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Nicholas Pinter, Mark Hardiman, Andrew C. Scott, R. Scott Anderson

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Discussion of "Fluvial system response to late Pleistocene-Holocene sea-level change on Santa Rosa Island, Channel Islands National Park, California (Schumann et al., 2016. *Geomorphology*, 268: 322-340).

Nicholas Pinter^{a,*}, Mark Hardiman^b, Andrew C. Scott^c, R. Scott Anderson^d

^a Dept. of Earth and Planetary Sciences, University of California, 1 Shields Ave., Davis, CA 95616, USA

^b Dept. of Geography, University of Portsmouth, Portsmouth, Hampshire, United Kingdom

^c Dept. of Earth Sciences, Royal Holloway, University of London, Egham, Surrey, United Kingdom

^d School of Earth Sciences and Environmental Sustainability, Northern Arizona University, Flagstaff, AZ, USA

Abstract

Schumann et al. (2016) presented a field assessment of late Pleistocene to Holocene fluvial sediments preserved in the valleys of Santa Rosa Island, California. This is a rigorous study, based on stratigraphic descriptions of 54 sections and numerous radiocarbon ages. The paper makes important contributions that we would like to highlight, but other parts of the paper rely upon overly simplistic interpretations that lead to misleading conclusions. In one case, a conclusion of the Schumann et al. paper has important management implications for Santa Rosa Island and similar locations, compelling us to discuss and qualify this conclusion.

Keywords: Fluvial aggradation, incision, sea level, Holocene, Last Glacial Maximum, Santa Rosa Island, Northern Channel Islands

1. Discussion

In this discussion, we will address three aspects of Schumann et al. (2016): (i) their model that base level is the dominant control on fluvial-system change, (ii) their assumption and

conclusion that post-Last Glacial Maximum (LGM, 18-20 kcal BP) fluvial aggradation on Santa Rosa island has occurred at uniform rates, and (iii) the suggestion that fluvial aggradation on Santa Rosa changed to deep incision during the last 500 to ≤ 150 years.

First, we would like to commend a number of the analyses and results in the Schumann et al. paper. In particular, their use of a local sea-level curve for the Channel Islands (after Clark et al., 2014) and new bathymetric data provide important new insights into local fluvial responses to sea-level change. Figures 10-12 and the associated discussion are particularly powerful, with broad implications for the geology, paleoecology, and archaeology of the study area.

However, we suggest that in focusing on sea-level control on stream evolution, Schumann and colleagues present an overly simplistic model that runs contrary to the complexity of fluvial systems in general and contrary to the stratigraphy on Santa Rosa Island. In the paper, the authors begin with an assumption and end with the same assumption as their primary conclusion—that 'a direct coupling exists between sea-level changes and river system responses, eliminating (or at least minimizing) the influences of indirect forcings,' purportedly because the field area is an island. This flawed assumption leads to flawed conclusions. The authors acknowledged other driving forces for fluvial change (e.g., climate and *complex response*: Schumm, 1973), but they did not incorporate these mechanisms into their sea-level-driven model or the island history based on that model. In fact, fluvial systems worldwide are strongly influenced by the climate, hydrology, vegetation, geomorphology, and broad land-cover change within the contributing drainage basins, and island streams are no exceptions to this. The LGM-Holocene fluvial deposits on

Santa Rosa Island record dramatic shifts in climate (Anderson et al., 2008), vegetation shifts from widespread pine forest cover to open brush and grasslands (Anderson et al., 2010), changes in fire regime (Scott et al., 2017), extinction of the island's endemic Pleistocene mammoths (Agenbroad, 2009), and the arrival of the first humans (Johnson, 2002).

Sea-level change can and does exert important influences on streams that drain to the coastline (e.g., Rittenour et al., 2007), but that response is more complex than presented in Schumann et al. (2016). Figure 1 here, for example, illustrates the importance of offshore slope relative to stream-profile gradients, and how sea-level rise can either promote aggradation, no change, or even incision depending on local topography and bathymetry. Schumann et al. assumed the simplistic case that sea-level rise = aggradation and sea-level fall = incision, which leads them to a similar conclusion that *Backfilling of valleys onshore (landward of present sea level) appears to have progressed in a more orderly and predictable fashion throughout the Holocene*. In fact, as detailed below, ~~we suggest that~~ fluvial sedimentation and age control on Santa Rosa Island clearly demonstrate the complexity of controls on these stream systems—not their simplicity, nor the predominate control of base level.

Schumann et al. utilized linear age models for their stratigraphic sequences, in which age is proportional to depth (*Our results form an essentially straight line*), with aggradation rates roughly constant over the full duration of record. Our group has worked extensively in many of these same fluvial fill sequences, with results to date published in Pinter et al. (2011), Hardiman et al. (2016), and Scott et al. (2017). Patterns of deposition do vary from

canyon to canyon on Santa Rosa Island as well as on the neighboring islands, but we have seen grossly similar patterns. In contrast to Schumann et al. (2016), we see unequivocal evidence of periods of nondeposition, periods of very rapid deposition, as well as multiple periods of downcutting within these same fluvial sequences.

Part of the discrepancy above can be traced to ages at the base of these deposits. At their exposure CV-52 (Verde Canyon), Schumann et al. reported a basal age of 13.15 ± 0.10 kcal BP, similar to our basal ages for that outcrop. However, about 25 m upstream and on the opposite bank of the stream we reported a clay- and charcoal-rich deposit that yielded ages of ~ 25 and ~ 29 kcal BP. In fact this deposit, thin and discontinuous but consistently yielding LGM ages, is widespread. The LGM unit is always low in elevation and often requires excavation down to or below modern stream level. By not sampling these basal deposits, Schumann et al. missed the earliest deposition history of these sequences, an element that clearly deviates from their linear age model.

Higher in the fluvial fill sequences, additional evidence clearly shows varying rates of fluvial aggradation. In Verde Canyon, at their section CV-1, Schumann et al. reported an unconformity located 4 m below the top of their section that records '*a change in slope of the age-depth plot*' (see their Fig. 5b [denoted as 1] and Fig. 6c). In fact, we have likely described the same unconformity in a number of sections. This unconformity is particularly strongly expressed in Arlington Canyon, where it locally forms a ravinement surface, with up to 6 m of relief and downcutting into underlying deposits and subsequent channel filling (see Fig. 2 here). On this ravinement surface as well as at sites without downcutting, the unconformity is marked by a strong paleosol. And this unconformity

overlies other channel fills—each several meters in relief, thus much more than ephemeral scours. Linear age models are a tempting simplification, but they are dangerous in any fluvial setting (e.g., Scott et al., 2017) and clearly do not apply to the complex LGM-to-Holocene history recorded in the Santa Rosa Island fluvial fills.

Finally, we are compelled to discuss Schumann et al.'s dates at the top of these fill terraces. 'The youngest samples, ranging in age from ~0.5 to 1.5 ka, were collected at depths averaging ~1 m (Table 2), indicating that floodplain aggradation generally continued until at least 0.5 ka, probably even later.' We question these young ages. Schumann et al. encountered the same challenge as we did in these sequences—that charcoal and woody debris are common at the bases, but this material becomes increasingly scarce and is essentially absent at the tops of the deposits. The large majority of late Holocene ^{14}C ages reported by Schumann et al. are from humic acids, bulk organics, or terrestrial snail shells (exceptions are charcoal ages from Quemada Canyon, a very different system on eastern Santa Rosa). Humic acids and bulk organics, in particular, are questionable radiocarbon sources (e.g., Rixhon et al., 2016) and are highly susceptible to contamination by modern material. Contamination of bulk organics and humic acids is almost inevitable in the top ~1 m below a modern soil-capped terrace surface, which here includes ubiquitous rootlets from modern plants. Similarly, terrestrial gastropod shells are widespread on the surface and in soils across Santa Rosa and the neighboring islands.

The Schumann et al. paper concluded that 'Late Pleistocene-Holocene aggradation ended with the modern episode of major incision'—'*modern*' reported as within the last 500 years and linked by the authors to sheep grazing during the late nineteenth century. In other

words, the authors concluded that all of the incision of the Santa Rosa Island fluvial terraces, 'cutting through as much as 12-14 m of accumulated floodplain sediment' (see for example their Fig. 5), occurred within the past few centuries and perhaps within a few floods in the late 1800s following intensive grazing on the island. We suggest that this conclusion is inconsistent with age control for aggradation and incision at some sites and is, at best, equivocal at other locations.

The idea that the tall fluvial terraces and deep gullies that characterize Santa Rosa Island and Santa Cruz Island, just to the east, are recent features resulting from sheep grazing has a colorful history. This suggestion can be traced back to Cushing et al. (1984), who reported sheep bones 16 m deep in the terrace fill sequence at Christy Beach on western Santa Cruz Island, suggesting that both the sedimentary fill and the subsequent incision all occurred within the past 150 years. This has been debunked. In fact, the Christy fill sequence is 35 ka or older at its base, younging to 5-6 ka at the terrace surface, with incision through the deposit during the late Holocene (Pinter et al., 1998). Those sheep bones were certainly within surface wash, which commonly mantles the face of these outcrops until cleared. Other well-dated fill sequences on the islands also show a transition from aggradation to incision dating to the mid Holocene—i.e., much older than Schumann et al. suggest—for example at Arlington Springs on Santa Rosa (Orr, 1962; Johnson et al., 2002). Nonetheless, profound grazing-driven incision during the late nineteenth century is an idea still widely persistent among managers of these islands as well as in some scientific reports (e.g., Jaszwa et al., 2016), with implications for management, investment, and Park policy.

Sheep grazing on the California islands certainly had dramatic geomorphic and ecological impacts (e.g., Johnson, 1972; Pinter and Vestal, 2005; Anderson et al., 2010). Indeed, we have documented extension and deepening of local gullies on these islands over historical time, as have others (e.g., Perroy et al., 2012). However, Schumann et al.'s suggestion that all the incision on Santa Rosa Island is historical needs to be corrected. For example, Schumann et al. (2016) noted that late Holocene archaeological middens on Santa Rosa, including historical occupation sites, are cut by arroyo walls, providing evidence, the authors argued, of very recent incision. However, these middens and occupation sites are located on terrace surfaces, and exposure of archaeological material in arroyo walls requires lateral retreat of those walls, not downcutting.

Rather than a simple model of abrupt island-wide fluvial incision in the late nineteenth century, all available evidence suggests a more complex fluvial response. In the larger stream systems, like at Christy Beach and at Arlington Springs, terrace aggradation ceased by the mid-Holocene, influenced perhaps by the inflection point in the local sea-level curve nicely illustrated by Schumann et al. (2016). In some smaller valleys on Santa Rosa and Santa Cruz islands, the aggradation-incision transition clearly did occur later. Rather than a single, instantaneous fluvial switchover, we suggest that drainage systems on these islands, and in general, are more nuanced. We suggest a counter-hypothesis in which age of the transition from fluvial aggradation to incision on Santa Rosa and Santa Cruz is related to drainage basin area—with the largest drainages generating sufficient discharge and stream power to counterbalance the waning rates of sea-level rise earlier than smaller fluvial systems. Within individual drainage networks, we suspect, incision also probably progressed upstream in a time-transgressive manner.

2. Summary

In summary, Schumann et al. are esteemed colleagues, and their paper demonstrates extensive rigorous work and important contributions. Their research highlights the role of eustatic base level and potential base-level control on fluvial aggradation. We urge caution, however, in reaching conclusions about fluvial-system evolution. Drainage basins and streams, even on islands, reflect a complex dynamic balance in which fluvial processes depend upon climate, vegetation, hydrology, fire regime, sediment supply, as well as base-level change. Santa Rosa and the neighboring islands contain sedimentary records of dramatic changes from the Last Glacial Maximum to the present. This is not a simple story of uniform aggradation and incision, but rather complex responses to change over this complex period of time. In particular, the transition from fluvial aggradation to incision in island streams was not a single event within the past 150-500 years; this suggestion should be purged from on-going discussion. Grazing-related erosion and incision is superimposed upon a process that began as early as the mid Holocene at some sites.

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SEA-LEVEL FALL

SEA-LEVEL RISE

Fig. 1. Illustration of the potential impact of offshore topography (e.g., slope of a continental shelf) on fluvial response to sea-level change. Sea-level rise need not necessarily trigger fluvial aggradation.

Fig. 2. Channel fill sequences, Arlington Canyon, Santa Rosa Island. This pattern is widespread and records a complex history of incision, soil formation, aggradation, and renewed incision.