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INSIDE...

Active continental extension: The Woodlark Basin

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In October 1995, a four-day multi channel seismic and bottom sampling survey was conducted aboard the R/V *Ewing* in the Pacific's western Woodlark Basin. This site augmentation effort, supported by USSSP, was associated with JOIDES Proposal #447. New data from this survey provide further evidence for active extension on a low-angle (~25°) normal fault but do not support a metamorphic core complex origin for Moresby Seamount.

Background

The processes by which continental lithosphere accommodates strain during rifting and initiation of seafloor spreading are presently known primarily from the study of either (1) passive margins bordering rifted continents, where extensional tectonics have long ceased and evidence for active tectonic processes must be reconstructed from a record that is deeply buried in post-rift sediments and thermally equilibrated, or (2) regions of intra-continental extension, such as the U.S. Basin and Range and the Aegean, where extension has occurred recently by comparison to most passive margin examples, but has not proceeded to the point of continental breakup.

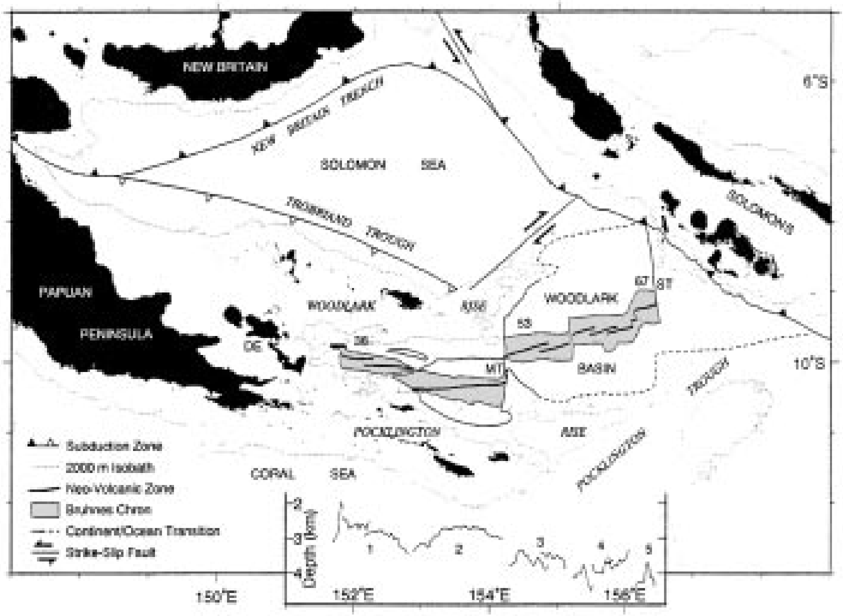

Fig. 1: Tectonic setting of the Woodlark Basin, plus a depth profile along the spreading axis. Spreading rates vary from 36-67 mm/yr.

One particularly controversial conjecture from these studies is that aereally large, normal detachment faults dip at low angles and accommodate very large amounts of strain through simple shear of the entire lithosphere. The role of low-angle normal detachment faults has been contested strongly, both on observational and theoretical grounds. Observationally, it has been suggested that intra-continental detachments have been misinterpreted and actually formed by roll-over of originally high-angle features, or that they occur at the brittle-ductile boundary in a pure shear system. Theoretically, it has been shown that normal faulting on detachment surfaces would require that the fault be extremely weak – almost frictionless – in order to allow horizontal stresses to cause failure on low-angle planes.

The mechanisms by which friction might be effectively reduced on low-angle normal fault surfaces are not understood. One possibility is that active shearing in the fault zone creates a strong permeability contrast with the surrounding crust (by opening cracks more quickly than precipitation can heal them). This would allow pore pressure

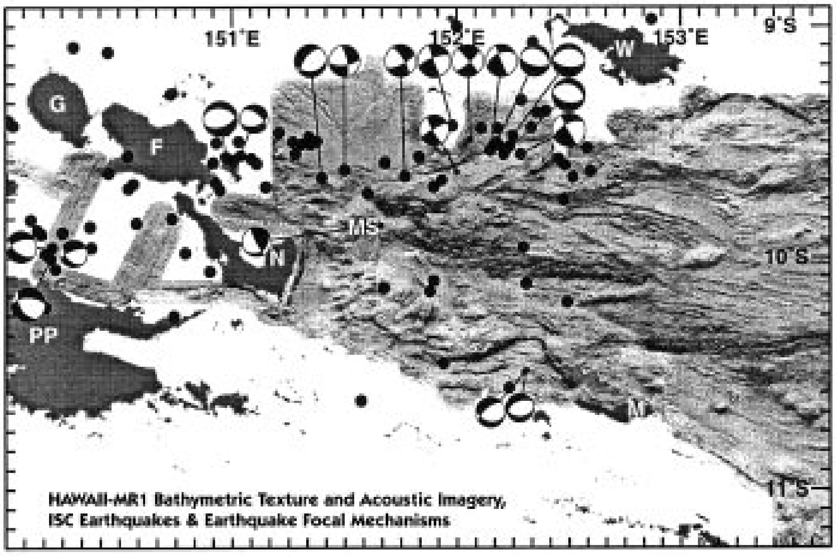

*Fig. 2: Shallow (2-10 km) normal and strike slip faults, with northerly T-axes, bound the north side of the rifting-spreading transition. Margin faulting continues for up to one million years after spreading initiates [*Taylor et al.*, 1995].*

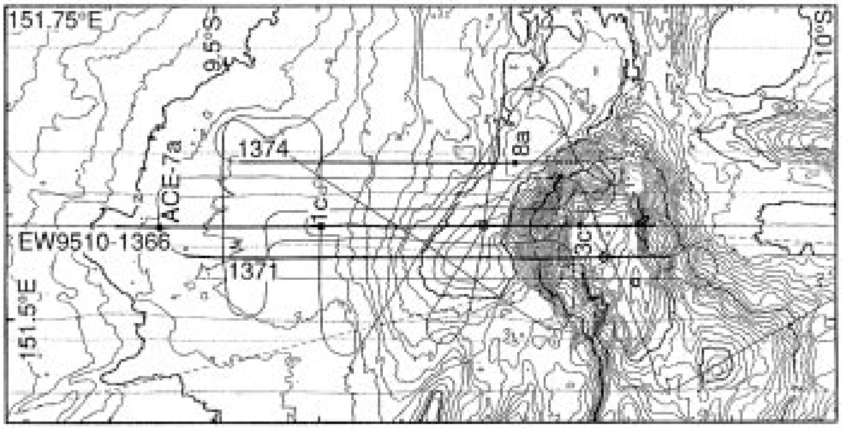

Fig. 3: MCS track chart on 100 m bathymetry base with proposed drill sites (ACE-1c, 3c, 7a, 8a) and new bottom sample locations (cores: open circles, dredge: oblong box). EW9510 track is solid line, with bold seismic segments shown in Figure 4.

distributions that are high and near to the fault-normal compressive stress within the fault zone, but that decrease with distance into the adjacent crust. Testing for such fault-proximal high permeability and pore pressures and the associated local rotation of stress axes requires drilling into an active system. This would also allow determination of the properties of the fault rock at depth as well as studies of the mechanisms by which fluid-rock reactions affect deformation.

The proximal variation from active rifting of continental New Guinea to seafloor spreading in the Woodlark Basin (Figure 1) makes this an attractive area to investigate the mechanics of lithospheric extension. Earthquake source parameters and seismic reflection data indicate that low-angle normal faulting is active in the region of incipient continental separation ([*Abers*, 1991; *Taylor et al.*, 1995; *Mutter et al.*, 1996], Figure 2). Our proposal (JOIDES #447) recommends drilling a transect of sites (just ahead of the spreading tip) above, below, and through a low-angle reflector to test the interpretation that it is a primary low-angle normal fault, to determine the vertical motion and horizontal extension history prior to spreading, and to initially characterize, and subsequently monitor, the *in situ* properties of an active low-angle normal fault.

New Data and Interpretation

In October 1995 on R/V *Ewing*, we conducted a site-specific survey of the rifting region just ahead of the apex of spreading (Figure 3). Here, a continental fault block (Moresby Seamount) forms the footwall to a low-angle reflector that dips north at ~25° beneath a 3.2 km deep rift basin with over 2 km of sediment fill. We deployed a 196 channel, 4.9 km long streamer together with an 8470 cubic inch tuned airgun array to acquire reflection lines that would enable good seismic velocity control and multiple suppression. We also collected bottom samples with three piston cores and one dredge.

Prior to the site survey we hypothesized that Moresby Seamount might be a metamorphic core complex below a regional low-angle normal detachment. The survey results significantly revised our interpretation: Moresby Seamount is more likely an upper crustal block with a pre-rift metamorphic basement, bounded by a regional low-angle normal fault that is the youngest and northernmost of a series of extensional structures.

Figure 4 shows migrated versions of three of the new MCS dip lines (located in Figure 3). The basement geometry and seismic stratigraphy is similar in each case. The northern slope of Moresby Seamount continues in the subsurface as a reflector that, corrected for velocity effects, dips north at ~25° (Figures 4 and 5). Seismic cross lines confirm a generally easterly strike for the reflector, but with a gentle arch plunging NNE from the Seamount. We interpret this reflector as a low-angle normal fault. The reflector is progressively better imaged eastwards, towards the spreading center, possibly as a result of more focused strain and/or fluids. Line 1374 clearly shows the low-angle fault continuing beneath an antithetic higher angle fault in the hanging wall, but on no line is the fault well imaged below 8 seconds two-way time (~ 10 km below sea level). This is also the depth range of the well-located, low-angle normal fault earthquakes [*Abers,* 1991].

Jump-correlation from the commercially drilled sections in the Trobriand Basin to the northwest suggests that on the northern margin the north-dipping stratified reflectors beneath the rift-onset angular unconformity are from Miocene forearc basin fill above Paleogene basement.

Within the summit region of Moresby Seamount, discontinuous (faulted) reflectors dip NNE above a strong reflection that intersects the seafloor at about 0.8 s two-way travel time on the NE corner of the Seamount. Two previous dredge hauls from the lower northern flank of the Seamount are consistent with the material below this reflection being metamorphic basement. They are similar to greenschist metamorphics on eastern Normanby and Misima Islands, not the core complex amphibolite metamorphics on Goodenough, Fergusson and NW Normanby Islands [*J. Hill, pers. comm.,* 1996].

In contrast, our dredge from 1211-541 m (~ 1.6-0.7 s two-way travel time) on the upper southern flank of the Seamount recovered a dredge bag full of late Pliocene (N21 = 1.9-3.1 Ma) sedimentary rocks of equivalent facies to the Awaitapu Formation of the Trobriand Basin. Benthic forams indicate sediment deposition in water depths of 340-800 m. These rocks are equivalent in age, paleodepth and thickness to those that

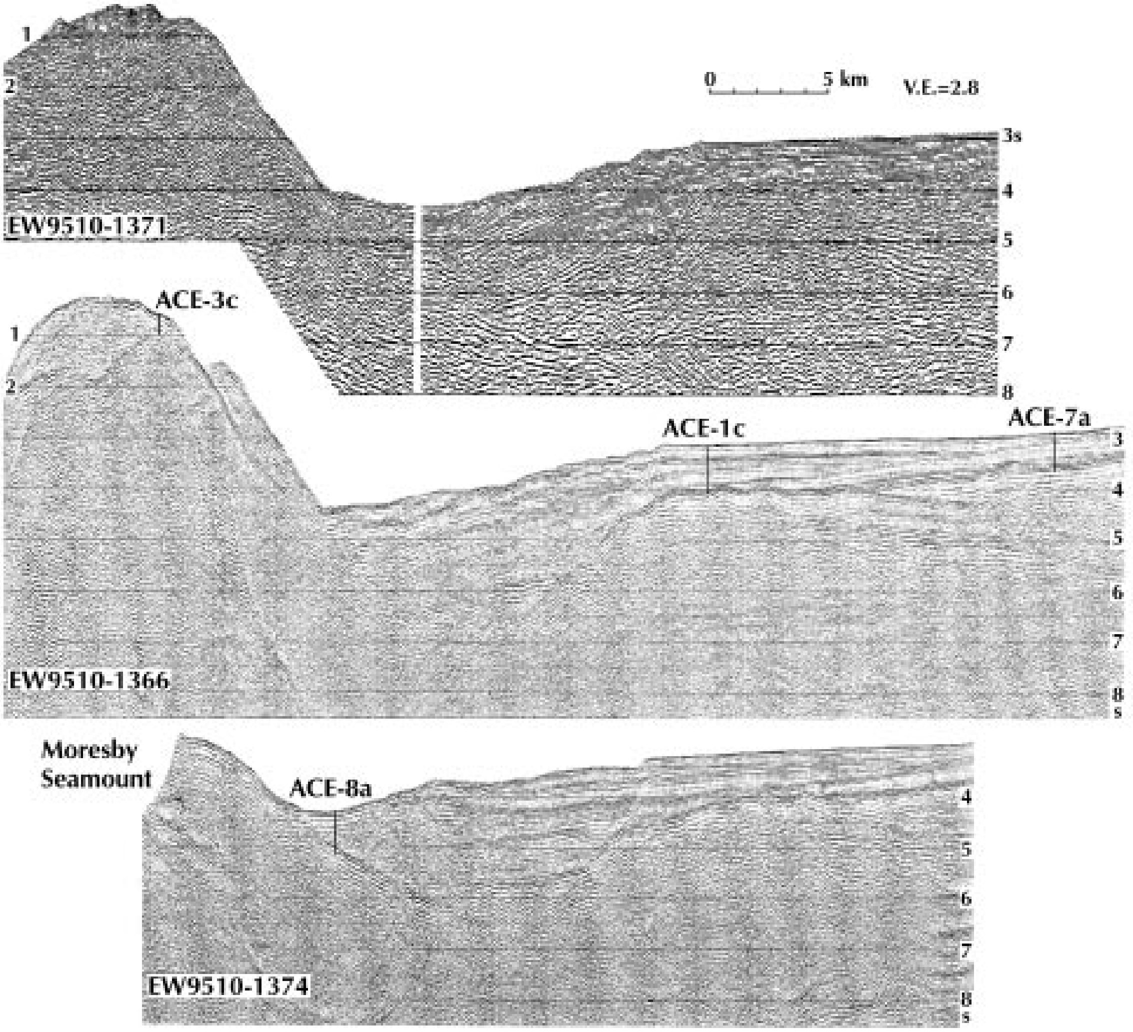

Fig. 4: Migrated seismic profiles, located in Figure 3. The north slope of Moresby Seamount continues as a low-angle reflector (fault) beneath the asymmetric rift graben and the down-flexed northern. The proposed drill sites are ACE-1c, 3c, 7a, and 8a.

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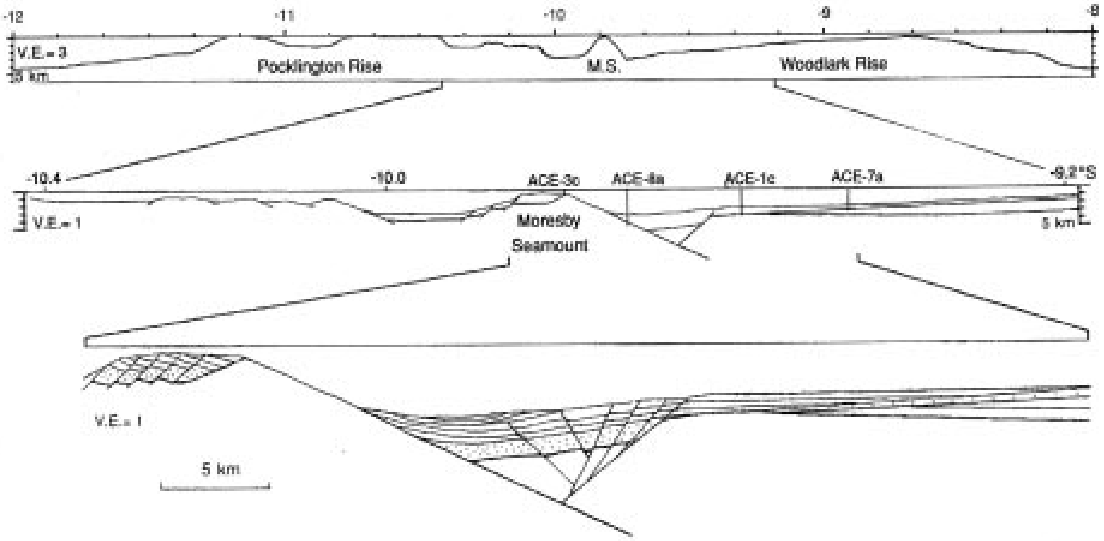

Fig. 5: Nested meridional sections showing the regional and local structures across the incipient conjugate margins. The proposed drill sites are ACE-1c, 3c, 7a, and 8a.

we infer lie near the base of the sediment filling the rift basin to the north.

A cross section consistent with the available seismic and dredge data is drawn in Figure 5. At the end of the Miocene, the Paleogene basement and a forearc basin filled with Miocene sediment were being eroded at or near sea level. Pliocene rifting formed sediment-filled graben in the southern, orogenically thickened, arc province, accompanied by gradual subsidence of the thinner, colder (and therefore stronger) forearc to the north (inferred Pliocene sediments are dotted in Figure 5). Quaternary stretching localized on a low-angle normal fault (the antithetic hanging wall fault accommodated little additional extension); the northern margin flexed down southwards and was offlapped by sediments delivered via submarine channels incising northwards. Recently, continued extension on the low-angle fault variably collapsed the hanging wall graben, into which sediments are now prograding from the north.

This interpretation predicts about 12 km of heave on the inferred low-angle fault. This compares with at least 130 km of total extension prior to spreading at this longitude, calculated from the pole of opening derived from seafloor spreading magnetic anomalies (the adjacent segment is spreading at 36 mm/yr, for example, Figure 1). We infer that the locus of current extension must be the northernmost of a series of similar structures that extended weak crust to the south, forming the asymmetrically block-faulted Pocklington Rise (Figure 5). This rugged province of mainly inactive faults probably accommodated 120 km of total strain as it collapsed from heights comparable to the 3 km high Owen Stanley ranges that form the backbone of the Papuan Peninsula.

A primary insight gained by this site survey is that low-angle normal faulting has not exposed a metamorphic core at Moresby Seamount, but rather a complex sedimentary package with structures comparable to those associated with collapse and infill of the localized basin formed immediately adjacent the fault. While the importance of low-angle normal faulting in the formation of metamorphic core complexes is called into question, the existence of an active low-angle normal fault is not. The seismic data acquired show evidence for very recent motion, and support our assertion that the Woodlark Basin is perhaps the best place in the world to investigate the mechanics of lithospheric extension along an active low-angle normal fault through ocean drilling.

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