Controls on relief and sediment fluxes of active subduction margins at «geological» time scales : 20-100ka and 1Ma
The Hawke Bay forearc domain example from New Zealand

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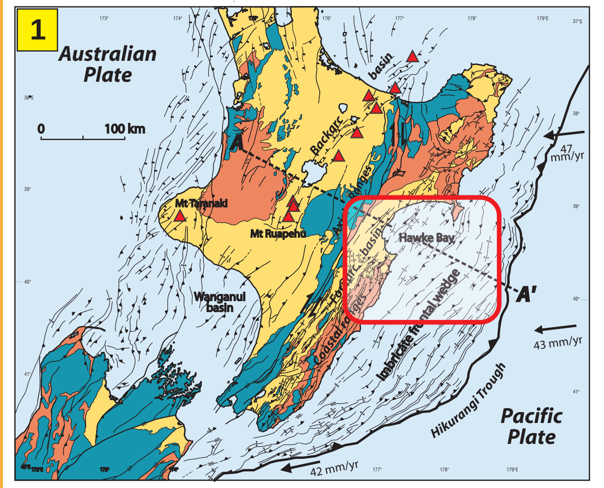
OBJECTIVES

Tectonics and climate are the two key parameters that control the evolution of relief and sediment transfers, from source to sink, in tectonically active areas, but their respective influences are difficult to distinguish as they act simultaneously and can generate similar signals in the sedimentary record. Nonetheless, these influences and their record are scale-dependant providing a chance to untangle the record.

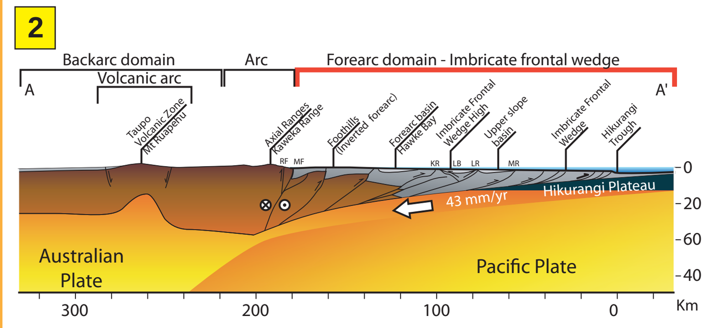
However covering this goal requires fully integrated qualitative and quantitative approaches of well-documented sedimentary systems, from catchment source to the deep ocean basin, to proper estimate their relative contributions and their consequences on relief evolution and erosion, sediment pathways and budget as well as internal storage and remobilizations within the different segments of the dispersal systems.

This work presents the results of a quantitative and three-dimensional source-to-sink study of the Pleistocene Hawke Bay forearc domain of the Hikurangi subduction margin of New Zealand based on the interpretation and integration of an extensive geophysical and geological data set.

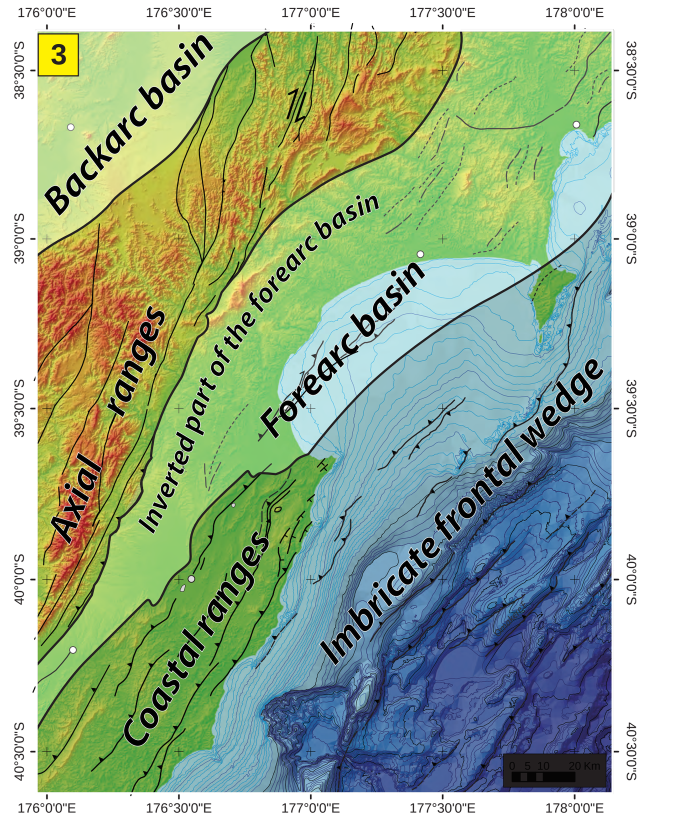
REGIONAL SETTING

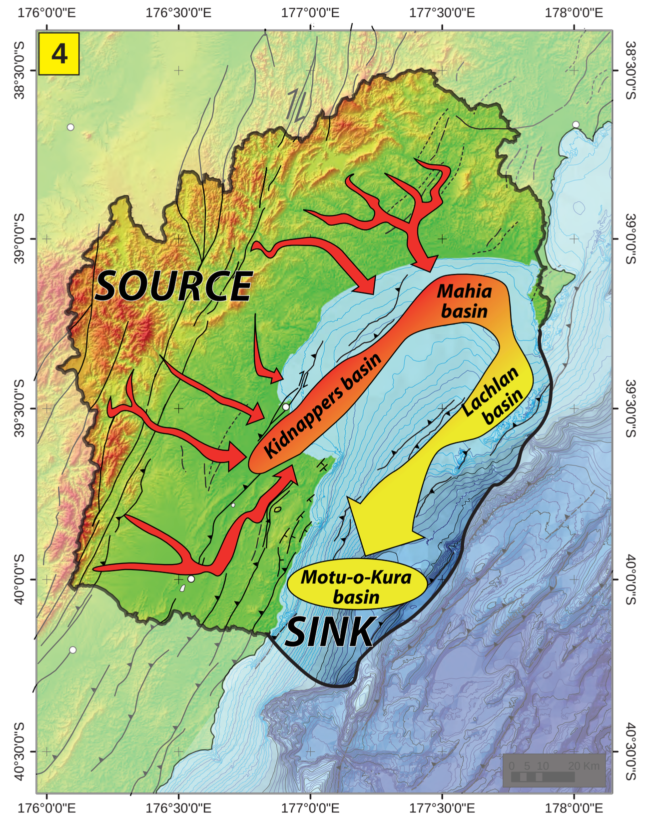


1. The Hawke Bay forearc domain is located on the east coast of the North Island, where the Pacific plate subducts beneath the Australian plate at a rate of about 43 mm/yr 1. The overall morphostructure of the margin includes from trench to arc (1) **an imbricated frontal wedge**, comprising a frontal accretionary wedge and an inner foundation of imbricated Cretaceous and Paleogene rocks, with several thrust-related ridges and associated slope basins of Miocene-Recent age, (2) **an emerging coastal high** that corresponds to the highest ridge of the frontal wedge (3) **a forearc domain** spanning both terrestrial and marine environments, (4) a 1700m-high axial ranges, strike-slip faulted, and (5) **a continental backarc rift and active volcanic arc system.** 2 3
2. The geological evolution of the margin since subduction initiation in the early Miocene is complex. Significant events in the Pleistocene include the emergence and growth of the axial ranges, inversion of extensional structures in the forearc domain, the development of a margin-wide unconformity at 1.1 Ma, and the subduction of series of seamounts on the Pacific plate.
3. In Hawke Bay, the forearc basin fill succession reaches up to 6000 m-thick and is characterized by Mio-Pliocene deep marine turbidites and Plio-Pleistocene shallow marine to fluvial sediments. This study concentrates on the uppermost, c.1000 meter-thick Castlecliffian-Haweran sequence (c. 1.1 Ma to Present) of the forearc basin fill preserved in structurally controlled sub-basins which represent individual storage domains or segments of the dispersal system.



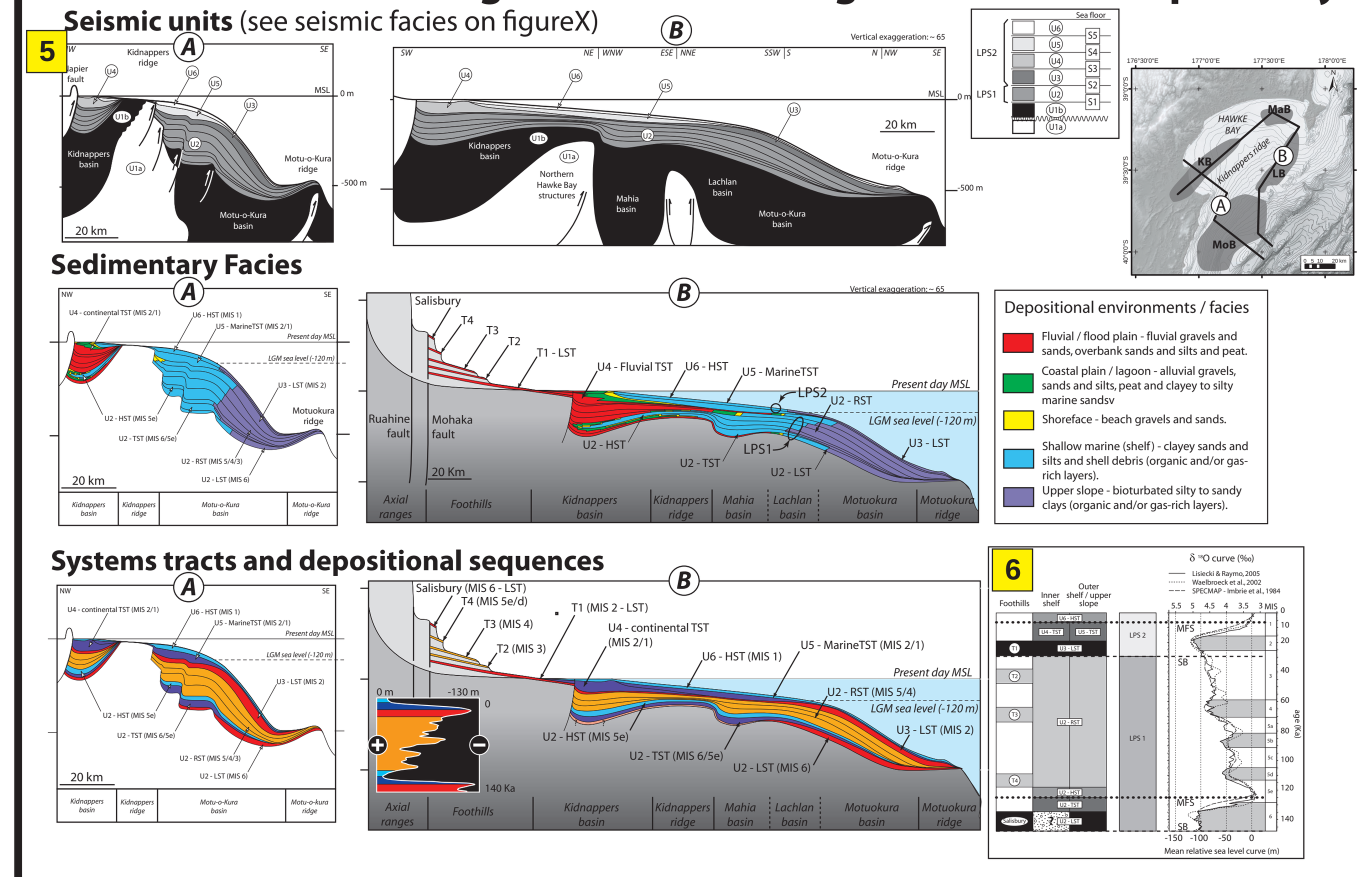
4. Onshore, sediments are preserved at the foot of the axial ranges in the uplifted forearc, or buried beneath the present day coastal plains. Offshore, sediments fill forearc sub-basins 4 and create a large shelf with smoothed morphology despite the presence of active structures. Farther offshore, the stacking of clinoforms in the upper-slope Motu-o-Kura basin results in a prominent shelf edge. Across the continental slope, the Castlecliffian succession thins out progressively in a series of slope basins between thrust ridges on the imbricated frontal wedge.
5. The shallow marine and fluvial Pleistocene age sediments are very well exposed along coastal cliffs in Hawke Bay. This section together with the stratotype section in the Wanganui basin provides one of the most complete calibrated sequence stratigraphic models for the last c. 1 Ma.



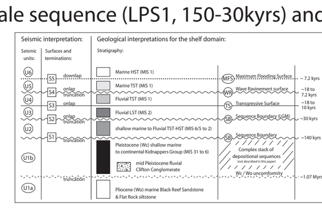


THE «SHORT» 20-100 Ka TIME SCALE

1- Cross sections through the different segments of the dispersal system: the last 100ka (LPS1) and 20 ka (LPS2) sequences

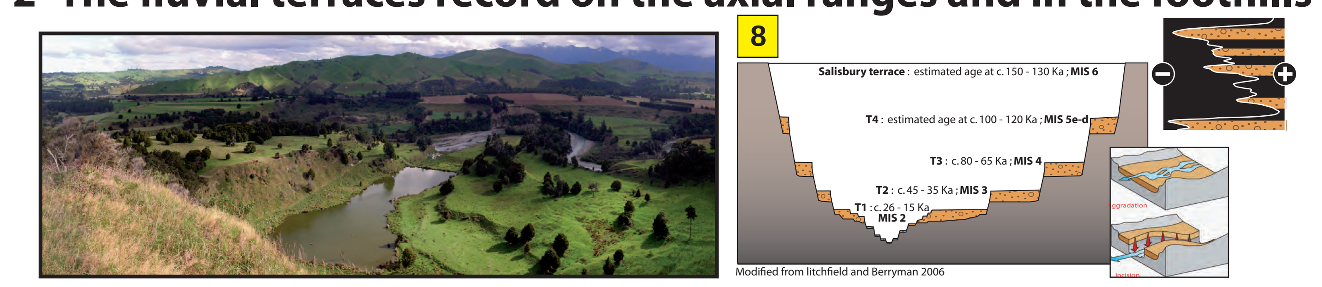


1. Four long-lasting tectonically-controlled depocenters constitutes the main segments of the forearc dispersal system 4
2. The late Pleistocene (c.150 ka) sedimentary units and unconformities were interpreted as systems tracts constitutive of two sea-level-cycle depositional sequences including a 100ka-scale sequence (LPS1, 150-30kyrs) and a 20ka-scale sequence (LPS2, 30-present) 5

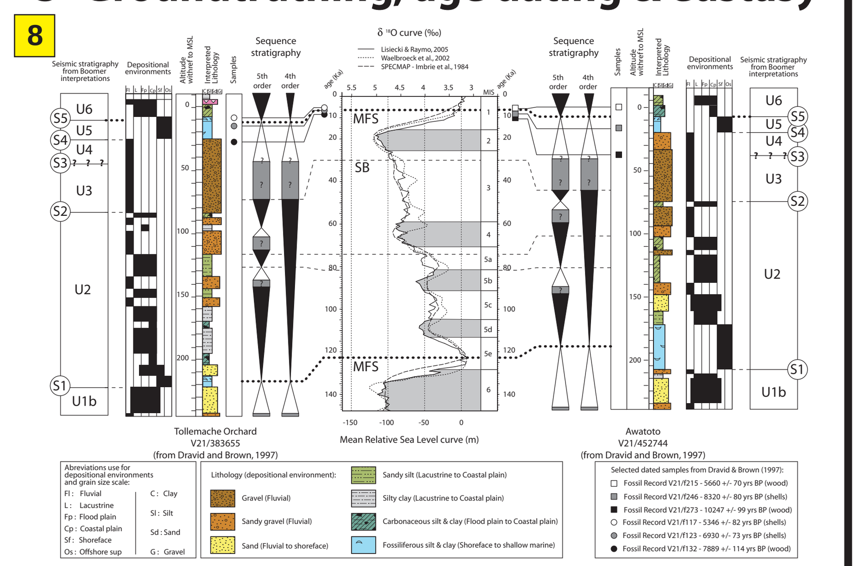


3. Sea-level is a major driver of sediment storage pattern: Rates of sea-level fall and rise -4 to +11mm/yr, Rates of vertical deformation -2 to 4mm/yr 6 8 7
4. But the strength of the tectonic signature depends on the duration of the depositional sequence. LPS1 is circuitous 10. The lengthening of the depositional profile implies that the effect of sea-level is attenuated with regards to the permanent high rate of tectonic deformation.
5. Fluvial terrace aggradations occurred during phases of rapid sea-level fall (terraces T1, T2, T3, T4, Salisbury) and climate cooling whereas river incision occurred during sea-level rise and climate warming 5 6 7. We consider that lengthening and shortening of river profiles during rapid sea-level changes modifies the accommodation space, whilst climatically induced changes in erosion rate and uplift tune the sediment supply. These processes are jointly responsible for the behavior of the major rivers on this subduction margin.
6. Estimates of mass accumulation rates reveal higher rates during climato-eustatic extremes and abrupt transitions as for the LST, TST– early HST (LPS2) period 9 at LGM and Holocene optimum and related transition. Estimated late Pleistocene mass accumulation rates are half of the present-day estimates of the Hawke's Bay sediment yield. This can be attributed to sediment export out of the studied area and/or a recent increase of sediment supply due to anthropogenic deforestation.
7. Paleogeographic reconstructions of two environmental extremes 11 show that postglacial rising sea level tends to restrict sedimentation on the shelf (from c. 0 m to c. -2 150 m), whereas glacial falling sea level tends to lengthen the depositional profile from the onshore range front (c. +300 m) to the toe of the lowstand wedge (c.-2 500 m)

2- The fluvial terraces record on the axial ranges and in the foothills



3- Groundtruthing, age dating & eustasy



4- Sediment budget

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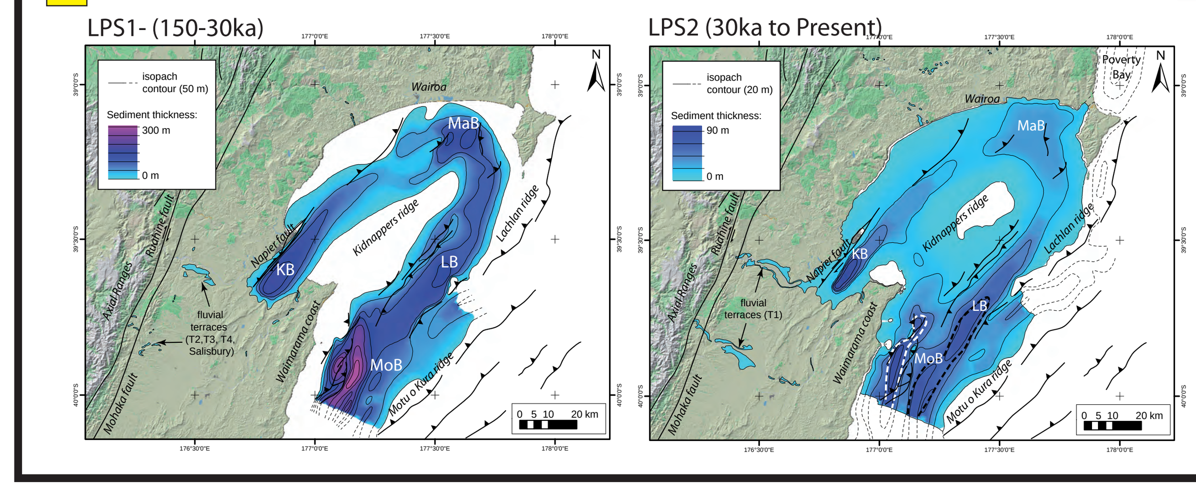
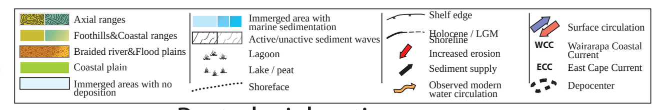
Mass accumulation rates			
LPS1	**LPS2**	**Average** (latePleist.)	**Present Day**
3,95 +/- 1.15 Mt/yr (err. 29%)	**5.67** +/- 1.97 Mt/yr (err. 34%) *LST - 5.56 +/- 2.18 Mt/yr (err. 39%)* *TST - early HST - 5.75 +/- 1.8 Mt/yr (err. 31%)* *less in late HST*	**4.23** +/- 1.09 Mt/yr (err. 26%)	**12** Mt/yr * **(*)** suspended sediment yield for Hawke Bay rivers *from Hicks and Shankar 2003*

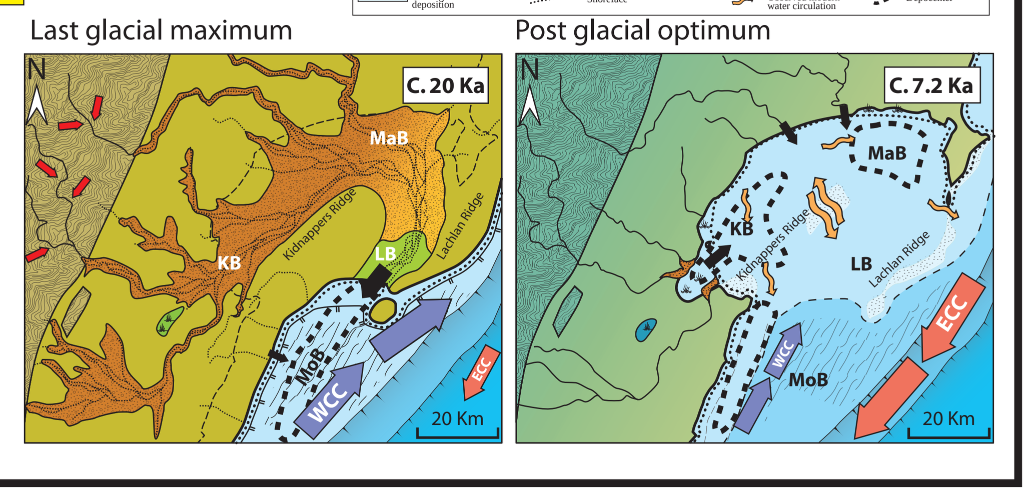
5- Main controls on sediment storage patterns

10 *Tectonic influence (100ka)*



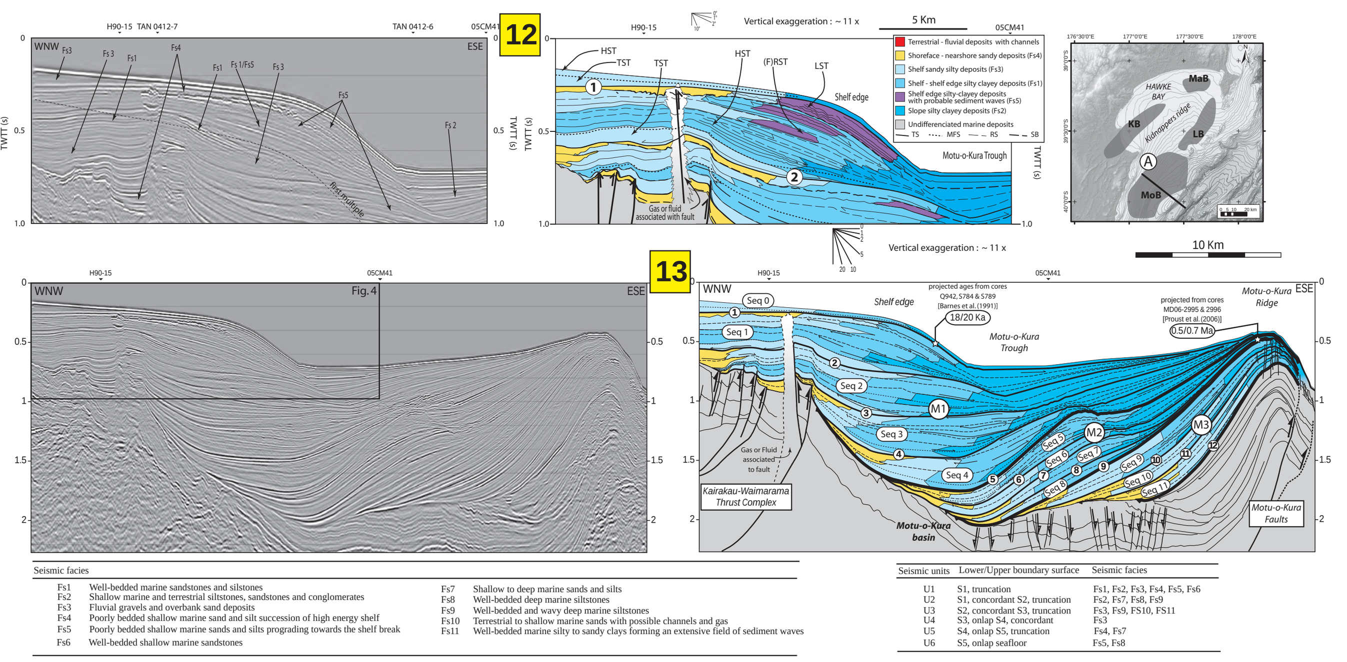
11 *Climate influence (20 ka)*





THE «LONG» 1 Ma TIME SCALE

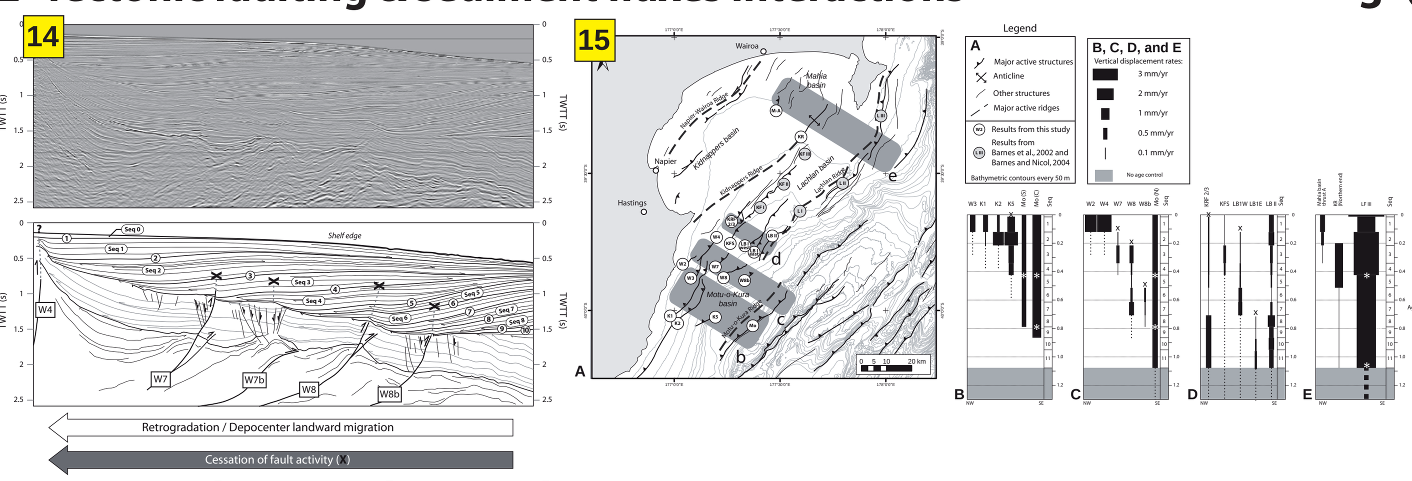
1- Stacking pattern of the 100ka sequences in the Motuokura depocenter



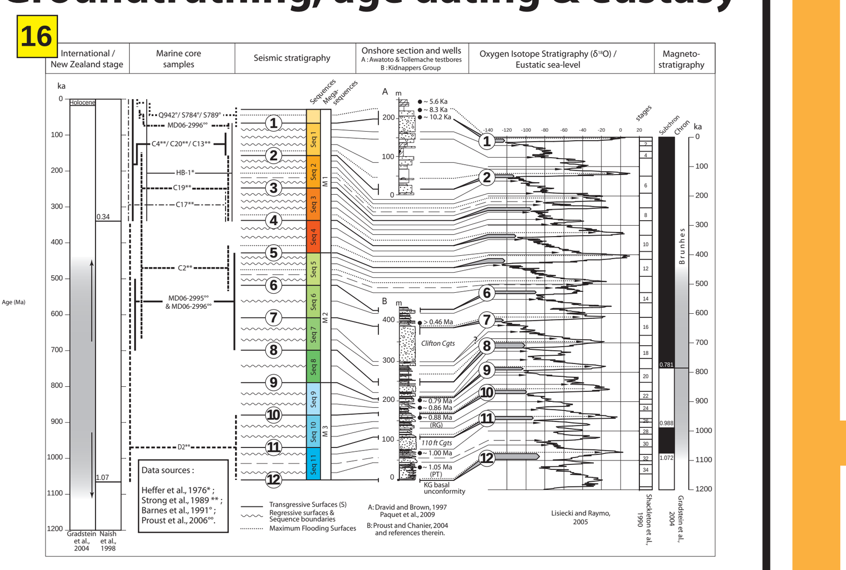
The interpretation and correlation of a dense set of geophysical and geological data covering the Hawke Bay forearc domain resulted in the following:

1. Eleven 100ka-scale (12) depositional sequences developed during the last ~1.1 Ma into four segments of the forearc dispersal system (Motu-o-Kura, Lachlan, Mahia, and Kidnappers basins). 4 13 These sequences are due to high-amplitude, 100 k.y. cycles in the Pleistocene climate-eustasy 6 16
2. The 100ka-sequences are bundled into three megasequences (M1 to M3).A major unconformity S5 (ca. 430 ka) separates megasequences M1 and M2 due to increased erosion on S5, compared to other ravinement surfaces. 13 This surface corresponds to reactivation of major structural ridges.
3. The three-dimensional geometry of the basin fill show an overall retrogradational pattern of sequences associated with a landward migration of the local depocenters and a change of basin configuration 13 14 This retrogradational trend is attributed to the interplays between sediment load–induced isostasy and tectonic deformation, particularly, the reactivation of the mid-shelf Kidnappers Ridge and upper slope Motu-o-Kura Ridge since ac. 430 ka. 15
4. The volume of sediment preserved in each sequence reveals a significant increase of preserved sediment flux since ca. 430 ka (M1 megasequence) 18. This increase results from: (A) variation of the long-term preservation potential of the basin, controlled by the combined effects of tectonically induced changes in basin configuration and "cannibalism" of the older M2 and M3 megasequences 17, and/or (B) an increase in climatically induced erosion rates and sediment delivery corresponding to the completion of the mid-Pleistocene transition (MPT), which has been documented elsewhere to have occurred regionally at ca. 435 ka.

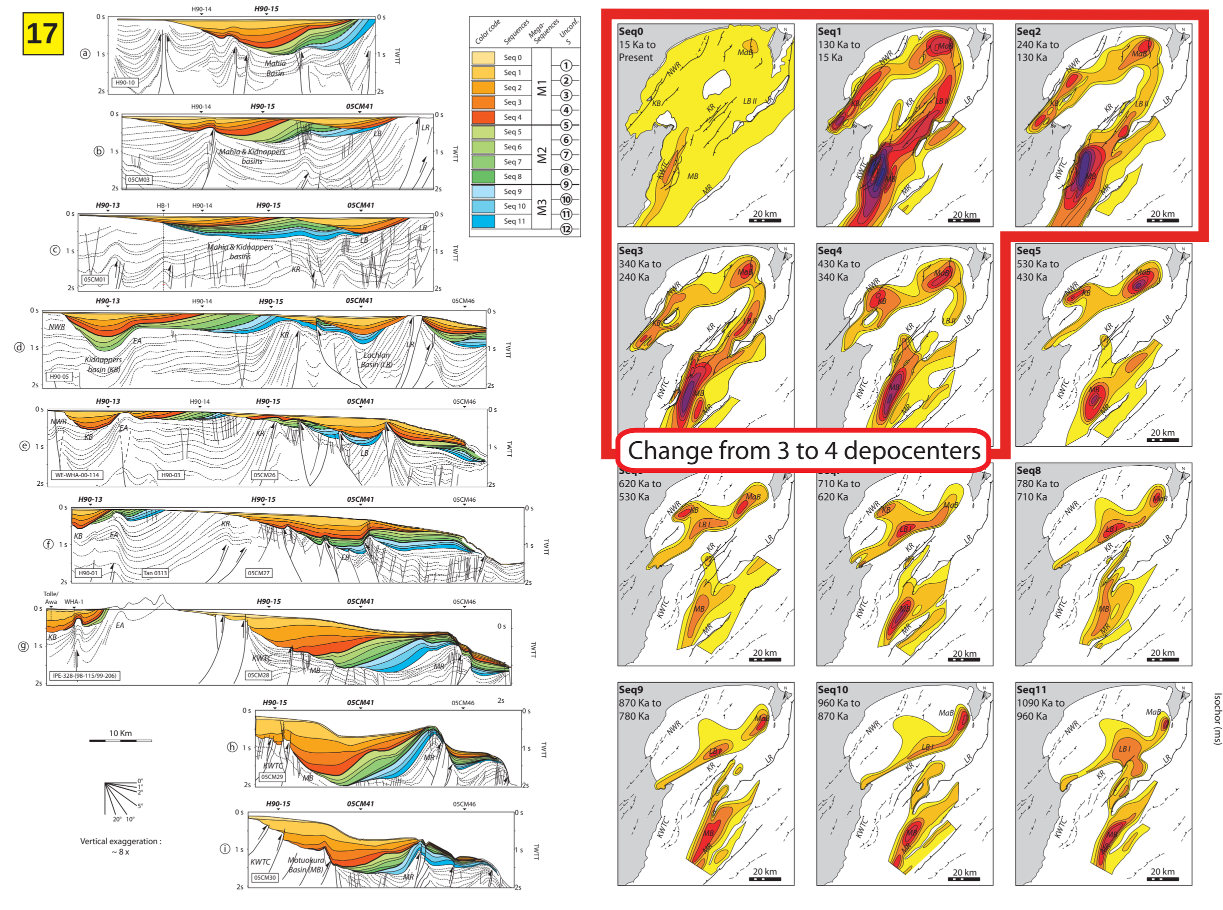
2- Tectonic faulting & sediment fluxes interactions



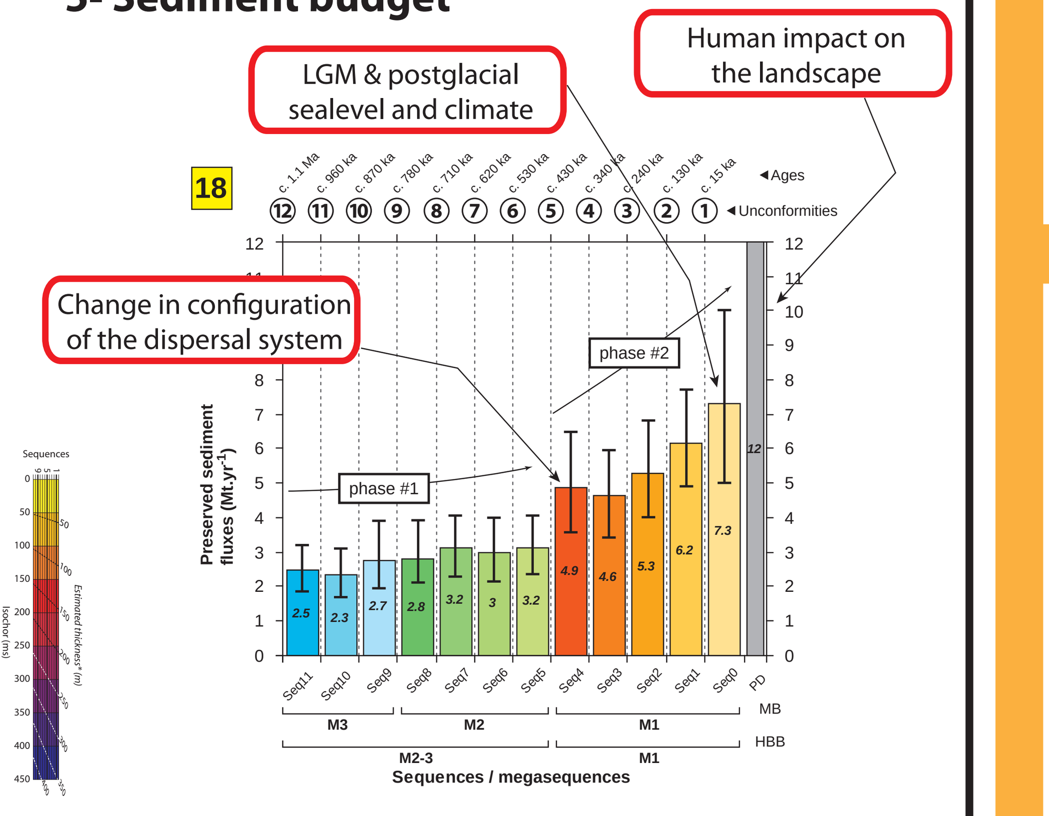
3- Groundtruthing, age dating & eustasy



4- Basinscale controls on sediment storage



5- Sediment budget



CONCLUSIONS

1. **Structure of subduction margin dispersal system**
Four long-lasting tectonically-controlled depocenters constitutes the main segments of the Pleistocene Hawke Bay forearc dispersal system of the Hikurangi margin of New Zealand
2. **Main controls on the dispersal systems**
At short time scales (20-100ka), climato-eustasy controls the internal storage of sediments within segments when at a long time scales (1Ma), tectonic deformation controls the number of segments and their geometries.
3. **Dynamic of sediment transfer**
At short time scales (20-100ka), lenghtening and shortening of depositional profiles control accommodation space, sediment transfer and paleogeographies. Leading to unusual river incision during rise of sea-level and warming and fluvial terraces aggradation during sealevel fall and cooling. At long time scales (100-1Ma), rate of sediment transfer into each segment enhance the tectonic deformation (sealing of faults, compensating sediment load by isostasy etc…).
4. **Sediment budget**
At short time scales (20-100ka), maximum accumulation rates are observed at abrupt climate-eustatic transitions. At long time scales (1Ma) accumulation rates increase during periods of subduction margin rejuvenation relocating of the different segments. Land use is at the origin of a present day sediment suspended load 3 times higher than the Holocene and Pleistocene calculated sedimentation rates.

References

1. Paquet F., Proust J.N., Barnes P.M., Pettinga J.R. (2009). Inner forearc sequence architecture in response to climatic and tectonic forcing since 150ka: Hawke's Bay, New Zealand. J. Sedim. Research, 79, 3-4, 97-124

2. Paquet F., Proust J.N., Pettinga J.R., Barnes P.M. (in press) Controls on active forearc basin stratigraphy and sediment fluxes: the Pleistocene of Hawke Bay, New Zealand. Geol. Soc. Amer. Bull.

Acknowledgements

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