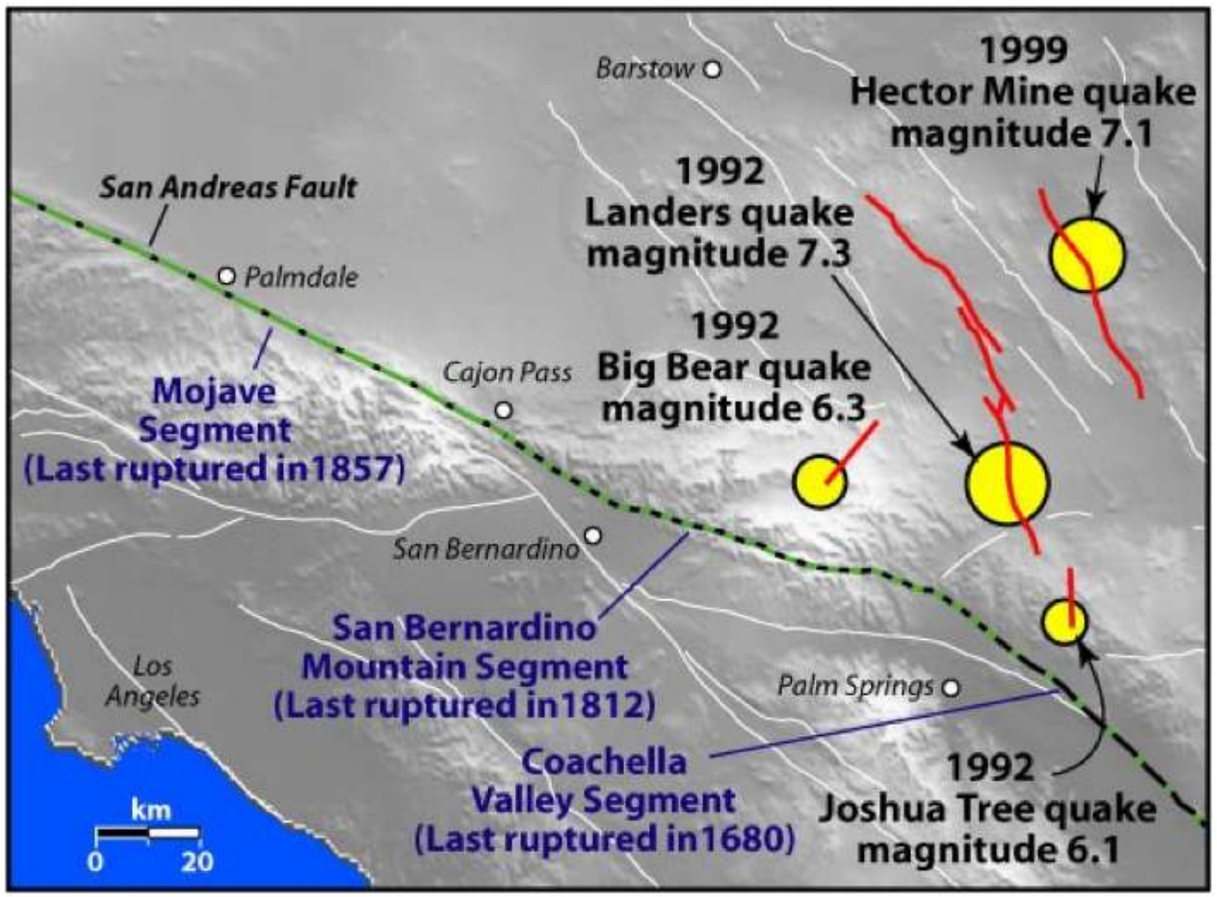
Susan Hough
@SeismoSue

June 28, 1992, 25 yrs ago #OTD, the M7.3 Landers earthquake struck SoCal. We learned so much from this one: how faults & quakes interact.



6/28/17, 8:43 AM

The 14 Nov 2016 M 7.8 Kaikoura, South Island, New Zealand Earthquake: Notes from the Field

Mark Hemphill-Haley - Humboldt State University

ACKNOWLEDGEMENTS

GNS SCIENCE
TE PŪ AO

GEER

UNIVERSITY of OTAGO
SAPERE AUDE
Te Whare Wānanga o Otāgo
NEW ZEALAND

HUMBOLDT STATE UNIVERSITY
H
FOUNDED 1913

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

VICTORIA UNIVERSITY WELLINGTON
TE WHARE WĀNANGA
O TE ŪPOKO O TE IKA A MĀUI

NIWA
Taihoro Nukurangi

USC University of Southern California

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha

UNIVERSITY OF MICHIGAN

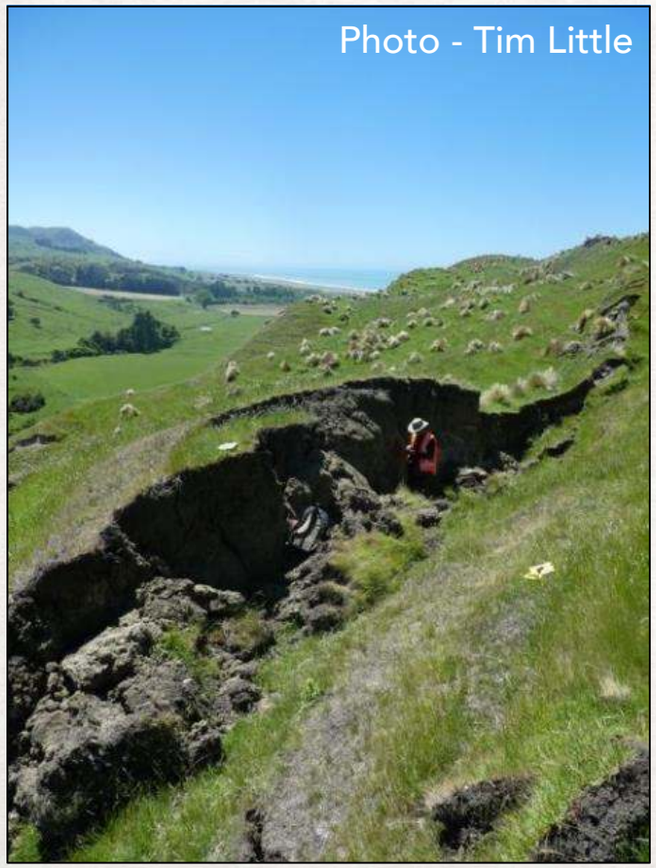
GEOTECHNICAL EXTREME EVENTS RECONNAISSANCE

http://www.geerassociation.org

The Kaikoura Earthquake Surface Fault Rupture Response Team:

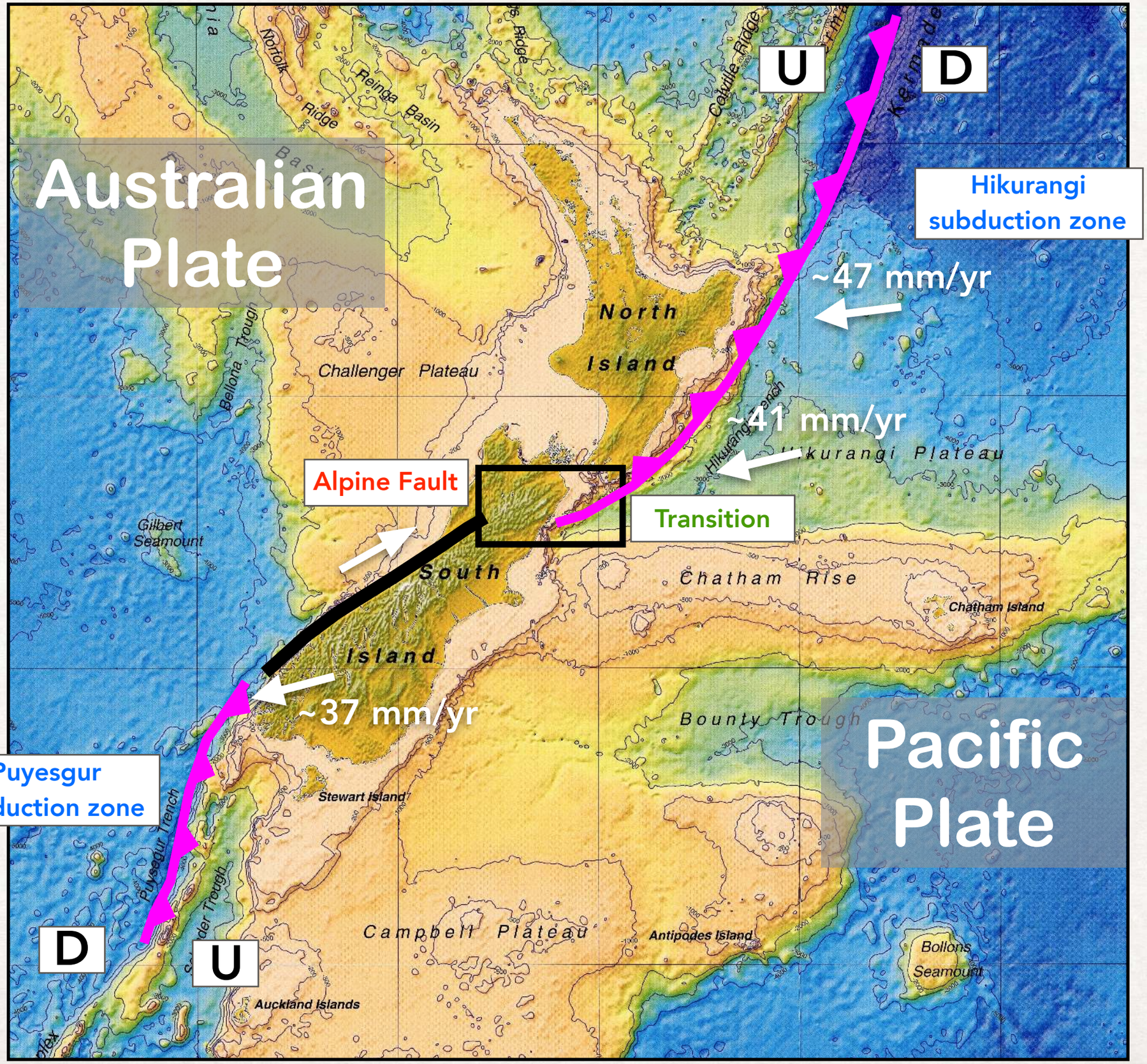
Benson, A., Bischoff, A., Hatem, A., Barrier, A., Nicol, A., Wandres, A., Lukovic, B., Hall, B., Gasston, C., Asher, C., Grimshaw, C., **Madugo, C.**, Fenton, C., Hale, D., Barrell, DJA., Heron, DW., Strong, DT., Townsend, DB., Noble, D., Howarth, JD., Pettinga, J., Williams, J., Kearse, J., **Manousakis, J.**, Borella, J., Mountjoy, J., Rowland, J., Clark, KJ., Pedley, K., Sauer, K., Berryman, KR., **Hemphill-Haley, M.**, Stirling, MW., Villeneuve, M., Cockroft, M., Khajavi, N., Litchfield, N. J., Barnes, P., Villamor, P., Carne, R., Langridge, RM., Zinke, R., Van Dissen, R., McColl, S., Cox, SC., Lawson, S., Little, T., **Stahl, T.**, Cochran, UA., Toy, V., Ries, WF., Juniper, Z. *(alphabetical order by first name).*

Blue = GEER Surface Fault Rupture team



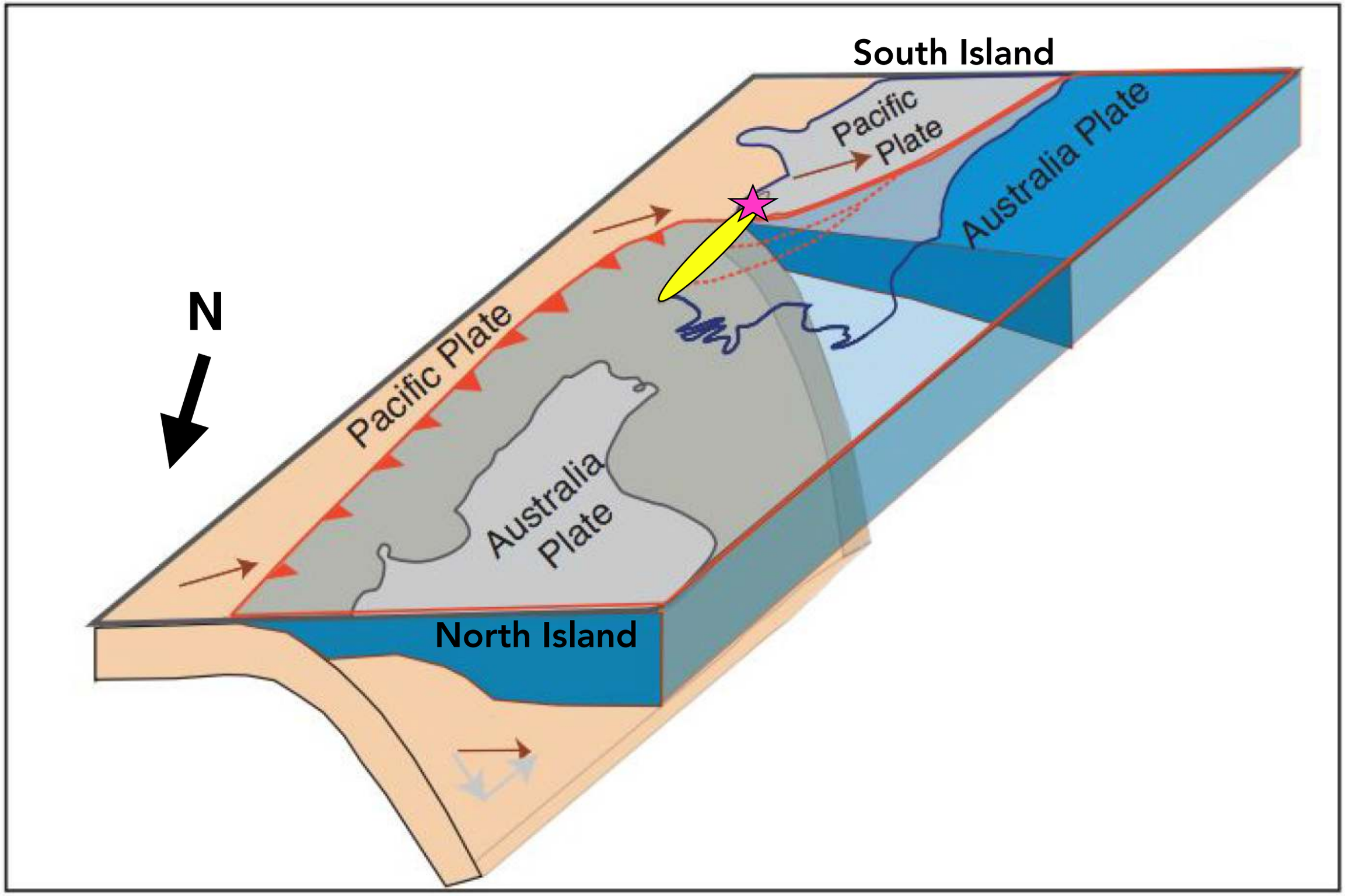
★ Indicates slides contributed in whole or part by Russ Van Dissen, Tim Little or Rob Langridge - Thanks!

NEW ZEALAND CONTINENT



GNS SCIENCE TE PŪ AO

2002



from Matt Herman and Kevin Furlong, Penn State

Hope fault, Jordan thrust, and uplift of the Seaward Kaikoura Range, New Zealand

Russell Van Dissen,* Robert S. Yeats
Department of Geosciences, Oregon State University
Corvallis, Oregon 97331-5506

ABSTRACT

In the northern South Island of New Zealand, displacement at the Pacific-Indian plate boundary is accommodated by the east-northeast–striking, right-lateral strike-slip Marlborough fault system. The southernmost Marlborough fault is the Hope fault; the late Pleistocene–Holocene horizontal slip rate on this fault is 20–25 mm/yr, about half of the rate of Pacific-Australian plate motion. Near the eastern end of the Hope fault, most displacement is transferred to the north-northeast–striking Jordan thrust, but the average dip-slip rate at the surface trace of this thrust is less than 4 mm/yr. We propose that most slip takes place on a blind thrust, expressed at the surface by the fault-propagation folding of the Seaward Kaikoura Range, and that the rate of uplift of this range is as high as that of the Southern Alps, 6 to 10 mm/yr. The major restraining bend of same average slip rate as the Wairau fault, 4- the Alpine fault is an east-dipping, reverse-se straining bend, this low slip rate results in Mountains east of the bend at a rate lower th Alps and Seaward Kaikoura Range.

INTRODUCTION

The present-day tectonic setting of the Sout is dominated by the diffuse transform boundary Australian plates. The boundary links the east- Hikurangi trench to the north, where the Pacifi subducted beneath the Australian plate, and t Trench and Macquarie Ridge to the south (McK The southern extent of the Hikurangi Trough is isobath off the northeast coast of the South Islan

*Present address: New Zealand Geological Survey, Box 30368, Lower Hutt, New Zealand.

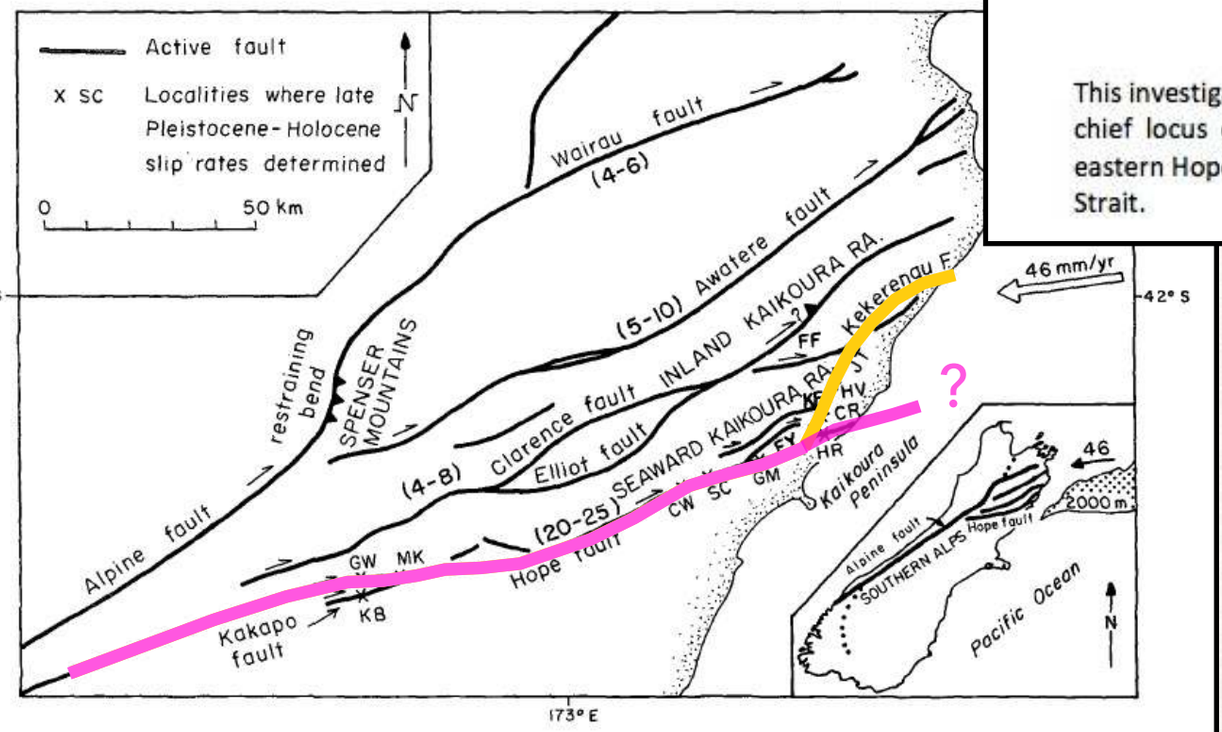


Figure 1. Active faults of northern South Island of New Zealand. Marlborough fault system is composed of Wairau, Awatere, Clarence, and Hope faults, Jordan thrust, and Fidget fault (from Officers of New Zealand Geological Survey [1983]; revised for Kaikoura region by Van Dissen [1989]). Barbs point toward hanging wall of active thrusts. Numbers in parentheses are late Quaternary slip rates for Marlborough faults (in mm/yr; see text for references). Localities discussed in text are Charwell River (CW), Clinton River (CR), Glynn Wye (GW), Goldmine Creek (GM), Happy Valley (HV), Hapuku River (HR), Kakapo Brook (KB), Manuka Stream (MK), and Sawyers Creek (SC). FF = Fidget fault; FY = Fyffe fault; JT = Jordan thrust; KF = Kowhai fault. (RA. = range.) Lower right inset: South Island of New Zealand, including Alpine fault, Southern Alps, Marlborough faults, and offset tectonostratigraphic terranes (dots). Off coast of Marlborough, 2000 m isobath locates southwestern end of Hikurangi Trench; area below isobath is shaded. Arrow shows azimuth and rate, in mm/yr, of relative motion of Pacific plate with respect to Australian plate (from Walcott, 1979).

LATE QUATERNARY DEXTRAL SLIP RATE OF THE KEKERENGU FAULT: NEW ZEALAND'S THIRD FASTEST ON-LAND FAULT

R.J. Van Dissen[1], T.A. Little[2], R.M. Burke[3], P.J. Tonkin[4], K.P. Norton[2], S.N. Bacon[3,5], R. Bowers[3], H.L. Goldstein[6], J.R. Redwine[3,7], D.G. Sutherland[3], S.F. Tillinghast[3], J.R. Kearse[2], J. Whattam[2], D.B. Townsend[1], A.M. Benson[2], & N. Wang[2]

[1] GNS Science, P O Box 30-368, Lower Hutt, NZ
[2] Victoria University of Wellington, P O Box 600, Wellington, NZ
[3] Humboldt State University, 1 Harpst St, Arcata, CA 95521, USA
[4] 16 Rydal Street Christchurch 8025, NZ
[5] Desert Research Institute, 2215 Raggio Pkwy, Reno, NV 89512, USA
[6] U.S. Geological Survey, Box 25046, MS 980, Denver, CO 80225, USA
[7] U.S. Bureau of Reclamation, P O Box 25007, 86-68330, Denver, CO, 80225, USA
r.vandissen@gns.cri.nz

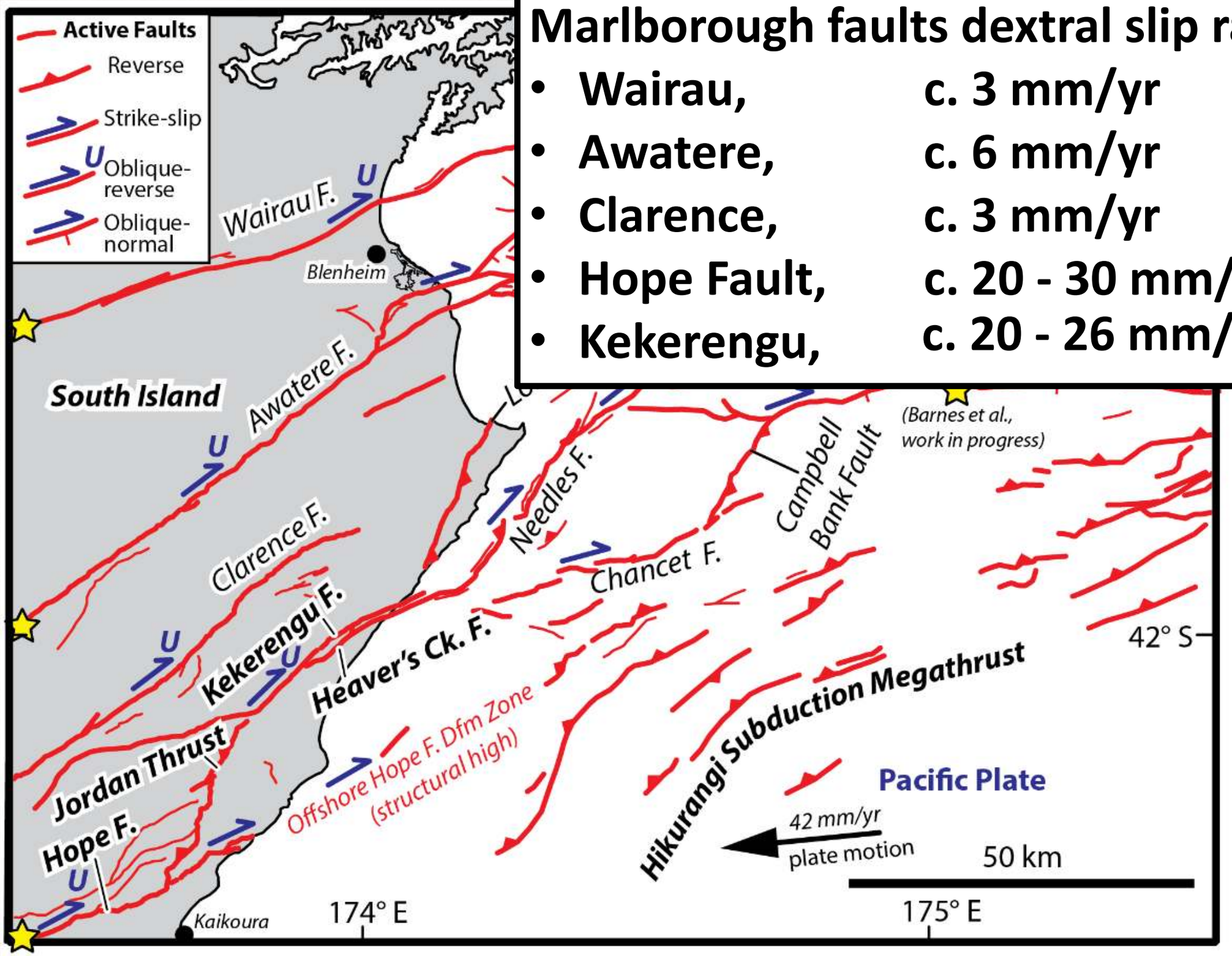
This investigation establishes a lateral slip rate for the Kekerengu Fault, and tests the hypothesis that the chief locus of plate boundary deformation in northern South Island steps northeastward from the eastern Hope Fault to follow the Jordan Thrust and Kekerengu Fault before extending offshore into Cook Strait.

Abstract submitted Sept 2016

Earthquake mid Nov 2016

Conference held late Nov 2016

Marlborough Fault System



Marlborough faults dextral slip rates

- **Wairau, c. 3 mm/yr**
- **Awatere, c. 6 mm/yr**
- **Clarence, c. 3 mm/yr**
- **Hope Fault, c. 20 - 30 mm/yr**
- **Kekerengu, c. 20 - 26 mm/yr**

References: Barnes et al., 2008, 2014, 2015, 2016 and pers communication, Ninis et al. 2013; Carne et al. 2011; Van Dissen et al., 2013; Nicol and Van Dissen, 2002; Van Dissen & Nicol, 2009; Eusden et al., 2005; Mason et al., 2006; Pondard and Barnes, 2010; Langridge et al., 2003, 2005, 2011; Cowan, 1990; 1991; Wallace et al., 2007. Map courtesy of Tim Little.

Earthquake Ground Rupturing

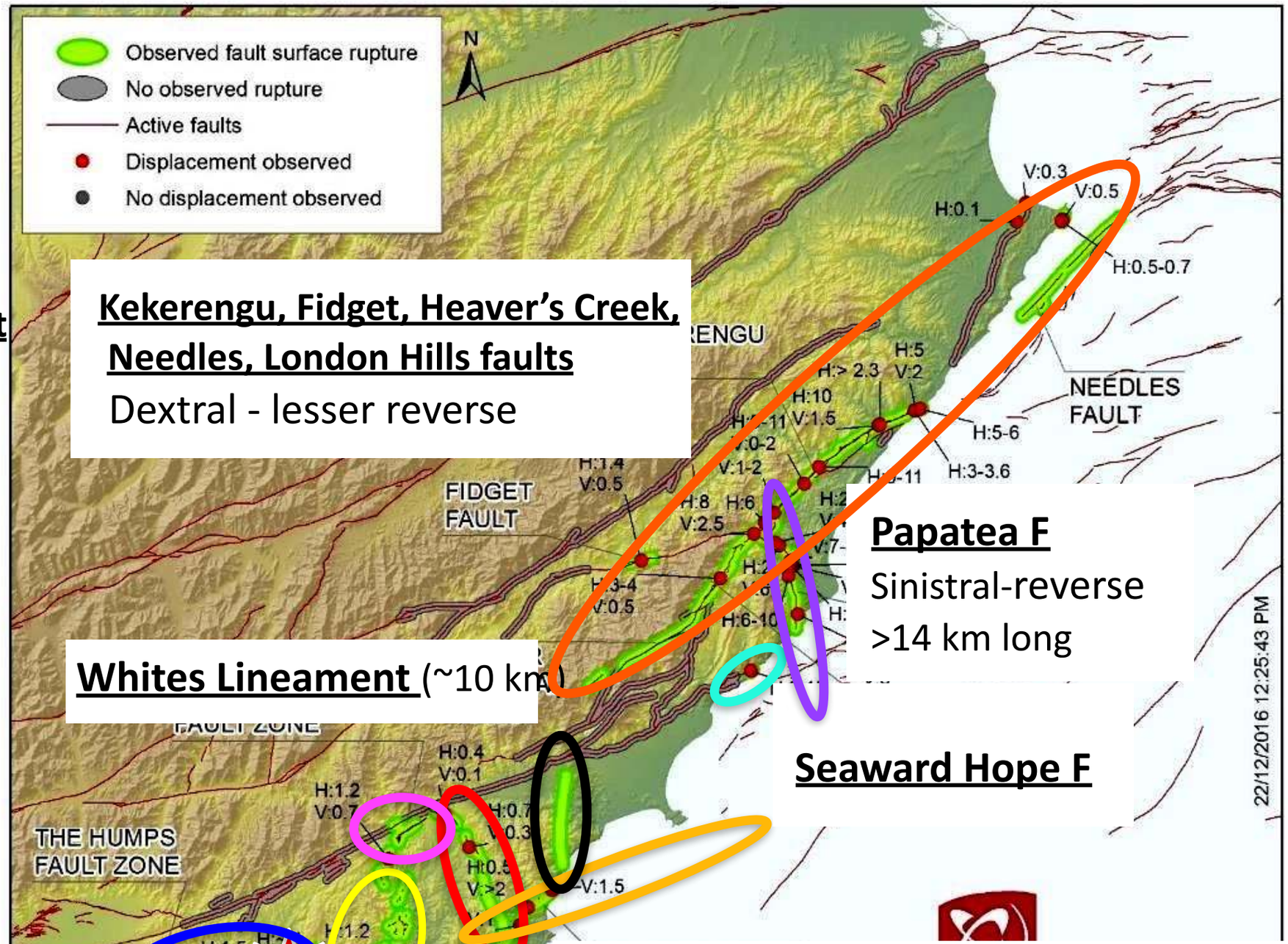
Image courtesy of Nicola Litchfield, GNS Science

Conway-Charwell FZ
Dextral-reverse

Stone Jug-Monument Fault Zone
Sinistral-reverse
Intersects Hundalee F

Leader Fault
Sinistral-reverse
Intersects Conway-Charwell Fault

Humps Fault Zone
Dextral-reverse
Intersects Leader F.



Kekerengu, Fidget, Heaver's Creek, Needles, London Hills faults
Dextral - lesser reverse

Papatea F
Sinistral-reverse
>14 km long

Whites Lineament (~10 km)

Seaward Hope F

Hundalee F
Dextral-reverse
H ~ 1 m,
V ~1.5 m at coast (up N)
> 12 km

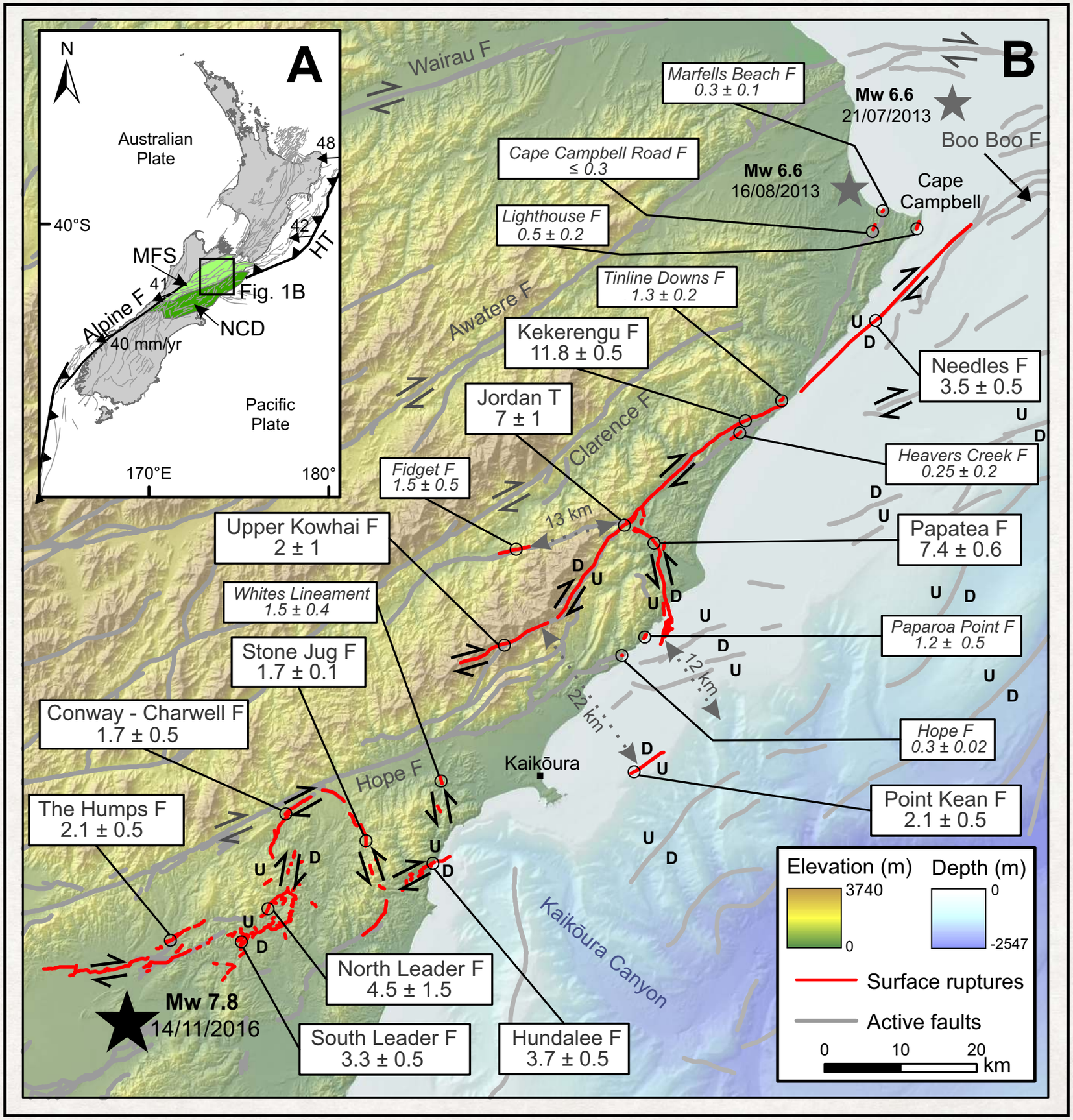
- Parts of or entirety of 21 faults

- L = 180 km
- Hypocentre - D ~15 km

- Rupture T = 120 sec
  - Included 30 sec “pause”

- Max D - ~ 12 m

- Avg D - ~ 6 m
- Dextral, Dextral Reverse, Sinistral, Sinistral Reverse



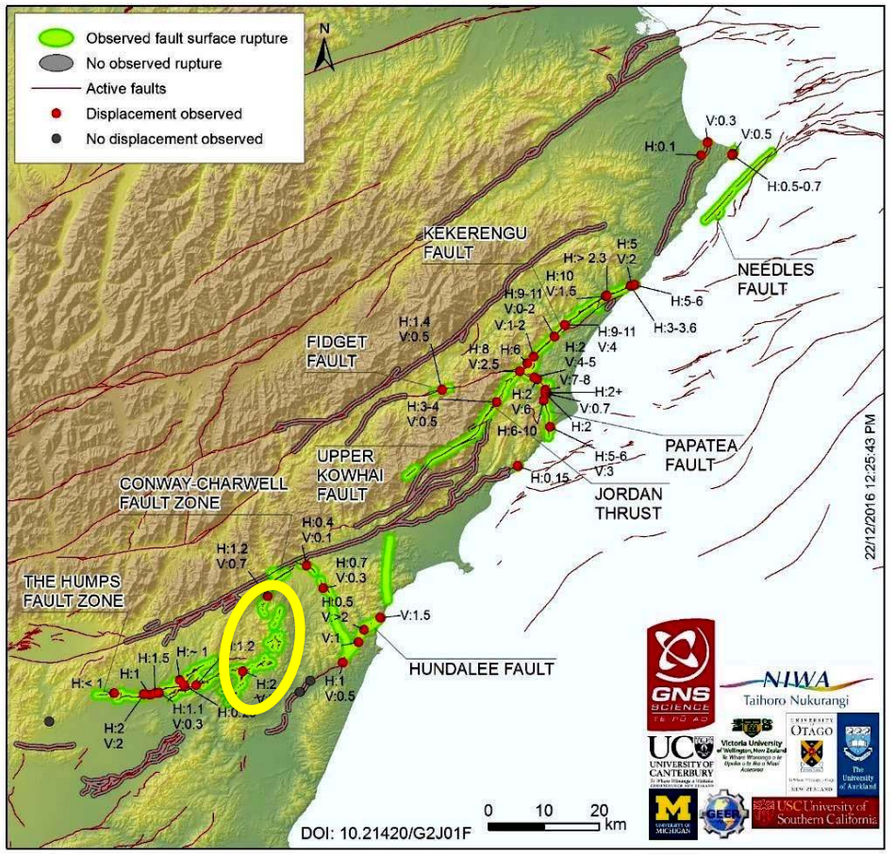
From Litchfield et al., in review

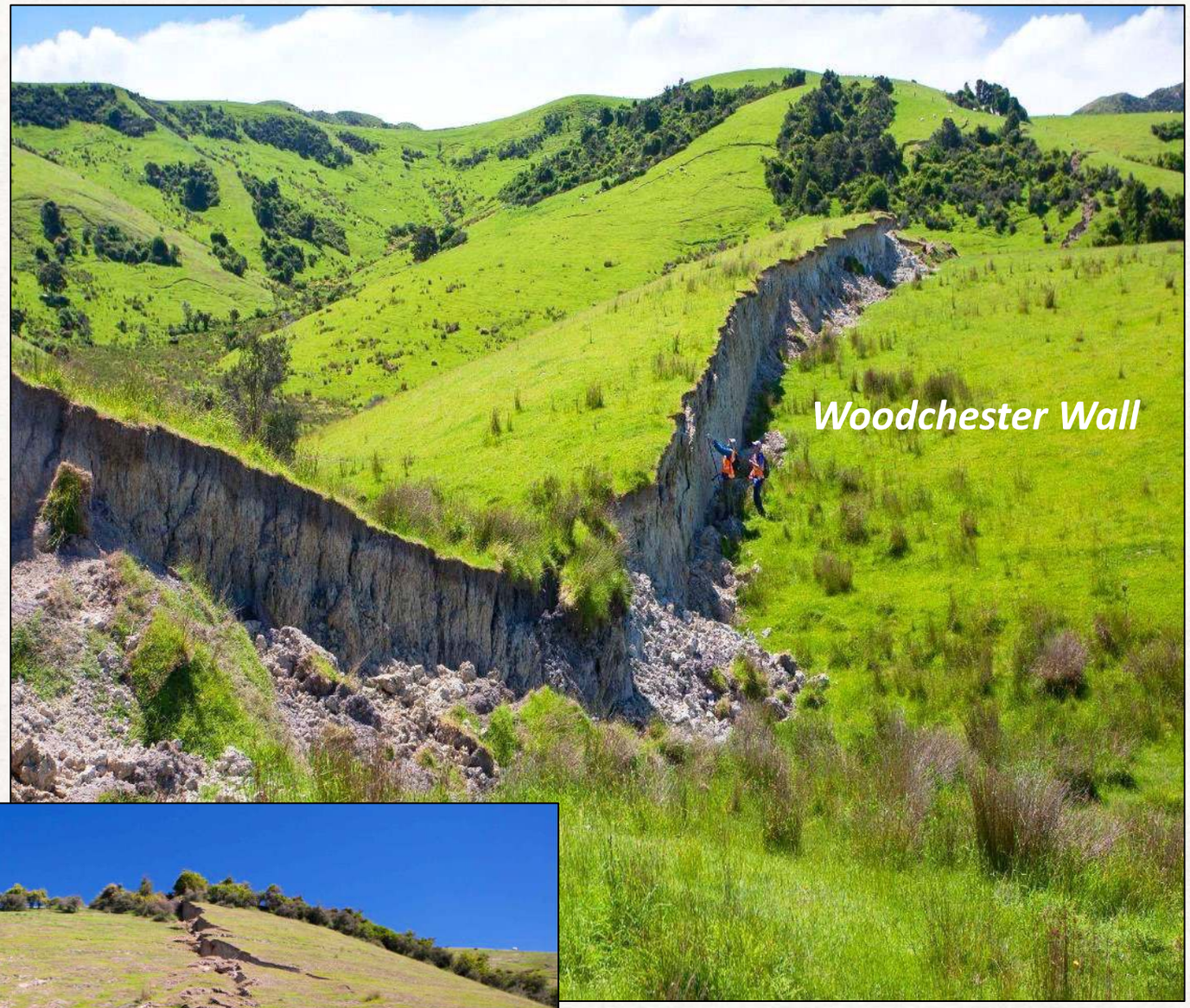
FIELD DOCUMENTATION OF DISPLACEMENT AND FAULT STYLE

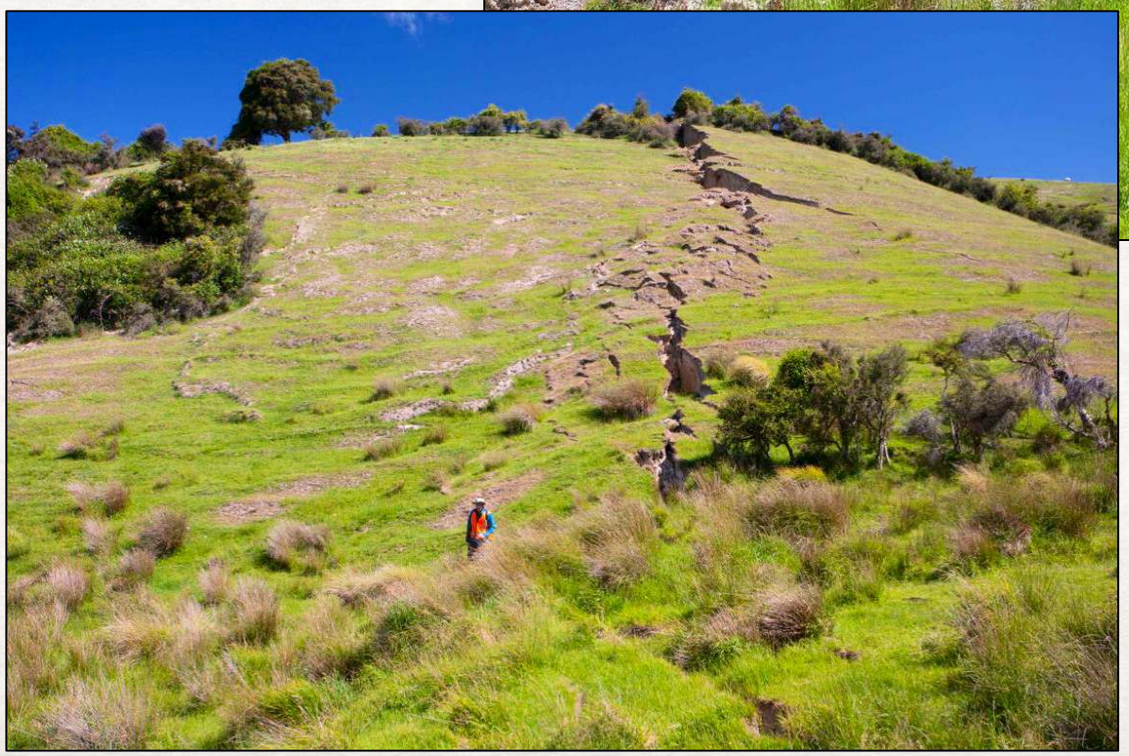
- Classic mapping directly on topo maps or air photos
- RTK GPS and Total Station
- Handheld GPS and cameras
- Phones and Tablets with GIS, GPS and camera
- Drones and Structure from Motion
- LiDAR
- Satellite imagery

Issues - often rugged terrain, distributed faulting and a long rupture, need details

QUICK PEAK AT RUPTURE TO SOUTH



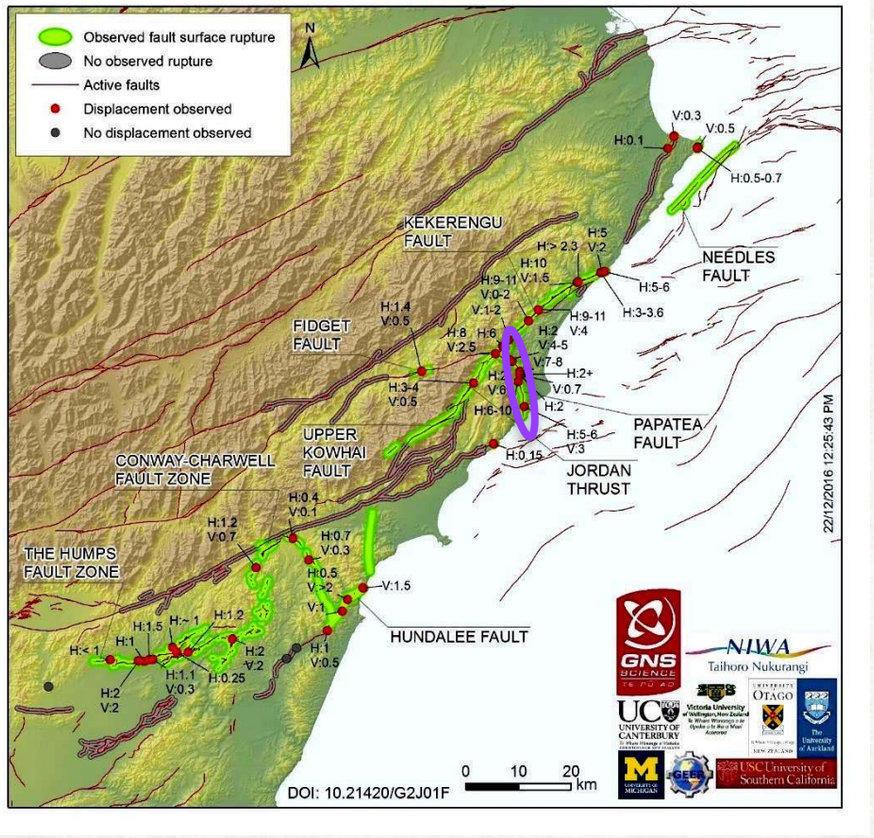




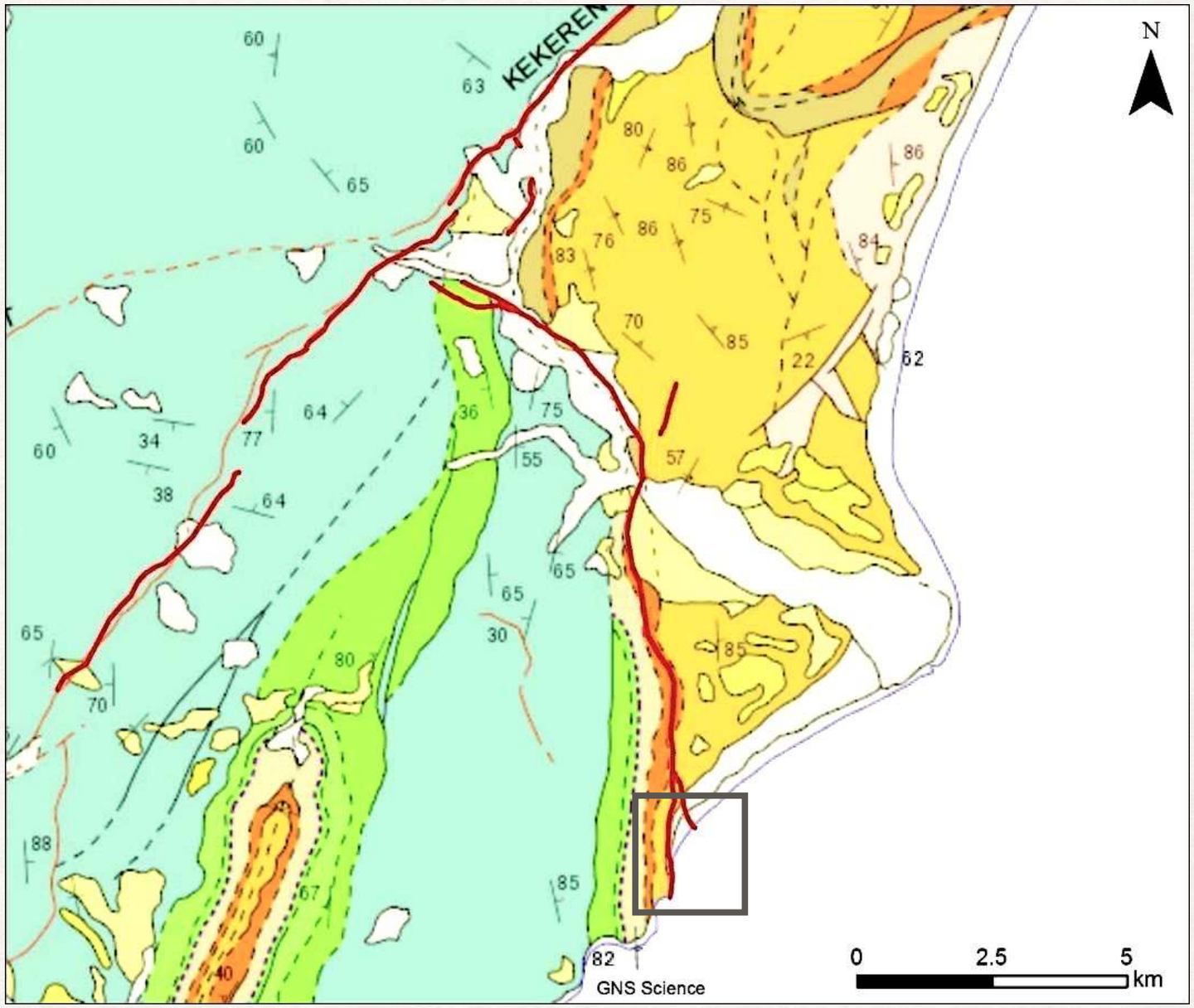
Leader Fault

Photos: Kate Pedley

PAPATEA FAULT

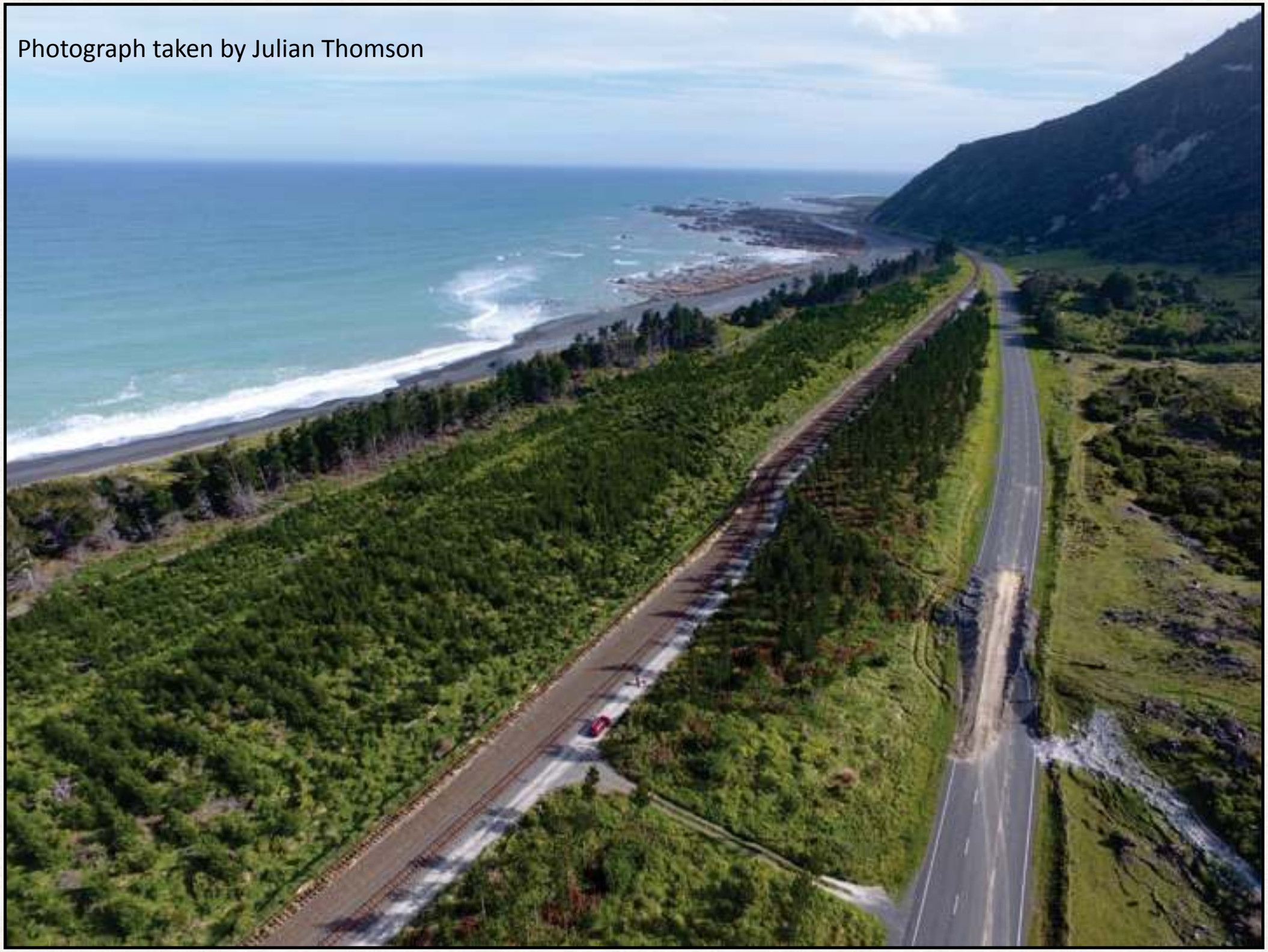


From Langridge et al, (GeoSciences 2016)



Papatea fault not considered active on national hazards map because no evidence for Holocene or even Quaternary activity

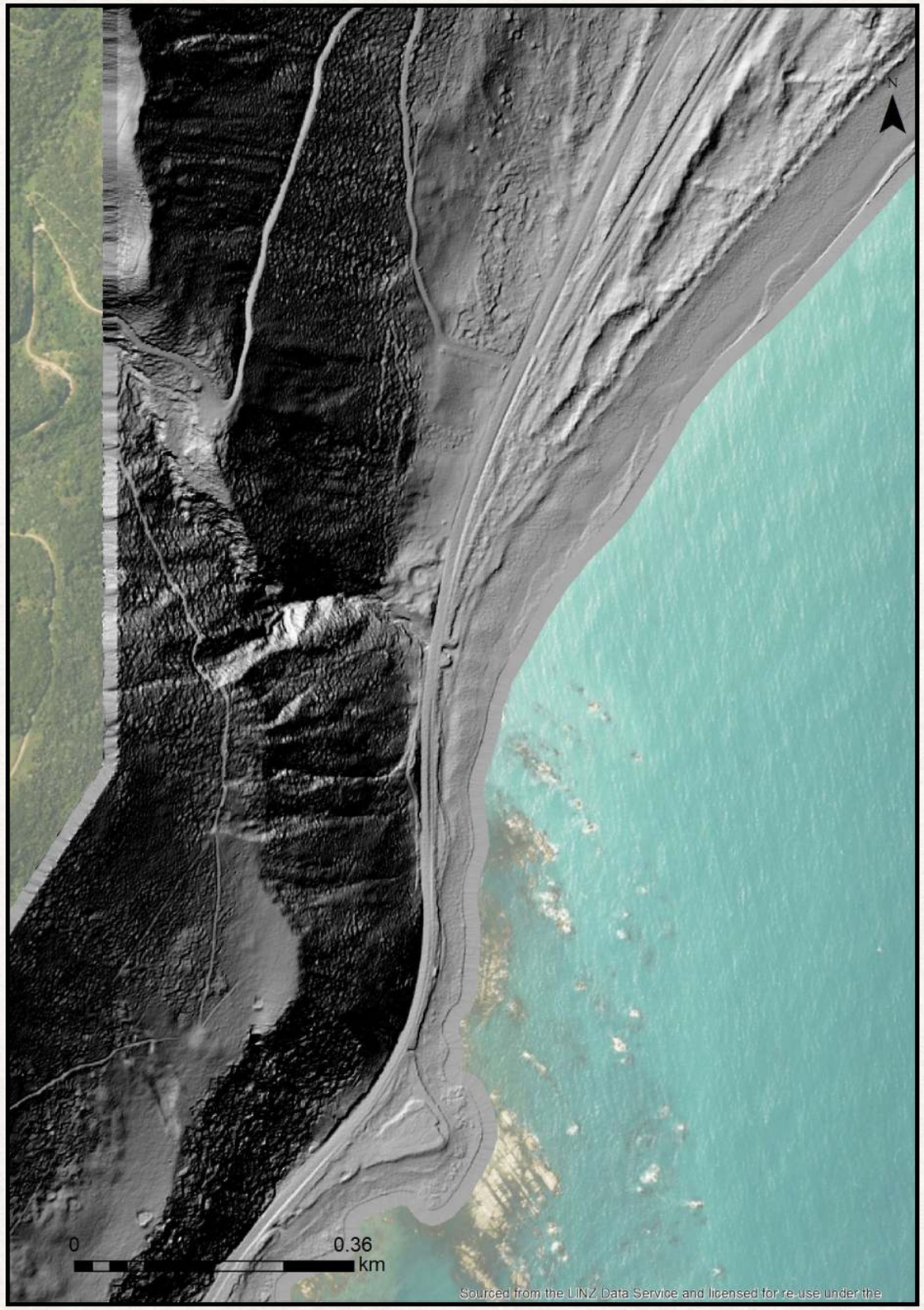
Paleogene 60 -23 Ma limestone (white) to W, vs Miocene 23-7 seds (tan) to E

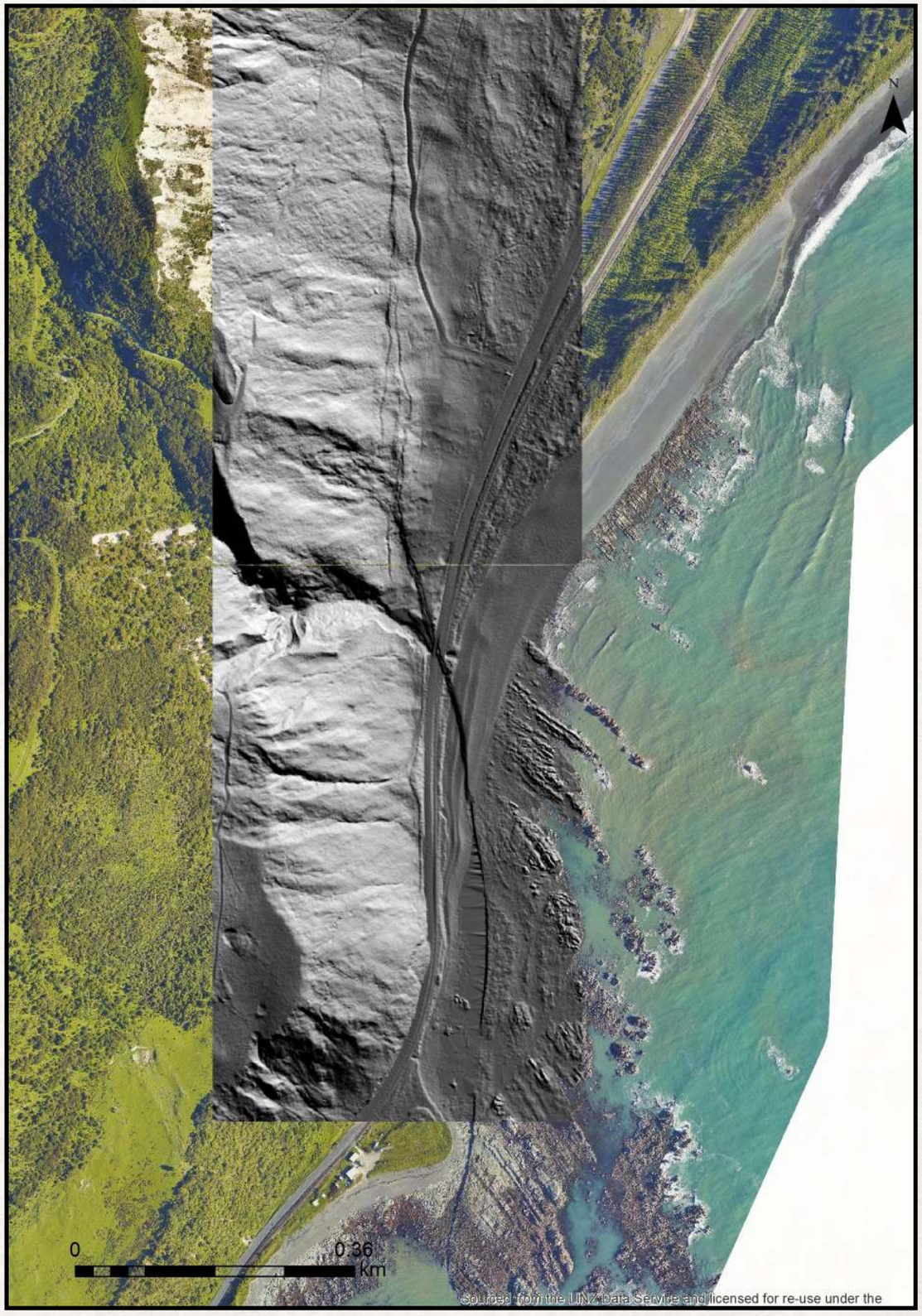

Photograph taken by Julian Thomson

Pre-2016

LIDAR

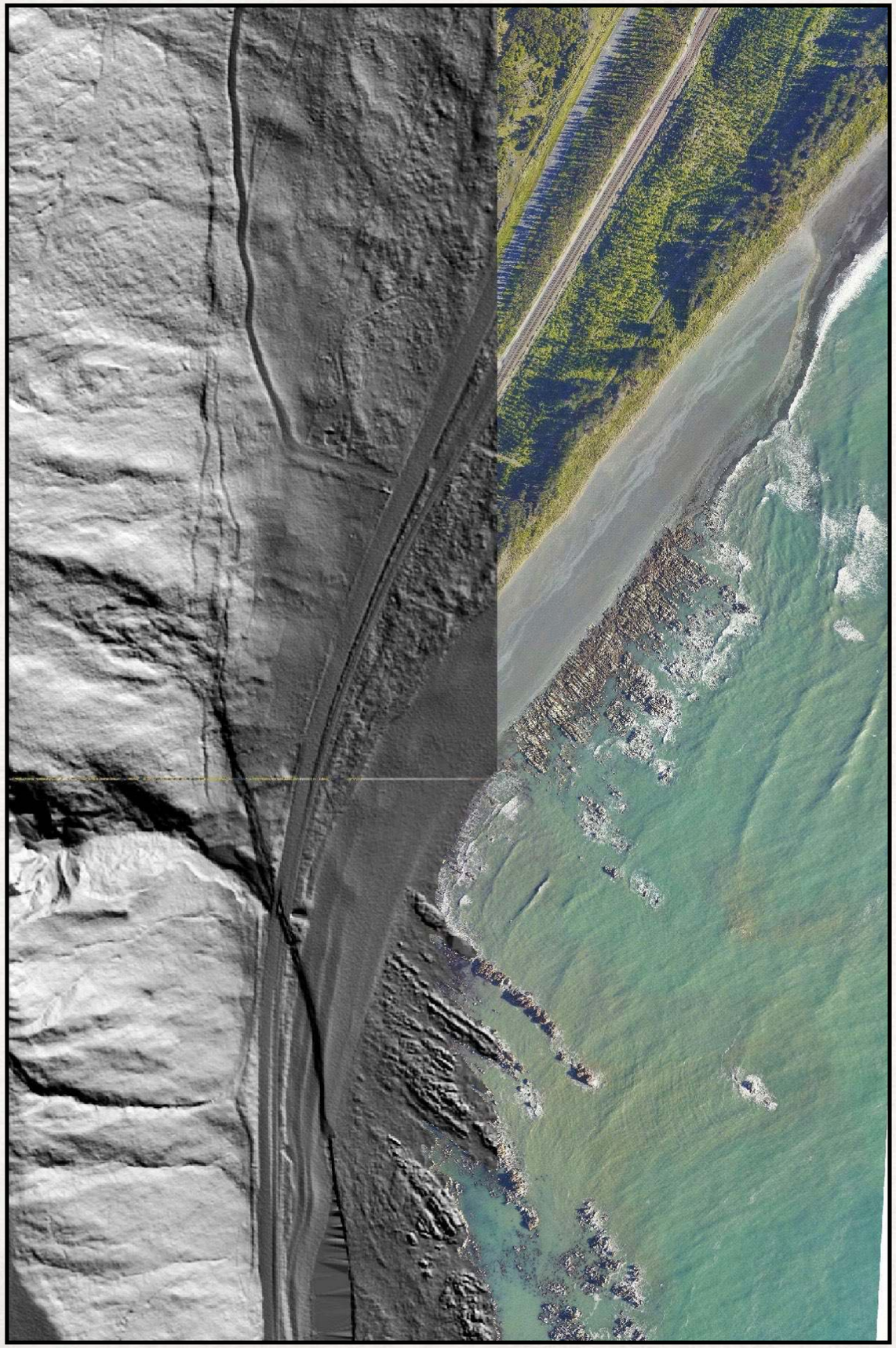
Post-event



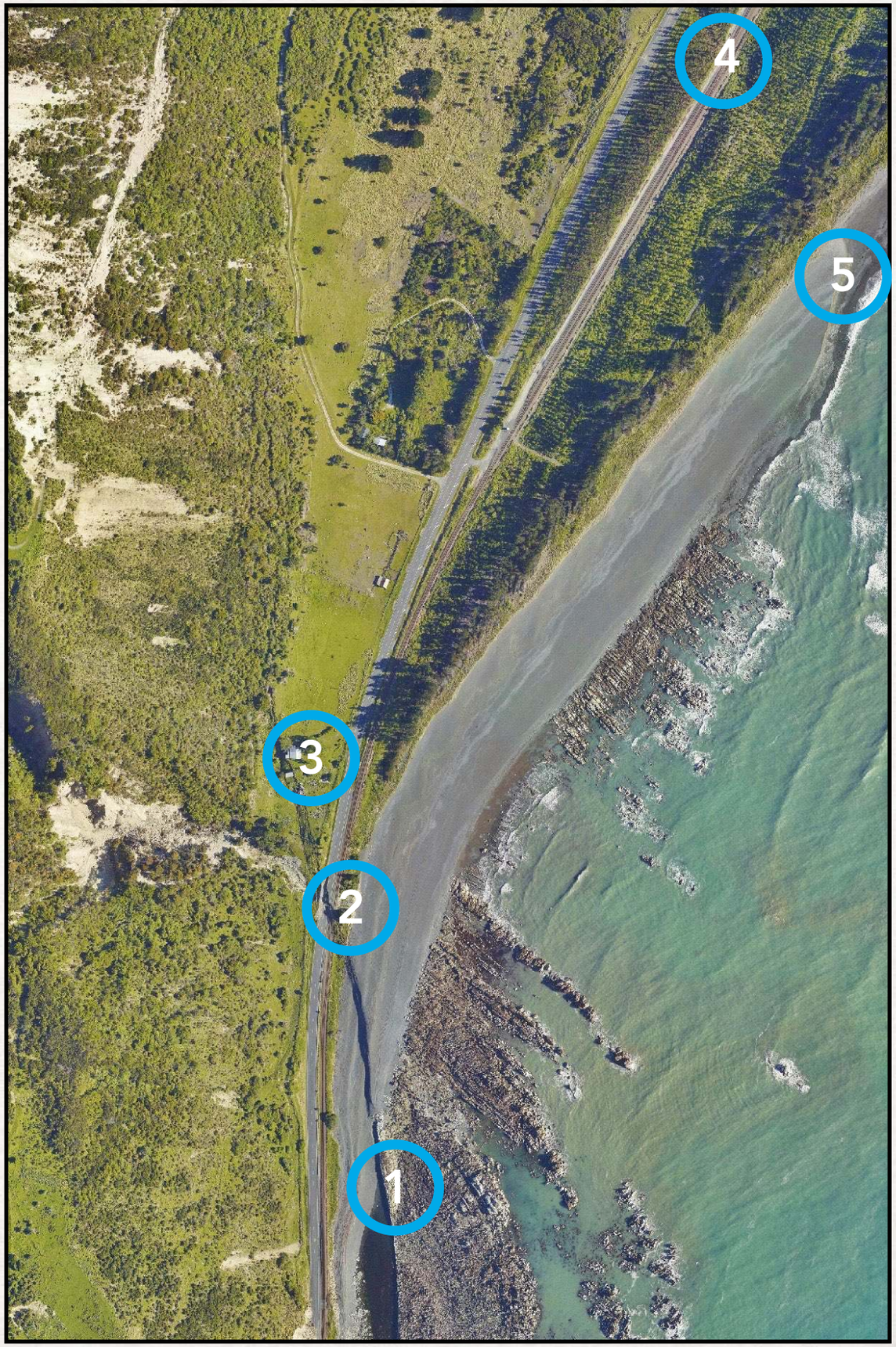


Imagery from Land Information New Zealand (LINZ)

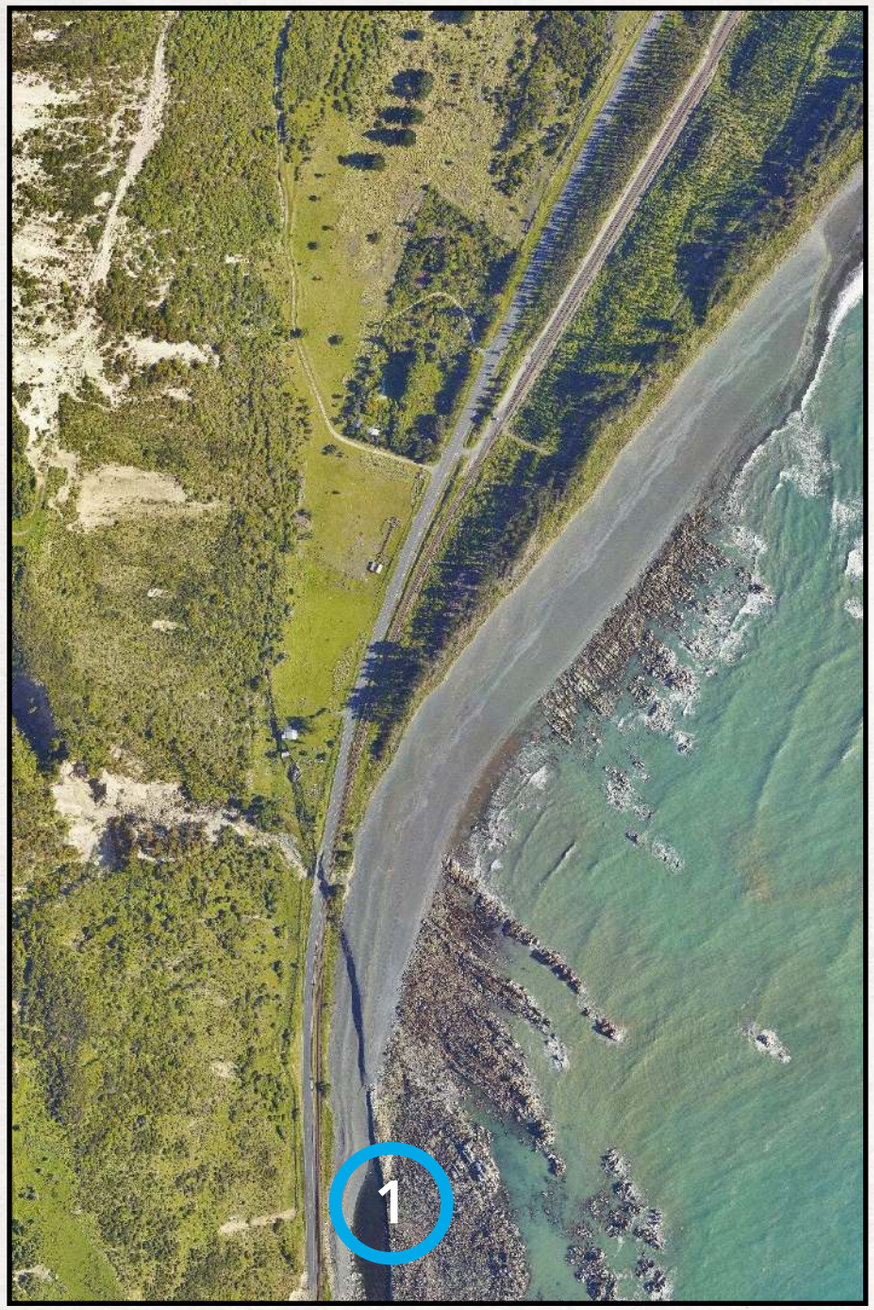
LIDAR



PHOTO

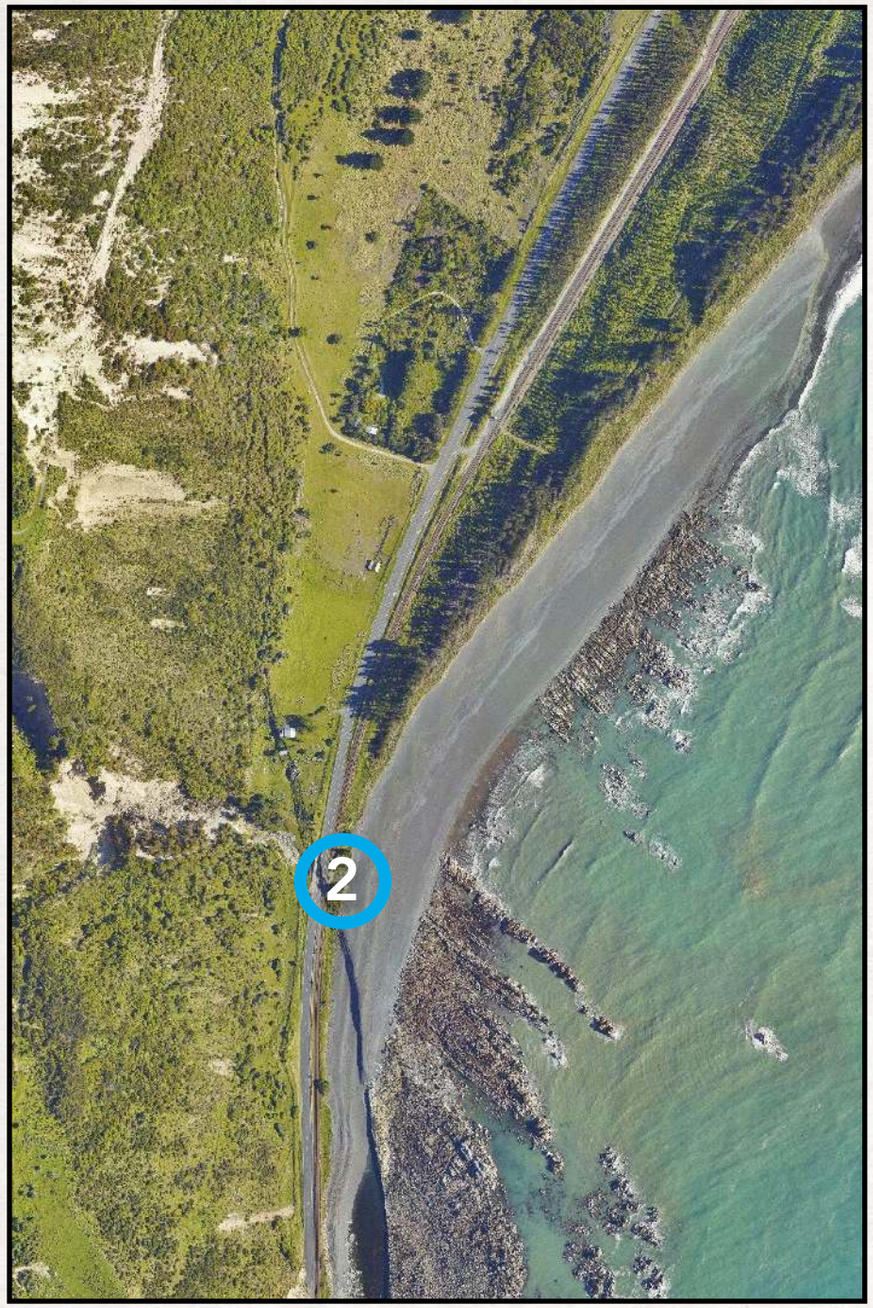


Imagery from LINZ



Imagery from LINZ

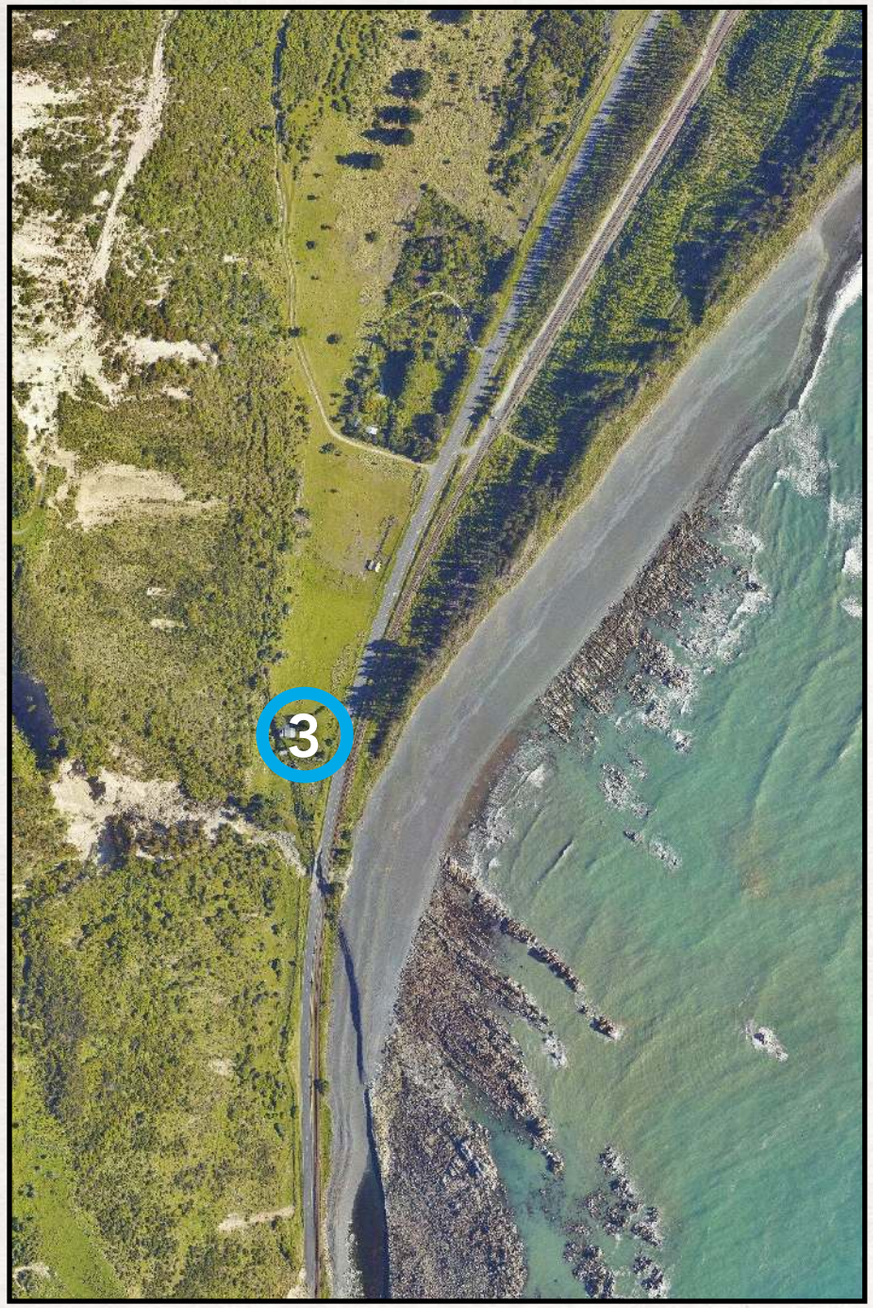
Photos Mark Hemphill-Haley



Imagery from LINZ

photo Mark Hemphill-Haley

photo Rob Zink



Imagery from LINZ

photo Rob Zink

photo Rob Zink

Paradise House

photos by Rob Zink

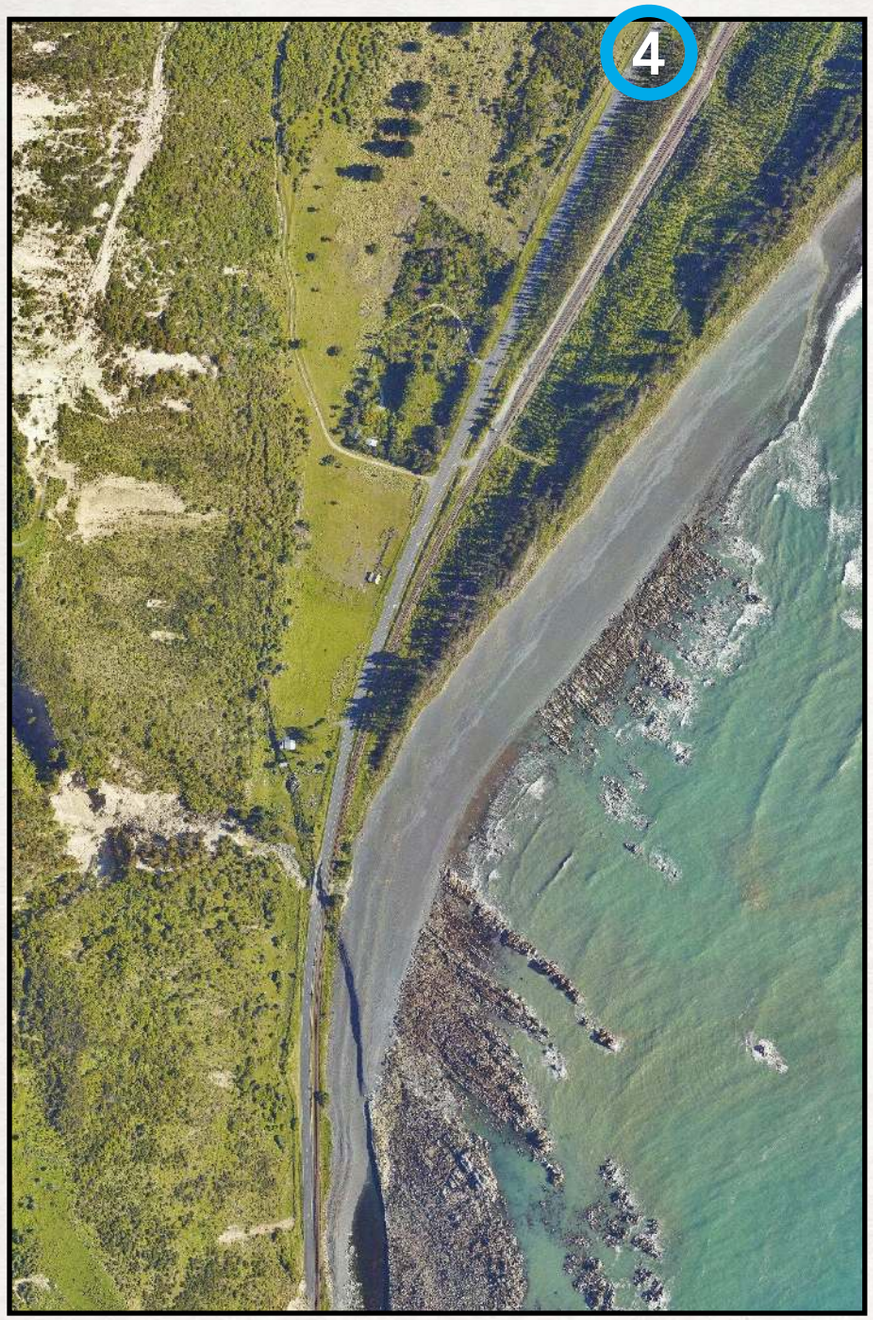
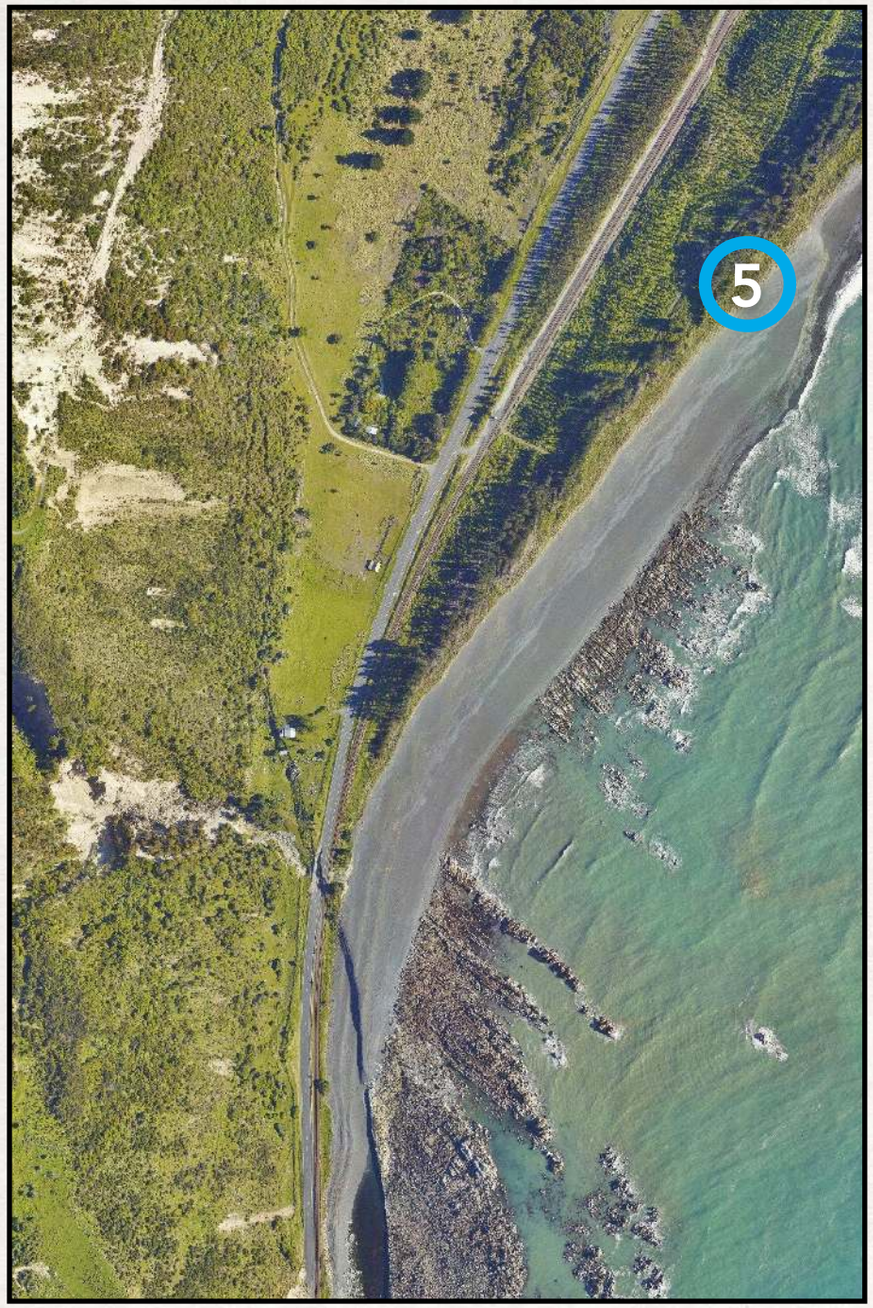


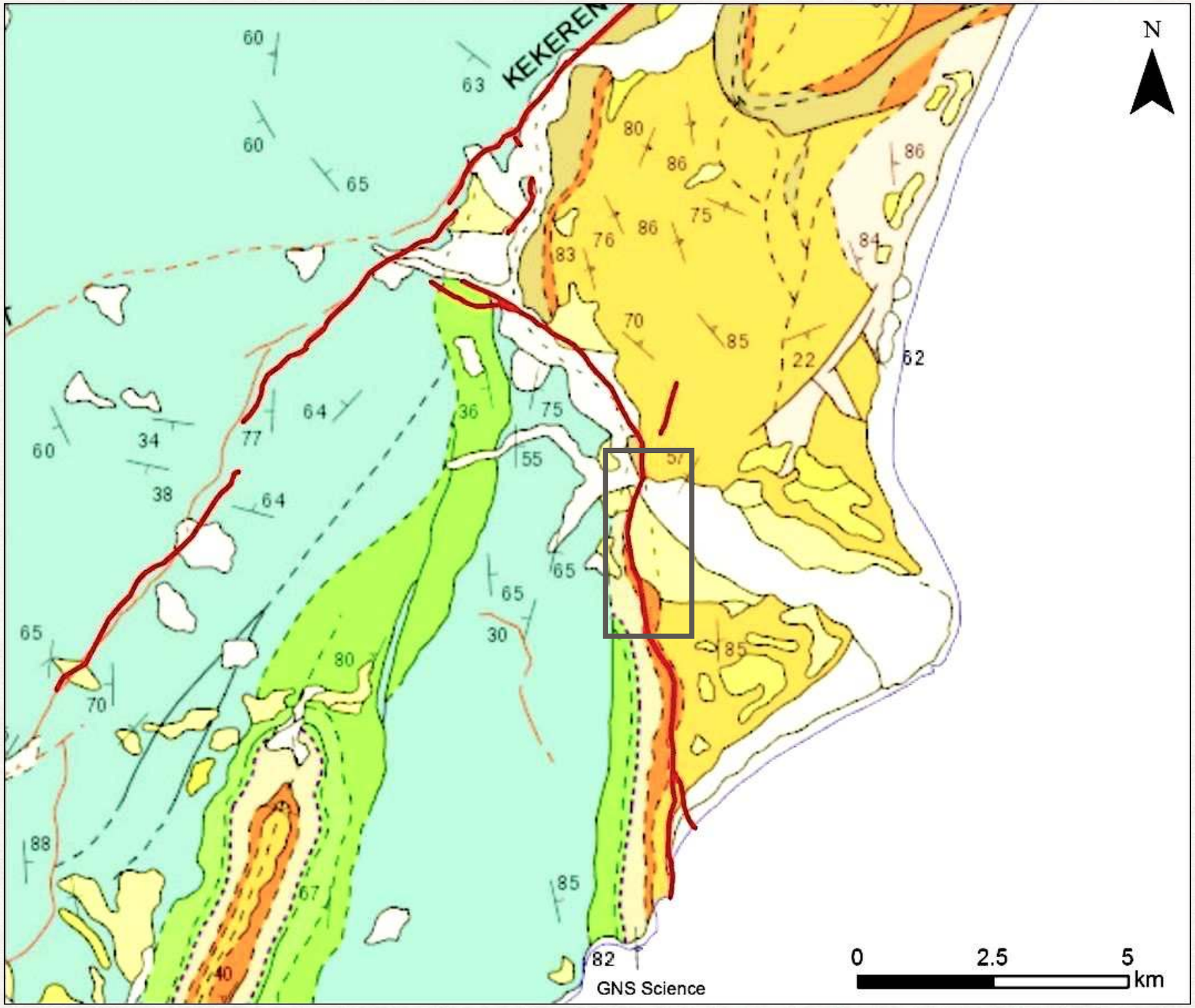

photo Mark Hemphill-Haley


photo Rob Zink

c. 5 m vertical (reverse) and
5 m left lateral



This was flat beach seconds before the surface rupture


KEKEREN
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40
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GNS Science
0
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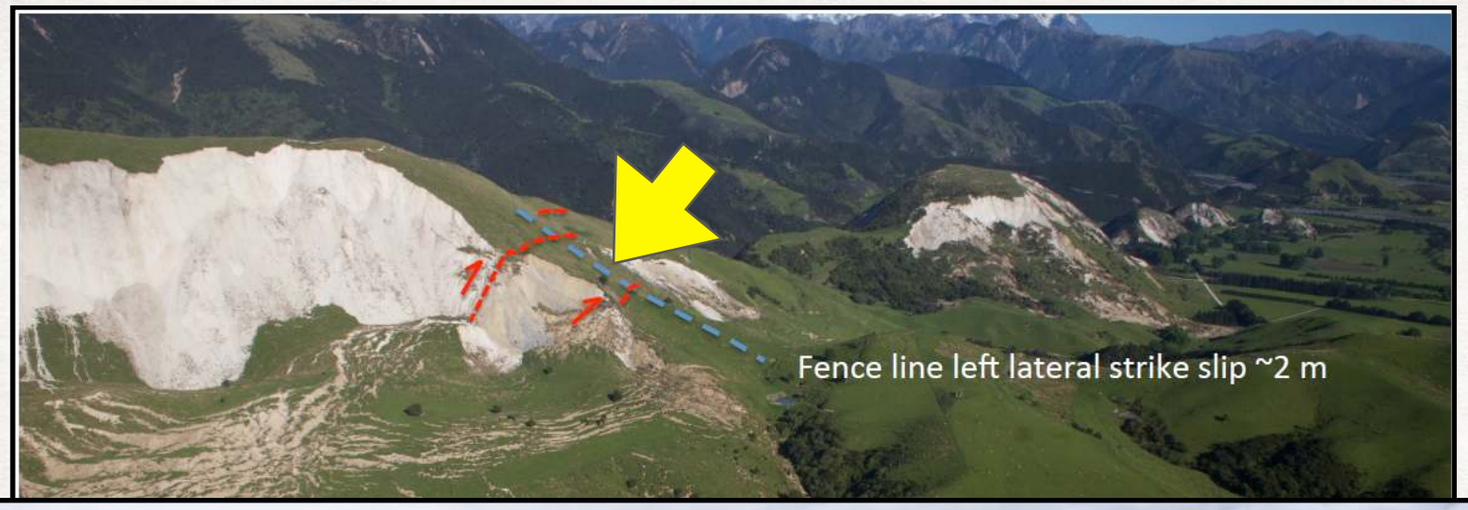
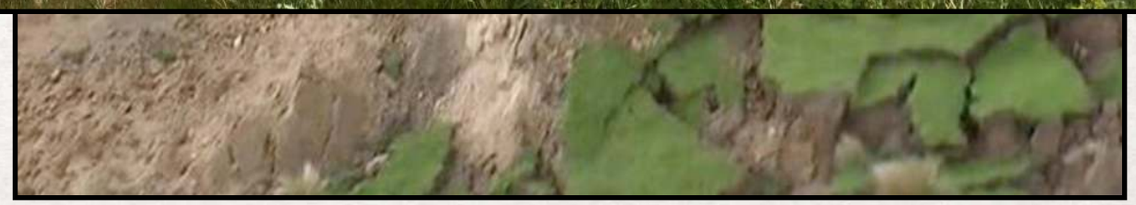
5
km

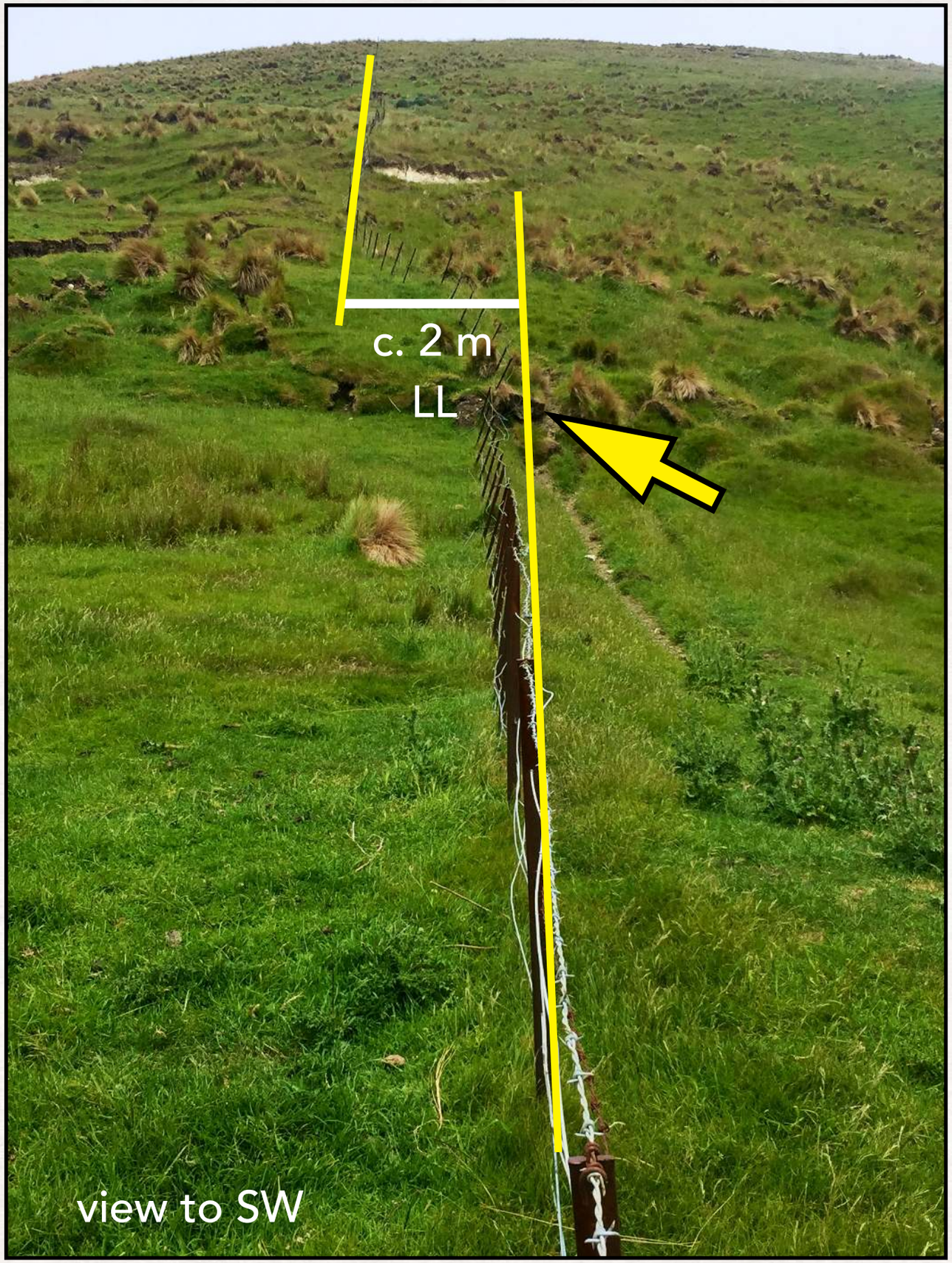
View to NW



Sea View slide

View to SE





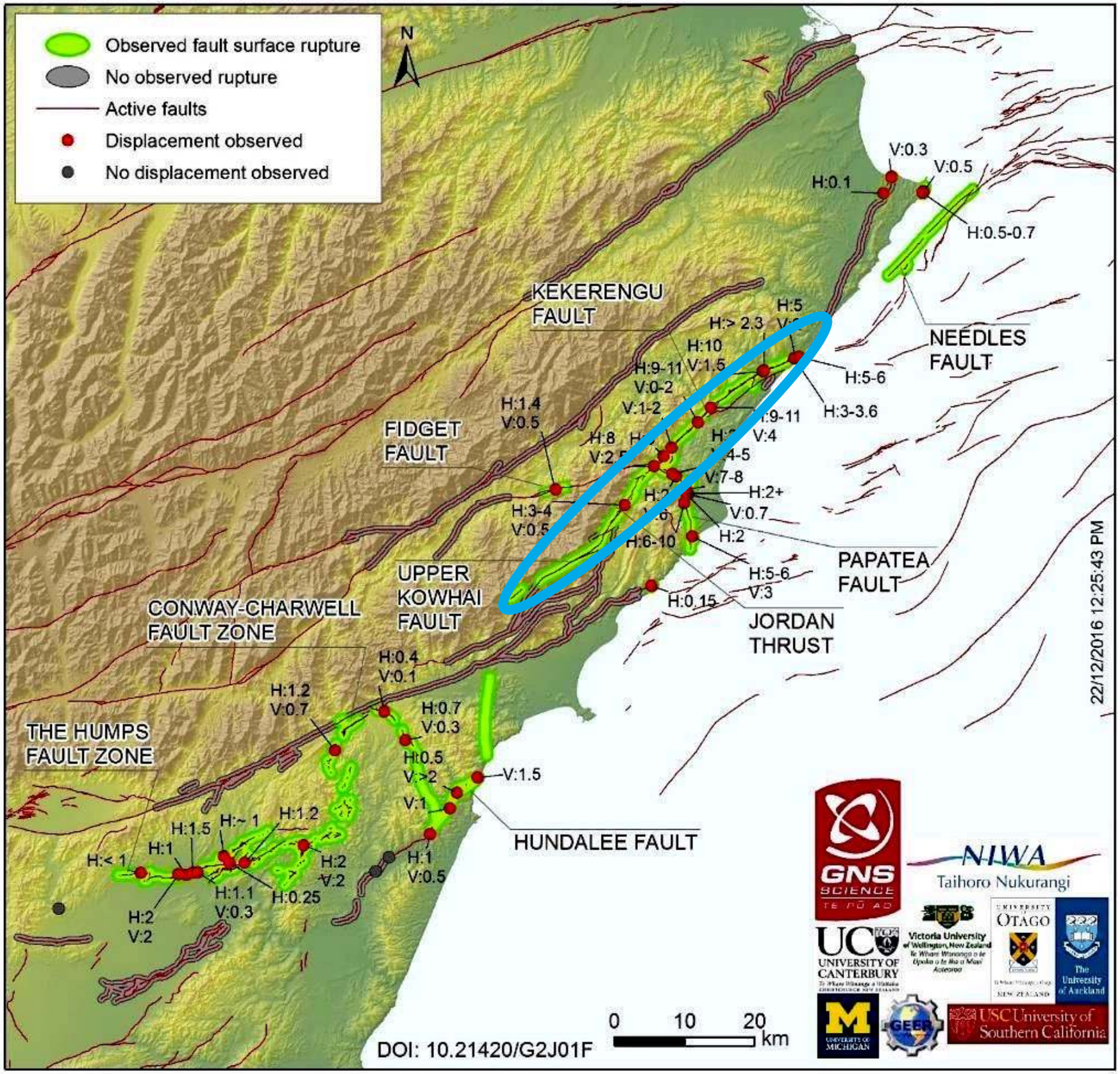
Photos Mark Hemphill-Haley


c. 2 m reverse
Photo Mark Hemphill-Haley

SEA VIEW - PAPATEA

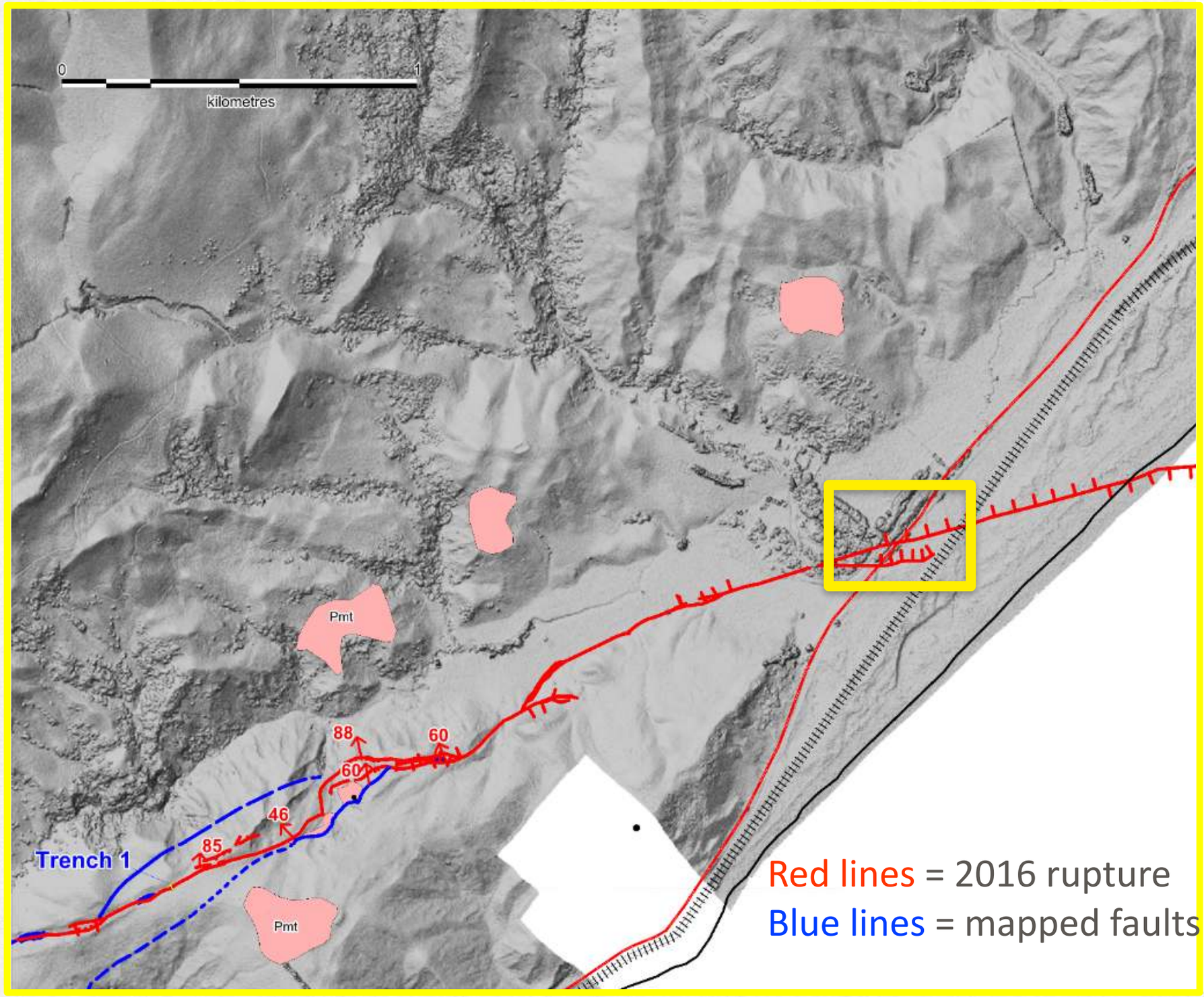
Kekerengu fault

Image courtesy of Nicola Litchfield, GNS Science



Kekerengu Fault

View to W



- *DSM is derived from 2014-2015 aerial imagery and gridded at 1 m. Courtesy of Matt Hill, GNS Science.*
- *2016 rupture map courtesy of Tim Little*

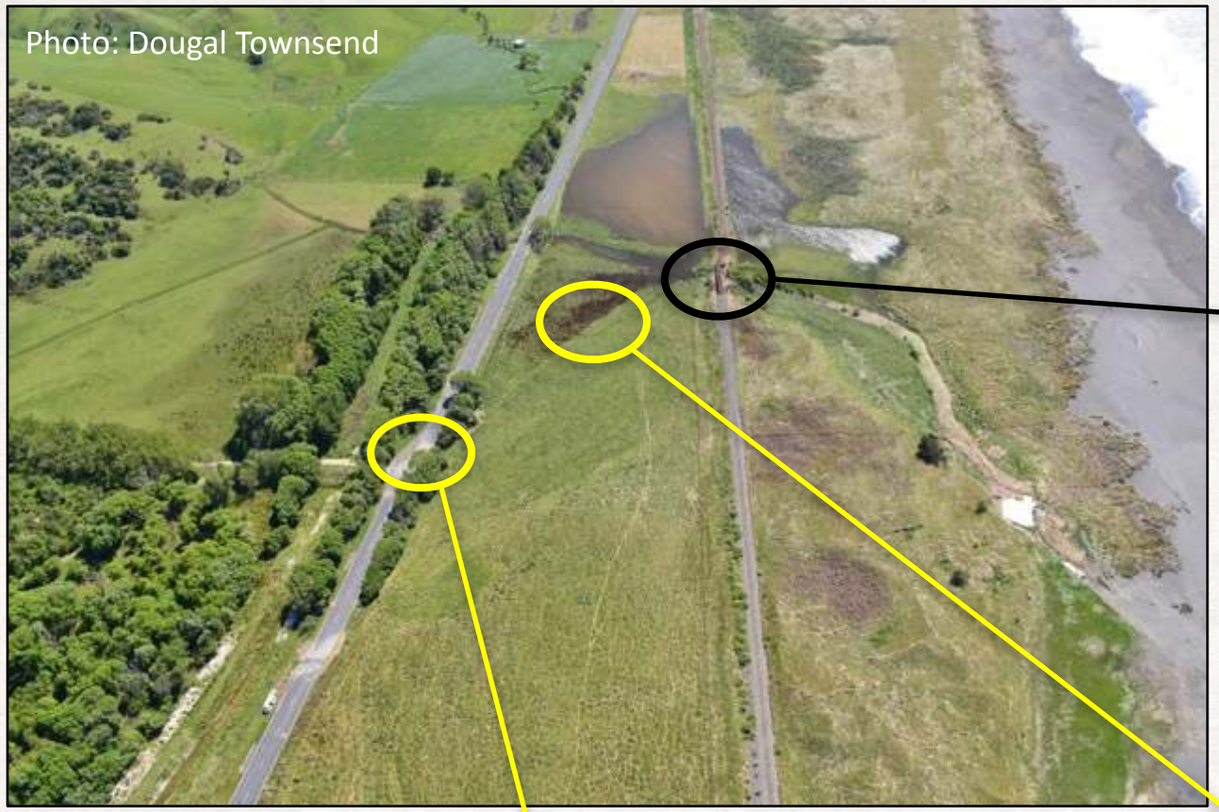


Photo: Dougal Townsend


Photo: Tim Little

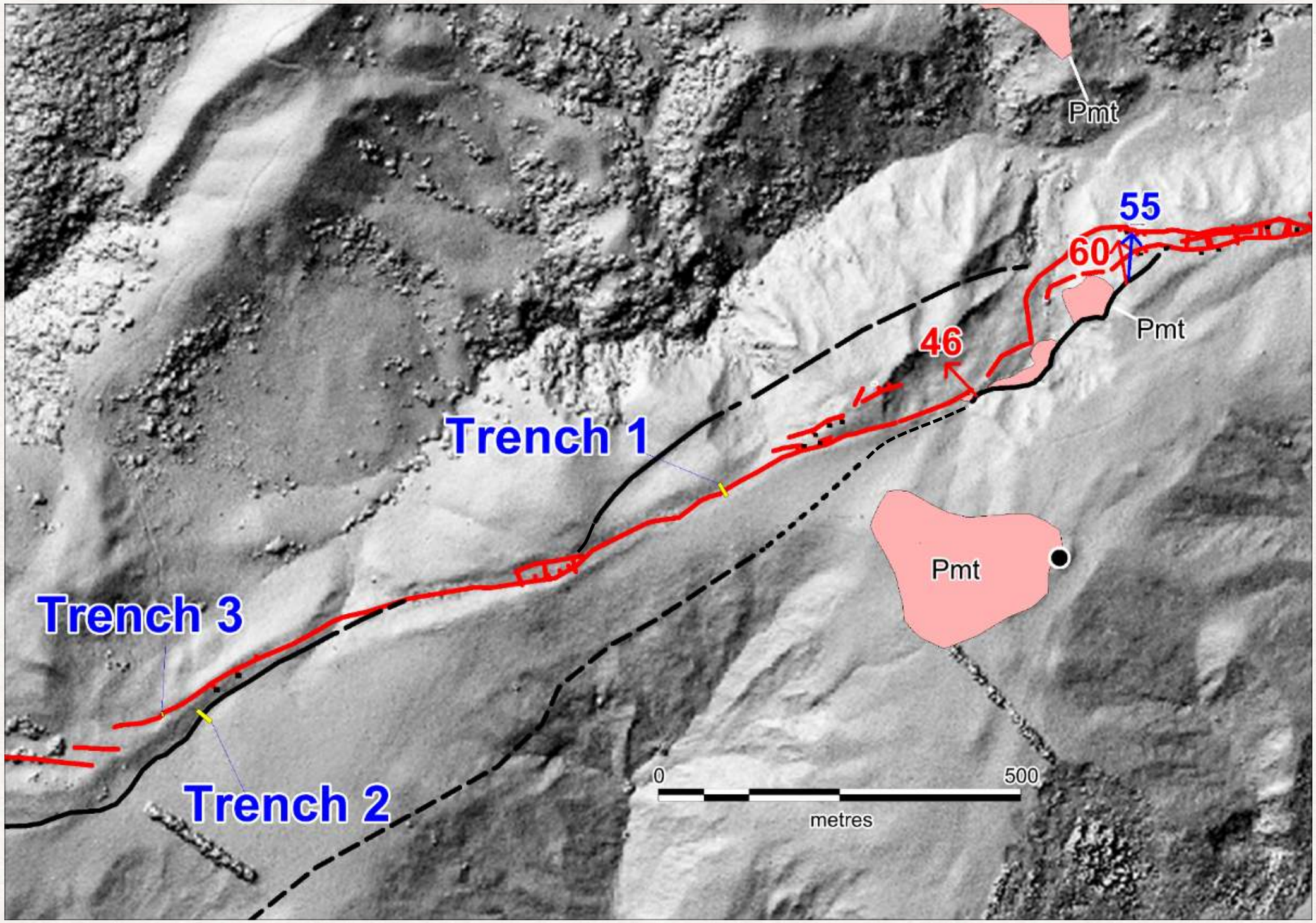

TOYOTA
Photo: Tim Little


Photo: Tim Little

Arrows indicate fault face dip direction and angle

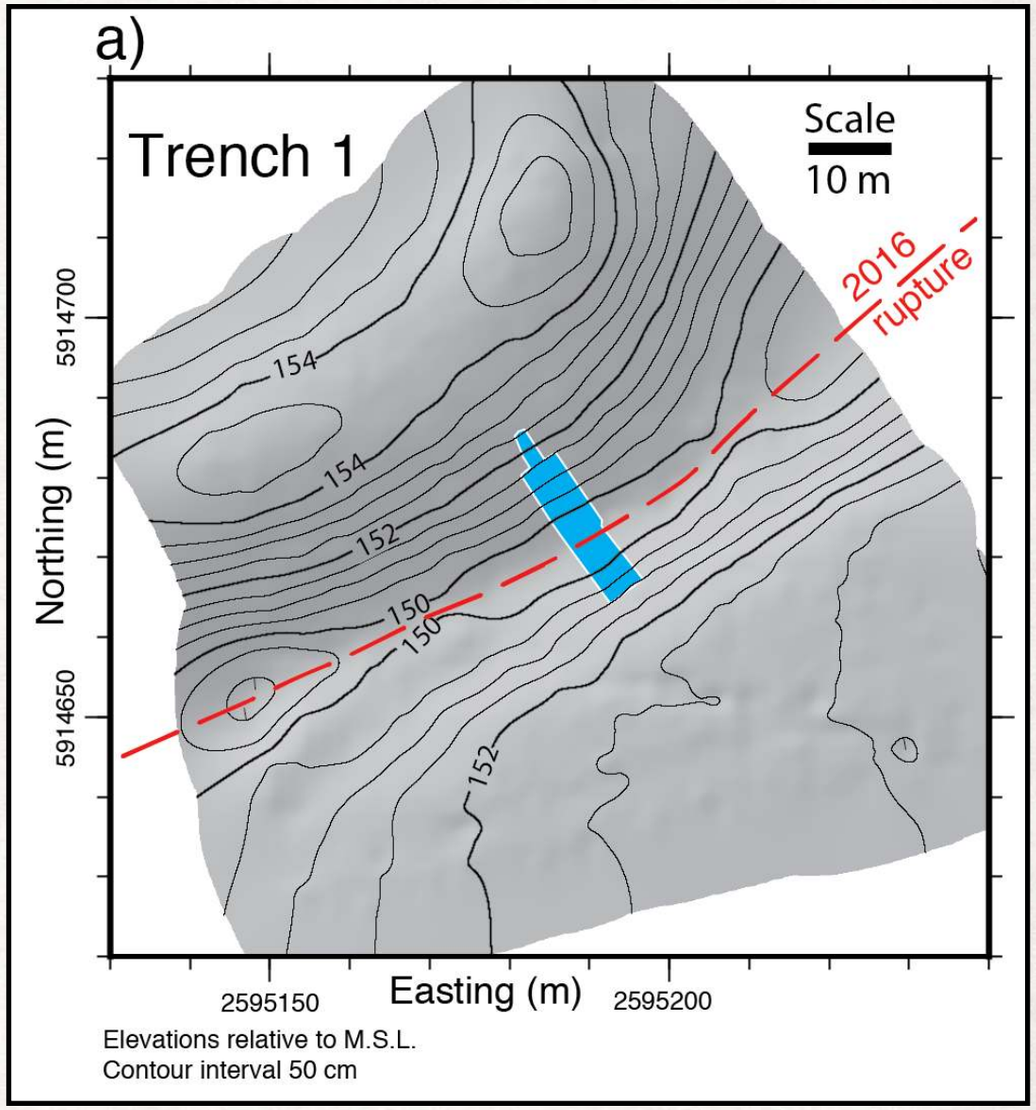
Red traces - 2016 rupture

Black traces - mapped but did not rupture



- *DSM is derived from 2014-2015 aerial imagery and gridded at 1 m. Courtesy of Matt Hill, GNS Science.*
- *Fault mapping courtesy of Tim Little*

February, 2016



Nov 20, 2016 *(looking NE)*

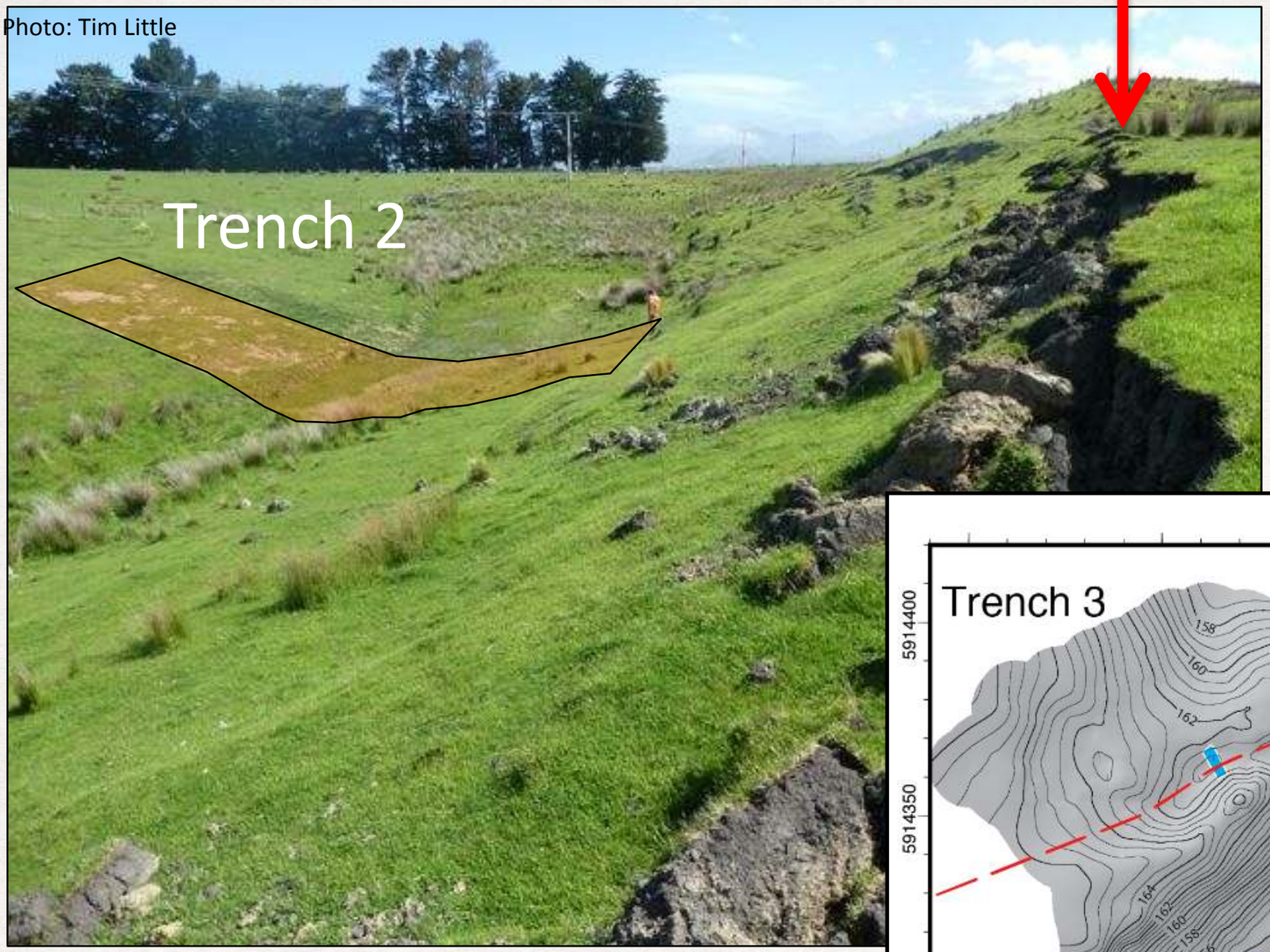
Drone Photo Courtesy Julian Thomson, GNS

Trench 1 post EQ

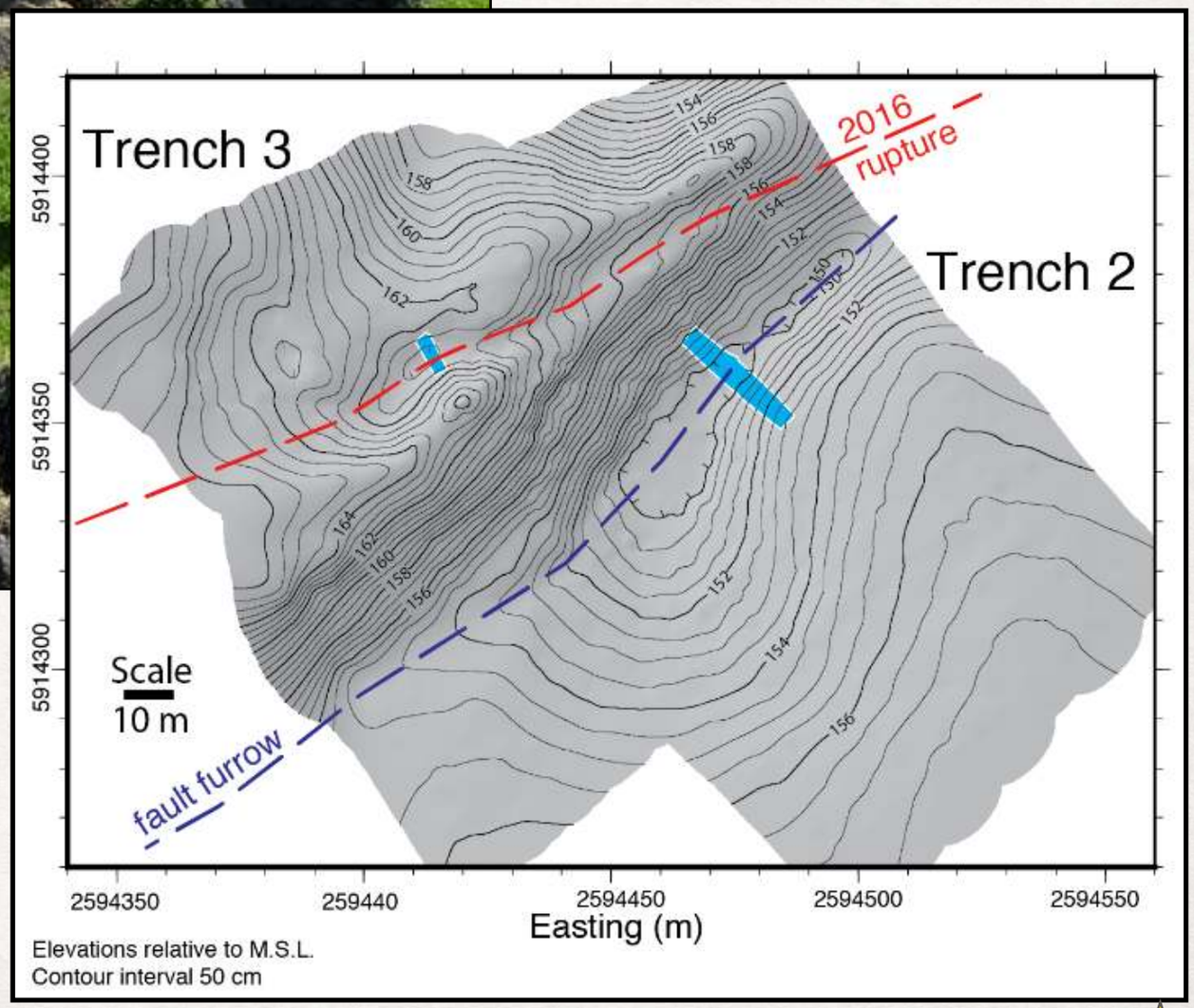
Trench 3

Photo: Tim Little

Trench 2



Trench 2, as of Nov 20, 2016 (looking NW)



KEKERENGU FAULT AT BEN MORE STREAM

Pre-2016 photo GNS

JOHN MANASOUKAS

Kekerengu fault near Ben More

- Drone image - c. 5 million data points

Dimitrios Zakkos (Structure from Motion)
John Manasoukas (Drone Pilot Extraordinaire)

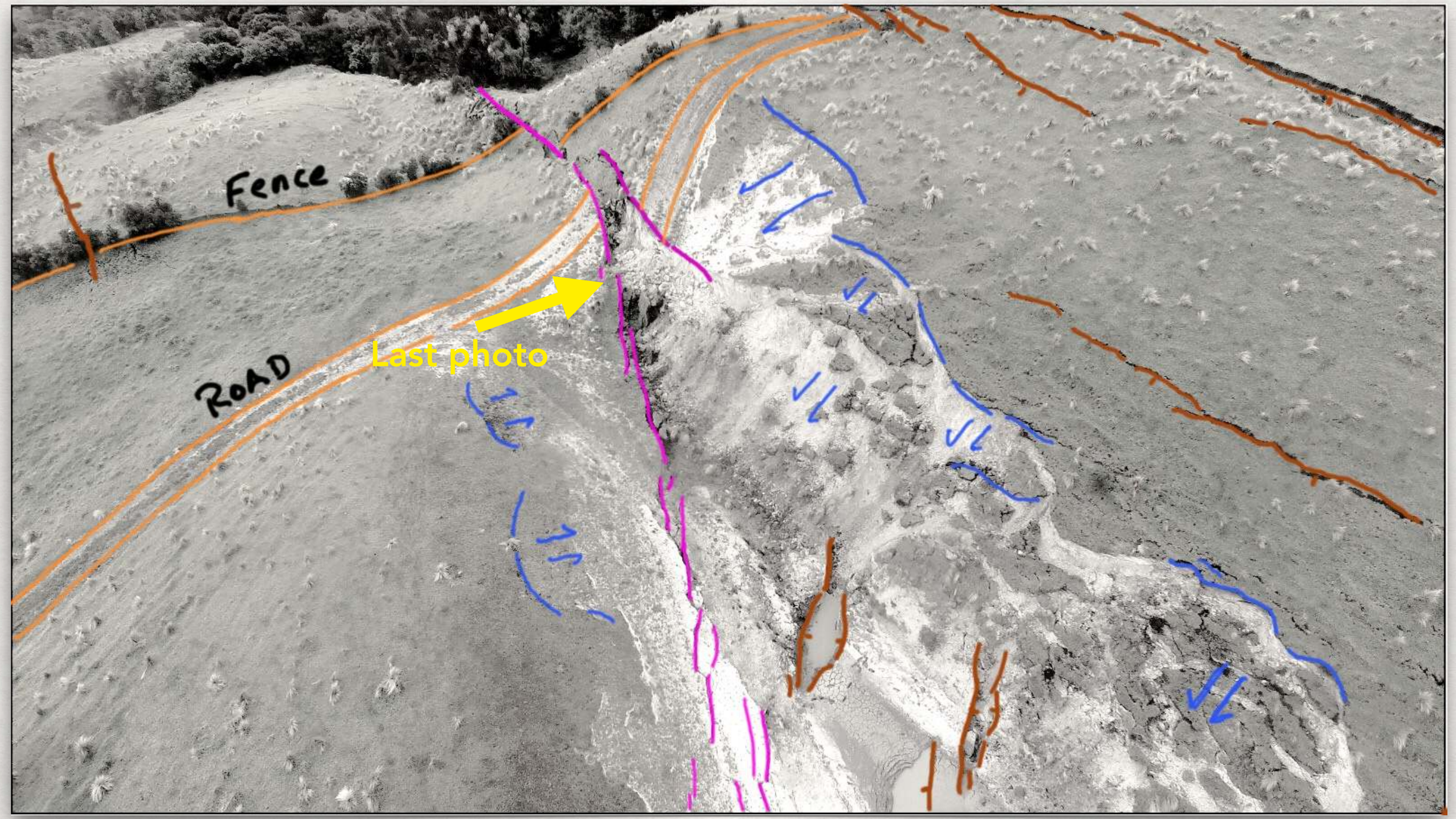
Photo Mark Hemphill-Haley

Photo Mark Hemphill-Haley

photo Mark Hemphill-Haley

photo Mark Hemphill-Haley

BEN MORE STREAM



DRONE AT BEN MORE STREAM

Bluff Station Cottage

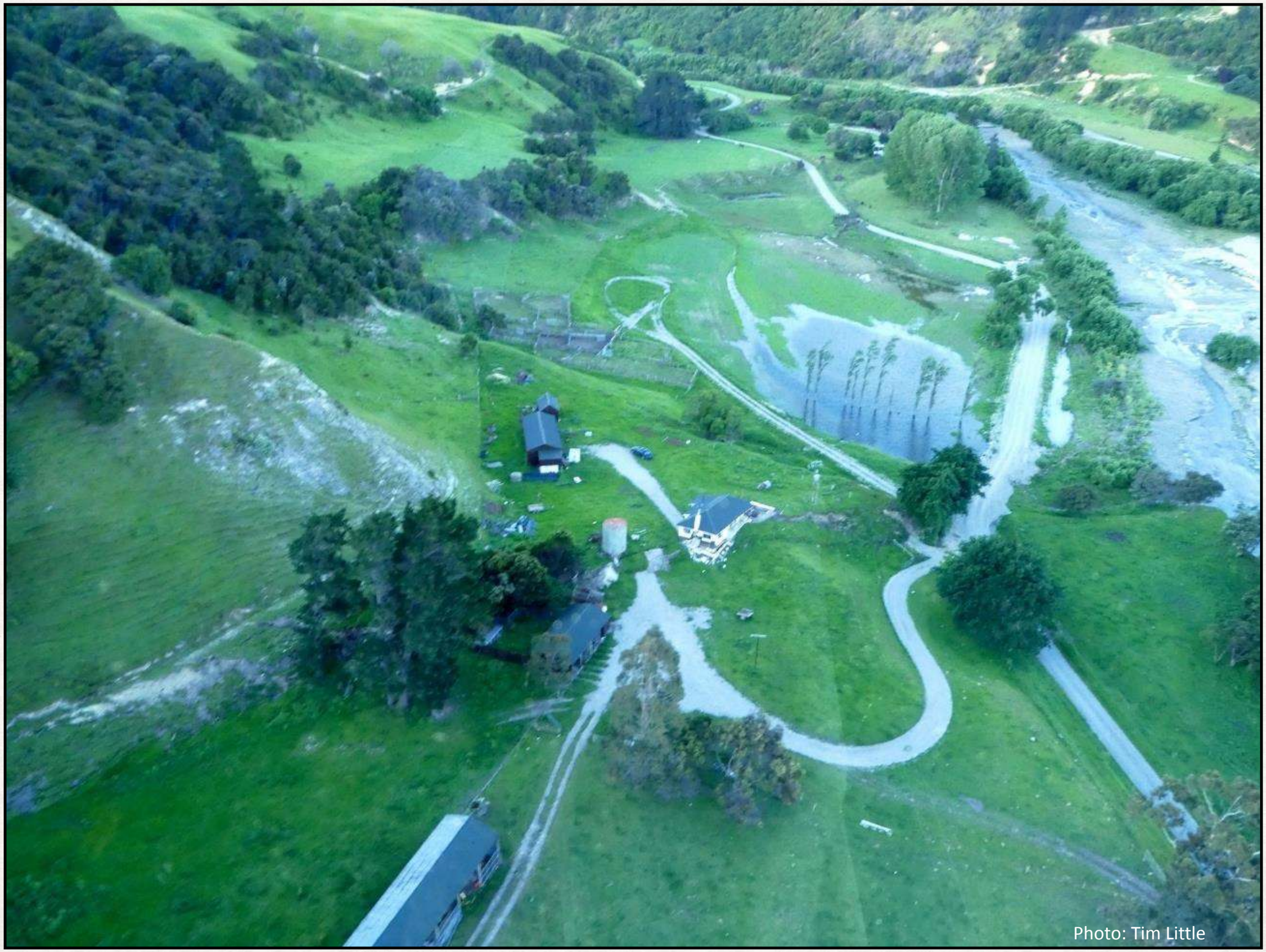
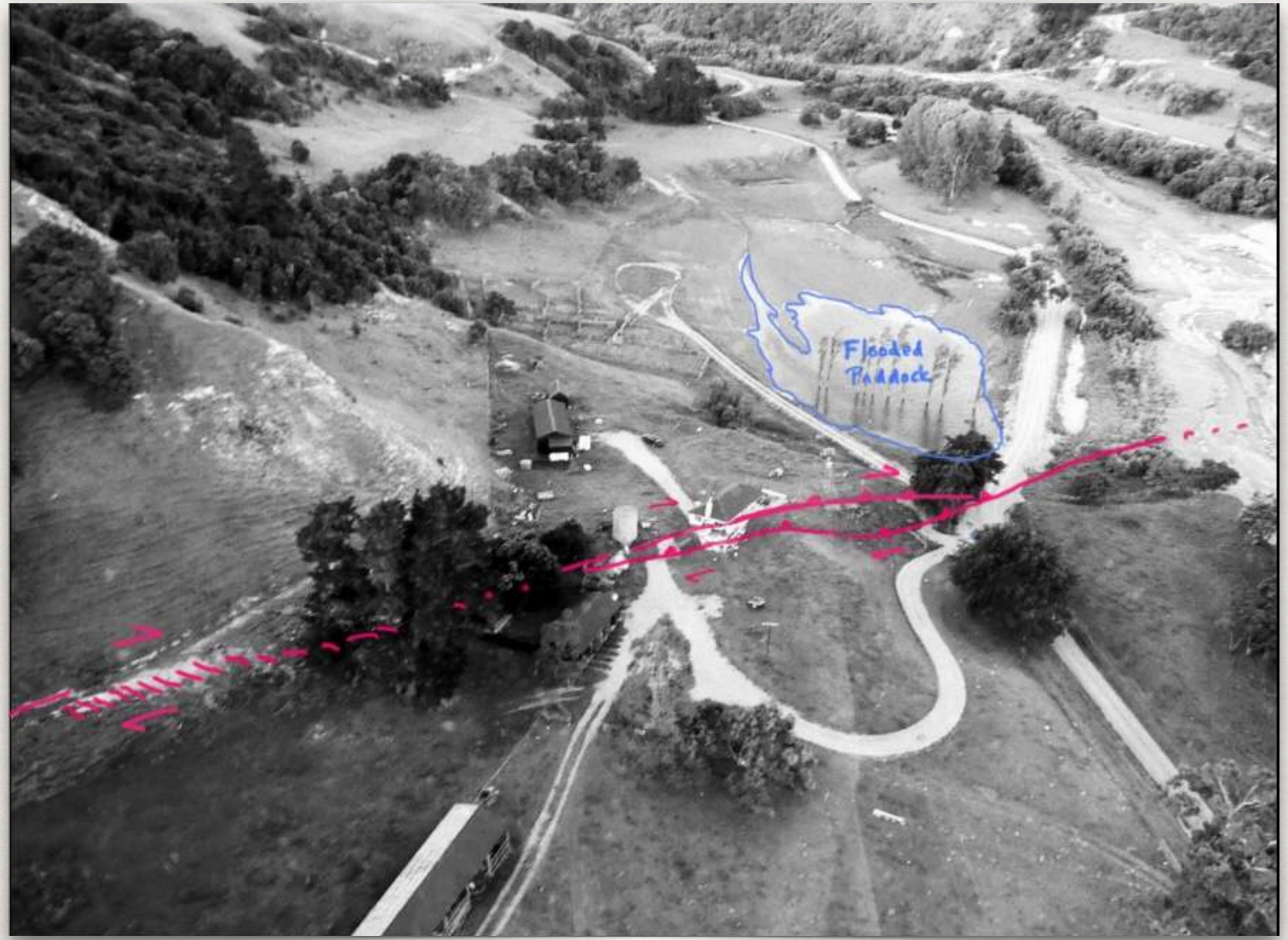


Photo: Tim Little


Flooded
Paddock

Bluff Station Cottage

Photo: Tim Little

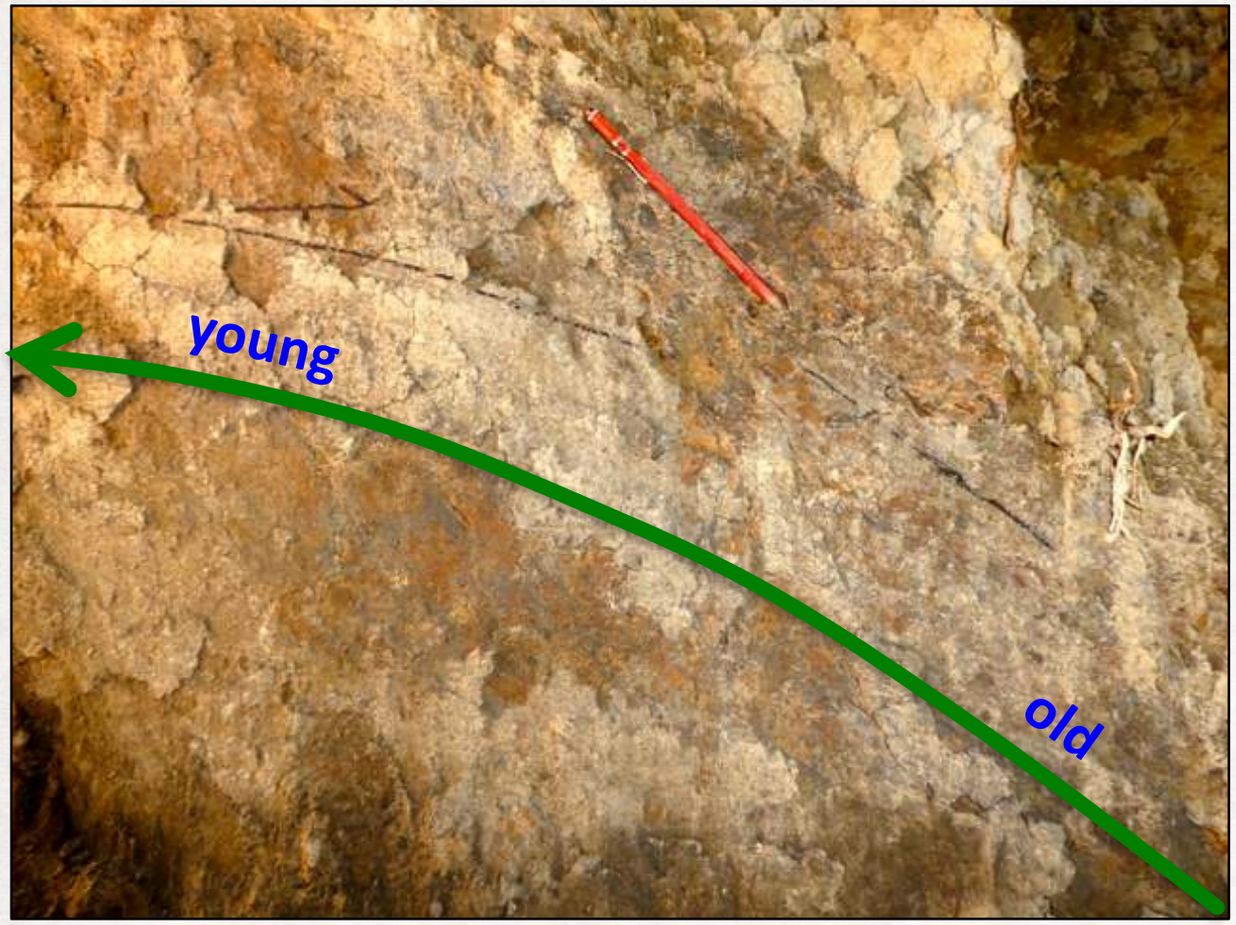
Photo: Tim Little

photo Mark Hemphill-Haley

photo Mark Hemphill-Haley

CLOSING ITEMS/OBSERVATIONS

Curved slickenlines record changes in coseismic slip direction



Looking SE onto NW dipping plane

Photos: Tim Little

Pattern:Early oblique-reverse slip typically became more horizontal with time…

Record of slip direction evolution during the EQ as a result, possibly, of evolving dynamic stresses during the EQ sequence…..

photo Mark Hemphill-Haley

Two discrete slickenline orientations

Could this record surface wave propagation during rupture?

12 m right lateral slip at this site

Strong Ground Motion variability


photo Mark Hemphill-Haley

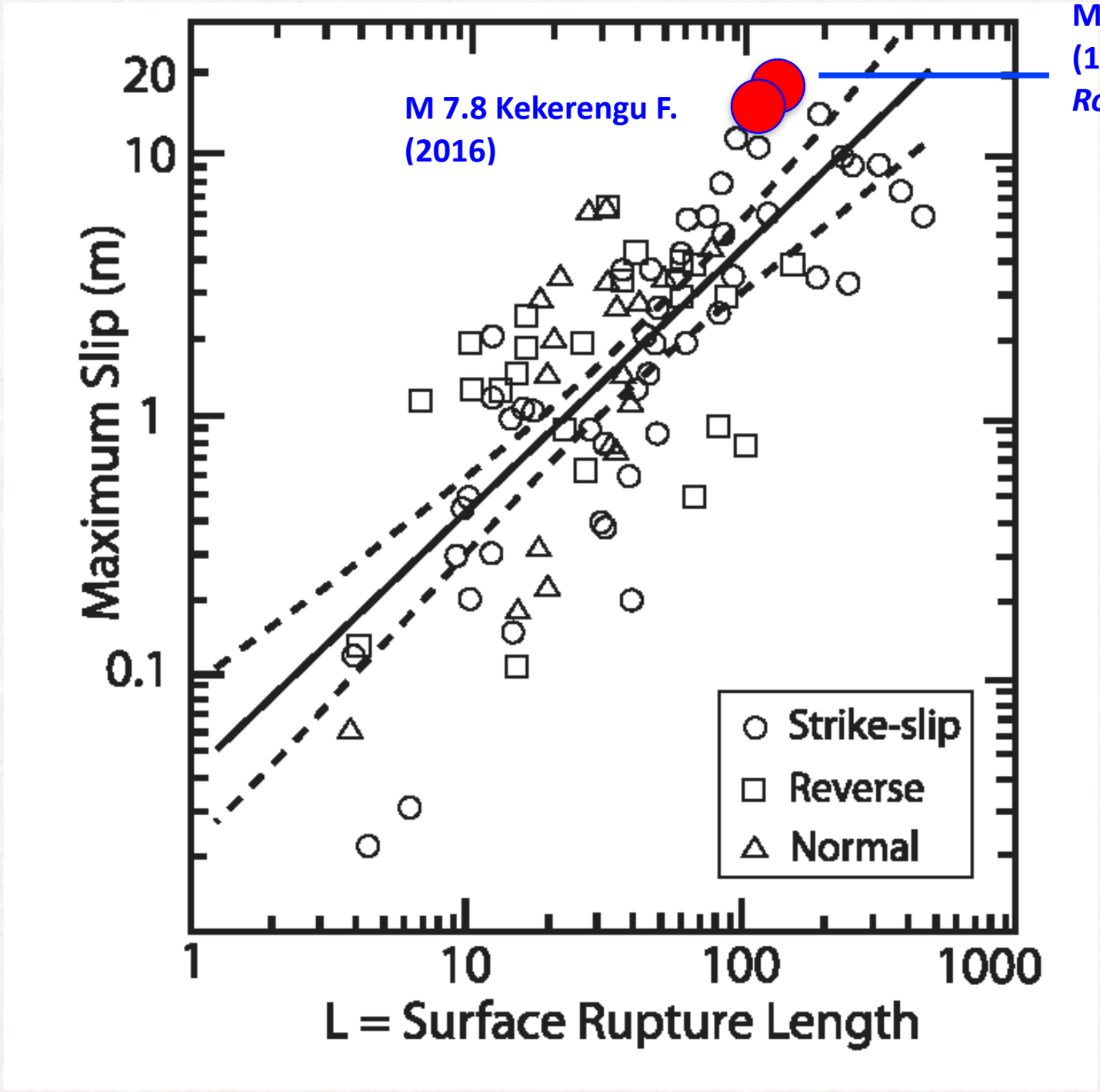

photo Rob Zink


photo Mark Hemphill-Haley

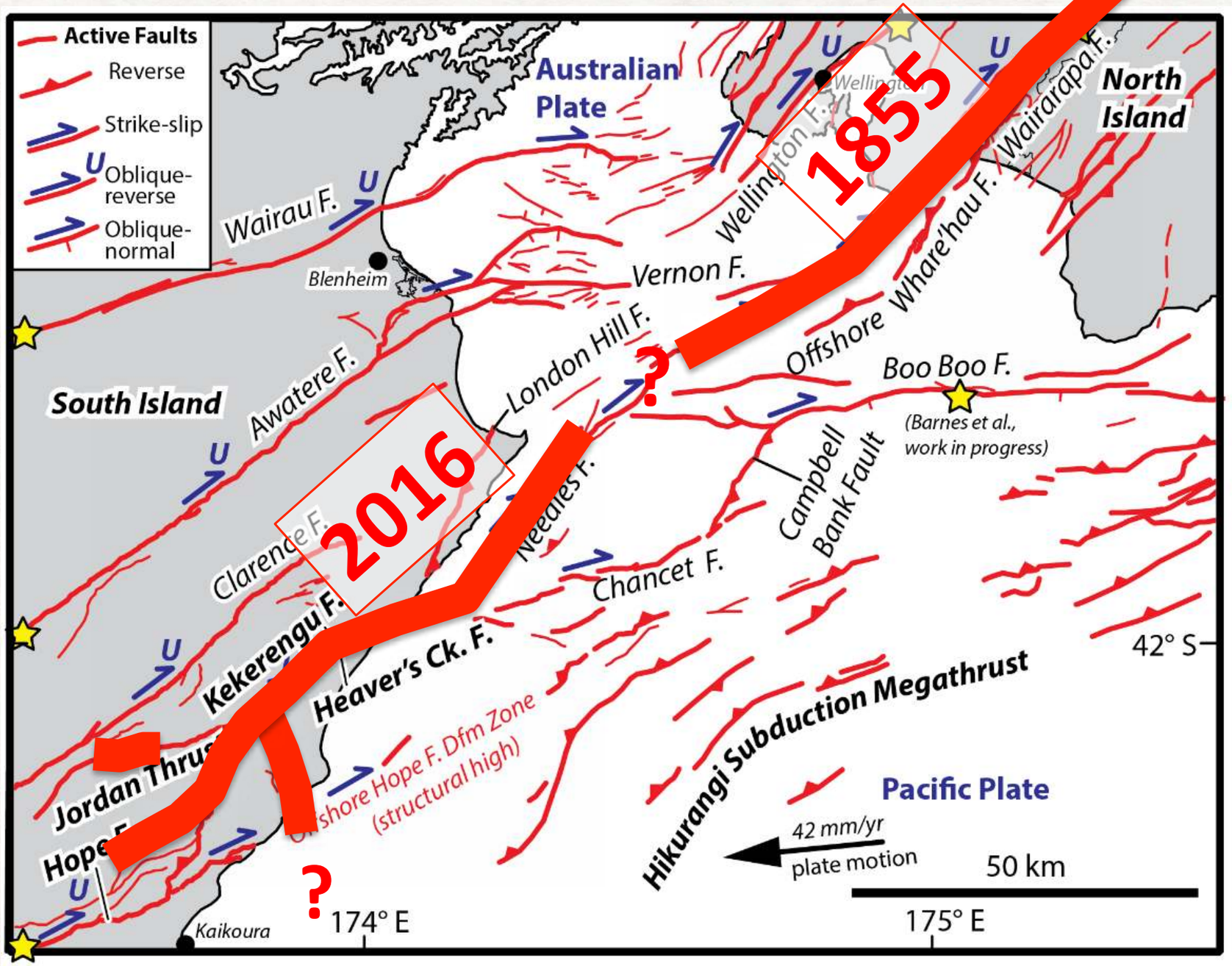

photo Mark Hemphill-Haley

photo Mark Hemphill-Haley

Maximum Slip vs Rupture Length



Wells and Coppersmith, 1994



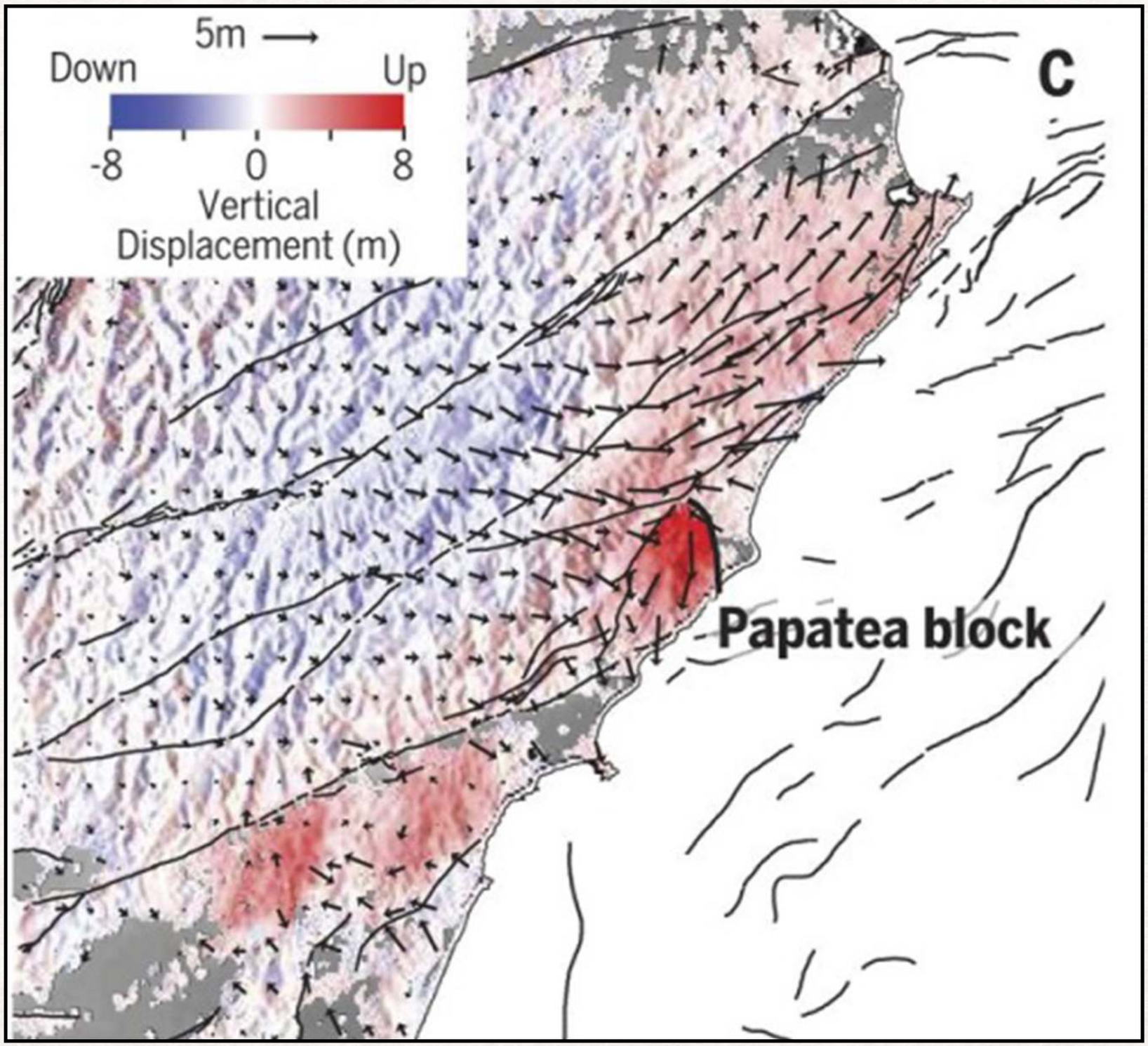
Mw 7.7
2013
Balochistan
(Pakistan)
12-13 m

The 1855 and 2016 (Kekerengu) earthquake ruptures share some characteristics: *R. Zinke et al., 2014*

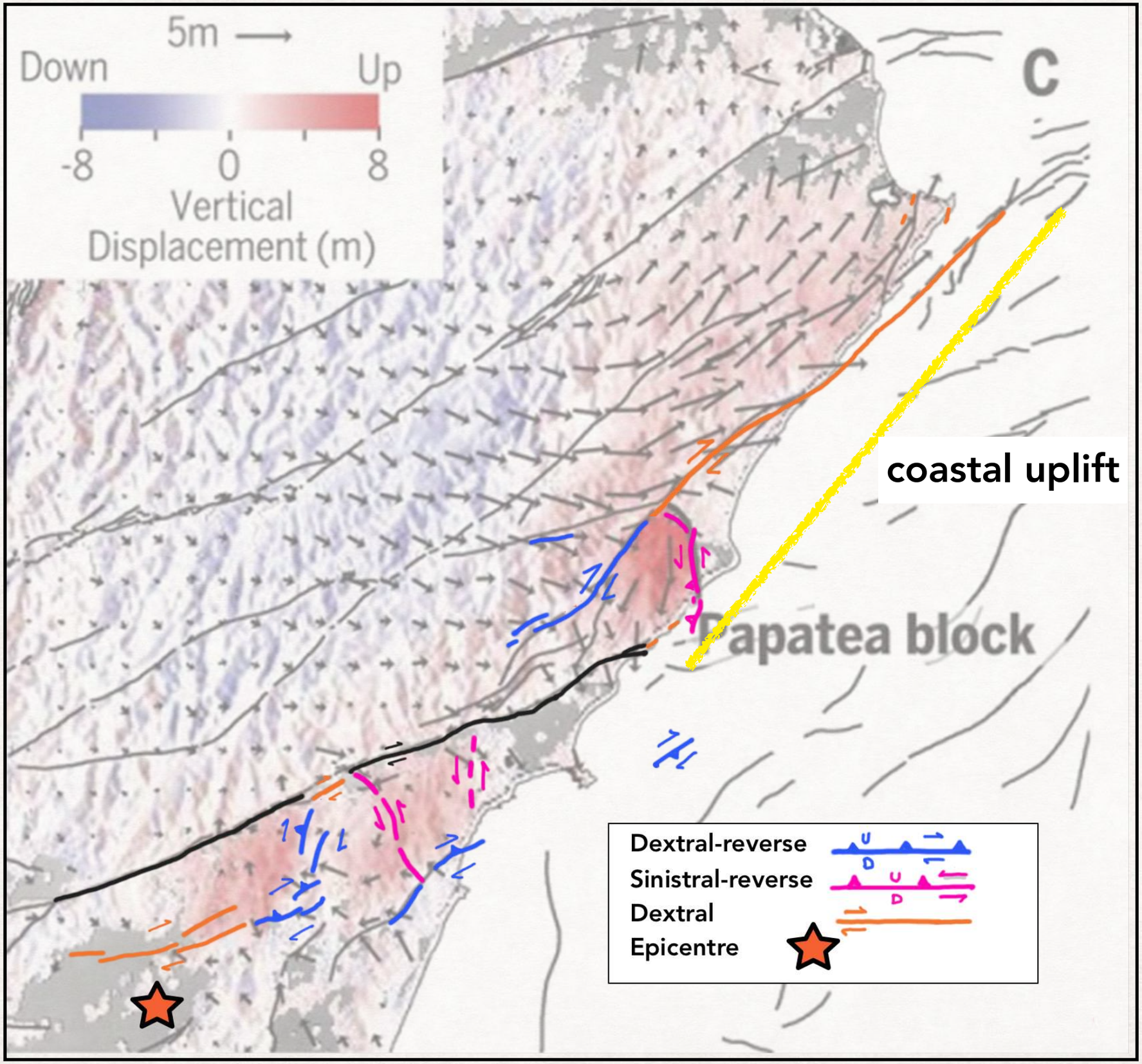
1. Face each other along strike on opposite sides of Cook Strait
2. Both have unusually large slips (two of the top 3 known single event displacements globally)
3. Both also have large slip/length ratios
4. Both are nonvertical, dipping, dextral-reverse fault planes

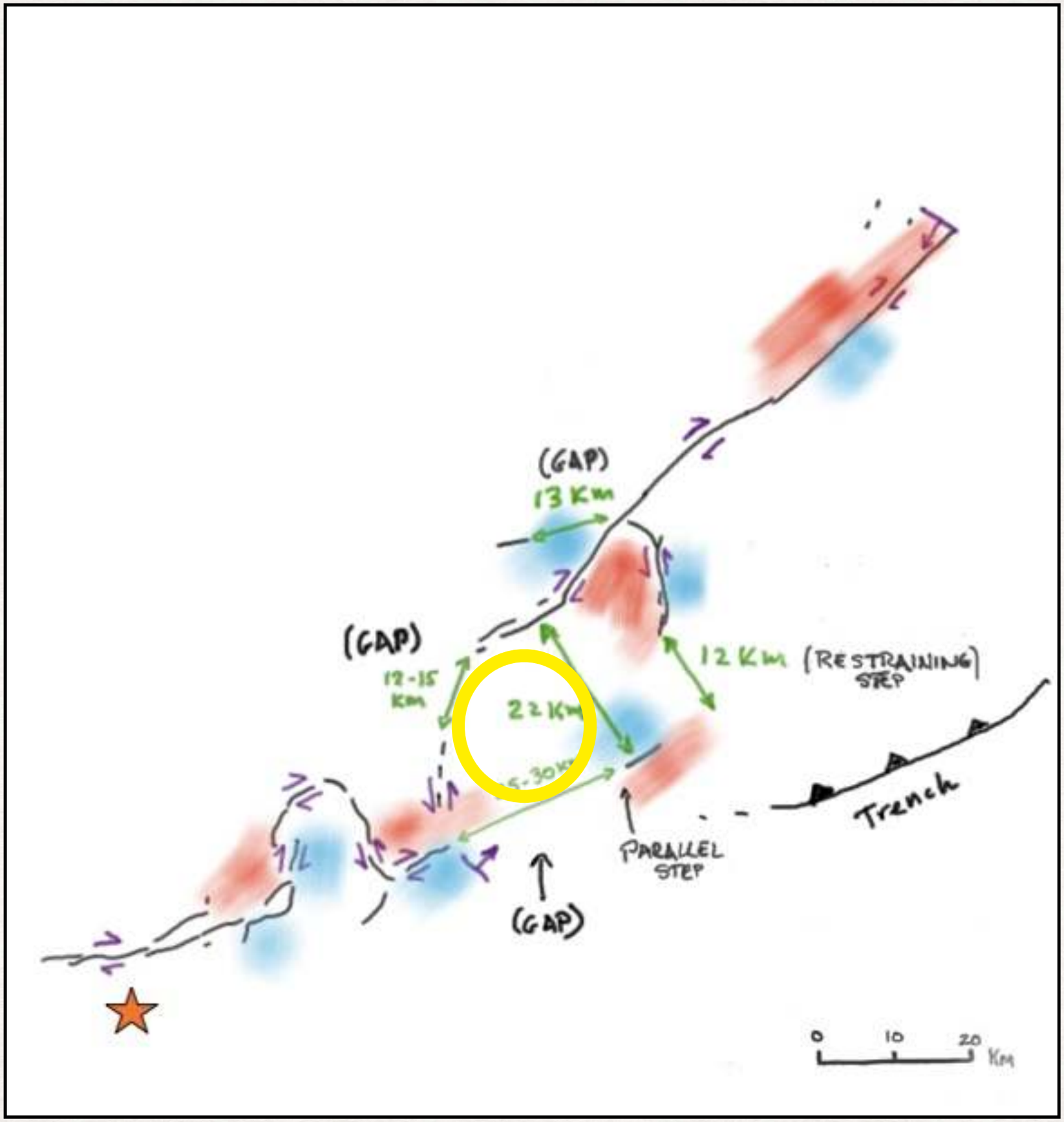
Geodetic Coseismic Displacement field

V and H

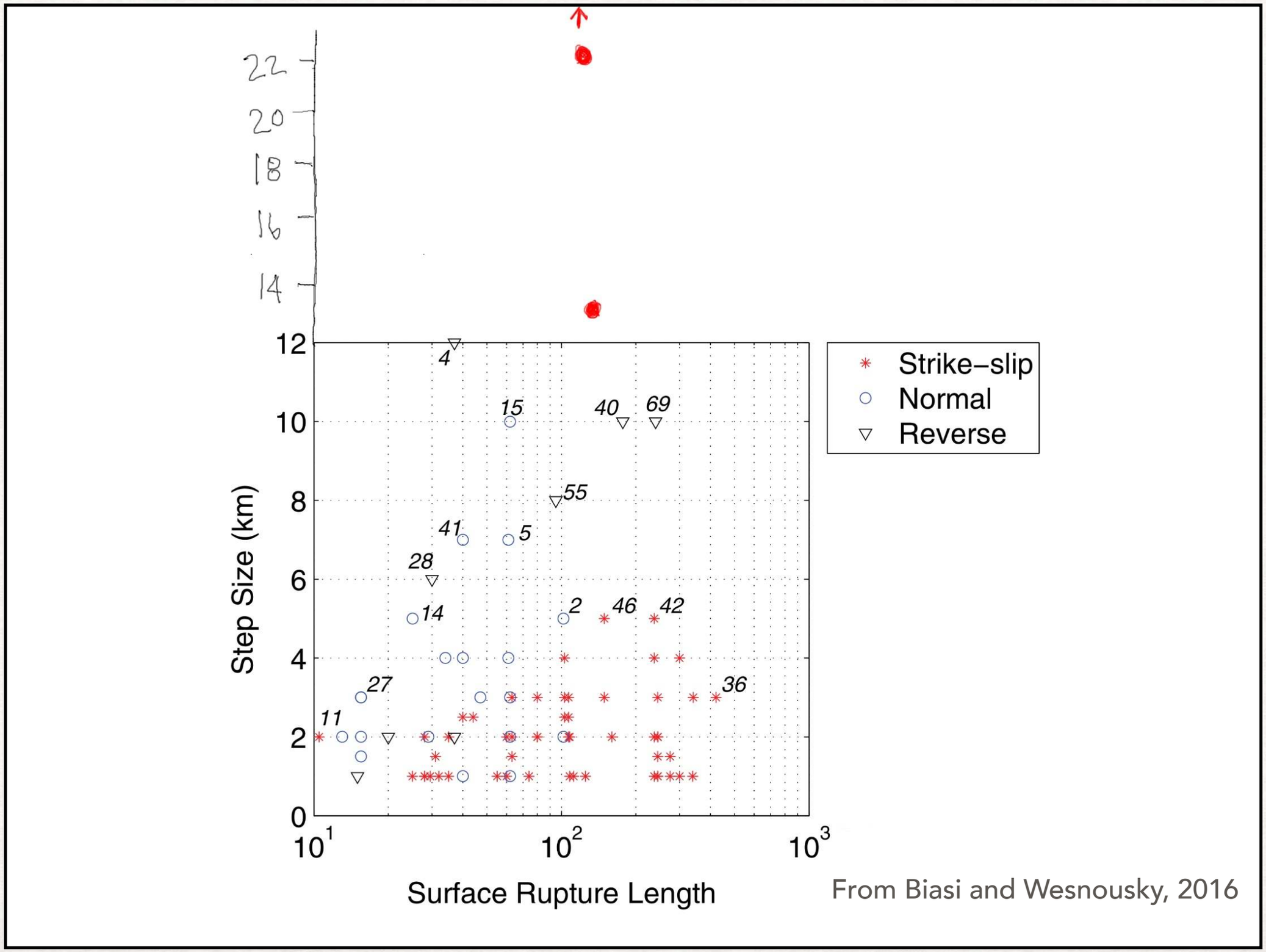


From Hamling et al. 2017

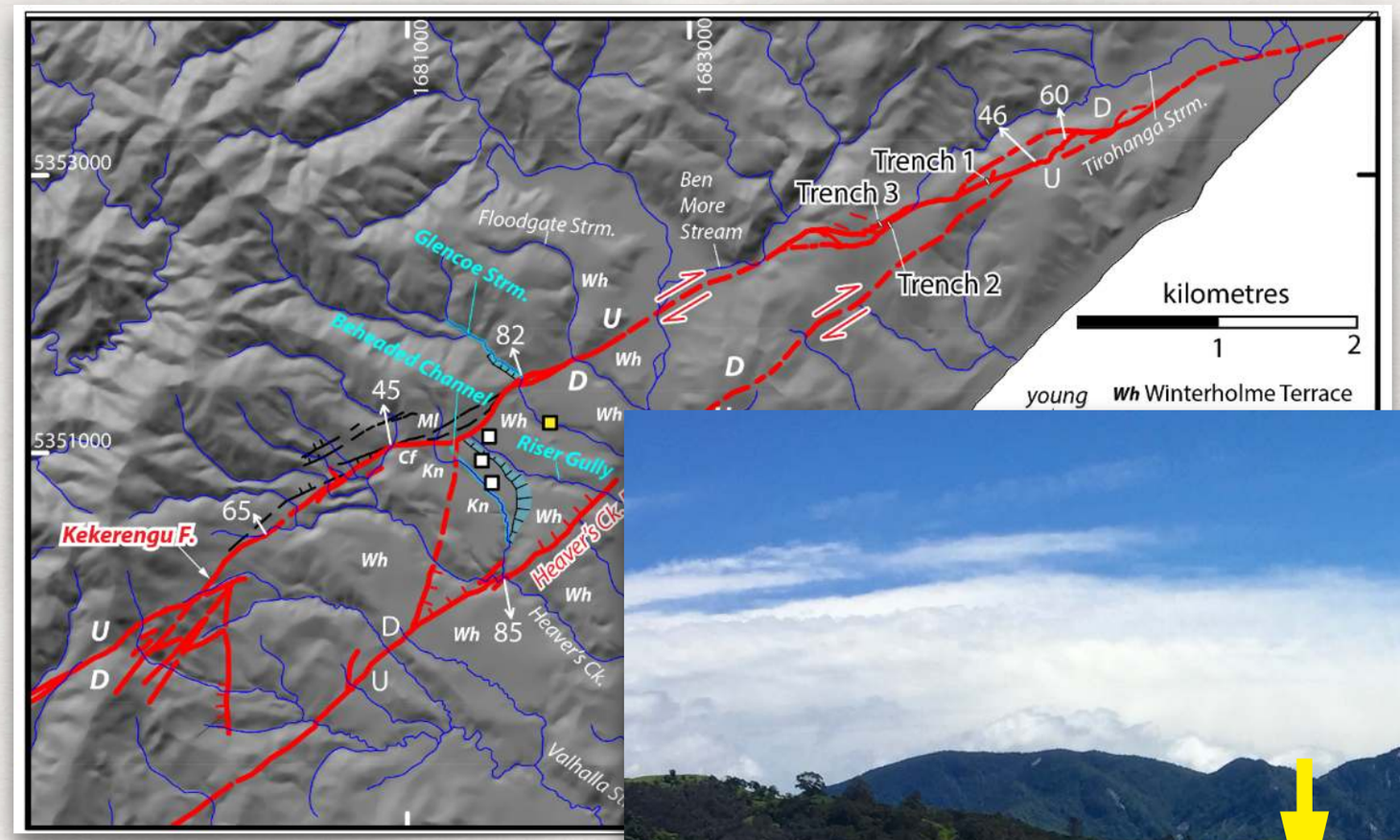

5m
Down
Up
-8
0
8
Vertical
Displacement (m)
C
coastal uplift
Papatea block
Dextral-reverse
Sinistral-reverse
Dextral
Epicentre

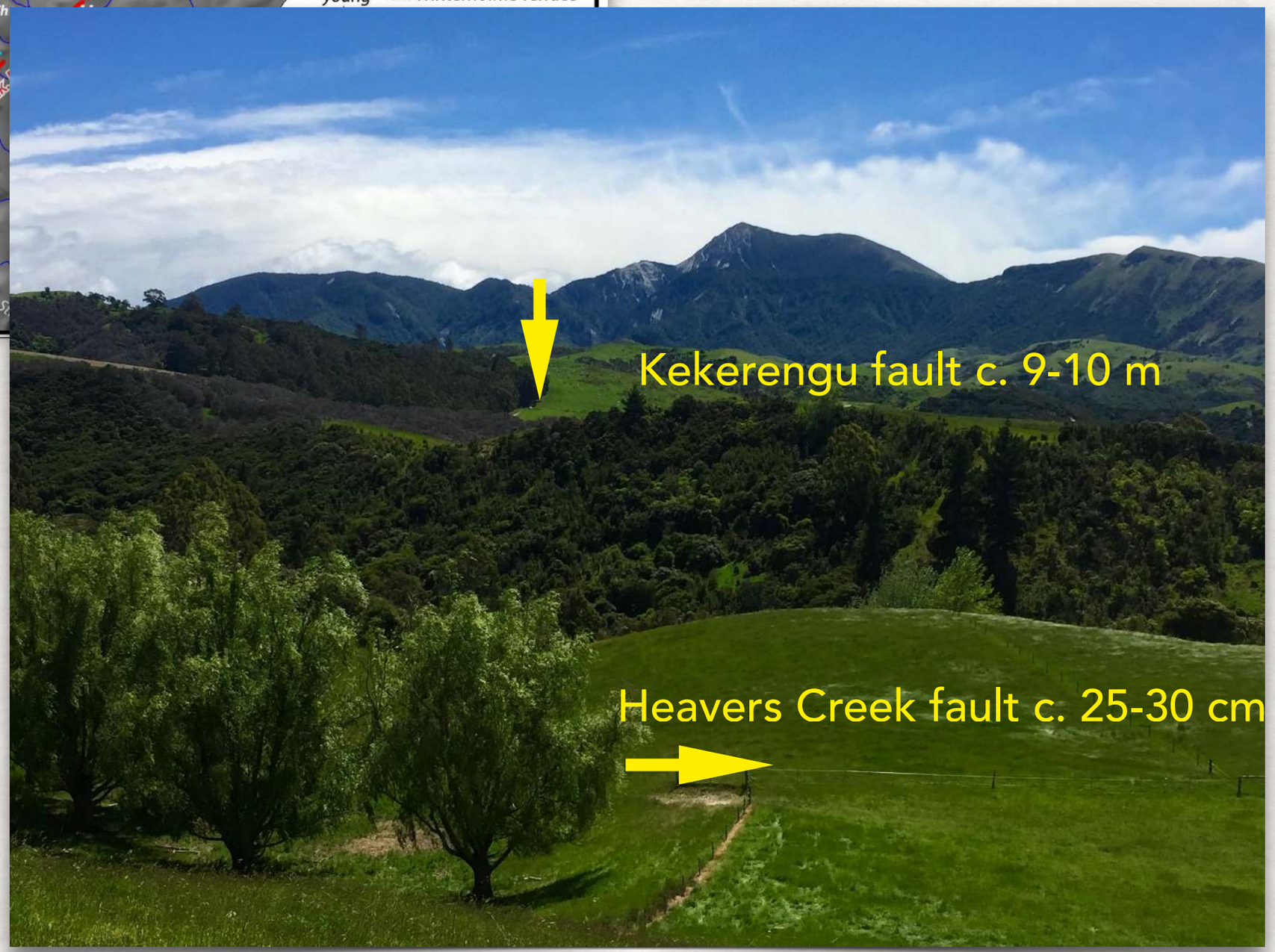

(GAP)
13 Km
(GAP)
12-15 Km
22 Km
12 Km (RESTRAINING STEP)
Trench
PARALLEL STEP
(GAP)
0 10 20 Km

SS FAULTS - STEPS AND GAPS

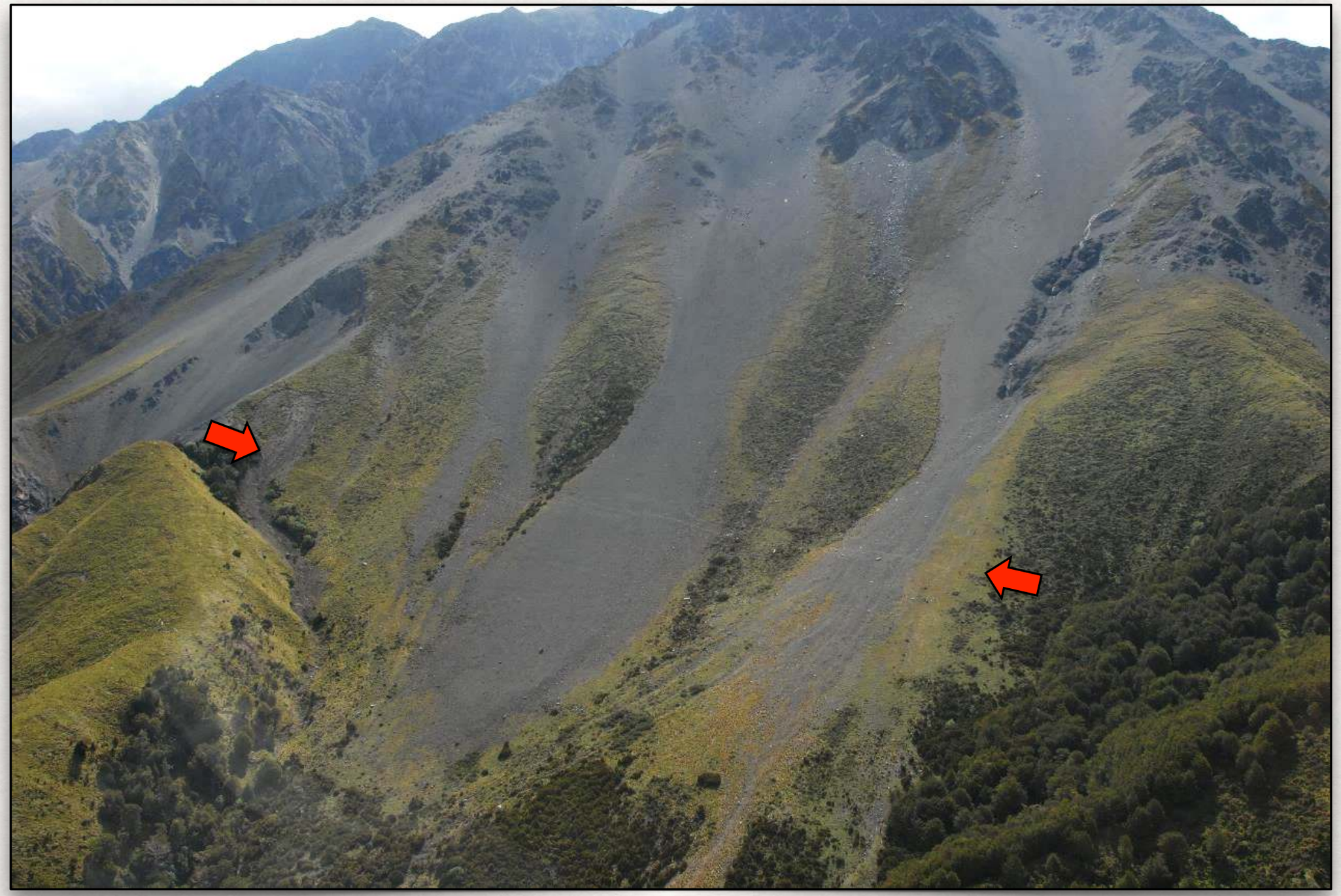


From Biasi and Wesnousky, 2016


1681000
1683000
5353000
5351000
Floodgate Strm.
Ben More Stream
Glencoe Strm.
Behrgadnd Channel
Riser Gully
Heaver's Ck.
Heaver's Ck.
Valhalla St
Tirohanga Strm.
Kekerengu F.
Trench 1
Trench 3
Trench 2
46
60
82
45
65
85
Wh
Ml
Cf
Kn
U
D
kilometres
1
2
young
Wh Winterholme Terrace

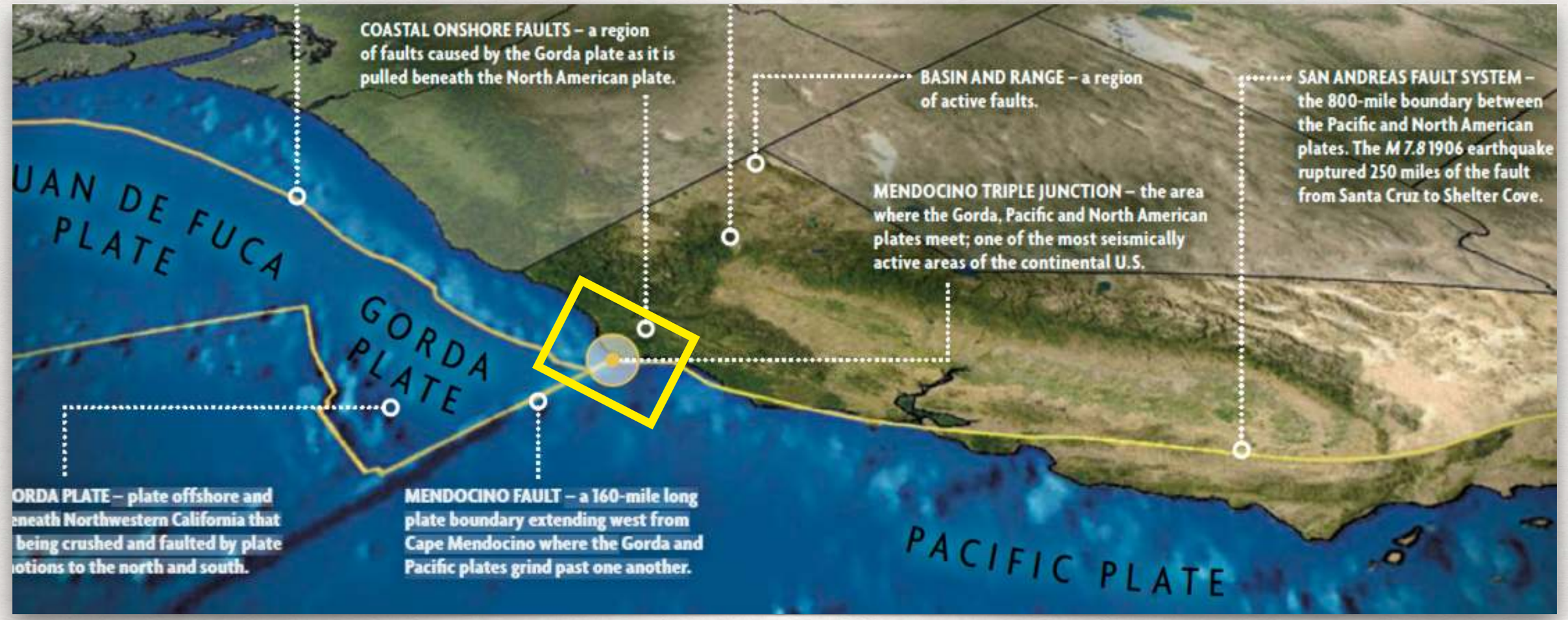

Kekerengu fault c. 9-10 m
Heavers Creek fault c. 25-30 cm

Jordan Thrust



Imagine trying to identify this event even 10 yrs from now

HOW DOES THIS RELATE TO OUR OWN SUBDUCTION TO TRANSFORM TRANSITION?.



Similarities

- plate rates
- subduction to transform transition
- evidence for large subduction zone and transform earthquakes

Differences too

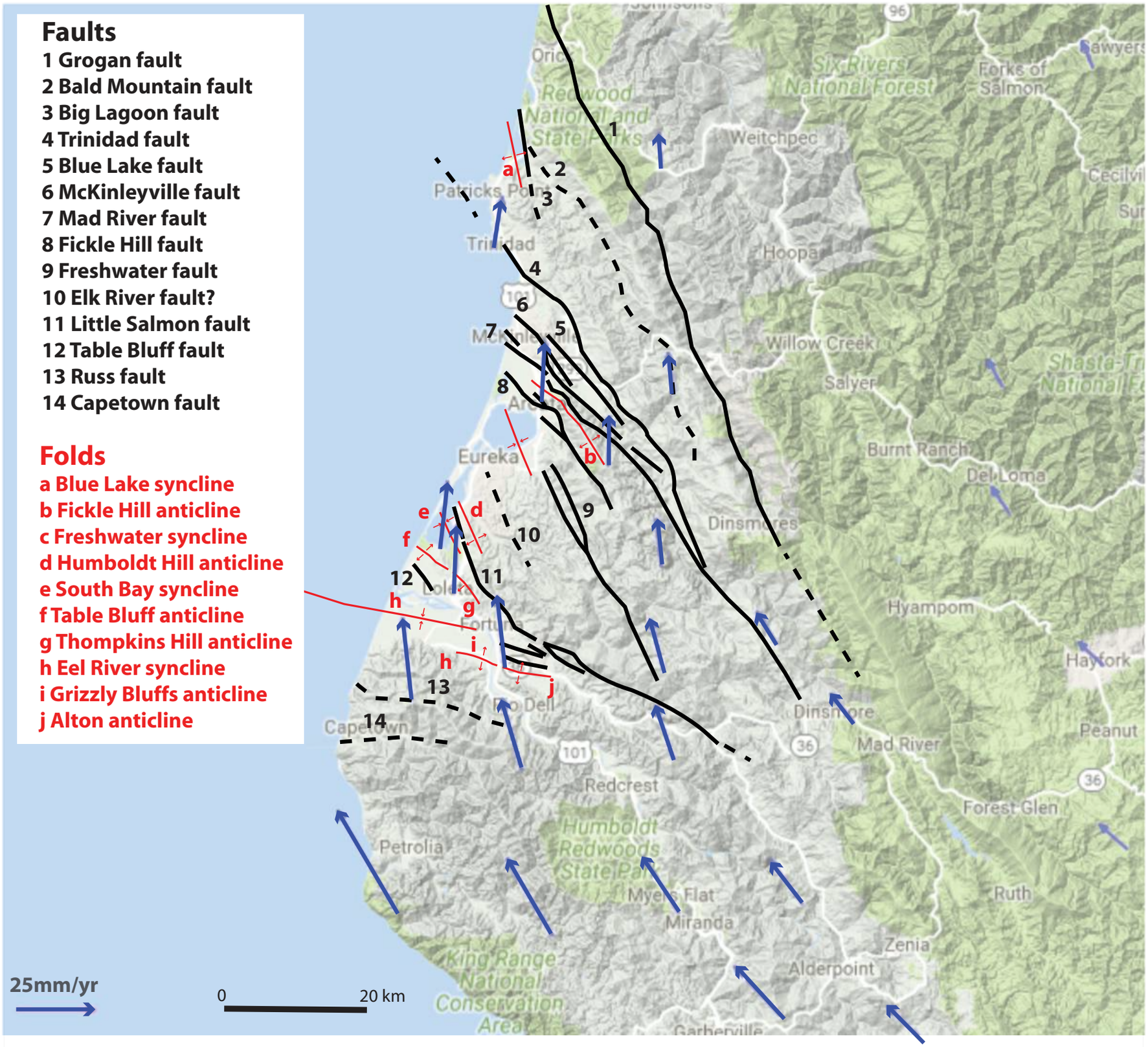
- MTJ has lower seismicity in upper plate
- NZ isn't a triple junction
- different subducting materials

Faults

1 Grogan fault
2 Bald Mountain fault
3 Big Lagoon fault
4 Trinidad fault
5 Blue Lake fault
6 McKinleyville fault
7 Mad River fault
8 Fickle Hill fault
9 Freshwater fault
10 Elk River fault?
11 Little Salmon fault
12 Table Bluff fault
13 Russ fault
14 Capetown fault

Folds

a Blue Lake syncline
b Fickle Hill anticline
c Freshwater syncline
d Humboldt Hill anticline
e South Bay syncline
f Table Bluff anticline
g Thompkins Hill anticline
h Eel River syncline
i Grizzly Bluffs anticline
j Alton anticline



Geodetic data and base map: https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html and Google

Faults and folds modified from Kelsey, Harvey M., 2001, Active faulting associated with the Southern Cascadia subduction zone in Northern California, *in* Ferriz, H. and Anderson, R. (eds), Engineering Geology Practice in Northern California, Assoiciation of Engineering Geologists, Special Publication 12, p. 259-274