Tectonics and genetics in topographic evolution

Geoscience Society of New Zealand

Hochstetter Lecture 2017

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in collaboration with:
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Ferdinand von Hochstetter (1829-1884)

German-Austrian pioneer geologist Auckland, Nelson 1858-59

Acknowledgements in memoriam

Richard Norris (1945-2016)

Mentor, colleague, friend for 40 years

Hochstetter arms *(from Gregor Macaulay)*

Dun Mountain, NZ

Dunite

South Island topography:
20 million years of geomorphic evolution

Little on-land evidence of this long history

Alpine Fault

Geological record:

Sediments
(sparse, large time gaps)

Fission tracks etc
(regional rock uplift, not topography)

OSL, ^{10}Be dating
(local points, not whole catchments)

www.geographx.co.nz

How do we determine the history of ranges and valleys when most of the record is continually removed by erosion?

Marlborough

Otago

Structure of talk

Background to fish biological memory

1. River capture and fish genetics, and molecular clock
   (a) Middle Pleistocene tectonic example: Otago/Southland
   (b) Late Pleistocene examples: Marlborough

Using geology and fish genetics to infer topographic evolution

2. Rise of Southern Alps and development of eastern drainages
3. Significance of inherited crustal structure
4. Drainage evolution in Southern Alps during on-going convergence

Larger scale synthesis of geomorphic inferences

5. Comparisons of fish to other biota in mountains: onset of glaciation
6. Regional topographic evolution in South Island
7. Speculations on other mountain belts

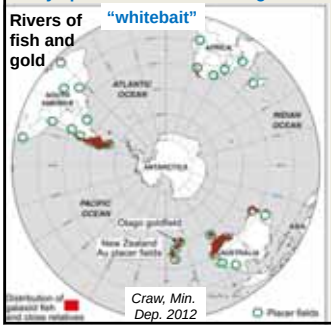
1. Galaxiid fish & biological memory in rivers

Some species are freshwater-limited
Live entire life in rivers
Common NZ freshwater species:

Many species have marine stage

Rivers of fish and gold

"whitebait"



Flathead galaxiids
G. vulgaris
G. depressiceps
G. teviot
G. divergens
G. paucispondylus

Roundhead galaxiids
G. anomalus
G. gollumoides

Pencil galaxiids
G. cobitinis
G. prognathus
G. macronasus

Fish DNA memory

GENETIC EVOLUTION (relative) → PRESENT

TIME (relative)

Becomes freshwater limited

Seagoing ancestor

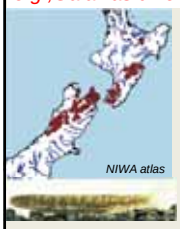
North Island

Retain "memory" of ancestral rivers

e.g.,Galaxias divergens

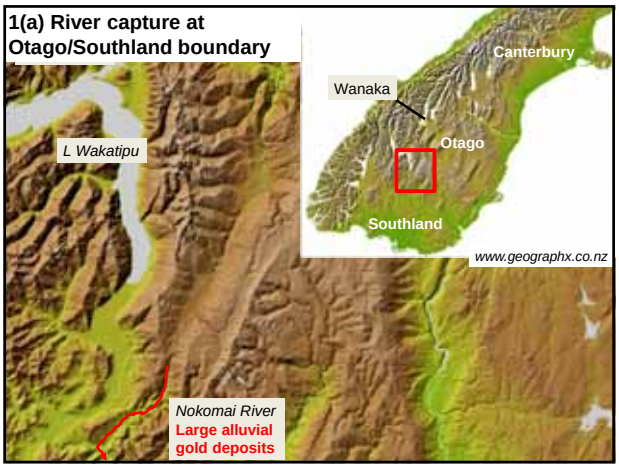
Marlborough, South Island

Genetic change since islands were connected (mtDNA, nDNA)



Sediments are constantly eroded & removed but fish remain in rivers (genetically) for millions of years

1(a) River capture at Otago/Southland boundary

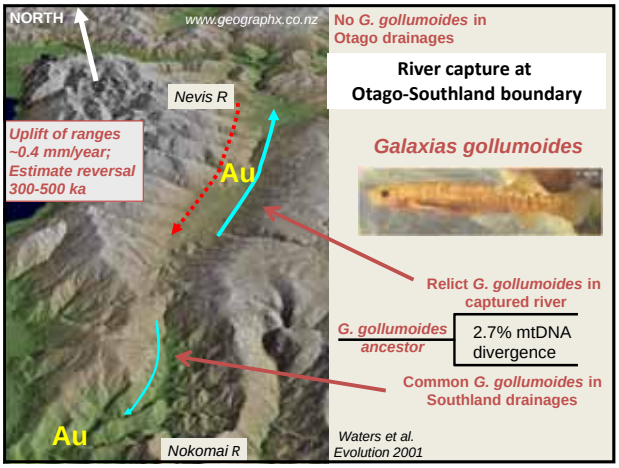


Southland gold mines contain some exotic minerals in sand

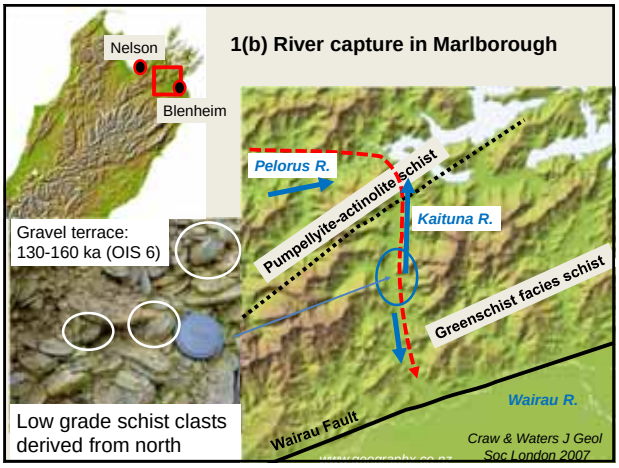
Magnetite from high grade schist

Fe-Mn-Ca garnet from high grade schist

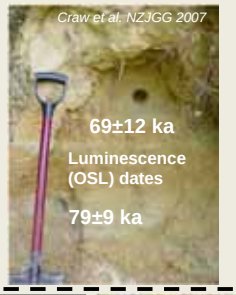
River capture at Otago-Southland boundary



1(b) River capture in Marlborough



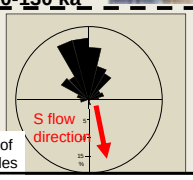
Geology at drainage divide



Terrace top Locally derived, 60-90 ka

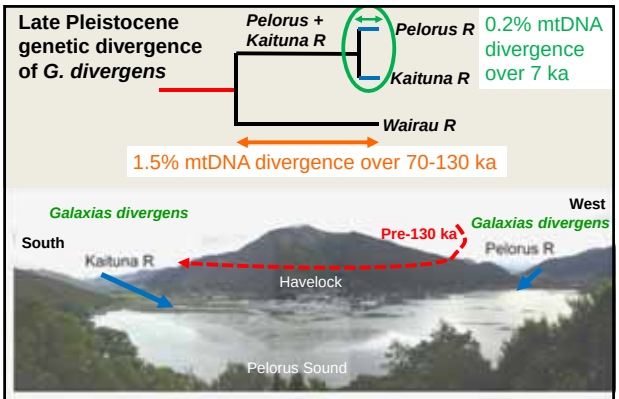
River capture between OIS 6 and OIS 4: last interglacial, 90-130 ka

OIS 6 terrace underlies divide Derived from north 130-160 ka



Imbrication of schist pebbles

Late Pleistocene genetic divergence of *G. divergens*

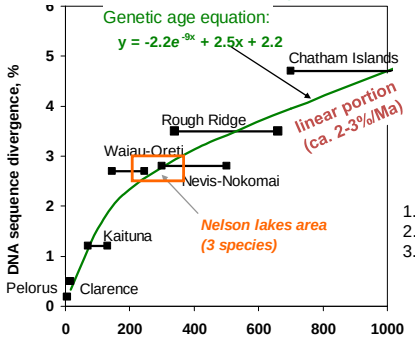


Rivers were connected in Pleistocene sea level low stand
Now isolated by sea level rise ca. 7 ka

Waters et al. Biol J Linn Soc 2006

Fish genetics as a geomorphological dating tool

Theoretical curve fitted through dated fish separation events

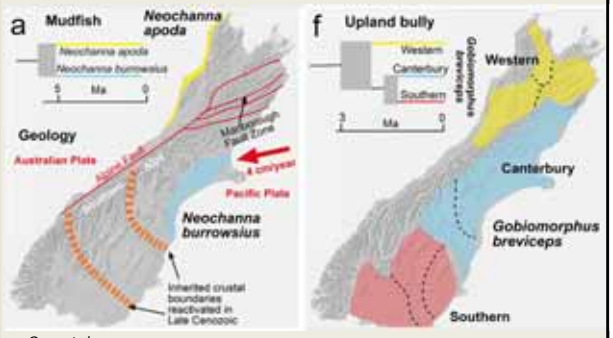


Dating tool for the last 1 Ma

Uses of fish biological memory:
1. Identify capture event
2. Define which rivers
3. Estimate timing

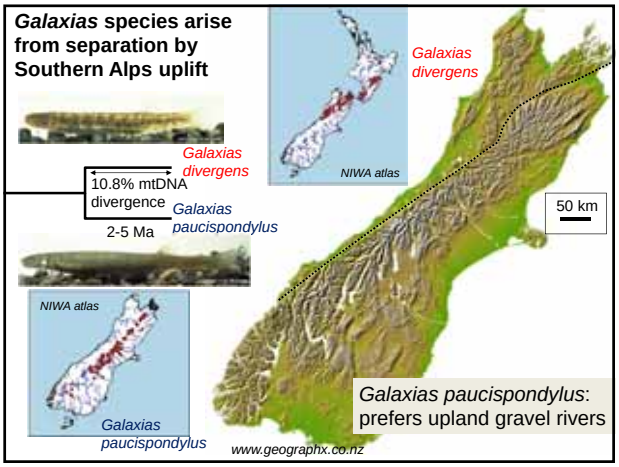
Craw et al. Geology 2008

2. Rise of Southern Alps in Pliocene:
Separated eastern and western fish populations
Different genera from *Galaxias:*

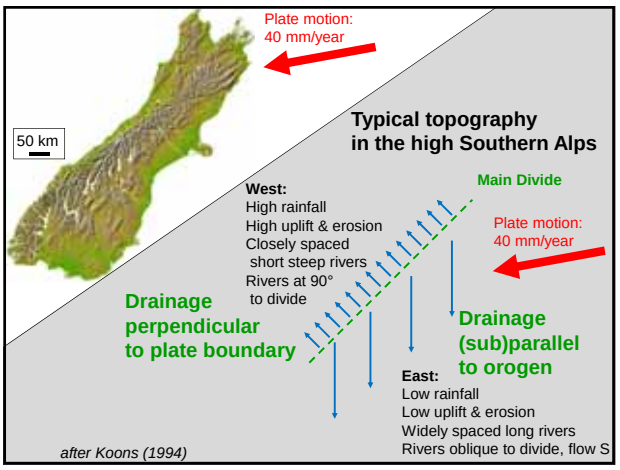


Craw et al. Nat. Geosci. 2016

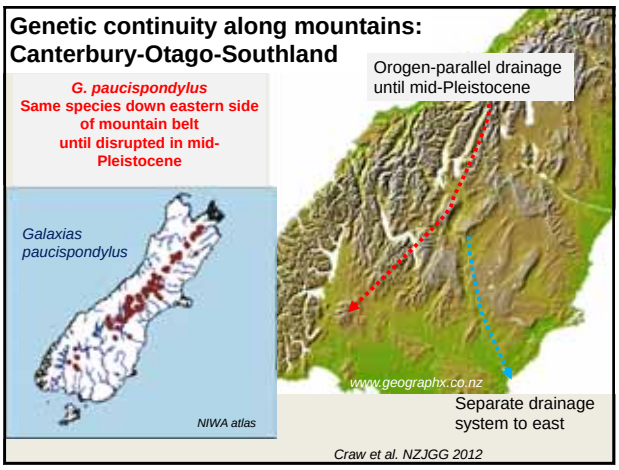
***Galaxias* species arise from separation by Southern Alps uplift**



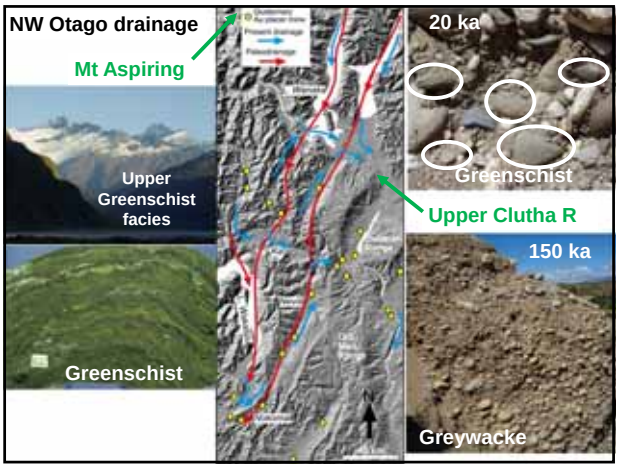
Galaxias paucispondylus: prefers upland gravel rivers

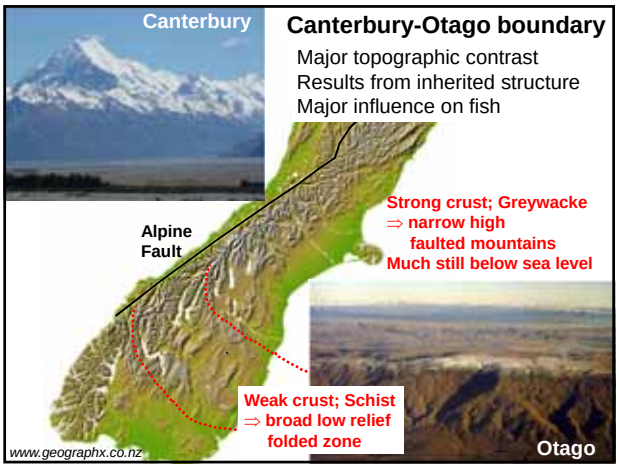


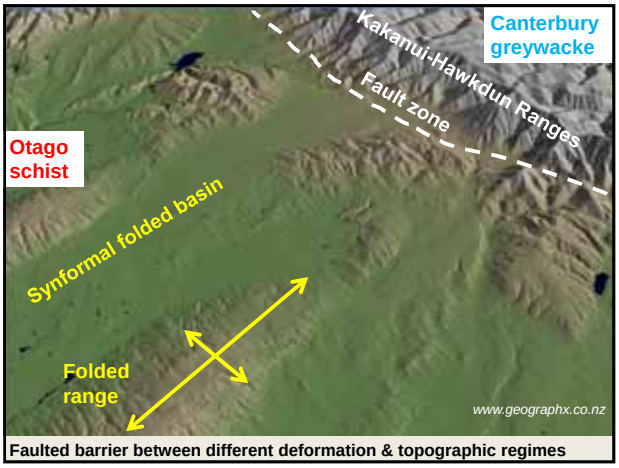
Genetic continuity along mountains: Canterbury-Otago-Southland



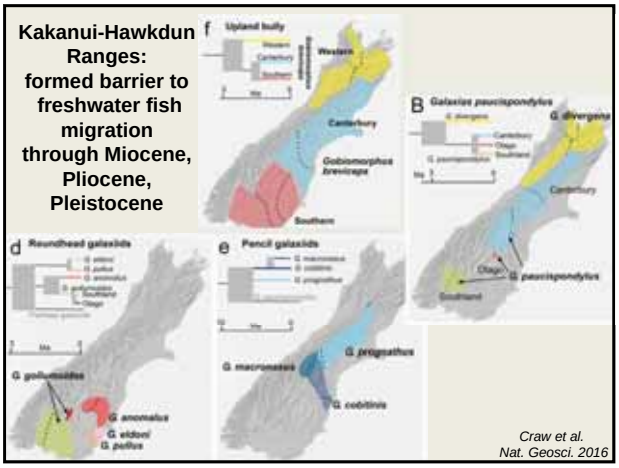
Craw et al. NZJGG 2012

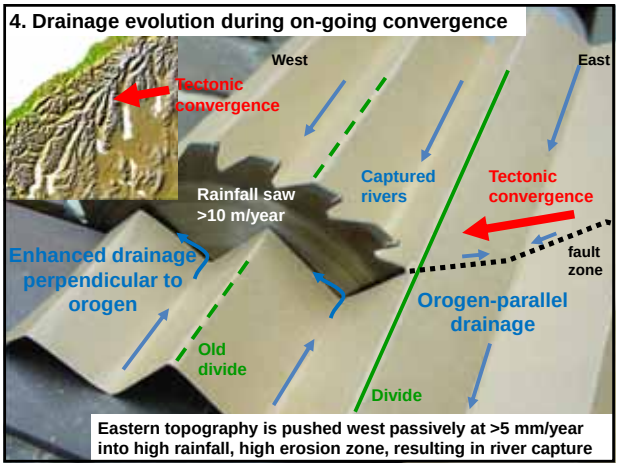


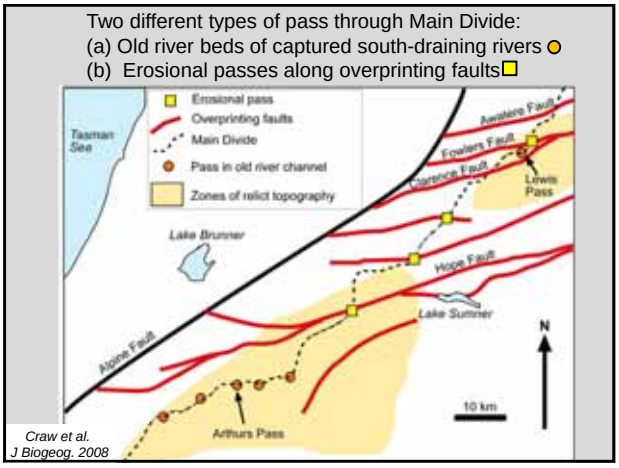


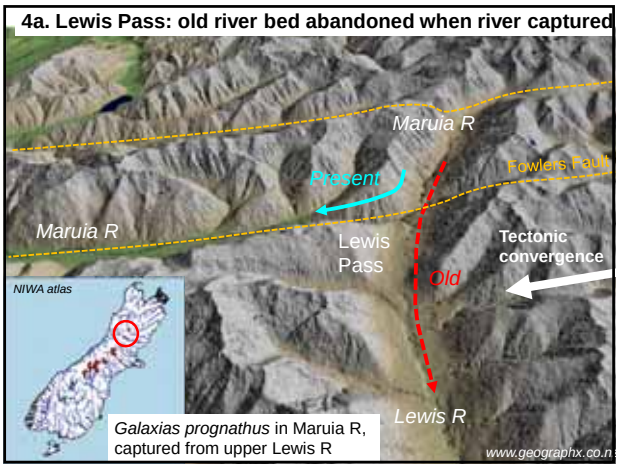


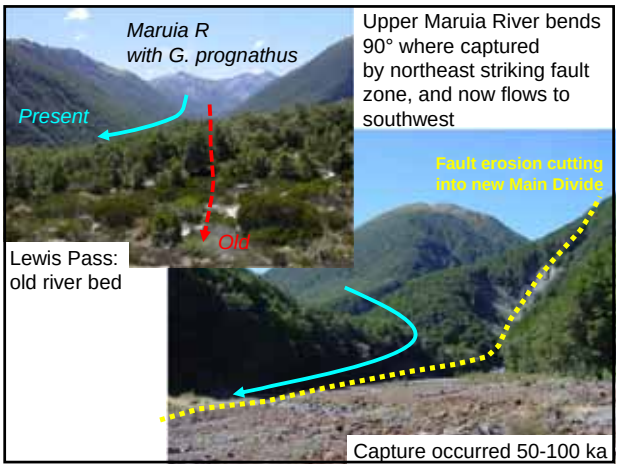
Faulted barrier between different deformation & topographic regimes

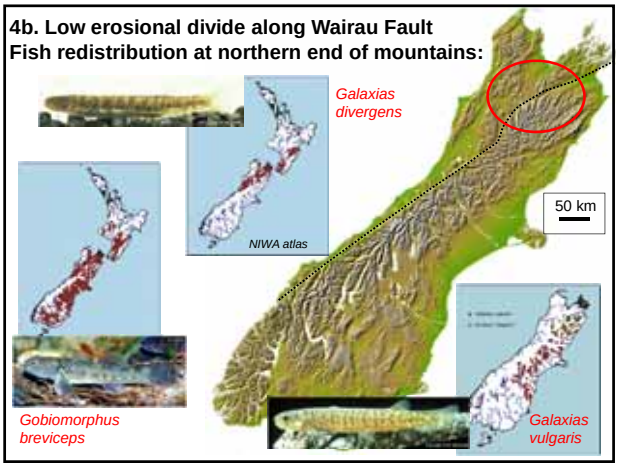


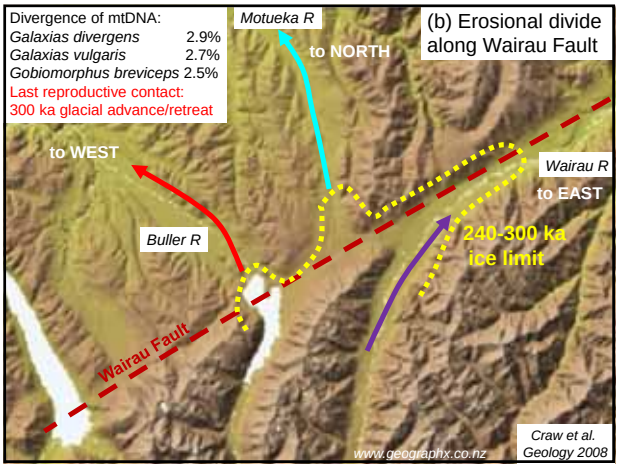


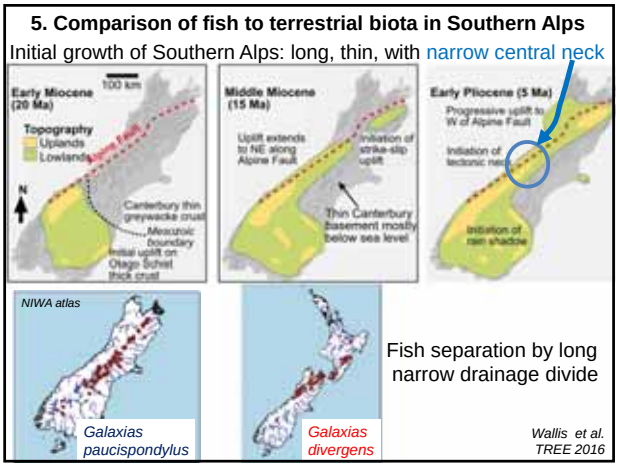


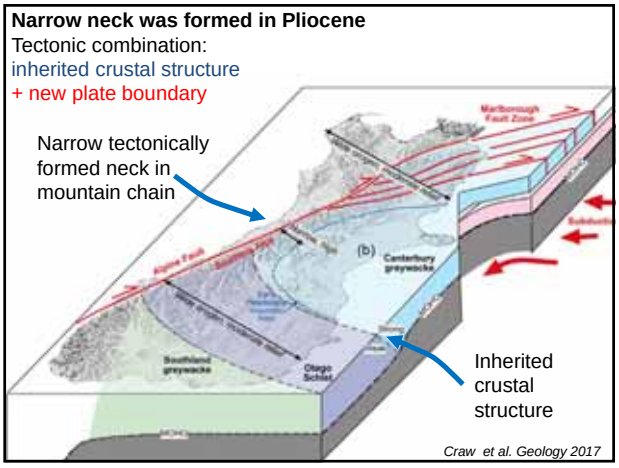

4a. Lewis Pass: old river bed abandoned when river captured
Maruia R
Present
Fowlers Fault
Maruia R
Lewis Pass
Tectonic convergence
Old
NIWA atlas
Lewis R
Galaxias prognathus in Maruia R, captured from upper Lewis R
www.geographx.co.n

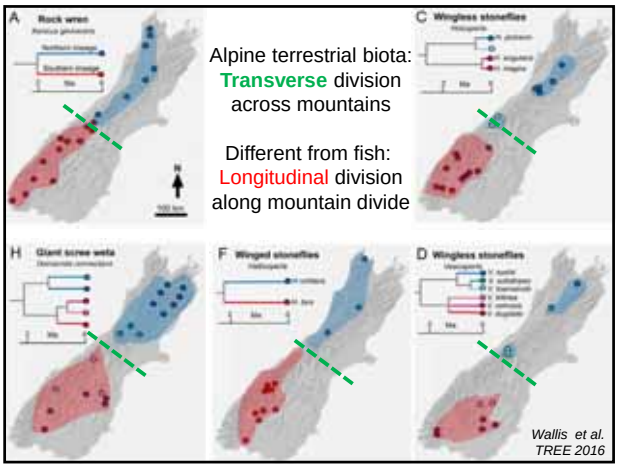

Maruia R with G. prognathus
Present
Old
Upper Maruia River bends 90° where captured by northeast striking fault zone, and now flows to southwest
Fault erosion cutting into new Main Divide
Lewis Pass: old river bed
Capture occurred 50-100 ka

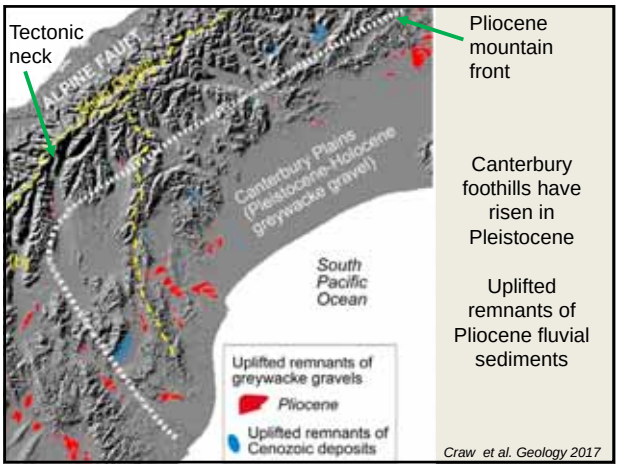

4b. Low erosional divide along Wairau Fault
Fish redistribution at northern end of mountains:
Galaxias divergens
NIWA atlas
50 km
Gobiomorphus breviceps
Galaxias vulgaris

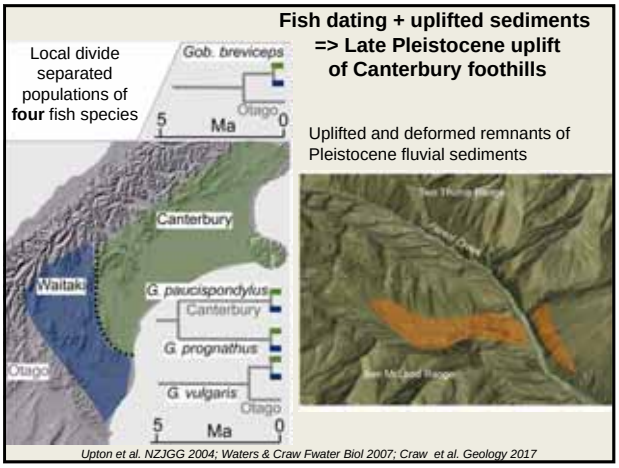

Divergence of mtDNA:
Galaxias divergens 2.9%
Galaxias vulgaris 2.7%
Gobiomorphus breviceps 2.5%
Last reproductive contact:
300 ka glacial advance/retreat
Motueka R
to NORTH
(b) Erosional divide along Wairau Fault
to WEST
Wairau R
to EAST
Buller R
240-300 ka ice limit
Wairau Fault
www.geographx.co.nz
Craw et al. Geology 2008

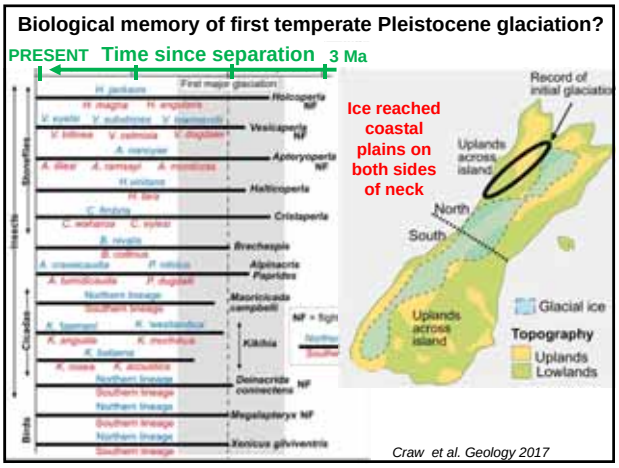

5. Comparison of fish to terrestrial biota in Southern Alps
Initial growth of Southern Alps: long, thin, with narrow central neck
Early Miocene (20 Ma)
Middle Miocene (15 Ma)
Early Pliocene (5 Ma)
NIWA atlas
Galaxias paucispondylus
Galaxias divergens
Fish separation by long narrow drainage divide
Wallis et al. TREE 2016

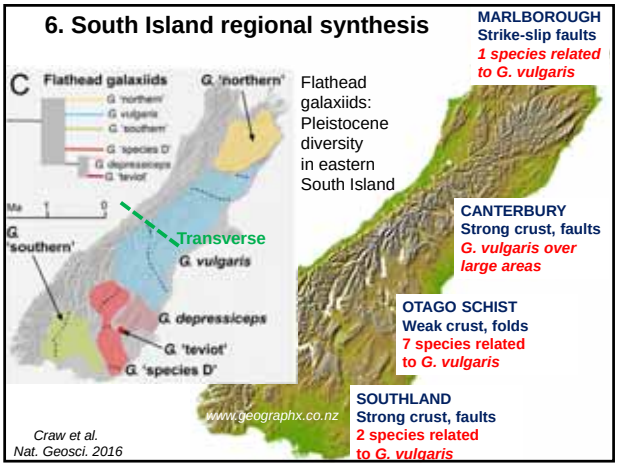

Narrow neck was formed in Pliocene
Tectonic combination:
inherited crustal structure
+ new plate boundary
Narrow tectonically formed neck in mountain chain
Inherited crustal structure
Craw et al. Geology 2017

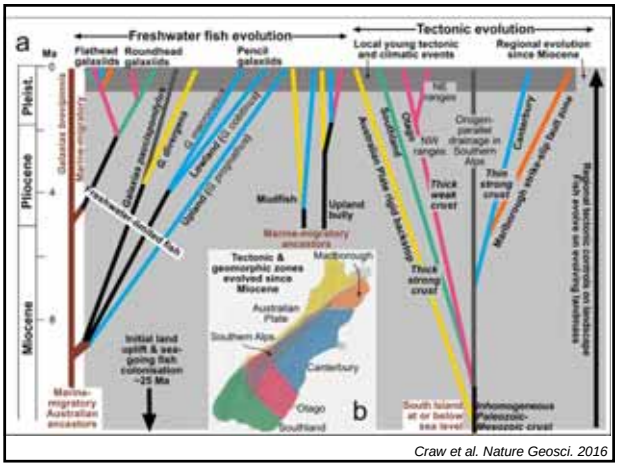

Alpine terrestrial biota:
Transverse division
across mountains
Different from fish:
Longitudinal division
along mountain divide
Wallis et al.
TREE 2016


Tectonic
neck
Pliocene
mountain
front
Canterbury
foothills have
risen in
Pleistocene
Uplifted
remnants of
Pliocene fluvial
sediments
Canterbury Plains
(Pleistocene-Holocene
greywacke gravel)
South
Pacific
Ocean
Uplifted remnants of
greywacke gravels
Pliocene
Uplifted remnants of
Cenozoic deposits
Craw et al. Geology 2017


Fish dating + uplifted sediments
=> Late Pleistocene uplift
of Canterbury foothills
Local divide
separated
populations of
four fish species
Gob. breviceps
Otago
5 Ma 0
Canterbury
Waitaki
G. paucispondylus
Canterbury
G. prognathus
G. vulgaris
Otago
Otago
5 Ma 0
Uplifted and deformed remnants of
Pleistocene fluvial sediments
Upton et al. NZJGG 2004; Waters & Craw Fwater Biol 2007; Craw et al. Geology 2017

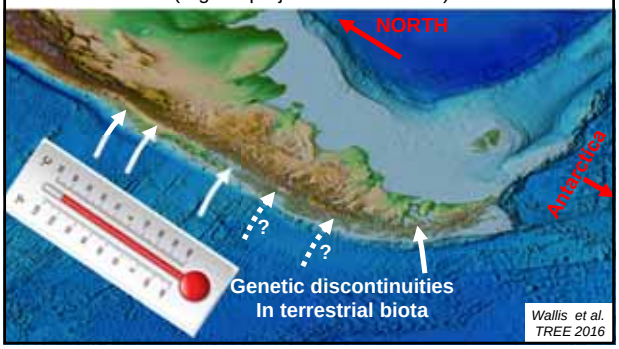

Biological memory of first temperate Pleistocene glaciation?
PRESENT
Time since separation
3 Ma
Ice reached
coastal
plains on
both sides
of neck
Record of
initial glaciation
Uplands
across
island
North
South
Glacial ice
Topography
Uplands
Lowlands
Craw et al. Geology 2017


6. South Island regional synthesis
MARLBOROUGH
Strike-slip faults
1 species related
to G. vulgaris
C
Flathead galaxiids
G. 'northern'
Flathead
galaxiids:
Pleistocene
diversity
in eastern
South Island
Transverse
G. vulgaris
G.
'southern'
G. depressiceps
G. 'teviot'
G. 'species D'
CANTERBURY
Strong crust, faults
G. vulgaris over
large areas
OTAGO SCHIST
Weak crust, folds
7 species related
to G. vulgaris
SOUTHLAND
Strong crust, faults
2 species related
to G. vulgaris
www.geographx.co.nz
Craw et al.
Nat. Geosci. 2016


Freshwater fish evolution
Tectonic evolution
Flathead galaxiids
Roundhead galaxiids
Pencil galaxiids
Local young tectonic and climatic events
Regional evolution since Miocene
Pleist.
Pliocene
Miocene
Mudfish
Upland bully
Tectonic & geomorphic zones evolved since Miocene
Initial land uplift & sea-going fish colonisation ~25 Ma
Canterbury
Otago
Southland
b
Craw et al. Nature Geosci. 2016

7(a): South American terrestrial biota as a thermometer for progressive early Pleistocene global cooling?

Biological memory may retain the only on-land record
(A good project for the future?)

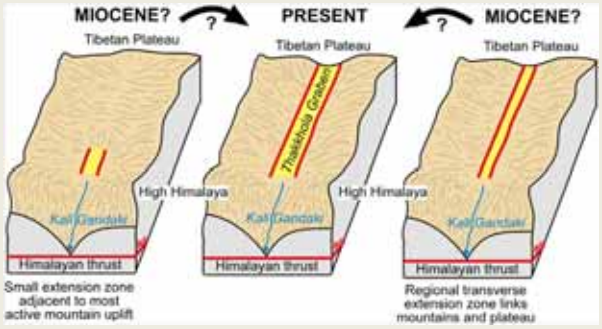


7b. Himalayan transverse faunal discontinuities

Glacial, in deep erosional gorges

Transverse extension: Kali Gandaki R graben

Geological record cannot distinguish evolutionary histories



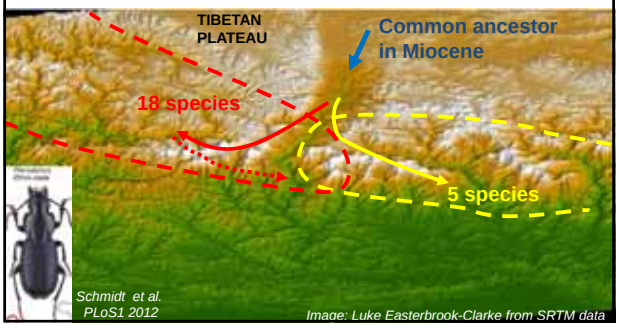
Northward evolution of depression

Long-term transverse depression

Biological memory of long-term transverse corridor from Tibet

Flightless beetles: migrated south & speciated to east and west of graben (+ later dispersal & overlap)

DNA estimate: migration & speciation = middle Miocene (>8 Ma)



Conclusions

Separate tectonic-geomorphic zones evolved in South Island through Miocene-Recent uplift and evolution of landscape

Freshwater fish populations evolved in varying states of isolation in the separate geomorphic zones

Freshwater fish carry information about the geomorphic evolutionary history in their genes that is difficult to extract from the geological record otherwise

This genetic information can provide evidence for previous drainage connections and severance events, and can estimate timing for these

Alpine terrestrial biota carry an entirely different genetic memory dominated in NZ by the first Pleistocene glaciation, with a prominent transverse discontinuity

Genetic data can augment geological tools, with some limitations (like other tools), for unravelling geomorphological history in mountain belts