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Arc segmentation and seismicity in the Solomon Islands arc, SW Pacific

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ABSTRACT

This paper evaluates neotectonic segmentation in the Solomon Islands forearc, and considers how it relates to regional tectonic evolution and the extent of ruptures of large megathrust earthquakes. We first consider regional geomorphology and Quaternary vertical displacements, especially uplifted coral reef terraces. Then we consider geographic seismicity patterns, aftershock areas and vertical displacements for large earthquakes, focal mechanisms, and along-arc variations in seismic moment release to evaluate the relationship between neotectonically defined segments and seismicity. Notably, one major limitation of using seismicity to evaluate arc segmentation is the matter of accurately defining earthquake rupture zones. For example, shoreline uplifts associated with the 1 April 2007 M_w 8.1 Western Solomons earthquake indicate that the along-arc extent of rupture was about 50 km smaller than the aftershock area. Thus if we had relied on aftershocks alone to identify the 2007 rupture zone, as we do for most historical earthquakes, we would have missed the rupture's relationship to a major morphologic feature. In many cases, the imprecision of defining rupture zones without surface deformation data may be largely responsible for the poor mismatches to neotectonic boundaries. However, when a precise paleoseismic vertical deformation history is absent, aftershocks are often the best available tool for inferring rupture geometries.

Altogether we identify 16 segments in the Solomon Islands. These comprise three major tectonic regimes or supersegments that correspond respectively to the forearc areas of Guadalcanal–Makira, the New Georgia island group, and Bougainville Islands. Subduction of the young and relatively shallow and buoyant Woodlark Basin and spreading system distinguishes the central New Georgia supersegment from the two neighboring supersegments. The physiographic expression of the San Cristobal trench is largely absent, but bathymetric mapping of the surface trace of the interplate thrust zone defines it adequately. The New Georgia supersegment has smaller arc segments, and more islands due to general late Quaternary forearc uplift very close to the trench where vertical displacement rates tend to be faster; prior to the 2007 earthquake it had much lower rates of seismic activity than the neighboring supersegments. Generally the mean along-arc lateral extent of Solomon arc segments is about 75 km, somewhat smaller than the segments reported in some other island arcs such as Japan (~100–260 km), but larger than those of the Tonga (30–80 km) and Central New Hebrides arcs (30–110 km). These differences may be real but it may occur simply because the coral-friendly tropical environment of the South Pacific arcs, numerous emerged forearc islands, and high seismicity rates provide an unusually favorable situation for observing variations in vertical tectonic activity and thus for identifying segment boundaries. Over the past century seismic slip in the Solomons, as indicated by seismic moment release, has corresponded to about half the plate convergence rate; however, there are notable variations along the arc. Even with the 2007 earthquake, the long-term moment release rate in the New Georgia supersegment is relatively low, and this may indicate that large earthquakes are imminent.

1. Introduction

Arc segmentation is the observation that forearcs are partitioned into multiple blocks or segments along the arc trend. These blocks tend to have different uplift geographies and rates as documented in Japan, Tonga, the New Hebrides and elsewhere (e.g. Ando, 1975; Dickinson, 2001; Marshall and Anderson, 1995; Taylor et al., 1980, 1990; Taylor and Bloom, 1977). Forearcs have thus been likened to the "keyboard on a piano", with the individual segments moving independently (Collot et al., 2008; Lobkovsky et al., 1991). This paper is motivated in part because in the Central New Hebrides and Western Solomons we have found a distinct correlation between

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neotectonically recognized arc segment boundaries and rupture zone boundaries as constrained by coseismic vertical deformation measurements (Taylor et al. 1980, 1990, 2008). Examples of distinct geological or seismological characteristics include: (1) differences in the directions or rates of longer-term permanent vertical tectonism (Barckhausen et al., 2001; Calmant et al., 2003; Dickinson, 2001; Fisher et al., 1998; Gutscher et al., 2000; Mann et al., 1998; Monzier et al., 1997; Taylor et al., 1990, 1995; von Huene et al., 2000); (2) amounts of strain accumulation and release (Ando, 1975; Nishenko and Jacob, 1990; Sykes et al., 1981) and (3) patterns and rates of seismic activity, focal mechanism orientations, and recurrence intervals for megathrust ruptures (Cummins et al., 2002; Geist et al., 1988; Jacob, 1984; Lobkovsky et al., 1991; Regnier et al., 1995; Schwartz, 1999).

The overriding plate of the Solomon Islands subduction zone (Fig. 1) is a favorable location to investigate arc segmentation for several reasons. Plate convergence rates are relatively high (~10 cm/yr) and this is accompanied by abundant seismicity including many large (M ≥ 7.0) historical earthquakes. The rate and obliquity of convergence for the subducting plate vary along the arc; the subducting plates differ in age and carry significant topographic features including transform plate boundaries separating them.

Finally, for investigating segmentation, the most important feature of the Solomon arc is that it is tropical and possesses an abundance of islands, both along and perpendicular to the arc trend. Thus, coral reefs have grown prolifically along many shorelines and record uplift and subsidence on vertical scales from cm to hundreds of m throughout the late Quaternary. Reefs that grew during the peak of Holocene sea level in this region at ~6000 yr BP are easily identified today as a distinct terrace level that makes a convenient datum to compare uplift from place to place. The present-day reef geometry and elevations provide important information about the extent and relative motions of individual segments.

In the Solomon Islands, arc segmentation has previously been investigated in detail only near New Georgia (Mann et al., 1998; Taylor et al., 2005). Previous seismological investigations have focused primarily on delineating the spatial distribution of seismicity (Cooper and Taylor, 1987; Yoneshima, et al., 2005) and aftershock areas (Lay and Kanamori, 1980; Schwartz, 1999; Xu and Schwartz, 1993) in the northwest portion of this island arc.

The Solomon Islands are composed of two parallel chains of islands formed at the convergence of the Pacific plate in the north and the Australian, Woodlark, and Solomon Sea plates in the south (Coleman, 1966; Cooper and Taylor, 1985; Goodliffe, 1998; Martinez et al., 1999; Ridgeway, 1987). The double chain of islands is the result of a tectonic history that includes a reversal in the direction of subduction about ~5 Ma (Gladczenko et al., 1997; Mann and Taira, 2004; Miura et al., 2004; Petterson et al., 1999). Today most active subduction occurs along the San Cristobal and New Britain trenches with only slight convergence along the North Solomon trench; the New Britain and San Cristobal trenches are separated by the Woodlark Basin, an actively spreading ridge-transform system forming the boundary between the Woodlark and Australian plates (Crook and Taylor, 1994; Taylor and Exon, 1987). Woodlark rifting began at about 5 Ma (Taylor, 1987), apparently coincident with arc polarity reversal (Mann and Taira, 2004). The rifted margins of the Woodlark basin are marked by

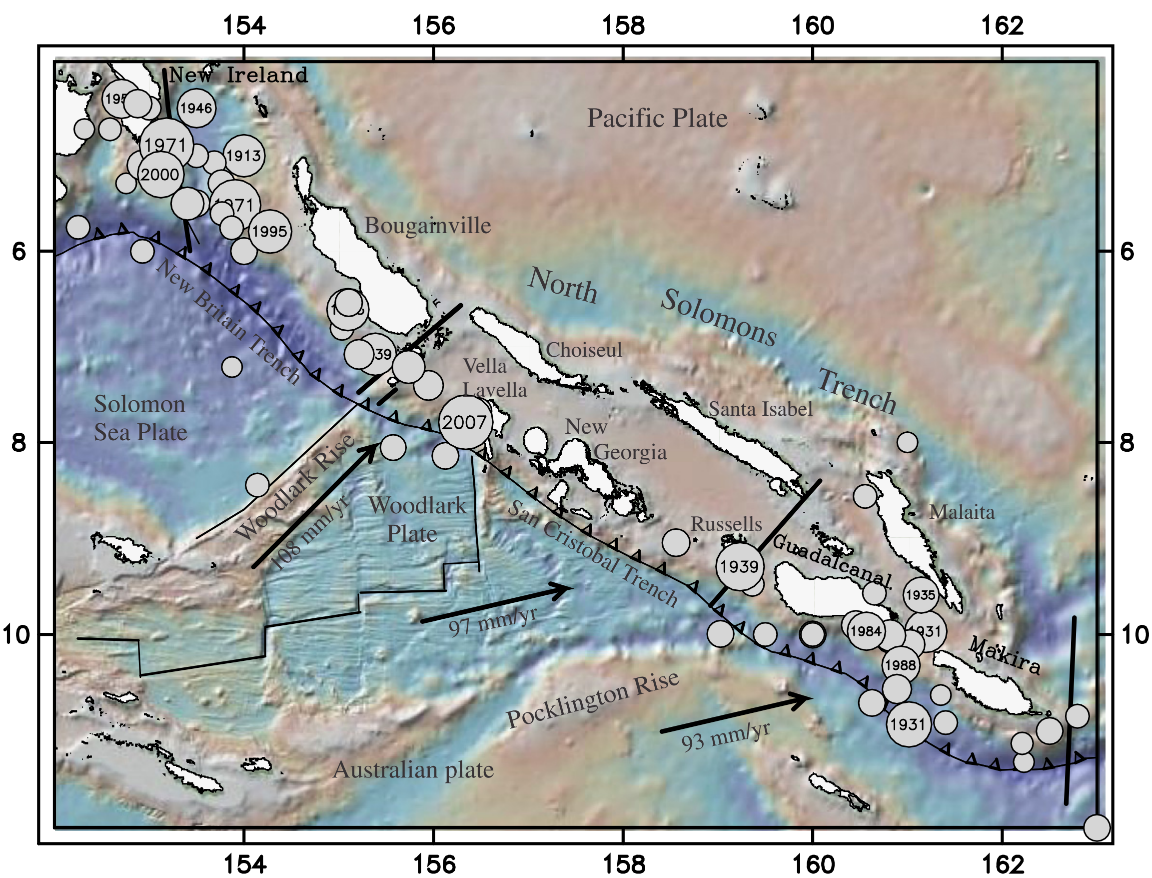

Fig. 1. Plate tectonic setting and seismicity for the Solomon Islands. Circles are earthquake depths less than 60 km and magnitude ≥ 7.0 in the Solomon Islands region occurring between 1900 and 2009 (Engdahl and Villaseñor, 2002 and Global CMT catalog); earthquakes with magnitudes > 7.5 are labeled by year of occurrence. Arrows indicate convergence directions with respect to the Pacific plate; rates are determined from the NUVEL-1A model of DeMets et al. (1994) and Taylor (1987). Thick solid lines indicate the boundaries between the three major 'supersegments' in the Solomons: Guadalcanal–Makira, New Georgia, and Bougainville. Bathymetric base map from Ryan et al. (2009).