Adakites from collision-modified lithosphere

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[1] Adakitic melts from Papua New Guinea (PNG) show adakitic geochemical characteristics, yet their geodynamic context is unclear. Modern adakites are associated with hot-slab melting and/or remelting of orogenic mafic underplate at convergent margins. Rift-propagation over collision-modified lithosphere may explain the PNG adakite enigma, as PNG was influenced by rapid creation and subduction of oceanic microplates since Mesozoic times. In a new (rift) tectonic regime, decompressional rift melts encountered and melted remnant mafic eclogite and/or garnet-amphibolite slab fragments in arc collisional-modified mantle, and partially equilibrated with metasomatized mantle. Alternatively, hot-slab melting in a proposed newborn subduction zone along the Trobriand Trough could generate adakitic melts, but recent seismic P-wave tomographic models lack evidence for subducting oceanic lithosphere in the adakite melt region; however they do show deep subduction zone remnants as a number of high P-wave anomalies at lithospheric depths, which supports our proposed scenario. **Citation:** Haschke, M., and Z. Ben-Avraham (2005), Adakites from collision-modified lithosphere, *Geophys. Res. Lett.*, *32*, L15302, doi:10.1029/2005GL023468.

1. Introduction

[2] Quaternary hornblende-bearing dacites and trachytes from the Lusancay Islands and Aird Hills are among the first reported and show adakitic geochemical signatures (Mg# mainly 34–57, Sr = 1520–2650 ppm, Y = 7.7–9.9 ppm, Yb = 0.3–0.5 ppm, Sr/Y = 140–445, La/Yb = 108–238) [see *Smith et al.*, 1979], yet their geodynamic context is enigmatic (Figure 1). Such geochemical characteristics are commonly interpreted to reflect residual garnet (and amphibole) and absence of residual or cumulative plagioclase in the melt source [*Rushmer*, 1991; *Sen and Dunn*, 1994; *Rapp and Watson*, 1995], yet they are insensitive to provenance in the subducting or overriding plate [*Garrison and Davidson*, 2003]. PNG adakites do not satisfy the slab melting scenario because of the lack of current ongoing subduction [*Peacock et al.*, 1994], but adakite-like magmatism can be due to basaltic source material located somewhere besides the slab. We discuss tectonic and geophysical constraints and present a new model which accounts for rapid production and subduction of young and small oceanic microplates dominated the tectonic setting since Mesozoic times, simulating some plate tectonic processes which led to crustal growth in the Archean [*Martin*, 1999].

2. Tectonic and Geophysical Constraints

[3] The Lusancay Islands occur ~150 km north of the present Woodlark Rift (Figure 1), which narrows towards the Moresby Transfer Fault and widens like a fork into the eastern mainland of PNG. The propagating rift front shows numerous full and half grabens [*Smith and Simpson*, 1972], exhumed metamorphic core complexes [*Davies and Warren*, 1988; *Baldwin et al.*, 1993], major transfer faults and shallow-dipping (10–25°) normal faults with shallow (<70 km) low-intensity earthquake patterns offshore of PNG [*Abers*, 1991]. These fault systems are the locus of maximum extension [*Benes et al.*, 1997] and serve as permeable conduits for late Cenozoic rift-related peralkaline melts [*Smith and Johnson*, 1981; *Stolz et al.*, 1993]. The Normanby Transfer Fault propagates north towards the Lusancay Islands (Figure 1). Lateral offset probably postdates the adjacent Moresby Transfer Fault system, which was formed just before 1 Ma and the Jaramillo magnetic anomaly [*Taylor et al.*, 1995]. The Aird Hills adakites occur ~600 km west of the Lusancay Islands and are associated with late Cenozoic rift-related Highlands alkaline volcanic province [*Johnson et al.*, 1978], and occur at the edge of thick Paleozoic orogenic crust of an island-arc collisional suture zone which is interpreted as a remnant of previous arc-collision.

3. Geochemical Characteristics

[4] PNG adakites are mainly dacites (63–66% SiO_2) with moderate Mg# (34–57), high Sr/Y (140–445) and La/Yb (108–238) ratios. Their Mg#'s range between those of inferred clear slab melts (Mg# = 58–72) and mafic orogenic underplate melts (Mg# = 27–54, Figure 2a). Experimental melts show similar Mg#'s (44) when melting hydrous peridotite (Mg# = 47) [*Grove et al.*, 2003], and/or eclogite at 3.8 GPa and 1100°C which tend to increase from Mg# 44 to 56 when assimilating 10–16% peridotite [*Rapp et al.*, 1999] (Figure 2a). High Sr concentrations comparable to those of the Lusancay Islands and Aird Hills dacites (1520–2650 ppm, Figure 2b) are reported from Adak Island, Western Aleutians, Cerro Pampa and Cook Island. Some experimental adakitic melts show similar Sr contents when hybridized with 10–12% peridotite (Figure 2a), whereas melts from inferred mafic underplate tend to contain less Sr (mainly Sr <700 ppm).

[5] Low Yb (0.3–0.5 ppm) and Y concentrations (5–11 ppm) of PNG adakites are characteristic of both slab and underplate melts. Experimental melts show such low Yb concentrations when hybridized with 12% fertile peridotite

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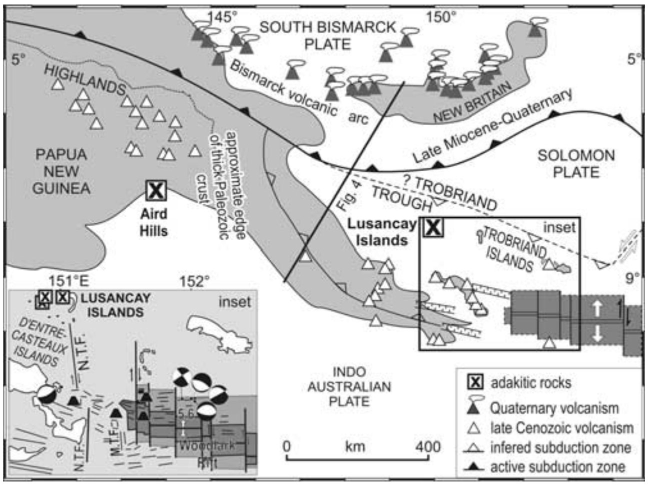

Figure 1. Tectonic map of PNG with Aird Hills and Lucancay Islands locations and late Cenozoic volcanic activity [after *Smith et al.*, 1979]. Inset: Neotectonic setting and seismicity at the Woodlark Rift front [*Benes et al.*, 1997; *Abers*, 1991; *Taylor et al.*, 1995]. MTF, Moresby Transfer Fault; NTF, Normanby Transfer Fault.

(Figure 2c). Consequently, PNG adakites show some of the highest Sr/Y and La/Yb ratios ever reported from Phanerozoic rocks, being much higher than those of inferred slab and underplate melts (Sr/Y = 25–93). Some PNG Sr/Y ratios lie within the range of Sr/Y ratios from experimental adakitic melts when hybridized with 10–12% peridotite [*Rapp et al.*, 1999] (Figure 2d). The extreme La/Yb ratios of PNG adakites are higher than any inferred slab, underplate or experimental melt, and are due to their low Yb (0.3–0.5 ppm) and very high La concentrations (58–90 ppm). High La/Sm (>10) relative to high Sm/Yb (>8) ratios are indicative of a amphibole and/or garnet-bearing source (Figure 2e) since distribution coefficients for Yb in garnet are higher compared to Sm [*van Westrenen et al.*, 2001]. The importance of these minerals during petrogenesis is illustrated by the listric-shaped REE patterns (Figure 3). Some experimental melts show both increasing Sm/Yb ratios and increasing La/Sm ratios when hybridized with peridotite (Figure 2e). PNG adakitic rocks show such

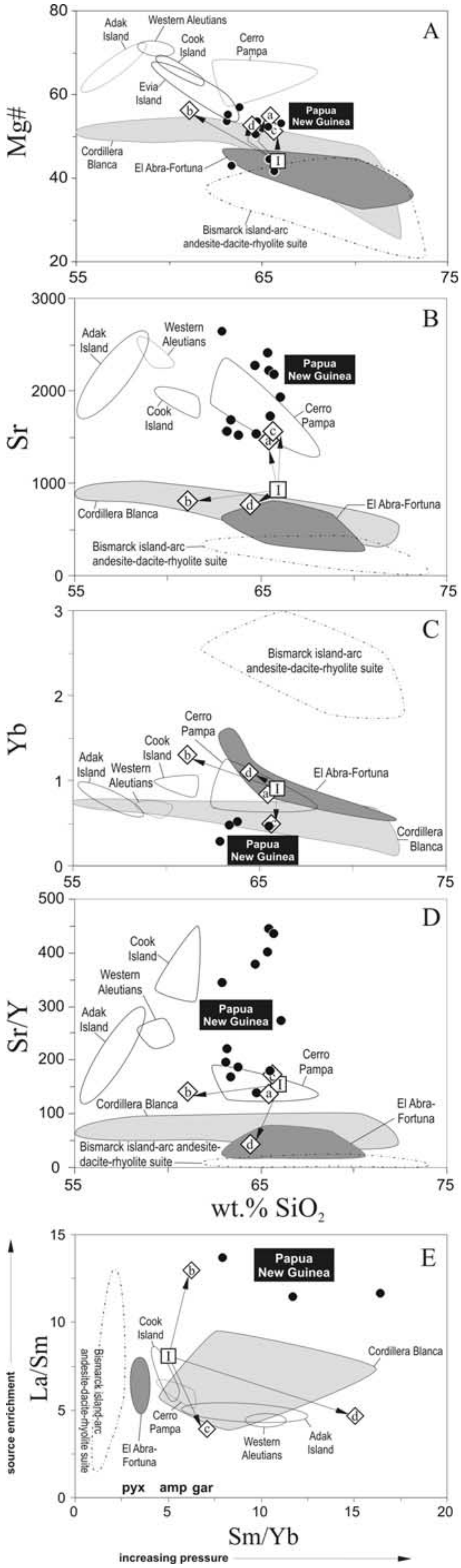

Figure 2. Plots of wt.% SiO_2 vs. (a) Mg# (100*MgO/[MgO + FeO^{total}]), (b) Sr [in ppm], (c) Yb [in ppm], (d) Sr/Y and (e) Sm/Yb vs La/Sm (pyx = pyroxene, amp = amphibole, gar = garnet) [*Kay and Mpodozis*, 2001]for adakitic dacites and trachytes from PNG, compared with adakites from Cerro Pampa [*Kay et al.*, 1993], Cook Island [*Stern and Kilian*, 1996], Adak Island [*Kay*, 1978], Western Aleutians [*Yogodzinski et al.*, 1995], island-arc rocks from the Bismarck volcanic arc [*Smith and Johnson*, 1981], and with the Andean Cordillera Blanca [*Petford and Atherton*, 1996] and El Abra-Fortuna batholith [*Haschke et al.*, 2002a]. Also shown are experimental melts at 3.8 GPa at 1100°C (square I) [*Rapp and Watson*, 1995] and hybridized slab melts with mantle peridotite (diamonds: slab melt + a, 10% depleted peridotite; b, 16% depleted peridotite; c, 12% fertile peridotite; d, 15% fertile peridotite) [*Rapp et al.*, 1999].

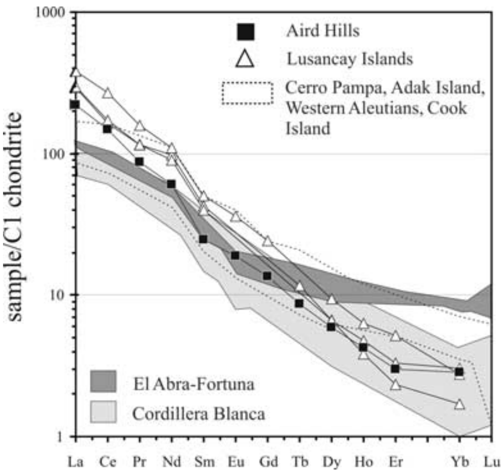

Figure 3. Normalized (C1 chondrite) REE patterns of the Aird Hills and Lusancay Islands adakitic rocks, which are more enriched in light REE relative to other adakitic rocks (dashed outline: REE patterns of adakites from Cerro Pampa, Adak Island, Western Aleutians, Cook Island. Light grey: Cordillera Blanca batholith. Dark grey: El Abra-Fortuna batholith).

patterns, reflecting an LILE and light REE-enriched mantle and garnet-dominated source component.

[6] Geochemical batch melting modeling indicates that low to medium-degree partial melting (1–15%) of a basaltic eclogite to garnet-bearing (30–42%) amphibolite source, and lack of plagioclase as a residual or source mineral can explain the high Sr/Y and La/Yb ratios of PNG adakites. Hybridization with 10–12% depleted and/or fertile and hydrous peridotite [*Rapp et al.*, 1999; *Grove et al.*, 2003] can explain the high La contents in some samples with extreme La/Yb and Sr/Y ratios.

4. Rift-Propagation Over Collision-Modified Lithosphere

[7] Subduction-related processes including arc-collision [*Davies and Warren*, 1988], continental lower crustal delamination [*Kay and Kay*, 1993], and slab-breakoff [*Haschke et al.*, 2002b] can leave eclogitic and/or garnet-bearing amphibolite fragments and introduce hydrous, slab-derived fluids rich in light REE and LILE into the mantle. In fact, the abundance of orphaned slab fragments in collision-modified lithosphere beneath PNG and the degree of metasomatism may have been underestimated, given the complex and frequent changes of subduction geometry since Mesozoic times. Most larger fragments may have sunk into the deep mantle, while some smaller portions remained frozen in the mantle lithosphere, before the Woodlark Rift propagated into this paleo-subduction assemblage during Quaternary times (Figure 4). Decompression melts at the rift front started to rise through the strongly hydrated paleo-mantle wedge. Some extension-related melts encountered and partially melted garnet-amphibolite and/or eclogite remnants producing the adakitic melts which migrated through the Normanby Transfer Fault to generate the Lusancay Islands adakites. Others ascended through the paleo-mantle wedge without encountering slab fragments generating the Eastern Papua volcanic suite. The light REE and LILE-enriched signatures of some PNG adakitic melts was imposed by assimilation of hydrous mantle peridotite.

[8] A similar mechanism can explain the Aird Hills adakites, which crop out above the edge of 25–50 km thick orogenic continental crust [*Taylor et al.*, 1995]. The presence of a deep mafic crustal source (>12 kbar or >40 km depth) [*Haschke and Günther*, 2003] and their Mg# and Yb content affinities to underplate melts (Figures 2a and 2c) suggest that the Aird Hills may be melts from an orogenic remnant (e.g. a torn off slab edge) from the Eocene collision of the Dabi island-arc with the Papuan peninsula cratonic fragment. Subsequent fractional crystallization processes may have modified their primary crustal melt composition [*Grove et al.*, 2003]. The coexistence of the Aird Hills adakites with rift-related melts (Highlands) is very similar to that of the Lusancay Islands (Eastern Papua), and implies that the heat sources for generating the PNG adakites may have been identical to those which produced the Pleistocene/Pliocene Highlands and Eastern Papua volcanic provinces. If correct, then the Aird Hills and Lusancay Islands adakites are thermally linked to rifting of collision-modified lithosphere, and adakitic melts may be generated from any hydrous basalt at depth, be it subducted slab or lower crust. This scenario is broadly similar to that proposed by *Richards et al.* [1990] for the origin of the mafic alkalic magmas associated with the Porgera gold deposit in the PNG Highlands.

[9] Our scenario provides an alternative to the more problematic newborn Trobriand subduction zone [*Davies and Warren*, 1988; *Taylor et al.*, 1995, 1999; *Benes et al.*, 1997]. Based on trench-like gravimetric anomalies, their model places the Lusancay Islands adakites in the foreland of a (future) volcanic arc, as expected from hot-slab melting, but the subducting Solomon Plate is older than the maximum age required for hot-slab melting (<25 m.y.) [*Peacock et al.*, 1994]. Even if the slab was sufficiently young, the Trobriand region lacks subduction-related earthquake patterns, dehydration reactions inducing arc magmatism, and isostatic responses which might suggest the presence of a

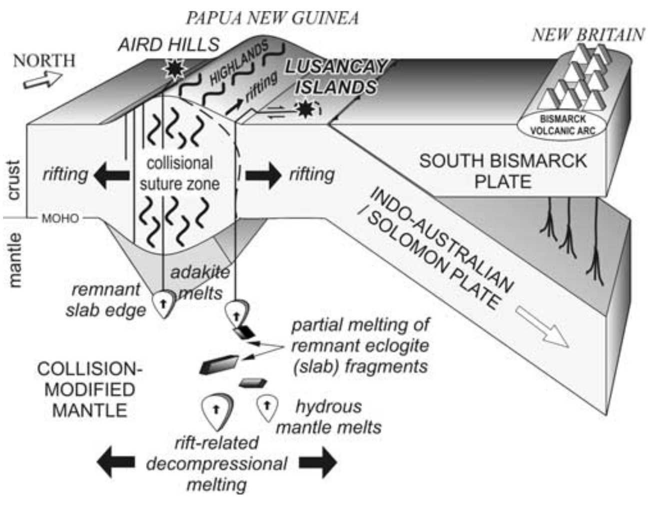

Figure 4. 3-dimensional lithospheric profile of PNG (see Figure 1 for orientation) showing the proposed petrogenetic and geodynamic setting of the Aird Hills and Lusancay Islands adakites.

dense subducting slab. The only monitored earthquakes are shallow and rift-related. The nearest igneous rocks of similar age occur 70–100 km from the PNG adakites, and they are not subduction-related. Furthermore, tomographic modeling of mantle P-wave structures beneath the PNG region [*Hall and Spakman*, 2002] show major and coherent positive P-wave anomalies beneath New Britain reflecting the downgoing Solomon Plate, but no such anomalies beneath the Lusancay Islands or Aird Hills which might support the existence of a subduction zone. They do show a number of deep, flat-lying and anomalously fast P-wave regions which *Hall and Spakman* [2002] interpreted as remnants from older subduction settings.

[10] Our model shares some features of modern analogues of adakites in a presently non-convergent geodynamic setting with Evia/Greece [*Pe-Piper and Piper*, 1994] and Isla San Esteban/Gulf of California [*Desonie*, 1992]. In both cases, rift-related melts encountered and eventually melted older, hydrous metabasalt fragments in the hot upper mantle, and produced adakite-like melts.

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