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NOTE AND CORRESPONDENCE

Exploring Quaternary Variability of the East Asia Monsoon, Kuroshio Current, and Western Pacific Warm Pool Systems: High-Resolution Investigations of Paleoceanography from the IMAGES III (MD106) - IPHIS Cruise

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ABSTRACT

We present the highlights of the 1996–1998 Taiwan IMAGES program, describing the objectives and some of the preliminary results from the third cruise in the western Pacific and the South China Sea (IMAGES III/MD106 - IPHIS Cruise). This cruise was successfully completed in June, 1997, with the cooperation of scientists from six countries. Specifically, we introduce the primary goals of the studies conducted in the South China Sea, which were mainly proposed and designed by scientists from Taiwan to further enhance our understanding of Quaternary variability in the East Asia monsoon, the Kuroshio Current, and the western Pacific warm pool systems. We also briefly describe the cores obtained from the South China Sea during this cruise and the preliminary scientific results drawn from shipboard measurements of the cores.

(Key Words: Paleoceanography, Paleoclimatology, Pacific Ocean, South China Sea)

1. TAIWAN IMAGES PROGRAM (1996-1998)

The IMAGES program was initiated to investigate the mechanisms and consequences underlying climatic changes using oceanic sedimentary records. Such a challenging project must be pursued on a global scale using sophisticated models based on high quality data which represent the variability in surface and deep ocean physical and chemical conditions during key periods of recent earth history. Studies by independent researchers are no longer suffi-

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cient to resolve this problem because the required acquisition of long sediment cores in high sedimentation rate areas is expensive, and characterizing such cores requires multiple tools and large numbers of measurements. Therefore, the IMAGES program was organized as an international effort for marine sediment research of PAGES-IGBP with the support of SCOR (IMAGES Science and Implementation Plan, 1994). Operational support based on specific scientific proposals has been sought from both national and international scientific agencies (IMAGES Newsletter, 1995).

The primary goals of the IMAGES science program are to quantify climatic and chemical variations in the ocean on time scales based on oceanic and cryospheric processes, to determine the sensitivity of these conditions to identified internal and external forcings, and to define their role in controlling atmospheric CO_2. In order to achieve these scientific objectives, IMAGES proposes to coordinate a global program to collect and study marine sediment records to address three fundamental questions (IMAGES Newsletter, 1996):

1) How have changes in surface ocean properties controlled the evolution of global heat transfer through deep and surface ocean waters and thereby modified the climate?

2) How have changes in ocean circulation, ocean chemistry, and biological productivity interacted to generate the observed record of atmospheric pCO_2 over the past 300 kyr?

3) How closely has the continental climate been linked to ocean surface and deep water properties?

As an active member with a full partnership in IMAGES since 1996, the Consortium of Taiwan Institutions (CTI; coordinated by the National Taiwan University and financially supported by the National Science Council, Taiwan, R.O.C.) has participated in the IMAGES program and played an active role in both shipboard and shore-based research in the second and third IMAGES cruises, during 1996 and 1997, respectively. The second cruise (MD105 - NAUSICAA: Namibia Angola Upwelling System and Indian Connection to Austral Atlantic) was a successful coring cruise which was conducted from September 20 through October 25 on the French R/V *Marion Dufresne*. On this cruise giant piston cores were taken from the continental margins and adjacent ocean basins off the coast of South Africa near Namibia, and Angola (Scientific Report of the NAUSICAA-IMAGES II Coring Cruise, 1997; Chen et al., in press). Min-Te Chen (Associate Professor, National Taiwan Ocean University) was on board during the entire cruise and identified cores for shore-based research in a study to be collaborated with Ein-Fen Yu (Associate Professor, National Taiwan Normal University).

The third cruise (MD106 - IPHIS: Indo-Pacific Pleistocene-Holocene IMAGES Study), from April 16 through June 30, was also conducted aboard the *Marion Dufresne*. This cruise was divided into two legs: (I) La Réunion - Hobart (Tasmania) - Christchurch (New Zealand), and (II) Christchurch - Cairns (Australia) - Kaohsiung (Taiwan) - Singapore (Scientific Report of the IPHIS-IMAGES III Coring Cruise, 1998; Figure 1). Leg I of the cruise focused on collecting cores to be used in a study correlating Pacific intermediate and deep water formations with hydrological front movements. Leg II, in the western Pacific and South China Sea (SCS), was designed to sample cores from the warm surface waters (Western Pacific Warm Pool, WPWP) which form a major component of the return flow in a "global conveyor belt" of the climate system. Natural variability in the warm pool needs to be characterized through

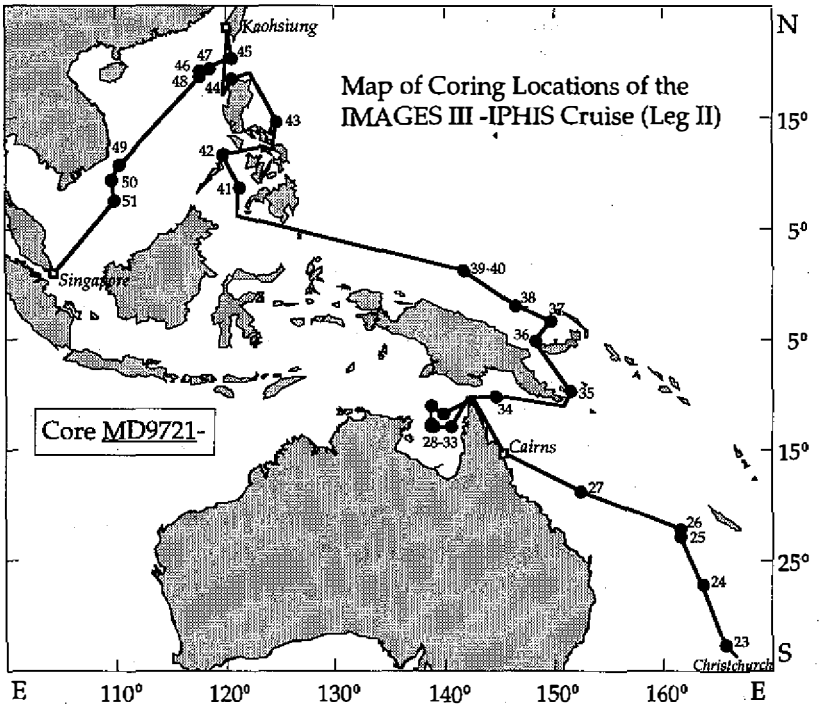

Fig. 1. Map showing core site locations and the cruise trajectory of IMAGES III/MD106 - IPHIS cruise (Leg II).

sediment record analyses to better understand its role in the climate system and its connection and interaction with the East Asia monsoon and the Kuroshio Current. The general scientific interests of Leg II of this cruise have drawn much attention from CTI scientists and are consistent with the long-term goals of Taiwan ocean science and paleoceanography programs. This correspondence paper describes the scientific objectives of the cruise and provides a summary of the core collections achieved in the western Pacific and the SCS. We briefly discuss the status and progress of the present research in Taiwan related to the activities of this cruise.

2. THE IMAGES III - IPHIS CRUISE (LEG II): SHIP-BOARD SCIENTIFIC RESULTS

The scientific objectives of Leg II of the IMAGES III cruise were to collect continuous and high sedimentation rate core records from the western Pacific Ocean and the SCS, to reconstruct the late Quaternary history of deep, intermediate, and surface circulation of the oceans, to better understand the paleoclimatic and geochemical history of this region, and to correlate the marine sedimentary records with other high quality terrestrial records to advance our knowledge of land–sea climate connections. This investigation involved the participation of 40 scientists from six countries (France, Taiwan, Australia, Germany, China, and Spain) and was highly successful with the recovery of 29 giant piston cores.

The cores taken from the southwest Pacific Ocean (MD9721-23 - 27; Figure 1) displayed a latitudinal distribution that was designed to reconstruct variations in surface water temperature and salinity that are closely related to the movements of the Intertropical Convergence Zone (ITCZ) and of the Tasman Front. Understanding past variations in the latitudinal/longitudinal positions of the frontal structures is critical for modeling the dynamics of the WPWP, which is closely related to global changes in climate due to El Niño Southern Oscillation (ENSO) phenomena. Previous investigations of late Quaternary records from this region (Martínez, 1994) have revealed that the Tasman Front migrated from 30°S to its present position at 26°S during the last glacial maximum. This northward migration of the Tasman Front may indicate a reduction in the volume of the WPWP waters and/or an increase in the strength of the current flow of cool subtropical waters.

The six short cores (MD972128 - 33; Figure 1) taken from the Gulf of Carpentaria were proposed by Australian scientists in order to study the environmental history of the semi-enclosed basin during the last glacial–interglacial cycles. The water depth in some parts of the Gulf is very shallow, approximately 60 m. The stratigraphic sequences in the basin, as determined from these cores, reaches old intercalated beds of lacustrine deposits and soils, indicating that the sedimentary environments were controlled by a rise in sea level of about 120 m since the last glacial maximum.

There is little data available to study the climatic history of the wide WPWP, which would provide an important component in understanding the dynamics of low-latitude ocean climate and global climate change. Towards the effort to provide such data, eight cores (MD972134 - 41; Figure 1) sampled in this cruise will permit us to investigate the climatic variability of the equatorial zone. Two cores (MD9721-39 and -40) with high sedimentation rates (3–4 cm/kyr), as estimated from biostratigraphic age controls, will allow us to reconstruct a history with greater resolution for the western Pacific Ocean.

To achieve the necessary temporal resolution for the IMAGES objectives, paleoceanographers have to sample in regions of the ocean where sedimentation rates are at least of the order of 10 cm/kyr. This, combined with the need for records of 300,000 years or longer, requires core lengths of no less than 15 m, and in many areas core lengths of 30, 50, and even 75 m will be required. Such samples were necessary in the core collection project in the SCS (Figure 2) where Taiwanese paleoceanographers obtained long and high-quality marine paleoclimate records from the high sedimentation rate area. Though previously it was technically difficult for Taiwanese paleoceanographers to use domestic research ships to take cores longer than 10 m, the excellent ability of the giant piston core system aboard the *Marion Dufresne* allowed us to retrieve cores of 30 to 50 m in length. Presently, the *Marion Dufresne* is the only platform that is able to routinely retrieve piston cores between 30 and 70 m long. The project in the SCS will specifically aid our understanding of late Quaternary variability in 1) responses of surface waters to the East Asia monsoon winds and rapid climatic changes, 2) the Kuroshio Current circulation and upwelling patterns, and 3) the heat and salt exchanges between the western Pacific Ocean and the SCS.

The SCS portion of the cruise was mainly supported by funding from the Ocean Science Program of the National Science Council. Seven scientists from institutions in Taiwan col-

laborated with international teams to fulfill the mission; they were Min-Te Chen (co-chief scientist for this part of the cruise), Chi-Yue Huang, Kuo-Yen Wei, and Min-Pen Chen (Professors, National Taiwan University), Teh-Quei Lee (Researcher, Academia Sinica), Ein-Fen Yu, and Bee-Deh Yuan (Associate Professor, National Sun Yat-Sen University). Six graduate students were also present to assist in the shipboard research. In this part of the cruise, 10 cores (MD972142 - 51; Figure 2) were taken from the SCS area and eight long and high quality cores (MD972142, 43, 44, 45, 46, 48, 49, 51) were identified, and transported to storage in Taiwan for shore-based research. The average length of these eight cores was 34 m. Among these, MD972148 was the longest (48 m). Based on the shipboard data on GRAPE density (Figure 3), magnetic susceptibility (Figure 4), color reflectance (Figure 5), and micropaleontological stratigraphy, core MD972146 seemed to have the highest temporal resolution

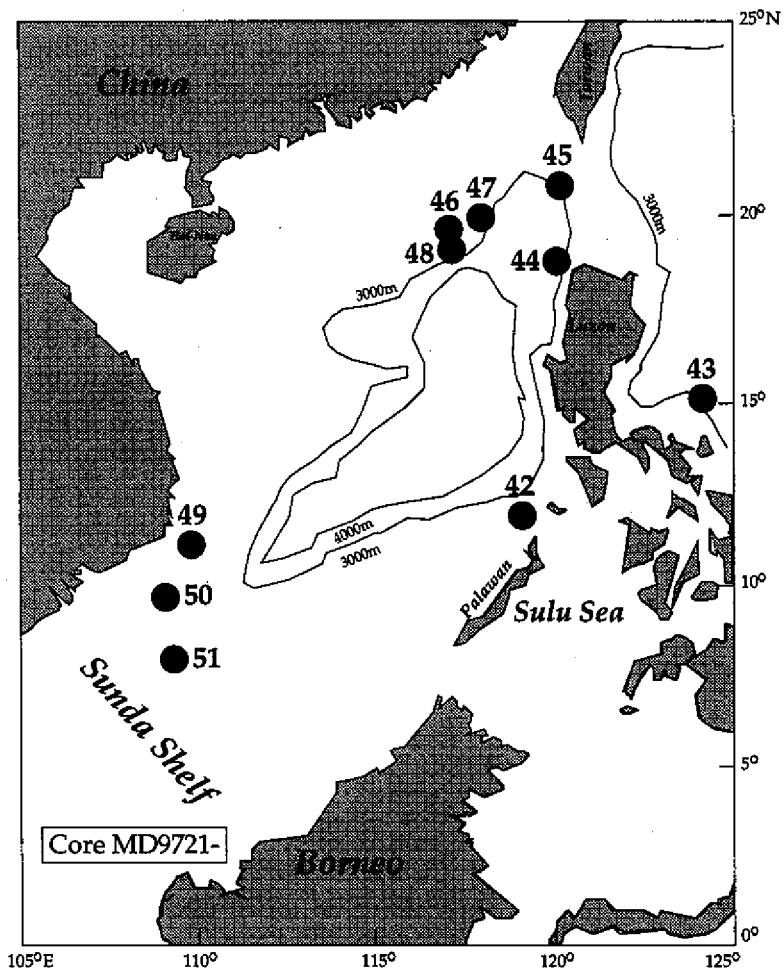

Fig. 2. Map showing locations of cores (MD972142 - 51) taken from the South China Sea Area in IMAGES III/MD106 - IPHIS cruise (Leg II).

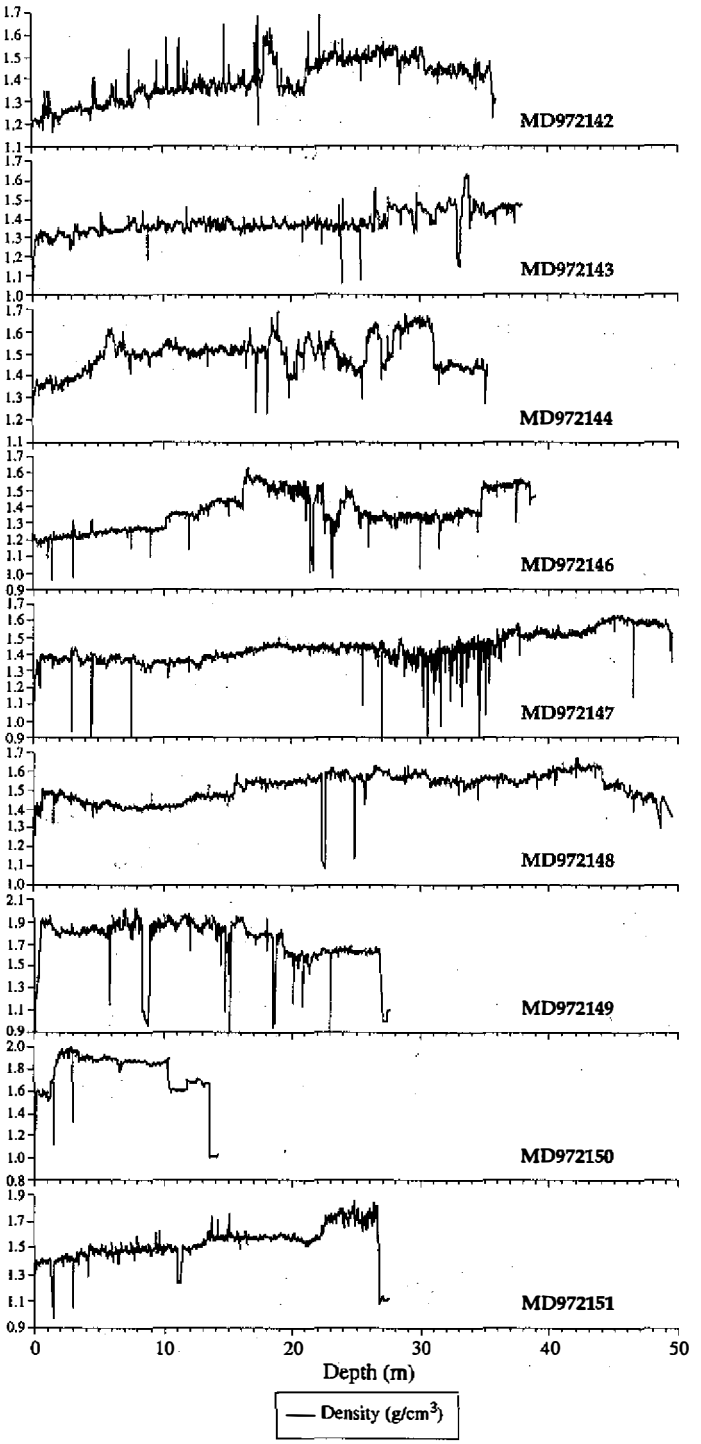

Fig. 3. GRAPE density data measured on board for cores MD972142 - 51.

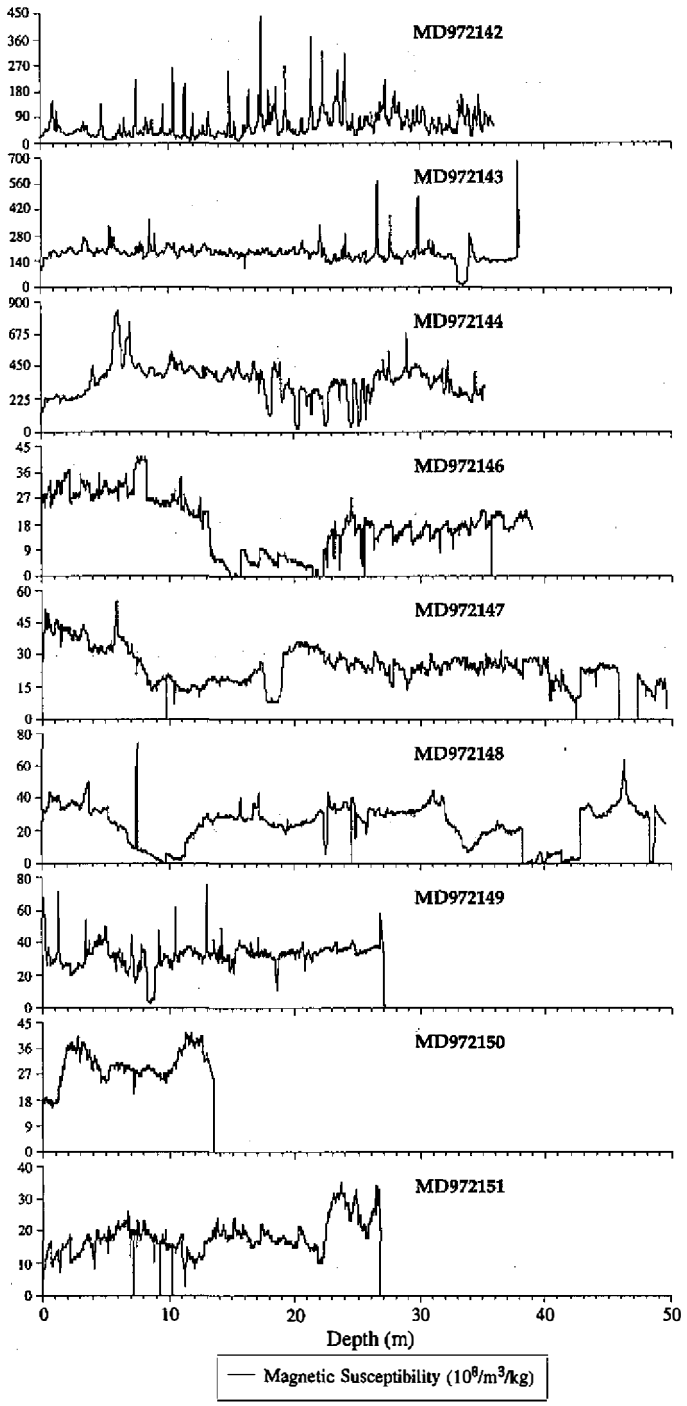

Fig. 4. Magnetic susceptibility data measured on board for cores MD972142 - 51.

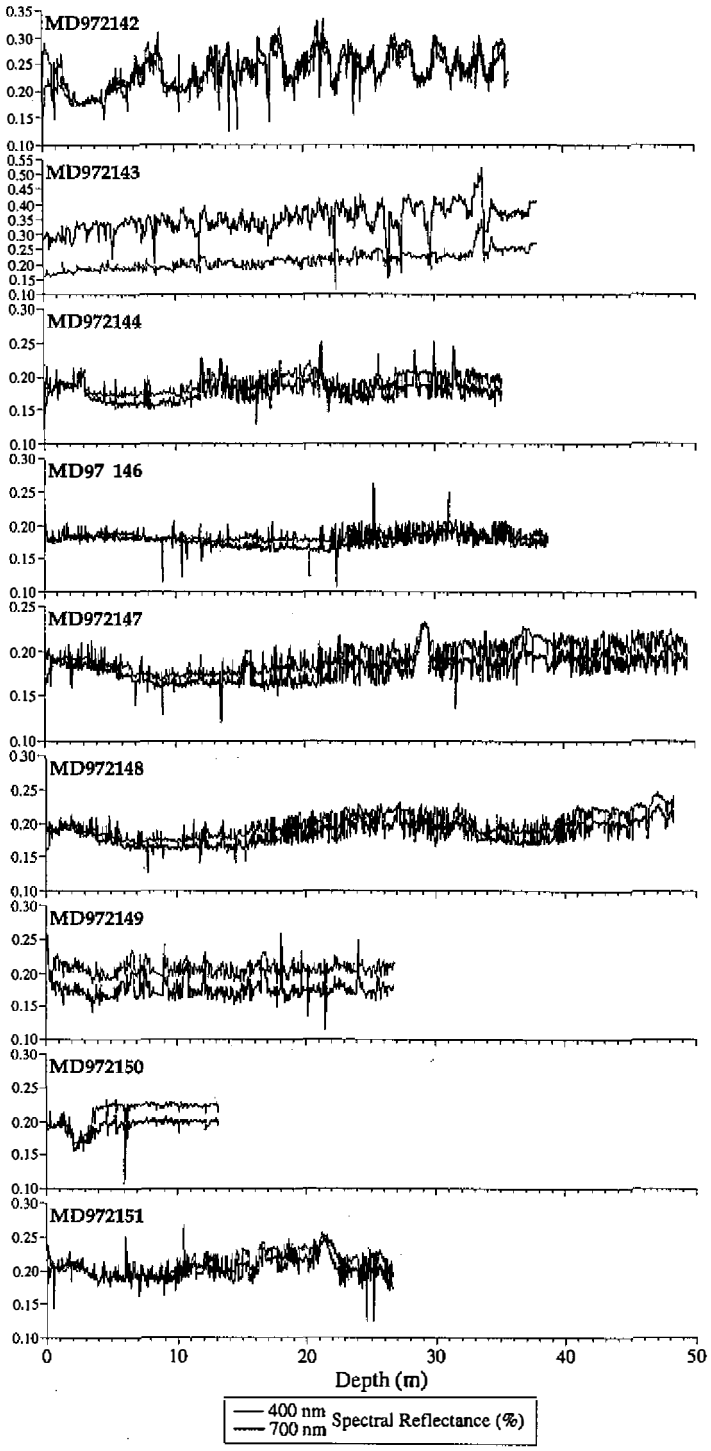

Fig. 5. Color reflectance data measured on board for cores MD972142 - 51.

(> 80 cm/kyr). This core, combined with core MD972148 which was also taken from the northern SCS, provided ultra-high resolution records for studying past changes in East Asia monsoons. Core MD972143, taken from Benham Rise east of Luzon, may represent a very long record covering the past 2.5 m.y. and reveal historic environmental changes that were mainly controlled by the circulation patterns of the Kuroshio Current. The detailed descriptions, scientific objectives, and ship-board preliminary results for each core are provided below.

Core Identification: MD972142 (Palawan Island)
Core Position: 12°41.133'N 119°27.90'E
Depth (mbsl): 1,557 m
Weight: 6 t
Tube Length: 42.50 m
Sediment: 35.91 m
Recovery: 84.5%
Core Quality: Good
Dominant Lithology: Light olive gray mud foram nanno ooze
Age of the Base: ~ 320 kya; < 460 kya

Scientific Objective: MD972142 provides data on high-resolution variability in the eastern slope of the SCS during the late Quaternary history. The seasonal contrast in sea-surface environmental conditions is minimal compared to other SCS regions. The sea environments represented by this core are primarily similar to those of the WPWP, in which the sea surface temperatures are annually constant and above 28°C. Characteristics of this core are complementary to other cores collected during the early part of this cruise in the western Pacific Ocean. A set of 12 short gravity cores located west of this site have been reported previously in a study examining the lysocline and the productivity variation in this region (Thunell et al., 1992).

Core Identification: MD972143 (Benham Rise)
Core Position: 15°52.262'N 124°38.96'E
Depth (mbsl): 2,989 m
Weight: 7.4 t
Tube Length: 50.20 m
Sediment: 37.95 m
Recovery: 75.6%
Core Quality: Good, flow-in structures shown in some sections
Dominant Lithology: Olive brown mud nanno ooze
Age of the Base: ~2.5 Ma

Scientific Objective: Data from MD972143 documents the late Cenozoic history of the Kuroshio Current in the western Pacific Ocean. The Kuroshio Current comprises the major western boundary current of the Pacific Ocean and plays an important role in regulating global

transport of heat and water vapor. This site is on Benham Rise, the region offshore from eastern Luzon, and is characterized by low sedimentation rates with undisturbed deposition of pelagic oozes. This core location is close to DSDP Site 292 (15°49.11'N, 124°39.05'E, 2,937 m) from which the top Pleistocene sections have not been well studied since its retrieval.

Core Identification: MD972144 (Western Luzon)

Core Position: 19°21.813'N 120°32.05'E
Depth (mbsl): 2.680 m
Weight: 7 t
Tube Length: 42.65 m
Sediment: 35.24 m
Recovery: 83.8%
Core Quality: Good
Dominant Lithology: Dark gray mud bearing nannofossils, radiolarians, spicules, and diatoms bearing
Age of the Base: < 270 kya

Scientific Objective: Core MD972144 is influenced by upwelling processes that are primarily driven by the northeast monsoon winds and the westward intrusion waters of the Kuroshio Current into the SCS during winter. Sedimentation in this region is characterized by hemipelagic mud and volcanic ash layers. The stratigraphic distribution of tephra in this region has been well documented from observations of cores collected during the Sonne-94 & -96 cruises (Preliminary Report on Sonne-95 Cruise, 1994). The high sedimentation rate at this site reflects the high-resolution history of the East Asia winter monsoon.

Core Identification: MD972145 (Luzon Strait)
Core Position: 21°15.94'N 120°35.27'E
Depth (mbsl): 1,408 m
Weight: 6 t
Tube Length: 29.20 m
Sediment: 24.02 m
Recovery: 82.3%
Core Quality: Reserved for shore-based research
Dominant Lithology: Reserved for shore-based research
Age of the Base: Reserved for shore-based research

Scientific Objective: MD972145 is located in the region offshore from southern Taiwan, on top of Hengchun Ridge. The records obtained from this site will be used for studying the influence of water exchange between the SCS and the west Philippine Sea during the late Quaternary history. Such water exchange is primarily driven by the northeast monsoon winds during winter. From studies of the benthic community in this core, the variation in bottom water properties in the Luzon Strait, which are influenced by incoming Pacific intermediate

and deep waters, can be documented.

Core Identification: MD972146 (Pratas/Dong-Sha)
Core Position: 20°07.019'N 117°23.08'E
Depth (mbsl): 1,720 m
Weight: 7 t
Tube Length: 42.30 m
Sediment: 38.69 m
Recovery: 90.6%
Core Quality: Good
Dominant Lithology: Dark gray nanno & foram oozes bearing radiolarians and diatoms
Age of the Base: < 126 kya

Core Identification: MD972148 (Pratas/Dong-Sha)
Core Position: 19°47.804'N 117°32.56'E
Depth (mbsl): 2,830 m
Weight: 7 t
Tube Length: 52.68 m
Sediment: 48.72 m
Recovery: 92.5%
Core Quality: Good
Dominant Lithology: Dark gray nanno & foram oozes bearing radiolarians and diatoms
Age of the Base: < 126 kya

Scientific Objective: MD972146 and MD972148 are located on the northern slope of the SCS, close to Pratas (Dong-Sha) Island. This region is influenced by the most intense winter monsoon winds and has very high sedimentation rates of up to approximately 80 cm/yr. The undisturbed stratigraphic sequence preserved in this region has been previously documented from many short (~15 m long) piston cores collected from the Sonne-94 cruise. The extended cores collected in the current study will enable a longer and more in-depth analysis of the late Quaternary history of the East Asia winter monsoon. These core locations are close to Sonne-94 cores 17940 (20°07.0'N, 117°23.0'E, 1,727 m) and 17938 (19°47.2'N, 117°32.3'E, 2,840 m), indicating that they should have the highest sedimentation rates and provide a longer record of the monsoon history.

Core Identification: MD972149 (Vietnam)
Core Position: 11°54.004'N 110°00.56'E
Depth (mbsl): 1,870 m
Weight: 7 t
Tube Length: 41 m
Sediment: 27.18 m

Recovery: 66.3%
Core Quality: Good, but with a deformed sequence at ~1,500 cm
Dominant Lithology: Gray to dark gray mud, occasionally silty, bearing nannofossil and forams with fragments of radiolarians
Age of the Base: > 126 kya

Core Identification: MD972151 (Wan-An-Tan)
Core Position: 8°43.73'N 109°52.17'E
Depth (mbsl): 1,589 m
Weight: 7 t
Tube Length: 32.15 m
Sediment: 26.72 m
Recovery: 83.1%
Core Quality: Good
Dominant Lithology: Olive to dark clay, slightly silty, bearing nannofossil, forams, and diatoms
Age of the Base: > 126 kya

Scientific Objective: MD972149 lies in the most intense upwelling region of the East Asia southwest summer monsoon. This core is located offshore from Vietnam and will enable us to address late Quaternary variability and migration of the upwelling cell. MD972151 is located on the eastern slope of Wan-An Tan where the influence of the summer monsoon upwelling can be somewhat avoided. The expected high sedimentation rate records and hemipelagic mud sequences from these cores will further our understanding of summer climatic conditions in the SCS, and will be compared with cores taken from the northern SCS which reflect winter climatic condition.

3. CONCLUSIONS

The great success of the IMAGES III/MD106 - IPHIS cruise has been demonstrated above by initial examination of the excellent, high-quality ship-board scientific data. While with the detailed geographic and temporal sampling completed, combined with the development of preliminary time-stratigraphic frameworks based on magnetic susceptibility, color reflectance, nannofossil biostratigraphy, and tephrochronology (Wei and Lee, and the Shipboard Scientific Party, this volume a; b), we are confident that our understanding of Quaternary variability of the SCS and the western Pacific Ocean will be greatly improved.

Examination of the preliminary ship-board measurement data reveals that the sedimentation rate in the SCS is extremely high on the northern slope, probably up to approximately 40cm/kyr over the past 100,000 years. Color reflectance and magnetic susceptibility data for the cores taken from the northern slope of the SCS indicate that these records may contain high-frequency / rapid oscillation signals of climatic changes, which can be well compared to records from the other regions to better understand the global climatic linkage in the late Quaternary. The cores taken from the southern part of the SCS will be used to reconstruct the

warm pool variability in parts of the western Pacific Ocean. Although these cores have relatively low sedimentation rates (~10cm/kyr) in comparison to those from the northern, these cores already have better resolution than previously analyzed western Pacific open sea records. We expect that these record will provide better constraints for defining the phase of orbital climatic variability in tropical oceans. The existence of volcanic ash layers (Wei and Lee, and the Shipboard Scientific Party, this volume a; b) offers great opportunities to better define the time-stratigraphy of these cores, and to improve understanding of the potential linkage between paleoclimate and volcanic activities in the western Pacific regions. Clearly, much work remains, however, the IMAGES III/MD106 - IPHIS cruise data provide many new insights to our understanding of Earth's climate systems during the Quaternary.

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