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Late Miocene to Pleistocene sedimentation and sediment transport on the Cocos Ridge, eastern tropical Pacific Ocean

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ABSTRACT

We use digital seismic reflection profiles within a 1° × 1° survey area on the Cocos Ridge (*COCOS6N*) to study the extent and timing of sedimentation and sediment redistribution on the Cocos Ridge. The survey was performed to understand how sediment focusing might affect paleoceanographic flux measurements in a region known for significant downslope transport. COCOS6N contains ODP Site 1241 to ground truth the seismic stratigraphy, and there is a seamount ridge along the base of the ridge that forms a basin (North Flank Basin) to trap sediments transported downslope. Using the Site 1241 seismic stratigraphy and densities extrapolated from wireline logging, we document mass accumulation rates (MARs) since 11.2 Ma. The average sediment thickness at COCOS6N is 196 m, ranging from outcropping basalt at the ridge crest to ~400 m at North Flank Basin depocenters. Despite significant sediment transport, the average sedimentation over the entire area is well correlated to sediment fluxes at Site 1241. A low mass accumulation rate (MAR) interval is associated with the 'Miocene carbonate crash' interval even though COCOS6N was at the equator at that time and relatively shallow. Highest MAR occurs within the late Miocene–early Pliocene biogenic bloom interval. Lowest average MAR is in the Pleistocene, as plate tectonic motions caused COCOS6N to leave the equatorial productivity zone. The Pliocene and Pleistocene also exhibit higher loss of sediment from the ridge crest and transport to North Flank Basin. Higher tidal energy on the ridge caused by tectonic movement toward the margin increased sediment focusing in the younger section.

1. Introduction

Pelagic ridges can be relatively high-energy abyssal environments where basement may be exposed when particulate 'rain' is transported elsewhere. Sediment transport downslope from ridge tops can cause thick basin fill in basins downslope. Basins where sediment deposition is focused are often targets to take sediment cores for paleoceanographic study because the higher sedimentation rates result in better time resolution of the sedimentary record. While the basin sediments have better time resolution, studies of paleoceanographic conditions via measurements of sediment flux become more complex because of the uncertainty of whether they reflect behavior of the sea surface above or changes in horizontal transport. It has been proposed that ^{230}Th contents in sediments can serve as a constant flux proxy, and can be used to compensate for the effects of sediment focusing into basins and that the normalized measurements can then provide true flux information (Bacon, 1984; Francois et al., 2004). The model, unfortunately, lacks testing by comparison to geologic measurements (Lyle et al., 2005). Nevertheless, an important question in pelagic sedimentation is to what extent does a core from an individual site represent regional sediment fluxes from the surface ocean, and how well does a core represent changes in flux through time?

Sedimentation on the Cocos Ridge was originally studied 40 years ago as part of projects to understand sedimentation in the Panama Basin (van Andel et al., 1971; Dowding, 1977) and to locate drill sites for Deep Sea Drilling Project Leg 16 (Heath and van Andel, 1973). These studies were not only mostly concerned with the formation of the Panama Basin but also included interpretations of sedimentation from analog seismic reflection surveys. Van Andel et al. (1971) compiled the only comprehensive survey of sedimentation and sediment thickness of the Panama Basin region, based upon analog seismic reflection data. Extensive areas on top of both the Cocos and Carnegie Ridges were found to be clean of sediments despite crustal ages as old as 15 Ma. Van Andel et al. (1971) also noted significant erosional surfaces within the sediment column. Dowding (1977) studied part of the Cocos Ridge just to the northeast of COCOS6N and found evidence of winnowing and downslope transport from the ridge top. She concluded that sediment dispersal followed valleys subparallel to the ridge crest in the northeast of her area, switching to cross-ridge in the southwest where the COCOS6N area is located.

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In the tropical Pacific including the Panama Basin, seismic horizons in the sediment section are associated with major changes in carbonate content caused by changes in ocean chemistry or with plankton carbonate production (Mayer et al., 1985; Mayer et al., 1986; Bloomer et al., 1995; Lyle et al., 2002). Changes in carbonate content result in changes in density and acoustic impedance that in turn produce chronostratigraphic seismic horizons (Berger and Mayer, 1978; Mayer, 1979). By tracing distinctive seismic horizons, seismic profiles present an opportunity to map regional sediment patterns with a lateral resolution that cannot be achieved from discrete core data.

Deep sea drilling in the eastern tropical Pacific has identified depositional periods from 11 million years ago (Ma) that are distinguished by both changes in sediment composition and MAR (Farrell et al., 1995). These depositional periods have produced a distinctive eastern Pacific seismic stratigraphy (Bloomer et al., 1995). The late Miocene biogenic bloom (~8–4.4 Ma at 110°W) is found throughout the eastern tropical Pacific and consists of a series of low $CaCO_3$ content, high bio-SiO_2 MAR cycles that peaked at ~6.8 Ma. Within this period there are ~7 intervals that have much higher MAR, higher diatom abundance, and lower $CaCO_3$% partly caused by dilution of $CaCO_3$ by rapidly accumulating biogenic SiO_2 (Farrell et al., 1995). The Miocene carbonate crash (Lyle et al., 1995) is a low $CaCO_3$ interval now dated between 11.1 and 8.6 Ma at 118°W (Lyle and Backman, 2013). Originally Lyle et al. (1995) attributed the entire carbonate crash interval to higher $CaCO_3$ dissolution. However, the interval is also associated with occurrence of mat-forming diatom deposits throughout the eastern and central Pacific that indicate a change in the delivery of nutrients to the surface ocean as well (Pälike et al., 2010). How these events behaved on the Cocos Ridge provides important new data to understand the regional paleoceanography, since the COCOS6N survey area is above the lysocline in the Pleistocene and was even shallower when the crust was formed in the late Miocene.

This study makes estimates of sediment accumulation and sediment focusing on the Cocos Ridge using seismic stratigraphy and evaluates how sedimentation has changed with time. We chose the COCOS6N area because we could augment digital seismic reflection profiles collected in 2010 with others from a site survey for Ocean Drilling Program Site 1241, and also use Site 1241 to calibrate the seismic stratigraphy. We identify the large-scale sediment deposition patterns within COCOS6N from 11.2 Ma, then develop a seismic stratigraphy, and make estimates of sediment thickness and mass around COCOS6N. Using the seismic stratigraphy, we investigate patterns of sedimentation in 6 time slices. Sedimentation on the Cocos Ridge responded to large-scale changes in biogenic deposition in the eastern Pacific, as well as changes in magnitude of sediment transport downslope.

2. The COCOS6N survey area

The COCOS6N survey, shown in Fig. 1, encompasses two digital seismic reflection surveys, an ODP drill site, and several piston and multicores. COCOS6N is in a saddle on the Cocos Ridge where the ridge crest is relatively low (Fig. 1). Dowding (1977) proposed that sediment transport pathways in the COCOS6N region should be nearly upslope–downslope. A chain of seamounts marks the northern edge of the Cocos Ridge and northeastern corner of COCOS6N. Ar–Ar dates from two seamounts on this chain are surprisingly young (1.9–2.3 and 3.6 Ma, O'Connor et al., 2007), hypothesized to represent a period of rejuvenated volcanism, and may have formed after a significant part of the sediments was laid down.

The sediment section (ODP Site 1241; Leg 202 Shipboard Scientific Party, 2003) is essentially biogenic in origin, and is typical of eastern equatorial Pacific sections (Farrell et al., 1995). The basal sediments, in the late Miocene 'carbonate crash' interval (Lyle et al., 1995) have high biogenic SiO_2 and low $CaCO_3$ abundance despite Site 1241 being drilled at the shallow water depth of 2027 m. High deposition is found in the late Miocene–early Pliocene 'biogenic bloom' interval (Farrell et al., 1995; Leg 202 Shipboard Scientific Party, 2003) and the sediment is more carbonate-rich than below. Rapid changes between high and low carbonate cause significant changes in acoustic impedance and a chronostratigraphic regional seismic stratigraphy.

3. Seismic stratigraphy

See the Supplemental material for a more detailed description of data acquisition and processing. Two seismic acquisition cruises (NEMO-3 and MV1014) passed through the survey area using the same GI source configuration (dual GI guns with 45-ci generator, 105-ci injector), but with different streamers. Both cruises had GPS navigation for shot and CDP locations. Navigation and stacked SEG-Y files can be obtained through the Academic Seismic Portal at UTIG (http://www.ig.utexas.edu/sdc/), an NSF-funded seismic data archive.

Distinctive seismic horizons were noted in the seismic reflection profiles that make up the COCOS6N survey (Fig. 1). When calibrated with the Site 1241 sediment column, the seismic horizons can be used to measure the deposition of sediments through time. In order to use the seismic reflection profiles, two-way travel time (TWTT) for an echo to return to the seismic recording instrument must be converted to depth in meters below the seafloor (mbsf) via a velocity profile. When the seismic reflection profiles across Site 1241 are compared to a synthetic profile based on density of the drilled sediments, ages can be assigned to seismic horizons. After first estimating the change in acoustic velocity with depth in the sediment column to make a TWTT–mbsf conversion we then used the acoustic response from the physical properties profile to create synthetic seismograms to compare with the measured seismic reflection profile. Seismic reflection profiles acquired from the MV1014 and NEMO-3 cruises were compared with ODP Site 1241 core data to study the downcore biogenic sediment pattern and how it is translated into the seismic reflection signal. Once the acoustic response can be translated into changes in sediment type, ages can be assigned to seismic horizons and regional sedimentation patterns can be studied.

3.1. Time–depth conversion

An acoustic impedance profile is needed to calculate a synthetic seismogram to compare with seismic reflection profiles. Usually this is constructed from both velocity and density data but wireline log-derived velocity data from the Dipole Sonic Imager at Site 1241 are noisy. The p-wave velocities from the well logging are anomalously scattered from values expected from either density or resistivity logs (Leg 202 Shipboard Scientific Party, 2003). Large offsets in compressional velocity appear to represent borehole damage rather than the acoustic signal of the sediment. The velocity artifacts are sufficiently large to contaminate a synthetic seismogram constructed from the data.

p-Wave velocity is also measured on recovered core as part of the standard shipboard physical properties program in the Ocean Drilling Program (Mix et al., 2003). Shipboard measurements of p-wave velocity are reasonably accurate when sediments are truly unconsolidated but need significant corrections as the sediments consolidate (Mayer et al., 1985). The shipboard velocity measurements are typically used to reconstruct the velocity profile in the upper 50–100 m of a borehole that cannot be logged. Sediment rebound corrections can be made but can introduce errors in estimated velocity if the rebound is poorly known. Shipboard measurements of p-wave velocity from Site 1241 range between 1520 m/s near the surface and 1570 m/s near 300 mbsf in Site 1241. Expected velocities at 300 m based on logs in similar sediments are ~1700 m/s (Mayer et al., 1985; Bloomer et al., 1995).

We resolved the velocity problem by creating the synthetic seismic profile using a smoothed velocity profile estimated from the TWTT and depth to basement at Site 1241 (Fig. 2), that was then combined with measured density in order to create the acoustic impedance profile for the synthetic seismogram. The TWTT–depth curve is the integration