.2554	3700	Surface sediment	Brown calcareous clay
2014PAC-10	141.6851	19.5948	4540	Surface sediment, CTD, LISST	Deep brown deep-sea clay
2014PAC-11	142.8074	19.5898	2440	Surface sediment	Sandy gravel
2014PAC-12	142.5169	20.3679	1840	Surface sediment, CTD, LISST	Foraminifera sand
2014PAC-13	141.6757	20.7190	4523		Brown deep-sea clay
2014PAC-14	142.8909	20.7456	3746	Surface sediment, CTD, LISST	Deep brown deep-sea clay
2014PAC-15	142.8463	21.4619	3795	Surface sediment, CTD, LISST	Deep brown deep-sea clay
2014PAC-16	142.0751	21.0931	3880	Surface sediment, sediment core	Brown deep-sea clay

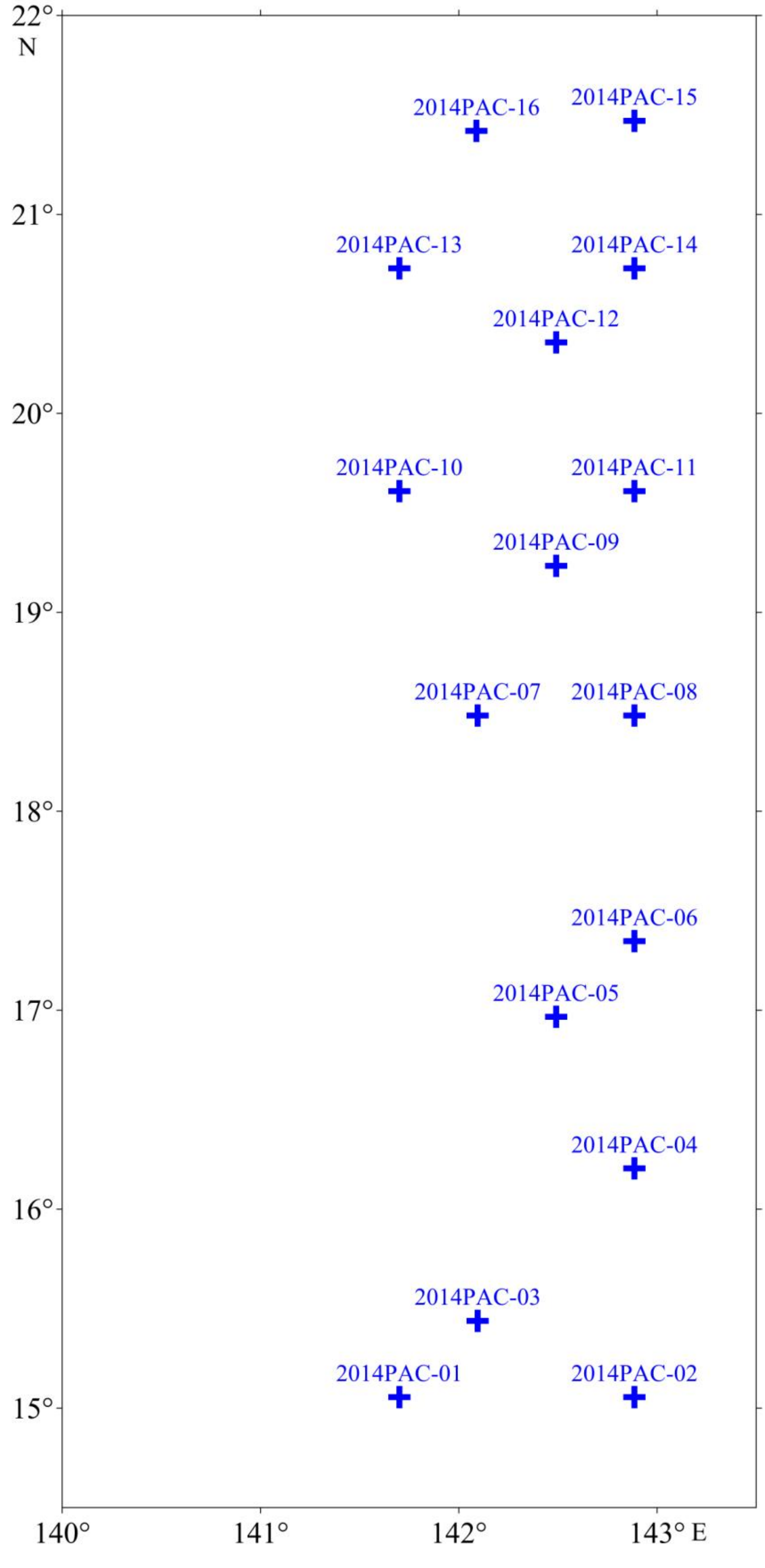

Fig 1. Location map of the sampling stations

5. Distribution characteristics of sediments and suspended matters near the West Mariana Ridge

5.1 Sediment type

There are four main types of sediments in the West Mariana Ridge: Brown deep-sea clay, foraminiferal sand, Sandy gravel and brown calcareous clay, and occasionally black ferromanganese nodules. Statistical results of sediment types in the West Mariana Ridge show that brown deep-sea clay is the main sediment type in the area, accounting for 75% of the total number of survey stations, and gravel is the sediment type at the top of the West Mariana Ridge.

5.2 Grain size distribution of surficial sediment

Silt is a major component of sediments, ranged from 59.07% to 76.50% with an average value of 67.01%. Sand content is from 10.42% to 27.67%, with an average of 17.85%. The distribution characteristics of sand and silt showed that their contents were obviously affected by the seamount matter from the eastern area. The content of clay components in sediments is relatively low, between 9.88% and 24.48%, with an average of 15.14%. The distribution characteristics of clay components in sediments show that the content is obviously increased in the deep water.

5.3 Clay minerals distribution of surficial sediment

Illite is the main clay mineral in the West Mariana Ridge, and its content ranges from 42.2% to 68.6%, with an average of 53.6%. The second clay mineral is mectite, which ranges from 6.6% to 39.8% with an average content of 23.7%. The content of chlorite varies from 12.3% to 19.2% with an average of 15.5%, while kaolinite content ranges from 5.6% to 9.1% with an average of 7.2%. In the surficial sediments near the West Mariana Ridge, the content of smectite content is higher thant illite, and the content of illite increases while that of smectite decreases from the west side of the Ridge to the Parisivilla Basin.

5.4 Major and trace elemental compositions

The average contents of major elements in the sediments are SiO_2 > CaO > Al_2O_3 > TFe_2O_3 > Na_2O > MgO > K_2O > MnO > TiO_2 > P_2O_5. The contents of SiO_2, CaO and Al_2O_3 vary significantly. The major elements in the survey area are significantly different from those in shallow sea sediments in China (Li et al., 2007). The contents of SiO_2 and Al_2O_3 were lower than those in the eastern of Philippines Sea (Xu et al., 2010). The content of Fe_2O_3 was significantly higher than that of east Philippines Sea, but less than that of South China Sea. The content of CaO is higher than that of South China Sea and deep ocean sediment, but lower than that of volcanic material of the Palau Ridge.

The average contents of trace metals in the surficial sediments ar eBa > Sr > Cu > V > Zn > Zr > Ni > Rb > Co > Cr > Pb > Sc > Li > Ga > Nb > Th > Cs > Mo > Hf > W > U > Be > Tl > Sb > Bi > Ta > Cd > In, in which the content of Ba is the highest with a variation range of 522 μg/g~1754 μg/g and a average value of (1012±411) μg/g.

Table2 The major elements of surface sediment from surrounding sea areas

	This study	Parece Vela Basin [1]	Shallow sea sediment[2]	South China Sea[2]	Ocean Sediment[2]	Volcanic material of the Palau Ridge[3]
SiO_2	38.45±12.30	49.16	62.51	47.40	47.72	49.81
CaO	17.88±11.48	9.36	4.43	3.93	5.83	13.33
Al_2O_3	10.58±3.29	15.64	11.09	9.54	12.29	14.43
Fe_2O_3	6.15±1.81	2.47	5.08	12.31	0.60	9.66
Na_2O	4.14±1.09	1.09	0.07	0.37	0.41	0.21
MgO	2.30±0.64	2.43	2.32	1.81	2.10	0.71
K_2O	1.35±0.55	3.58	1.82	2.04	2.18	6.23
MnO	0.37±0.19	4.24	2.00	-	1.10	3.13
TiO_2	0.51±0.15	0.78	0.58	0.53	0.59	1.18
P_2O_5	0.18±0.04	0.29	-	-	0.16	0.12

Source: 1.Xu et al. (2010); 2. Li et al.(2007); 3. Wood *et al*.（1981）.

5.5 Vertical distribution of water temperature, salinity, turbidity and fluorescence

The vertical profile distribution of salinity in the West Mariana Ridge shows that (Fig. 3a), the upper boundary of the saline cline appears in the water depth of about 50 m to 100 m, and the lower boundary of the saline cline is about 100 m. The vertical mixing of salinity in shallow water depth is obvious at 40 m, and the salinity below 100 m decreases gradually with the increase of water depth.

The temperature of the investigated sea area decreases slightly from the surface to the bottom from the surface to the depth of 50 m, and decreases rapidly below 50 m. Thermocline appears between the depths of 50 m to 100 m (Fig. 3b).

The turbidity of water body increases gradually from the surface to the bottom near the depth of 100 m. The maximum turbidity usually occurs in the water layer between 75 m and 125 m, and then decreases rapidly, and remains basically unchanged at the depth of 200 m (Fig. 3c).

The variation of chlorophyll fluorescence concentration is consistent with that of turbidity, and the maximum chlorophyll fluorescence usually appears in the water layer between 75 m and 125 m, then shows a rapid decline, and basically remains unchanged in the deep water layer below 200 m (Fig. 3d).

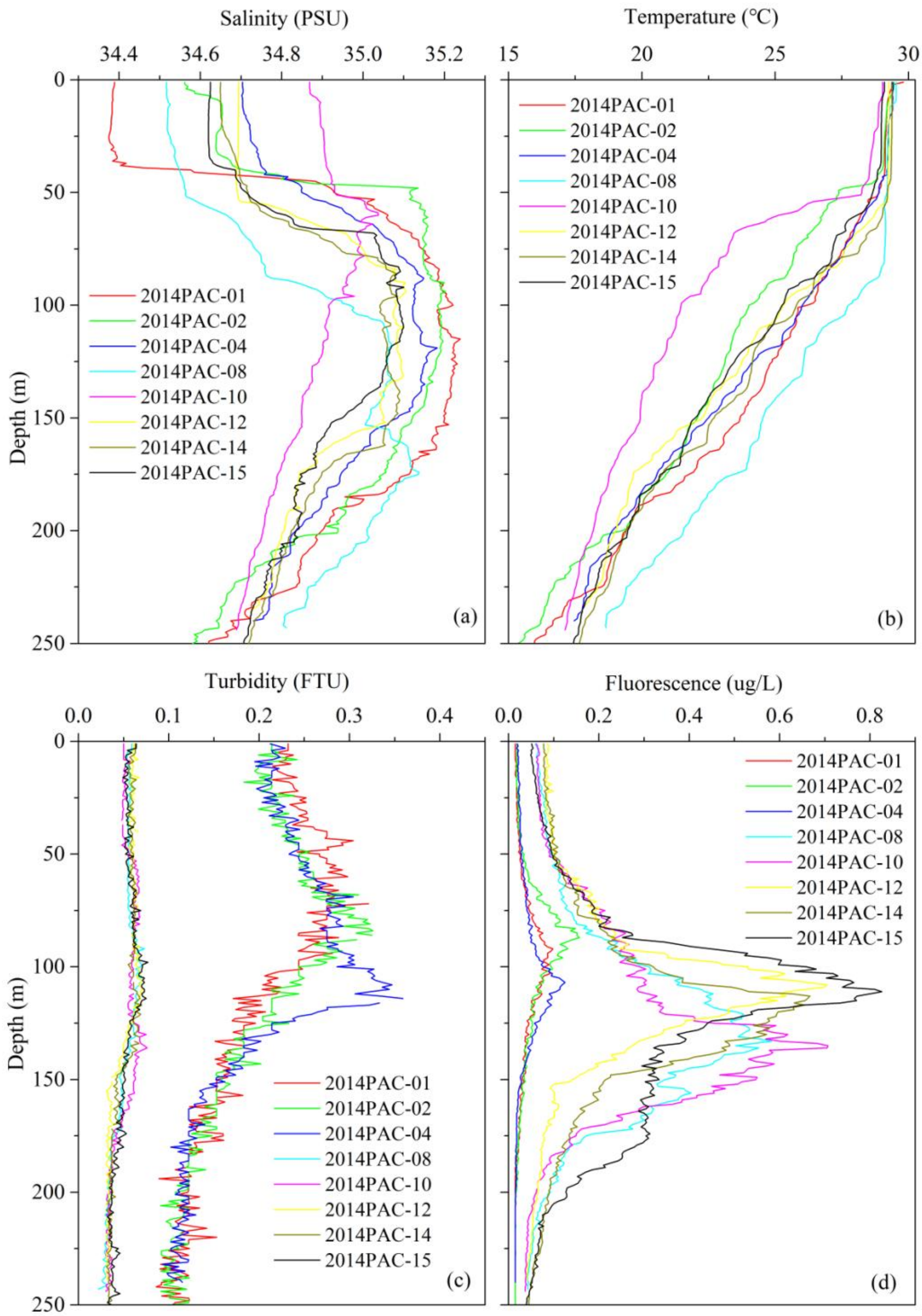

Fig.3 The vertical distribution of the water salinity (a), temperature (b), turbidity (c) and fluorescence (d)

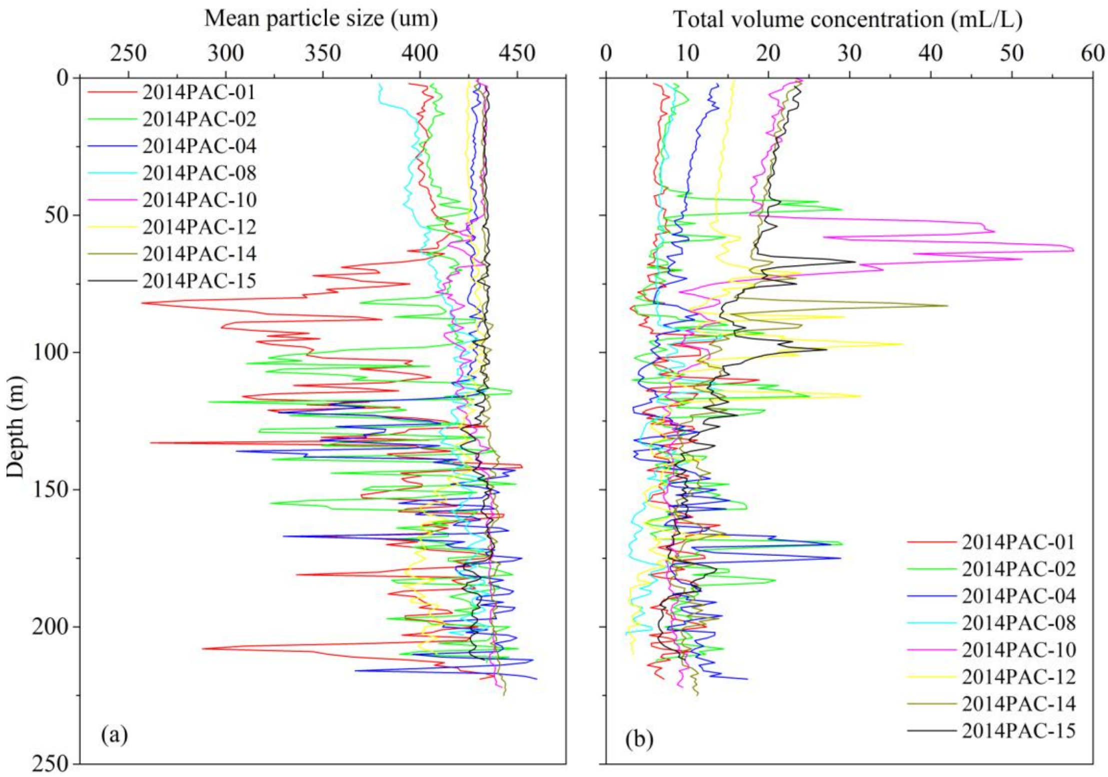

Fig.4 The vertical distribution of particle size (a) and total volume concentration (b) of the suspended particulate matte

5.6 Particle size and volume concentration of suspended particulate matter

The average particle size of surface suspensions ranged from 256.73 to 459.97 microns, with an average of 418.06 microns. The average particle size of suspended solids is generally over 390 microns in the depth of 50 m and 150 m. The average particle size of suspended solids in the depth of 50 m to 150 m is relatively small, especially in the southern part of the West Mariana Ridge. The average particle size of suspended solids in the depth of 50 m to 150 m is obviously smaller than that in the northern part of the sea. Overall, the average particle size distribution of suspended solids shows a clear distribution trend of low in the South and high in the north.

The total volume concentration of suspended matter in surface water generally varies from 2.45 mL/L to 57.63 mL/L with an average of 11.10 mL/L. Vertically, the total concentration of suspended solids in shallow water at 50 m shows a decreasing trend from surface to downward, but there is a rapidly increasing layer between 50 m and 150 m. Spatially, the total concentration of suspended solids in the southern side of the West Mariana Ridge is smaller than that in the northern side.

6. Sedimentary environment evolution near the Western Mariana Ridge since late Pleistocene

6.1 Sedimentary environment at station 2014PAC-02 in the south of the Western Mariana Ridge

On October 12, 2014, samples of gravity columnar cores were collected at the 2014PAC-02 station in the northwestern part of the survey area and the southern part of the West Mariana Ridge. The depth of the cores was 3200 m and the length of the cores was 291 cm. The lithological profile shows that the sediments are homogeneous, dark yellowish brown clay and massive structure (Fig. 5). The water content at the top of the columnar sample is slightly larger, and the sediment is soft. Under gravity compaction downward, the water content decreases and the viscosity increases.

The results of grain size analysis show that the main grain size components of sediments are silt, with an average content of 70.15%; the types of sediments are silt and sandy silt; the average grain size (Mz) is 5.72_; and the sorting coefficient is 1.89, which is slightly worse; the skewness is mainly positive skewness; the peak state is 3.47, with a peak state.

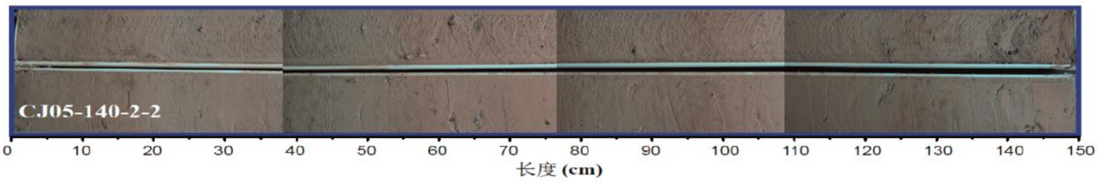

Fig. 5 Core Profile of 140cm~291cm Section of 2014 PAC-02 Column in Southern West Mariana Ridge

The results of geochemical analysis show that the two most abundant chemical constituents in sediments are CaO and SiO_2, which are 30.35% and 23.92% respectively. The average content of CaO is higher than that of SiO_2, which is the dominant chemical constituent. The major elements order are: $CaO > SiO_2 > Al_2O_3 > TFe_2O_3 > Na_2O > MgO > K_2O > TiO_2 > MnO > P_2O_5$ which is different compared with the abundance order of UUC ($SiO_2 > Al_2O_3 > TFe_2O_3 > CaO > Na_2O > K_2O > MgO > TiO_2 > P_2O_5 > MnO$). The average content of Ba in trace elements is less than Sr, which contents are 786.01×10^{-6} and 881.97×10^{-6}, respectively. The changes of Ba, V, Co, Cu and REE are obvious in 160 cm~230 cm interval, while the changes of Cr and Ni are obvious in 0 cm~140 cm interval, while the changes of Sr and Zr are not significant on the whole, especially in 0 cm~140 cM interval and 150 cm~270 cm interval.

The results of clay mineral analysis show that illite (51.67%) is the most abundant clay mineral in this station, followed by smectite (29.26%), chlorite (13.43%) and kaolinite (5.60%).

Three sediment samples were selected for $AMS^{14}C$ accelerator dating. Planktonic foraminifera were selected as the samples for dating, but the single species could not meet the requirement of quantity. Therefore, mixed samples were selected as the samples for dating. *Globigerinoides conglobatus* and *Orbulian unlversa* were the main samples, and a small number of *Sphaeroidinella dehis* were selected. $AMS^{14}C$ age data was calibrated using the calibration curve in Marine 13 for carbon pool calibration, which was suitable for marine environment. The calibration software was Beta experimental internal software (named BetaCal). The calibrated results show that the age of the sediments near the depth of 50 cm is over 43.5 kyrBP, the age of the sediments near the depth of 30 cm is 37.5 kyrBP, and the age of the sediments near the depth of 5 cm is 12.8 kyrBP. Therefore, the sedimentation rate of 2014PAC-02 station since 37.5 kyrBP can be calculated. The average sedimentation rate is about 1.01 cm/kyr.

Figure 6. Planktonic foraminifera dating samples from sediments of different layers at 2014PAC-02 station

（Note: Left is the samples at 5 cm layer, middle is the samples at 30 cm layer and right is the samples at 50 cm layer）

6.2 Sedimentary environment at station 2014PAC-08 in the central of the Western Mariana Ridge

On October 17, 2014, a gravity columnar core sample was collected at the 2014PAC-08 station in the middle part of the survey area. The water depth of the station is 3000 m and the length of the sample is 281 cm. Lithological profiles show that the sediments are homogeneous, dark yellowish brown clay and massive structure (Fig. 7). The water content at the top of the columnar sample is slightly larger, and the sediment is soft. Under gravity compaction downward, the water content decreases and the viscosity increases.

The results of geochemical analysis show that the two most abundant chemical constituents in sediments are SiO_2 and CaO, which are 33.21% and 23.59% respectively. The major elements order are: CaO＞SiO_2＞Al_2O_3＞TFe_2O_3＞Na_2O＞MgO＞K_2O＞TiO_2＞MnO＞P_2O_5 which is different compared with the abundance order of UUC (SiO_2＞Al_2O_3＞TFe_2O_3＞CaO＞Na_2O＞K_2O＞MgO＞TiO_2＞P_2O_5＞MnO). The content of chemical elements is not as uniform as that of lithology, and most constant curves show a trend change vertically. The chemical composition changes little with the depth profile downward, and the variation range of SiO_2, TFe_2O_3, MnO, CaO and K_2O is slightly larger, and the fluctuation cycle below 90 cm is relatively obvious. Trace elements change little with the depth profile downward, and the fluctuation is not obvious. The fluctuation cycles below 140 cm will be relatively obvious. The horizon above 120 cm decreases with depth, while the horizon below 120 cm tends to be stable. Sr content is similar to CaO content, but contrary to other trace elements, it shows a relationship between Sr content and CaO content.

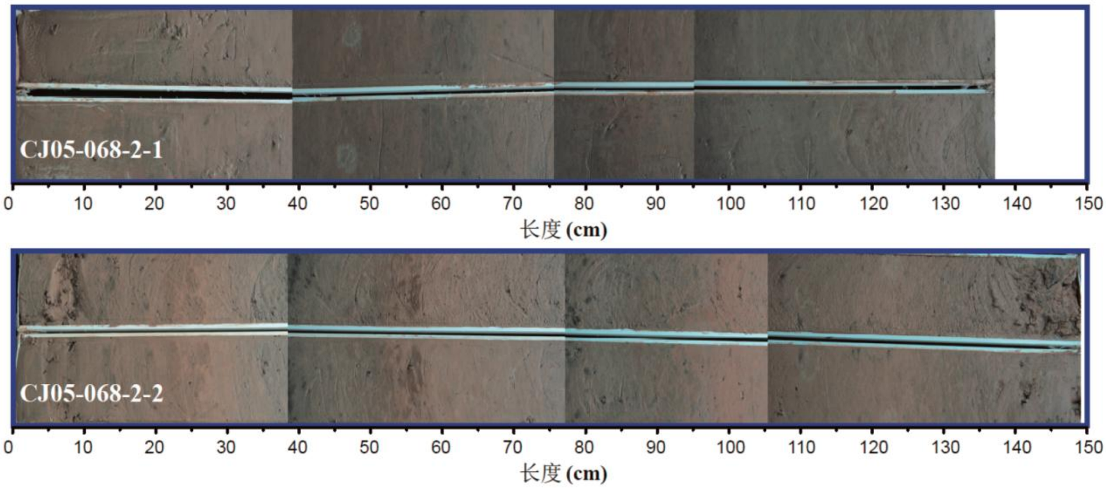

Fig. 7 Core profile of the 18cm-117cm section of the 2014PAC-08 station.

The results of clay mineral identification show that illite (46.75%) is the most abundant clay mineral, followed by smectite (30.97%), chlorite (15.64%) and kaolinite (6.64%). According to the relative content of clay minerals, the clay mineral assemblage at this station is illite-smectite-chlorite-kaolinite.

Three sediment samples were selected from the core of the station for AMS^{14}C accelerator dating. The samples for dating were planktonic foraminifera, but the single species could not meet the requirement of quantity. Therefore, mixed samples were selected as dating samples, in which common and *coccidial coccidia* were dominant, and with a small number of *Globigerinoides sacculifer*. AMS^{14}C age data was calibrated using the calibration curve in Marine 13 for carbon pool calibration, which was suitable for marine environment. The calibration software was Beta experimental internal software (named BetaCal). The calibrated results show that the calibration age is 8.3 kyrBP at the 5 cm layer, 18.0 kyrBP at the 20 cm layer and 41.6 kyrBP at the 40 cm layer. The average sedimentation rate of each period can be calculated as follows: the average sedimentation rate in the central area of the West Mariana Ridge from 41.6 kyrBP to 8.3 kyrBP is 1.05 cm/kyr; the average sedimentation rate in the period from 41.6 kyrBP to 18.0 kyrBP is 0.85 cm/kyr, and the average sedimentation rate in the period from 18.0 kyrBP to 8.3 kyrBP is 1.55 cm/kyr.

Figure 8. Planktonic foraminifera dating samples from sediments of different layers at 2014PAC-08 station

（Note: Left is the samples at 5 cm layer, middle is the samples at 20 cm layer and right is the samples at 40 cm layer）

6.3 Sedimentary environment at station 2014PAC-16 in the north of the Western Mariana Ridge

Gravity core was collected at 2014PAC-16 station in the north part of the investigation area on October 26, 2014. The water depth of the station is 3880 m and the length of the sample is 361 cm. Laboratory lithologic profile observation shows that (Fig. 9) sediment cores can be clearly divided into seven sections:

(1) 0-55 cm: light yellow-brown clay with uniform composition and color;

(2) 55-90 cm: yellowish-brown clay with uniform composition and color.

(3) 90-140 cm: light yellowish-brown clay with uniform composition and color.

(4) 140-180 cm: yellowish-brown clay with uniform composition and color.

(5) 180 cm to 200 cm: light yellowish brown clay with uniform composition and color.

(6) 200 cm-340 cm: yellowish-brown clay with uniform composition and color, containing a small amount of brown-gray disseminated layer and uniform lithology in other layers.

(7) 340 cm to 361 cm: light yellowish brown clay with uniform composition and

color.

The results of grain size analysis show that the main grain size components of sediments are silt, with an average content of 75.56%; the types of sediments are silt and sandy silt; the average grain size (Mz) is 6.20_; and the sorting coefficient is 1.76, which is slightly worse; the skewness is mainly positive skewness; the peak state is 3.66, with a peak state.

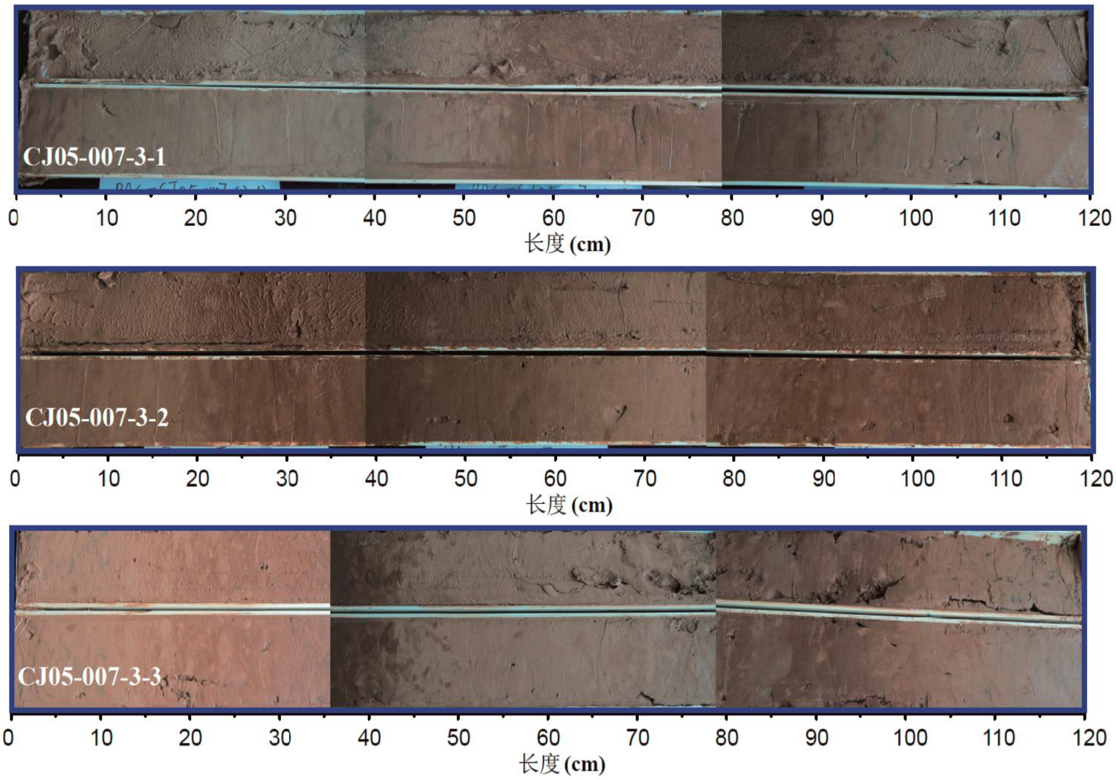

Fig. 9 Core profile of the of the 2014PAC16 station.

The results of geochemical analysis show that the two most abundant chemical constituents in sediments are SiO_2 and CaO, which are 38.30% and 16.84% respectively. The major elements order are: SiO_2>CaO>Al_2O_3>TFe_2O_3>Na_2O>MgO>K_2O>TiO_2>MnO>P_2O_5, which is different compared with the abundance order of UUC (SiO_2>Al_2O_3>TFe_2O_3>CaO>Na_2O>K_2O>MgO>TiO_2>P_2O_5>MnO). Most of the vertical profiles of major and trace elements can be divided into two sections: the curve above 90 cm has little fluctuation and stable content, and the cycles below 90 cm have obvious changes. For example, the content of SiO_2 ranges from 35.09 to 43.76% in the 0-90 cm section at the top of the core, and the vertical content is stable, while the content in the lower section ranges from 28.26 to 47.90%, and the range is enlarged. There are many fluctuation cycles. Other major elements such as Al_2O_3, TFe_2O_3, K_2O, TiO_2 and MgO also show similar characteristics to SiO_2. Although CaO and Sr also have two-stage characteristics, the cyclic trend is contrary to those of the above elements, which shows the relationship between them and each other.

The results of clay mineral identification show that illite (54.81%) is the most abundant clay mineral in columnar sediments, followed by smectite (24.87%), chlorite (14.09%) and kaolinite (6.23%). Generally speaking, the vertical distribution of the four clay mineral assemblages has little change, especially the vertical fluctuation of kaolinite and chlorite. On the contrary, the change of smectite and illite shows a trend of increasing and decreasing. From the bottom to 120 cm, the content of smectite increased slightly, from 23% to 35%, while illite decreased from 59% to 48%. From 120 cm to the top of the columnar sample, the content of smectite decreased slightly, from 35% to 26%, while illite increased from 48% to 60%.

Three sediment samples were selected from the core of the station for AMS^{14}C accelerator dating. The samples for dating are planktonic foraminifera, but the single species can not meet the requirement of quantity. Therefore, mixed samples are selected as dating samples. *Common coccidia*, *hydatid coccidia* and *coccidial coccidia* are dominant in the selection samples. A small number of *Goborotalia truncatulinoides,Pulleniatina obliquiloculata*, *Sphaeroidinella dehiscens* and *Goborotalia tumida* are also included in some stratigraphic selection samples. AMS^{14}C age data was calibrated using the calibration curve in Marine 13 for carbon pool calibration, which was suitable for marine environment. The calibration software was Beta experimental internal software (named BetaCal). The calibration results show that the calibration age is 13.4 kyrBP at the 10 cm layer, 32.8 kyrBP at the 30 cm layer and 42.7 kyrBP at the 60 cm layer. The average sedimentation rate of each period can be calculated as follows: the average sedimentation rate in the northern waters of the West Mariana Ridge from 42.7 kyrBP to 13.4 kyrBP is 1.71 cm/kyr; the average sedimentation rate in the period from 42.7 kyrBP to 32.8 kyrBP is 3.03 cm/kyr, and the average sedimentation rate in the period from 32.8 kyrBP to 13.4 kyrBP is 1.03 cm/kyr.

Figure 10. Planktonic foraminifera dating samples from sediments of different layers at 2014PAC-16 station

（Note: Left is the samples at 10 cm layer, middle is the samples at 30 cm layer and right is the samples at 60 cm layer）

Generally speaking, since 45 kyrBP, the sedimentation rate in the sea area near the West Mariana Ridge has gradually increased from south to north, that is, the average sedimentation rate in the south is 1.01 cm/kyr, and increases to 1.05 cm/kyr in the middle, and then continue to increase to 1.71 cm/kyr in the north of the West Mariana Ridge.

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