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Plio-Pleistocene Climatic and Volcanic Controls on High to Moderate Accommodation Space Systems in the Solo Basin, Central Java, Indonesia

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Late Pliocene to Pleistocene marginal marine, lacustrine and fluvial sediments exposed in the Sangiran Dome, 12-20 km north of the city of Solo in Indonesia's Central Java Province offer a stratigraphic window into the Solo Basin, part of a Plio-Pleistocene intra-arc basin along the southern margin of Sundaland.

The oldest exposed sediments, limestone, marl, siltstone, mudstone and muddy sandstone of the Puren (Kalibeng) Formation, ring four now inactive mud volcanoes at the Dome's center. Associated fauna includes an abundance of *Anadara* sp. marine mollusks, and rare freshwater forms such as *Corbicula* sp., suggesting deposition in a near-shore shallow marine environment.

The base of the overlying Sangiran (Puchangan) Formation is occupied by a 10 to 15m thick laharic diamicton (the "Lower Lahar Unit") abruptly overlain by 90 to 110 m of dark-colored organic-rich siltstones and mudstones that accumulated in shallow marine, brackish-water and fresh-water marsh environments (Bettis et al., 2004). Thin water-laid tuff layers occur throughout this part of the Sangiran to form about 3% of its total thickness (Yoshikawa and Suminto, 1985). The upper two-thirds of the Sangiran is occupied by marsh, lacustrine and lake-margin sediments that contain fossils of terrestrial vertebrates well adapted to marshy and lake-margin environments (Aimi and Aziz, 1985).

An abrupt change from limnic and plaudal to fluvial environments marks the contact between the Sangiran and overlying Bapang (Kabuh) Formation (Watanabe and Kadar, 1985; Bettis et al., 2008). The Bapang ranges from 30 to 50 m in thickness and is comprised of three upward-fining fluvial cycles consisting of fine to very coarse tuffaceous sandstones with lenses of pumiceous conglomerate that grade upward to silts and silty clay in which paleosols are developed. The sandstones are dominated by small-scale trough-cross bedding, parallel bedding and shallow cut-and-fill structures suggesting that the channels were relatively shallow and that small-scale dunes dominated. The overlying 20 to 40 m thick Pohjajar (Notoporo) Formation fills large channels incised into the Bapang Formation. Conglomerates in the Pojarjar are thin and restricted to the lower part of the unit. The Pojarjar contains a high proportion of fine-grained volcaniclastics occurring as air fall tuff, fluvially reworked ash fall, and two laharic diamictons, the Upper and Uppermost Lahars.

All these units thicken northward into the Kendeng Trough (Darman and Sidi, 2000) where they are intermittently exposed in outcrops along the Solo River and its tributaries and in the

Rembrang Hills. A general lack of studied outcrops and detailed subsurface information precludes detailed understanding of the relationships of facies in the Sangiran Dome with those exposed farther to the north.

The Dome's most recent alluvial deposits, tuffaceous sandstone, conglomerate and fine-grained sediments, occur beneath a series of terraces associated with major valleys on the modern landscape (the Solo River terraces). These deposits range up to 6m thick and consist of a basal conglomerate overlain by trough crossbedded tuffaceous sandstone that grades upward into tuffaceous siltstone and mudstone.

The Plio-Pleistocene succession in the Sangiran Dome can be interpreted in terms of interactions among tectonics and climate change over the past 2 million years that have controlled accommodation space and sediment supply. The Puren and Sangiran Formation represent high accommodation space sedimentation in the Kendeng Trough. Sedimentation in the Sangiran area initially was in a shallow marine setting and may have been influenced by glacioeustacy. After about 1.8 Ma, however no marine influence is recorded in the rocks and sedimentation patterns only reflect the influences of sediment supply and tectonically influenced accommodation space. Through the accumulation of the Sangiran Formation the ratio between accommodation and sediment supply (the A/S ratio; Martinsen et al.,1999) was greater than unity, but decreasing as indicated by the occurrence of poorly-drained paleosols in the upper reaches of the unit.

The erosional unconformity separating the Sangiran and overlying Bapang Formation represents a shift to an A/S ratio of zero or less and removal of sediment from the area at around 1.6 Ma. The overlying Bapang Formation alluvial sequence records three cycles where the A/S ratio varied between 1 and 0; some sediment filled available space, but some sediment bypassed since accommodation was inadequate. The Puchangan Formation represents a similar sequence, valley incision when A/S is less than zero followed by accumulation with some bypass as the A/S ratio varies between unity and zero. The most recent sequence, represented by Solo River Terraces, is a record where the A/S ratio has generally remained less than zero, punctuated by intervals of sedimentation when the A/S ratio has varied between about 0.5 and 0.

Tectonism (downwarping) formed the initial accommodation space filled by these rocks. Formational boundaries of these units are erosion surfaces marked by valley incision and thus most likely represent uplift or tilting related to development of volcanoes along the volcanic arc. Direct glacioeustatic influences on accommodation space are not likely in this setting more than 100 km from the coast.

Deciphering the relative effects of climate and volcanism on sediment supply is a complex task in this environment. Carbon and oxygen isotope data from pedogenic carbonates and soil organic carbon indicate intensification of the monsoon beginning about 1.55 Ma and continuing through accumulation of the Bapang Formation (Bettis et al., 2008). The relative abundance of tuff remains similar through the Bapang, suggesting that volcanism's effect on sediment supply alone cannot explain the shifts in A/S ratio that formed the three sedimentary cycles making up the formation. Thus climate change, likely related to glacial/interglacial cycles, is the most likely control on overall sedimentation of this unit. The influence of climate on sediment supply must have continued during accumulation of the Pojarjar Formation, but the dramatic increase in the amount of volcaniclastic material, including air fall tuff and laharic diamictons, indicates that volcanism significantly increased sediment supply to the area during this time. During development of the modern landscape and the Solo River Terrace sequence most fluvial sediment has bypassed central Java. Incision of the drainage network suggests that uplift has been the most significant influence on the A/S ratio during this period.

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