Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2020-288-RC1, 2020


# *Interactive comment on* "The last interglacial sea-level record of New Zealand (Aotearoa)" *by* Deirdre D. Ryan et al.

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Received and published: 10 November 2020

Overview

The paper by Ryan et al on "The Last Interglacial Sea-Level Record of New Zealand" is a very comprehensive and robust review/evaluation of the previous studies and the literature. It will be an important review for anyone considering further work and it makes some clear recommendations for future work. I commend the authors on this paper, but I do have some concerns about the way in which it assesses some of the previous work. I declare up front that I may be a little defensive having spent most of my career working on sea-level records in New Zealand, and I have worked closely with many of the researchers cited and assessed in this paper.



I think its very important that the authors show they understand the history and context of sea-level studies in New Zealand. Within the Quaternary community New Zealand has held a special place because of its wide range of terrestrial and marine deposits – owing to its convergent plate boundary setting. As I outline below, many of these studies were pioneering and well ahead of the thinking in the Northern Hemisphere that up until the 1980s was influenced by a "Pleistocene" containing 4 glacials and intervening interglacials. While I realise that this paper primarily focusses on the LIG sea-level records and deposits, the introduction and the discussion do refer to the earlier work on older deposits and the LIG is discussed in this context, but I believe a bit inappropriately in the context of the broader work.

Its all very well to say that the LIG deposits are poorly dated, measured and described for sea-level indicators, compared to modern standards, but New Zealand geologists have known that they have always been of limited value for global sea-level reconstructions, because of extensive and widespread tectonic deformation. As the authors quite rightly point out, the dated sea-level indicators where used for understanding long term rates of VLM, not global sea-level change. The paper shows quite clearly that after a robust re-analysis that there is only one site in Northland that has the potential to contribute to global sea-level studies. There is considerable uncertainty about the tectonic stability of Otago coastline based on recent reconstructions using salt marsh cores, GPS and INSAR and geodynamical studies. Also, the latest geodetic work actually shows that Auckland is not stable and is subsiding, slowly.

I initially thought this paper, rather than being a review, was going to contribute some new site elevation data or information on shoreline indicators or geochronology, but realised that that is not really the case. It concludes that New Zealand still has the potential to be an important South Pacific site, based on the one Northland site. I was slightly surprised by the GIA discussion that suggested there could be significant deviations from eustatic during interglacials, when the paper cited, for which Stocchi did the GIA modelling, showed this not be case, especially for the plausible range of

LIG ice sheet configurations and meltwater contributions.

My overall recommendation is that this is an important and useful review, but that the authors should relook at the context in which they introduce and discuss the review and adjust the text accordingly.

Specific comment follow

âĂć Introduction – I was surprised to see the Introduction treat previous work a little dismissively. There are many challenges to identifying, mapping, dating and correlating paleoshorelines, inferred strandlines and wave cut marine terraces in such a tectonically active setting. Given that much of this work occurred in the pre-1980s, with some outstanding geomorphic and geological descriptions and interpretations ahead of their time (e.g. Fleming, Chappell, Gage, Suggate and Pillans), a more generous approach could be taken recognising this early pioneering work. The work of Brad Pillans on the South Taranaki-Whanganui marine terrace sequences remains one of the classic examples in the world today of a suite of wave cut platforms and associated strandlines recording every interglacial from MIS 3-13. The authors should also appreciate more generously, the difficulty in dating these deposits, which also hampers many recent studies (e.g. Hearty et al. 2020 South Africa), and has long been acknowledged by people such as Brad Pillans and Kelvin Berryman as a challenge in NZ. Its only really in the last decade that new approaches for identifying shoreline indicators and the influence of post-depositional processes such as GIA and dynamic topography have been appreciated. However, the authors of this paper have done a nice job of recognising the need for modern approaches of analysing shoreline indicators in their reassessment of the NZ record.

âĂć Quaternary oxygen isotope records were published in the late 1970s and early 1980s, which provided a revolutionary tool to understand and date the NZ marine terraces mapped by earlier workers and interpreted within the existing paradigm of 4 NH glaciations. As the authors highlight, absolute age determination of strandlines was



limited to the intermittent tephra, biostratigraphic inferences, thermoluminescence and amino acid racemisation dating which have many assumptions and problems. Notwithstanding these challenges, it became clear that some strand lines and terraces could be correlated with specific interglacials identified in the benthic oxygen isotope record, and that based on this, particularly in coastal Taranaki and Whanganui, each interglacial shoreline could be matched to successively older orbitally-paced interglacials. This allowed two things to be established: 1) That there was far field physical evidence that confirmed interpretations of the newly developed benthic isotope sea-level proxy records, and that they really were measuring global ice volume and sea-level (older than the Huon Peninsula coral terraces) [I had this conversation several times with the late Sir Nicholas Shackleton, who always recognised this significance], and 2) based on this relationship, an orbital chronology could be established that allowed uplift rates to be estimated for western North Island.

âĂć It should be noted that pre-GPS surface elevations were largely achieved by hand-held altimetry. Moreover, the focus was never really on reconstructing the absolute magnitude of RSL because of the tectonic complication. Although, paleo shorelines were identified, dated and correlated to the benthic oxygen isotope stack the main outcome was constraining vertical land movements thought to be primarily driven by the active plate boundary setting.

âĂć Line 90 – Written negatively. This was not “an unfortunate outcome” that there were many different names for terraces around NZ, it was the correct stratigraphic approach at the time. Back when they were first described and named the relationship between marine terraces and their deposits in different parts of NZ could not be established, and in some cases are still difficult to establish. The recognition, through improved age control, the development and application of the benthic isotopic proxy of global sea-level then allowed different terrace sequences from different parts of New Zealand to be compared within a unifying chronostratigraphic framework. Pillans 1990 made a big step forward in this regard. Likewise the New Zealand Neogene sedimentary stratigraphy went through the same evolution, of initially being subdivided at regional scale and then national scale on the basis of endemic biostratigraphic criteria, and then meaningless correlations were established the type sections in the Mediterranean. With the advent of magnetostratigraphy calibrated by radiometric dating of tephra, it became possible to correlate orbital sequences with benthic oxygen isotope curve (global climate) and astronomically calibrate age models.

âĂć Table -1 For completeness you should cite Fleming 1953. For example he was the first to identify the Brunswick terrace, which Pillans subsequently dated as MIS 9 and adopted Fleming's nomenclature. Previously it had been incorrectly associated with the MIS 7 Ngarino Terrace.

âĂć Line 199 – I understand that this is a generalistaion but eastern North Island vertical land movements (VLMs) both short and long-term are complex, partly because of the TVZ and mostly because of the Hikurangi margin, with subsidence in the Hawkes Bay Basin and near Mahia Peninsula and in the Bay of Plenty near Whakatane.

âĂć Figure 3. Why did you not use the NT1 wave cut surface of Alloway et al. 2005 as a site?

âĂć Also there is a lot of work on the Southern Wellington-Wairarapa coastline in Dee Ninnis' PhD thesis, that the authors had access to and the potential to include and collaborate with. Some figures below that were made available to the authors. Was there a reason for excluding this data?

Line 933 – GIA. It's a bit unclear what the message from this section really is. A number of studies (Pliocene and Recent) have shown that New Zealand is largely unaffected by GIA and sits close to the GMSL in most reconstructions where polar meltwater contributions and viscosity models are varied. While a local signal due to water loading of the shelf has been implied for the Holocene, resolving the fingerprint and any flexural wave along NZ is extremely unlikely for the last interglacial given there is really only one site in Northland that is likely to be unaffected by tectonics, and considering the



uncertainties the authors discuss. It has been implied the effect of GIA could be 5% deviation from North to South. One of the co-authors did a range of GIA experiments for the Pliocene and showed that under a reasonable range of ice histories, NZ lay on the eustatic. For NZ to have a significant GIA deviation during the LIG most of the meltwater would need to come from NH (Greenland) which seems precluded by most geological and ice core reconstructions.

Line – 1134 - It wouldn't hurt the authors to cite Naish et al 1998 (QSR) or Pillans et al (2005) here, if they are going refer to these older sequences.

Line – 1150 – I would suggest the authors also read Grant et al 2019 (Nature), and some of the other Whanganui-based Pleistocene literature. This statement is misleading and shows a lack of understanding as to how the older sea-level reconstructions are established using the shallow-marine record. They are not absolute sea-level indicators like wave cut platforms and strandlines. They cannot be compared to MIS 5 sea-level indicators around NZ. They do however fundamentally record many transgressions and regressions of the shoreline in response to orbitally-paced global sea-level and associated water depth changes. But reconstructed water depth changes are also affected by local tectonic subsidence, compaction, and loading that all have to be accounted for when deriving the amplitude glacial-interglacial global sea-level change. The sea-level cycles reconstructed from the Whanganui sequences cannot be registered directly to present day sea-level because of late Quaternary uplift of western North island, which is the reason the marine terraces are preserved post MIS 15.

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