Geothermal energy from extinct volcanoes: the Dunedin experiment

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Pioneer Energy
Webster Drilling

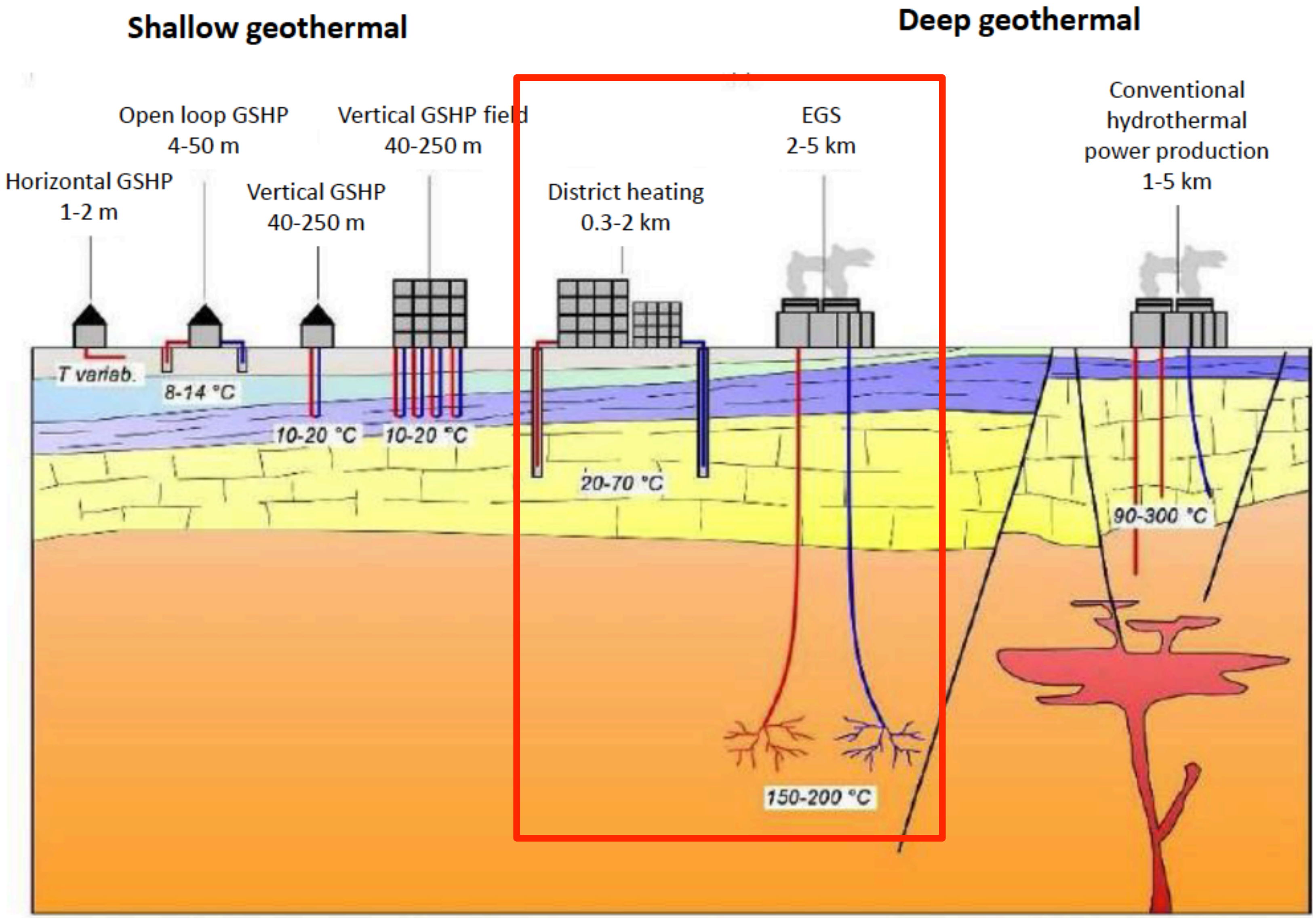
EDGE

- Positive anthropogenic GHG emission trends demand burning of carbon-based fuels to be phased out as rapidly as possible.

- The now solidified, but still warm magma body that lies beneath the extinct Dunedin Volcano provides anomalously high ground heat flow.

- Successful utilization of this geothermal resource would provide long-term economic and environmental benefits locally, nationally and globally.

WHAT is Geothermal energy



Low enthalpy sites for district heating

- ~80-150°C
- Used for district heat.
- Reykjavik, Iceland benefits from geothermal district heating schemes with a total capacity exceeding 660 MW.

- Possible to use organic Rankine cycle (ORC) to generate electricity at low temperature ~100°C

The 4MW Akça ORC geothermal plant in Turkey. Credit: Exergy.

8-story library heated with shallow geothermal energy saving over 1000 tons of coal annually

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Contents lists available at ScienceDirect

Geothermics

ELSEVIER

journal homepage: www.elsevier.com/locate/geothermics

Analysis of thermal performance and economy of ground source heat pump system: a case study of the large building

Jingyang Han[*,1], Minghui Cui[1], Junyi Chen, Wenjuan Lv

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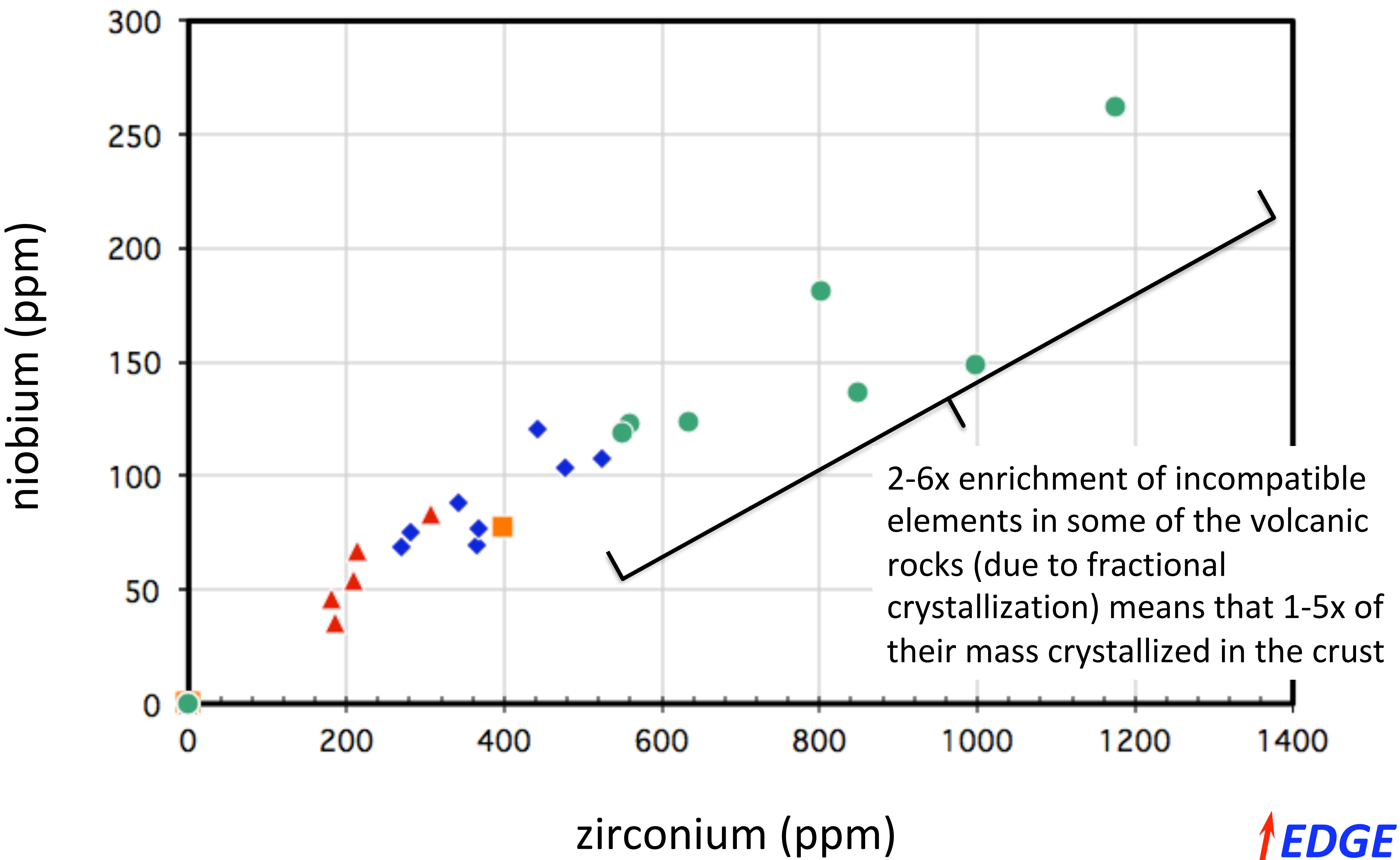
Dunedin is built on an extinct volcano.

EDGE


The compositions of the solidified
lavas tell us something lies deeper.
EDGE

Much of the magma was trapped and crystallized beneath the surface.



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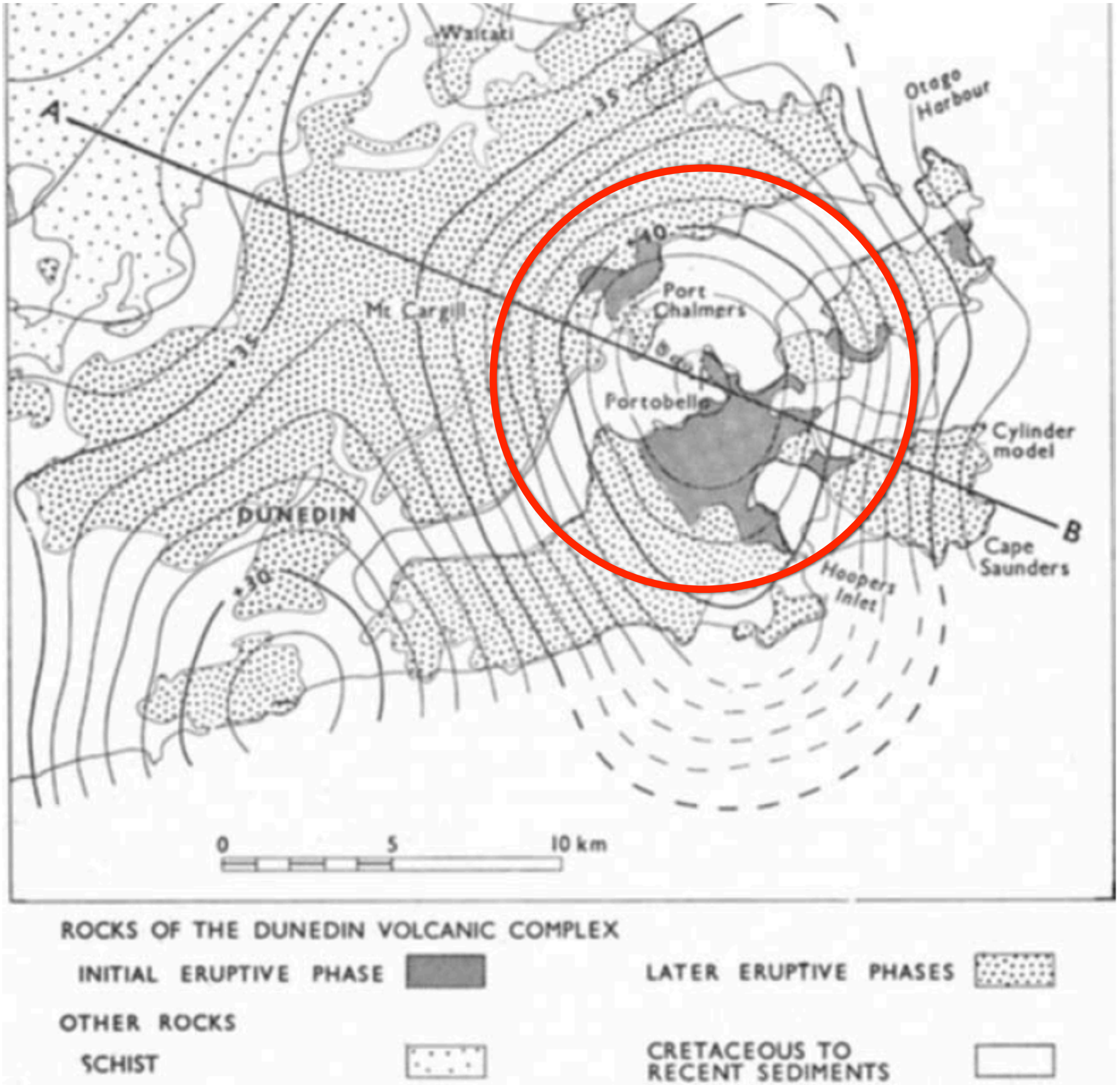
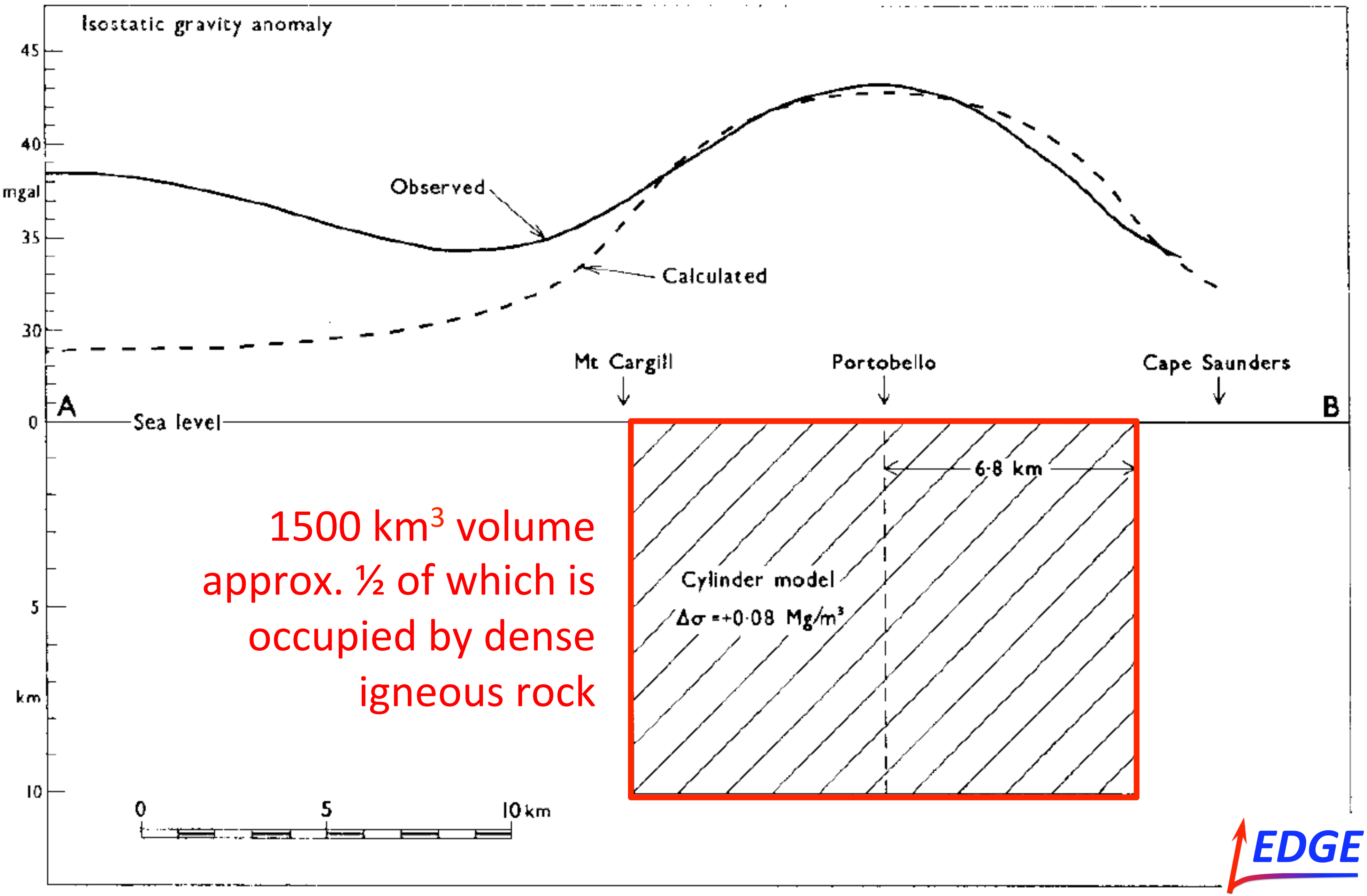
The ancient magma body now forms a large mass of dense igneous rock that perturbs our local gravity.



W.I. Reilly (1972) Gravitational expression of the Dunedin Volcano, New Zealand Journal of Geology and Geophysics, 15(1): 16-21.

EDGE

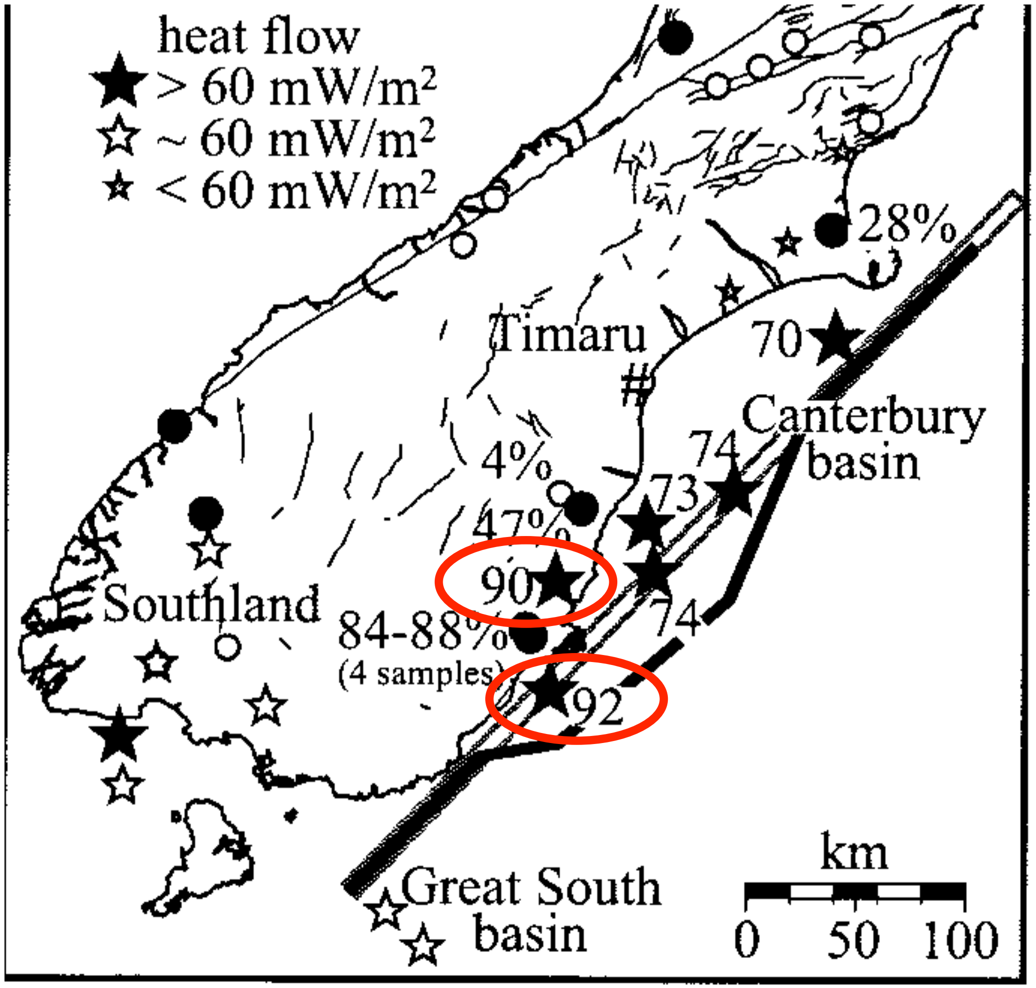
The gravity readings allow us to estimate its size.



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 106, NO. B12, PAGES 30,835–30,848, DECEMBER 10, 2001

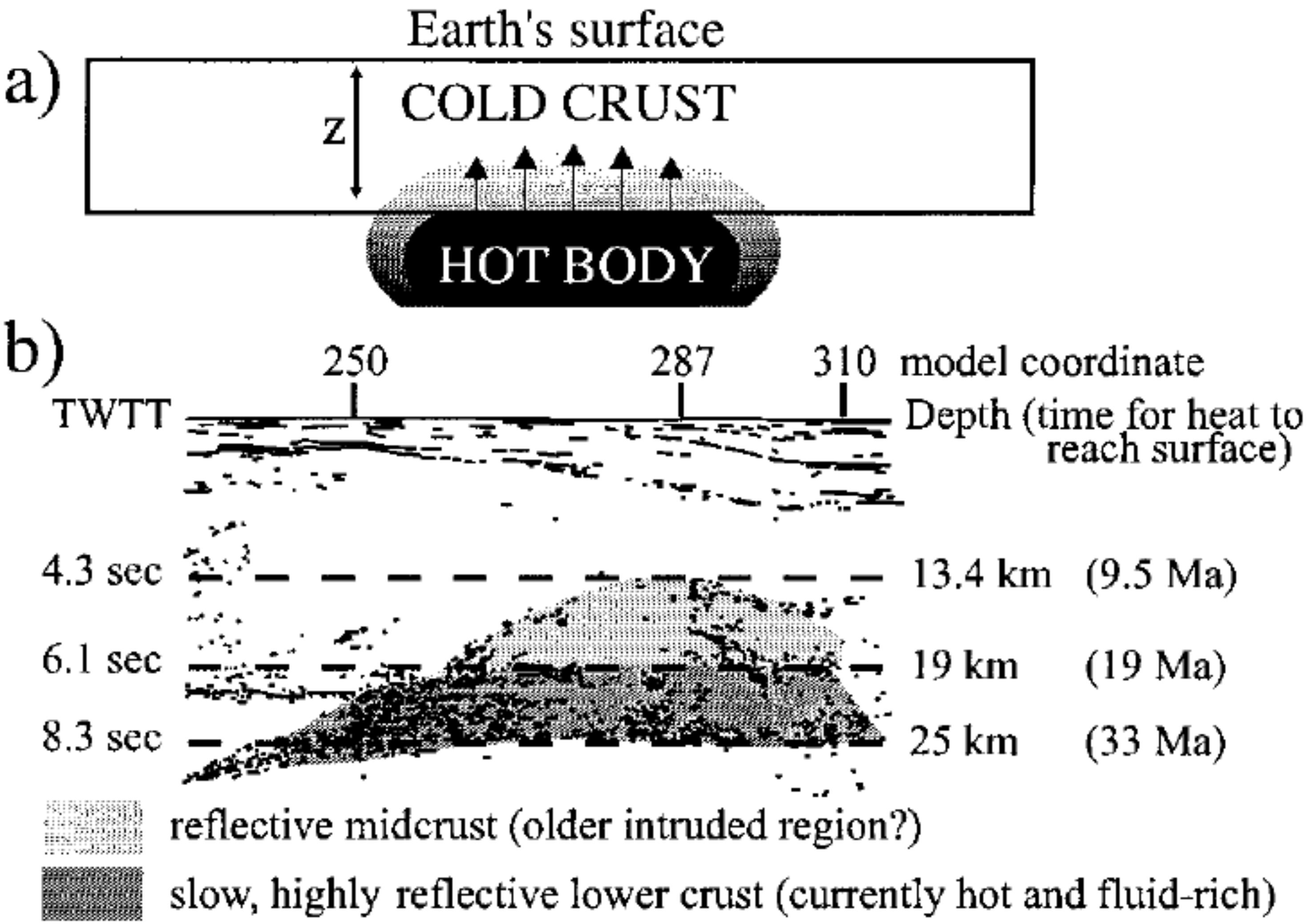
Crustal structure and thermal anomalies of the Dunedin Region, South Island, New Zealand

Nicola J. Godfrey,[1,2] Fred Davey,[3] Tim A. Stern,[4] and David Okaya[1]



The Dunedin region exhibits anomalously high heat flow – based on very limited data!

ratios measured in the Dunedin region suggest a current or recent mantle-melting event. High heat flow recorded in the Dunedin region is consistent with a hot body emplaced in the midcrust ~10 Myr ago (Miocene) whose heat is just reaching the surface today. Uplift of an Oligocene limestone horizon in the Canterbury basin can be explained by a buoyant



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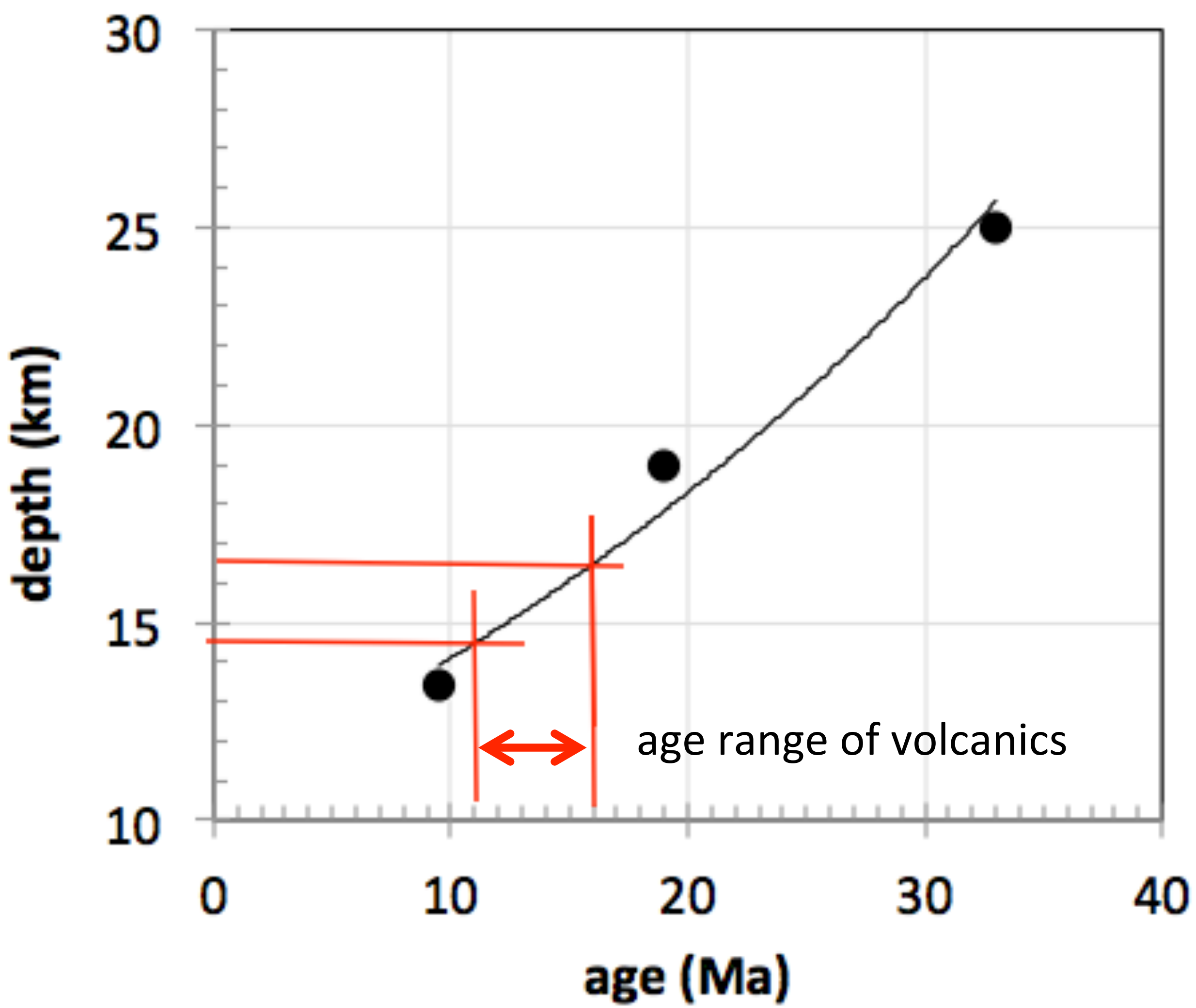
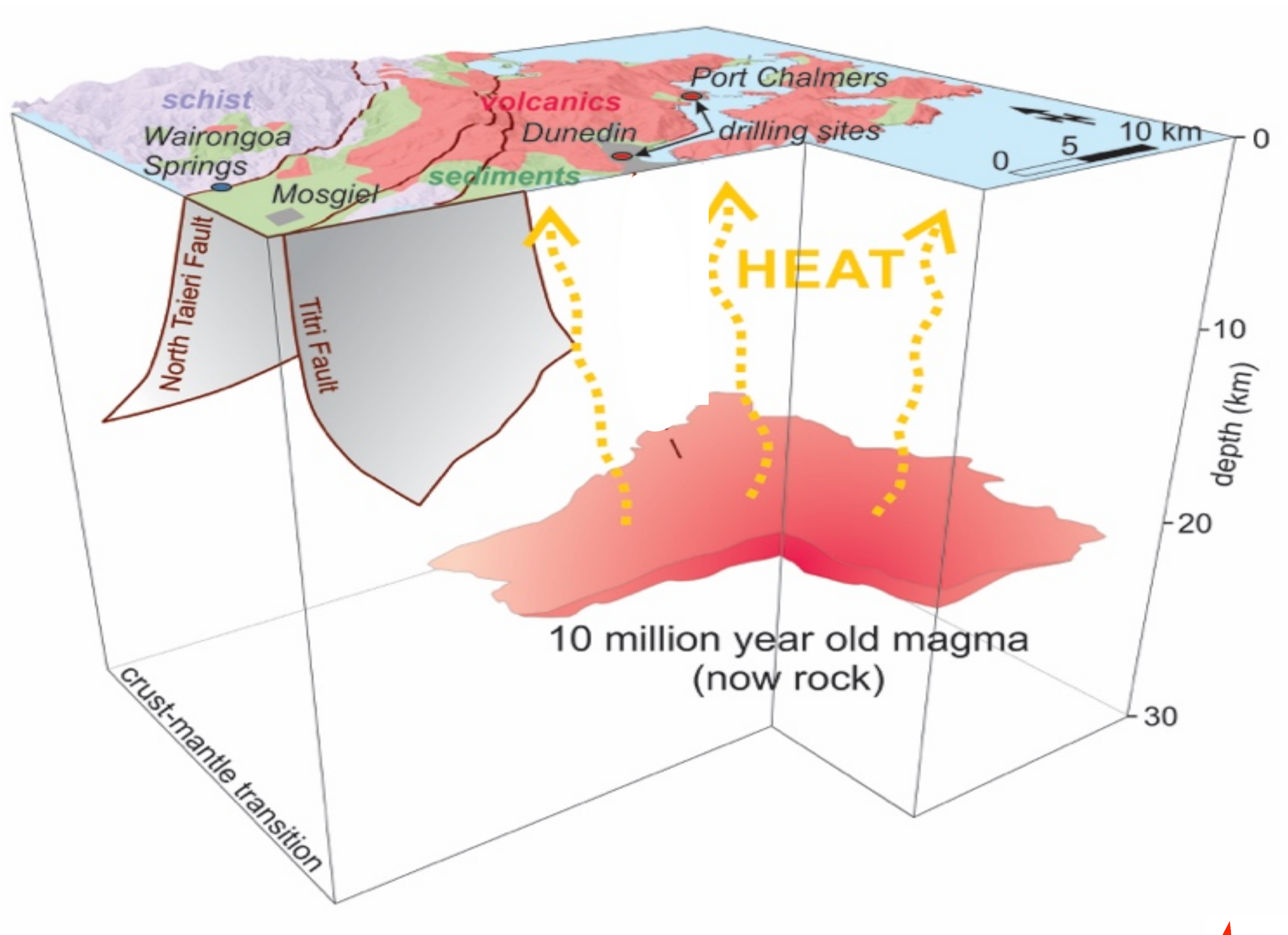
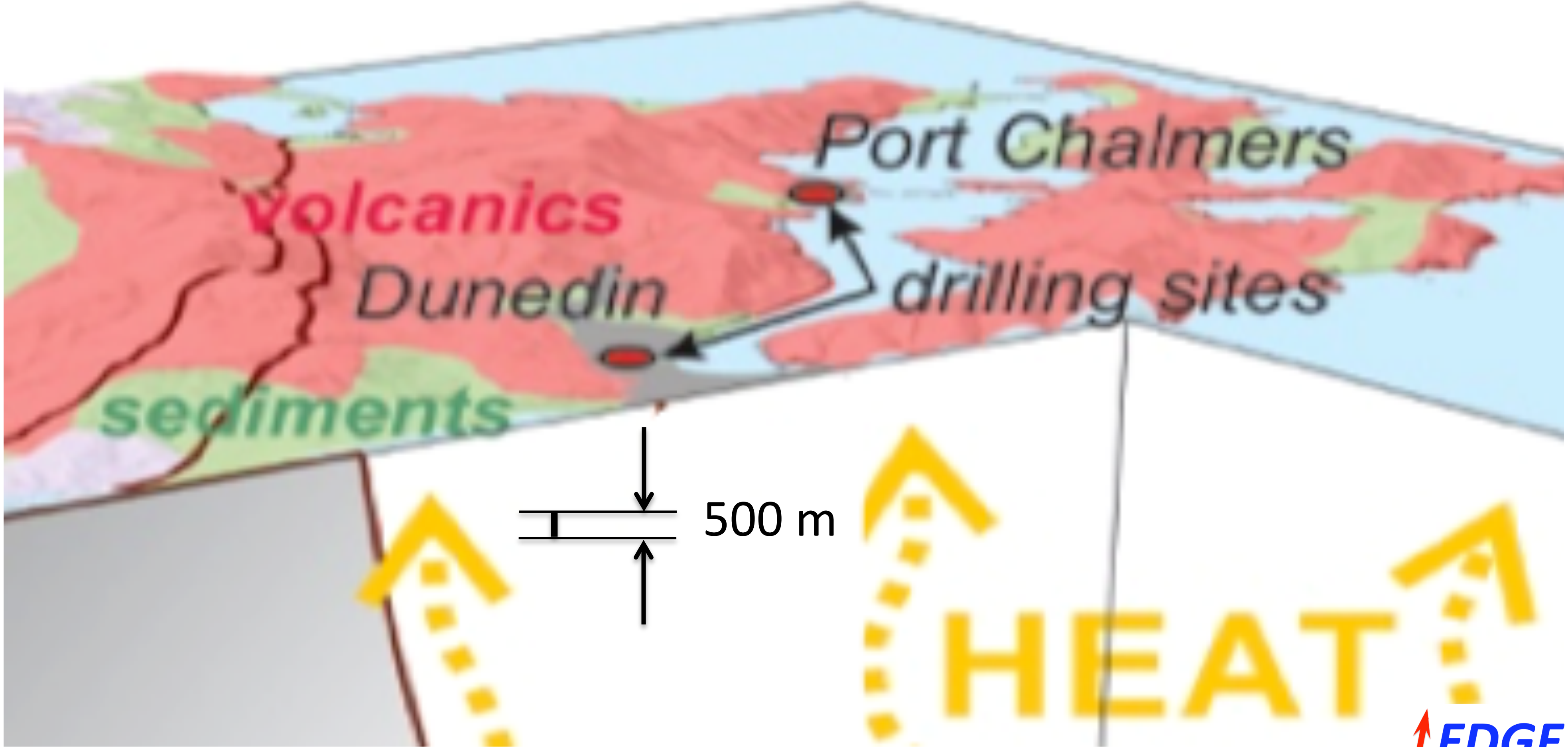


EDGE


schist
volcanics
Port Chalmers
Wairongoa
Springs
Dunedin
drilling sites
Mosgiel
sediments
0
5
10 km
0
10
20
30
depth (km)
North Taieri Fault
Titri Fault
HEAT
10 million year old magma
(now rock)
crust-mantle transition

MBIE "Smart Idea" Concept:

- drill 2x observation holes each ca. 500 m deep
- measure ground heat flow for 1+ year
- assess geothermal resource



EDGE

EDGE

Low-Enthalpy Dunedin Geothermal Energy

extra slides

Further evidence of a significant geothermal energy resource beneath Dunedin comes from a gas-rich well on the Taieri.

Journal of Volcanology and Geothermal Research 192 (2010) 117–141

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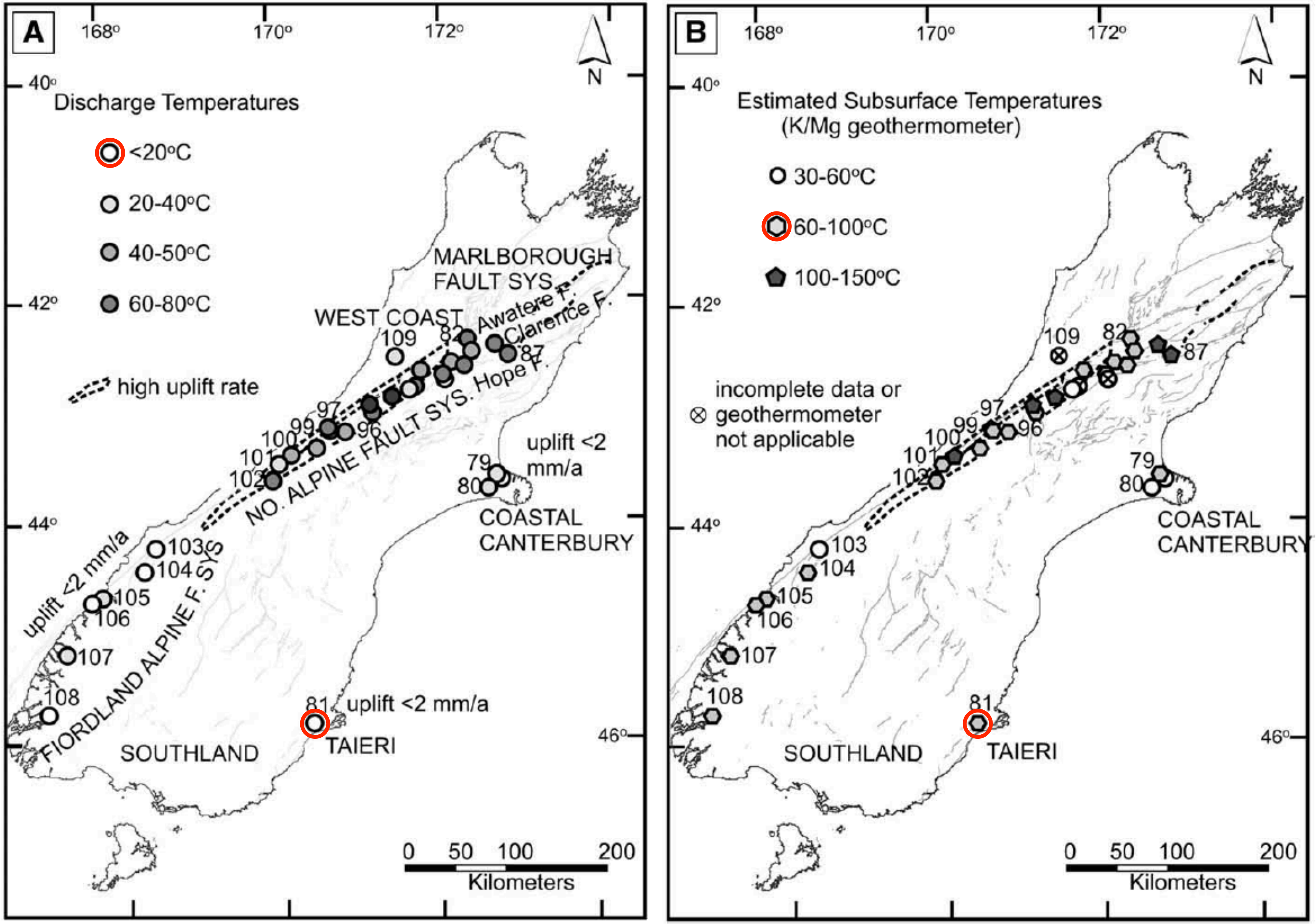
Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Sources of solutes and heat in low-enthalpy mineral waters and their relation to tectonic setting, New Zealand

A.G. Reyes [a,*], B.W. Christenson [b], K. Faure [a]

EDGE


A
168°
170°
172°
N
40°
Discharge Temperatures
<20°C
20-40°C
40-50°C
60-80°C
high uplift rate
42°
44°
46°
MARLBOROUGH
FAULT SYS.
WEST COAST
Awatere F.
Clarence F.
Hope F.
NO. ALPINE FAULT SYS.
uplift <2
mm/a
COASTAL
CANTERBURY
uplift <2 mm/a
FIORDLAND ALPINE F. SYS
uplift <2 mm/a
SOUTHLAND
TAIERI
109
82
87
97
99
96
100
101
102
79
80
103
104
105
106
107
108
81
0 50 100 200
Kilometers
B
168°
170°
172°
N
40°
Estimated Subsurface Temperatures
(K/Mg geothermometer)
30-60°C
60-100°C
100-150°C
incomplete data or
geothermometer
not applicable
42°
44°
46°
COASTAL
CANTERBURY
SOUTHLAND
TAIERI
109
82
87
97
99
96
100
101
102
79
80
103
104
105
106
107
108
81
0 50 100 200
Kilometers

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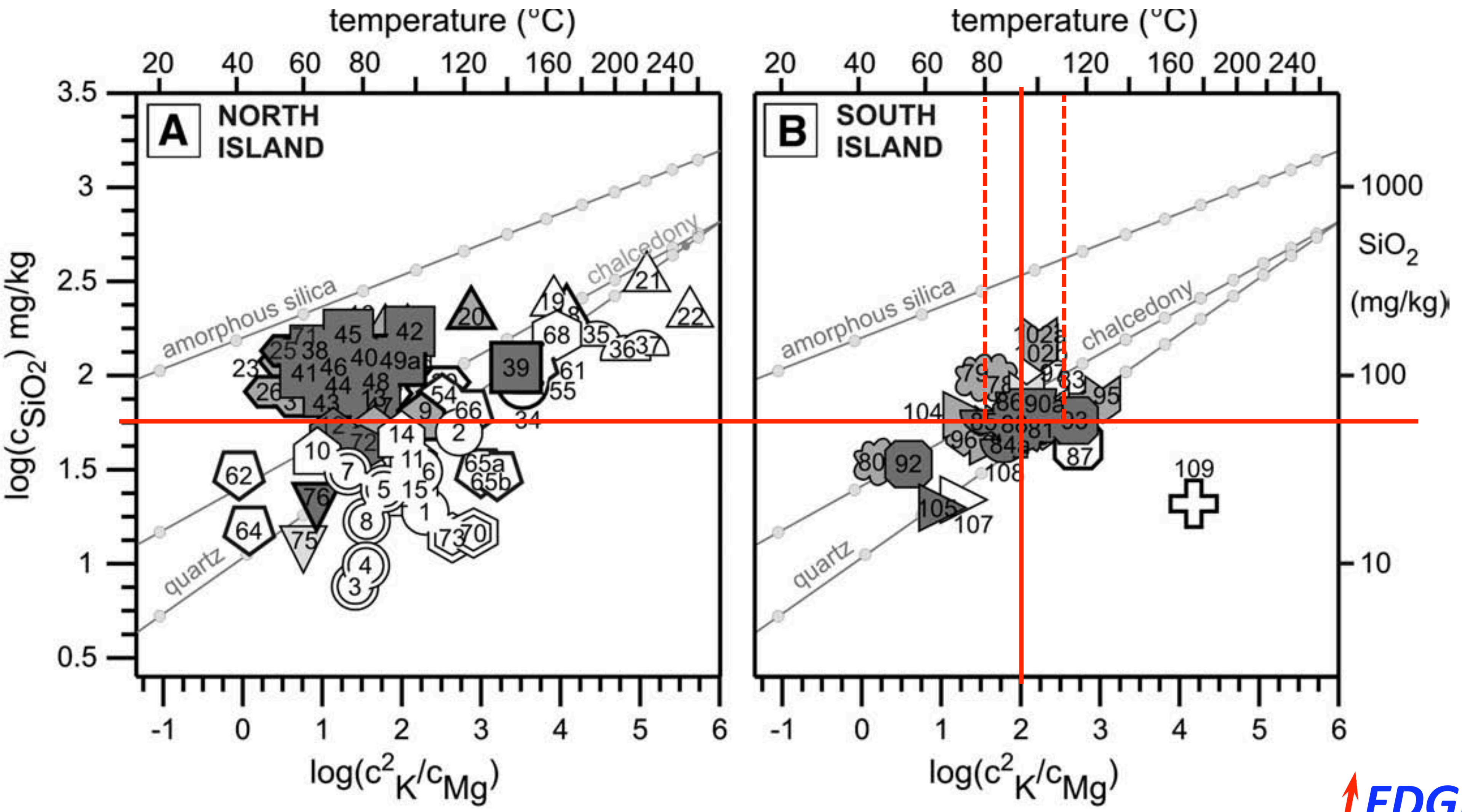
Chemical "thermometers" in the water indicate that it reacted with rock at ~ 80-110°C.



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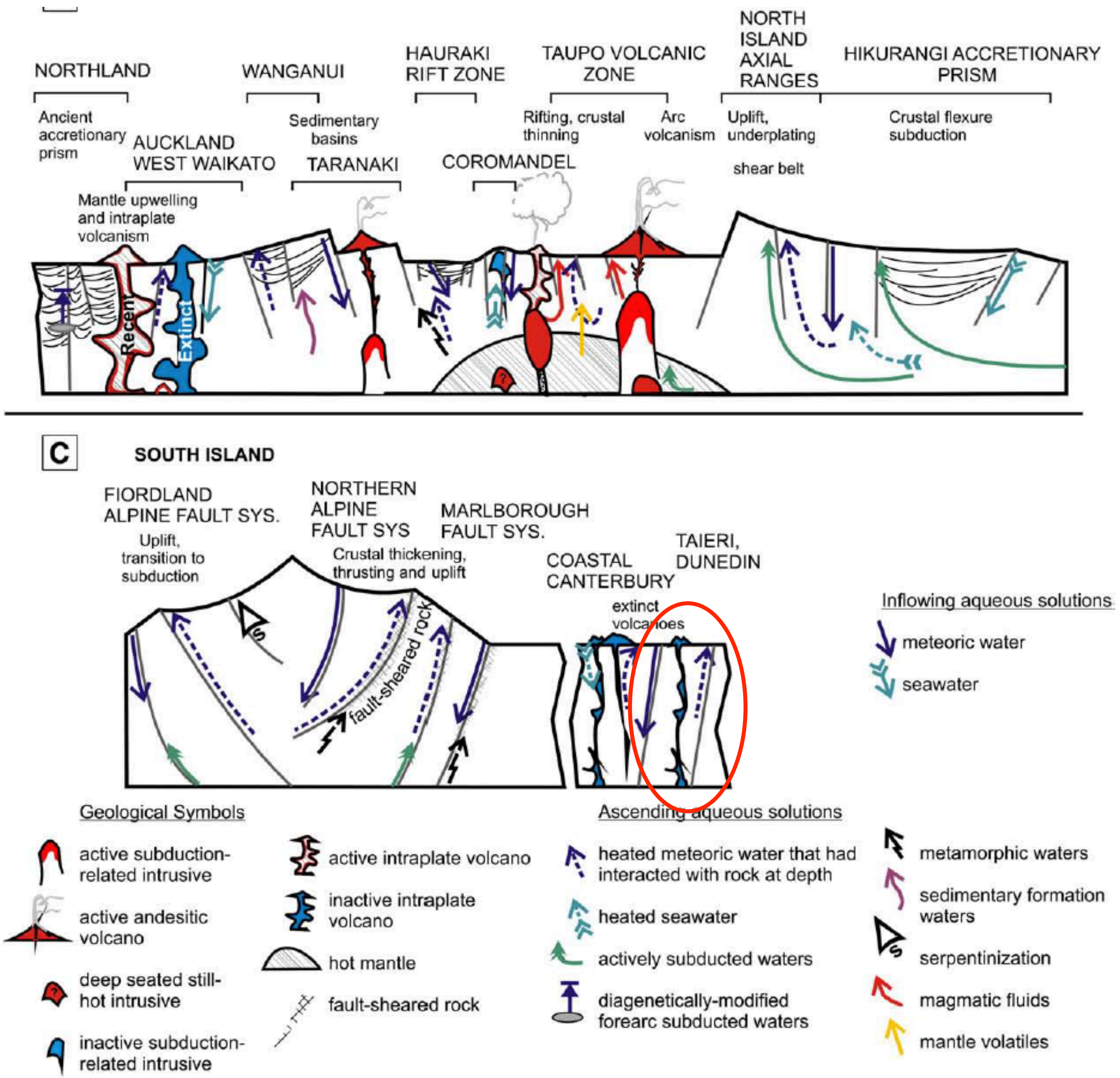

NORTHLAND
WANGANUI
HAURAKI
RIFT ZONE
TAUPO VOLCANIC
ZONE
NORTH
ISLAND
AXIAL
RANGES
HIKURANGI ACCRETIONARY
PRISM
Ancient
accretionary
prism
AUCKLAND
WEST WAIKATO
Sedimentary
basins
TARANAKI
COROMANDEL
Rifting, crustal
thinning
Arc
volcanism
Uplift,
underplating
shear belt
Crustal flexure
subduction
Mantle upwelling
and intraplate
volcanism
Recent
Extinct
C
SOUTH ISLAND
FIORDLAND
ALPINE FAULT SYS.
Uplift,
transition to
subduction
NORTHERN
ALPINE
FAULT SYS
Crustal thickening,
thrusting and uplift
MARLBOROUGH
FAULT SYS.
COASTAL
CANTERBURY
TAIERI,
DUNEDIN
extinct
volcanoes
fault-sheared rock
Inflowing aqueous solutions
meteoric water
seawater
Geological Symbols
active subduction-
related intrusive
active andesitic
volcano
deep seated still-
hot intrusive
inactive subduction-
related intrusive
active intraplate volcano
inactive intraplate
volcano
hot mantle
fault-sheared rock
Ascending aqueous solutions
heated meteoric water that had
interacted with rock at depth
heated seawater
actively subducted waters
diagenetically-modified
forearc subducted waters
metamorphic waters
sedimentary formation
waters
serpentinization
magmatic fluids
mantle volatiles

Further evidence of a potential geothermal energy resource beneath Dunedin comes from a gas-rich well on the Taieri.

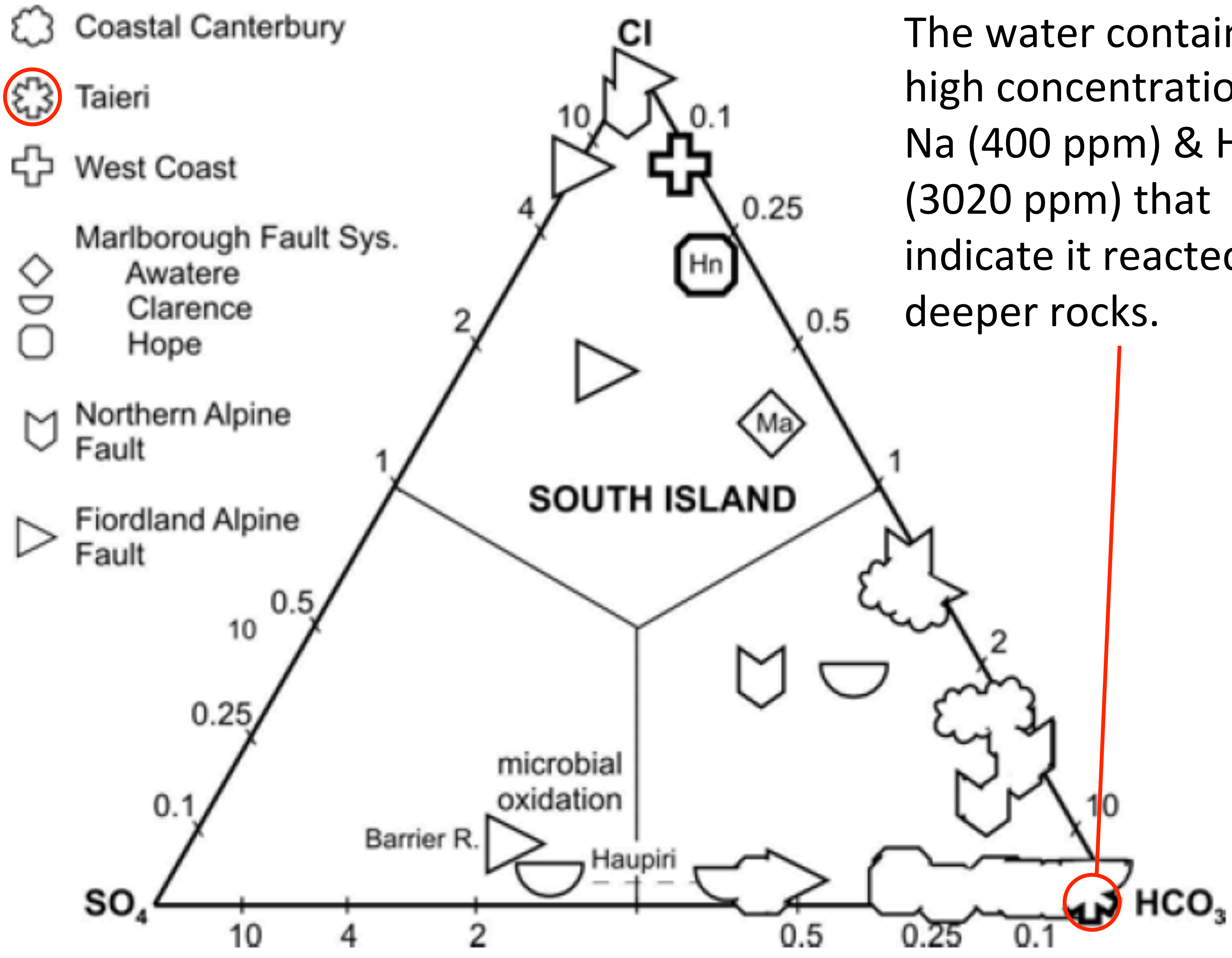
Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Assessing the Flow of Thermal Waters in Low-Temperature Mineral Spring Systems in the South Island, New Zealand

A. G. Reyes

EDGE

The latest active volcanism exposed on the surface in the Dunedin region, was about 10 Ma ago (Sewell and Weaver, 1989). However, an island of high heat flow, 80 mW^2 (Allis et al, 1998) and an above normal thermal gradient in the Taieri Basin, near Dunedin, exists. To explain these, Godfrey et al (2001) suggested that heat from hot mantle emplaced 10 My ago is just reaching the surface at present. The existence of an actively degassing hot mantle source is surmised from (1) seismic studies showing a low velocity crust coinciding with a highly reflective region (Godfrey et al, 2001) and (2) an isotopic He signature R/R_A of 6.64 indicating entrainment of about 83% of mantle volatiles (Giggenbach et al, 1993) from gas discharges in Taieri well, assuming that the source of CO_2 and He is not decoupled.



The water contains high concentrations of Na (400 ppm) & HCO_3^- (3020 ppm) that indicate it reacted with deeper rocks.

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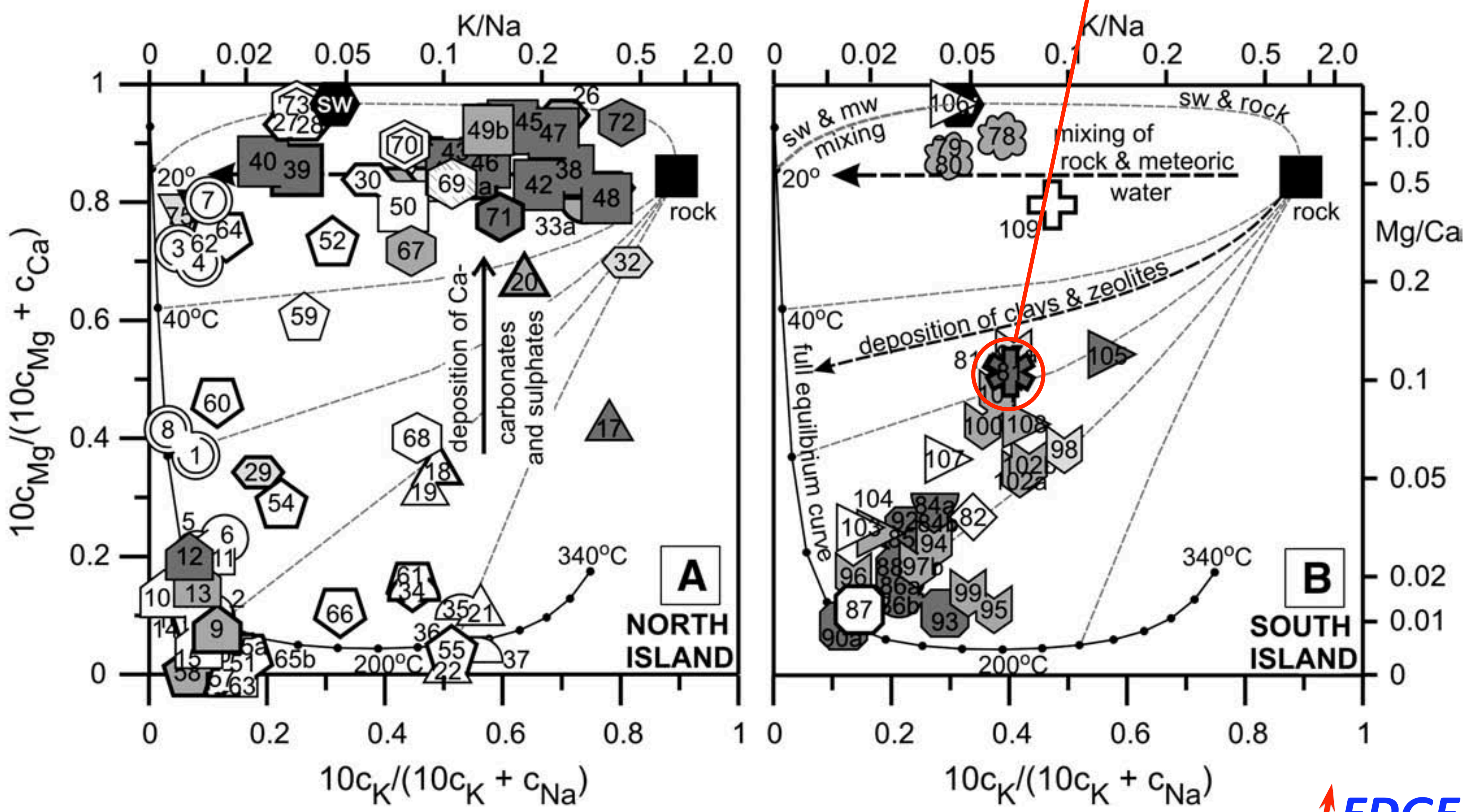
The composition of the fluid indicates these reactions took place at ≥ 40-60°C.



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Pergamon

Geochimica et Cosmochimica Acta, Vol. 64, No. 14, pp. 2489–2507, 2000

0016-7037/00 $20.00 + .00

PII S0016-7037(00)00346-X

The subcontinental mantle beneath southern New Zealand, characterised by helium isotopes in intraplate basalts and gas-rich springs

L. Hoke,[1,*,†] R. Poreda,[2] A. Reay,[3] and S. D. Weaver[4]

Table 3. The isotopic composition of helium measured in thermal and nonthermal gas emissions from the South Island of New Zealand.

Locality (ref. no.)	Lat.	Long.	Type	Date collected	°C	Rm/Ra	He/Ne	Rc/Ra	% Mantle helium	He	CO_2	N_2	CH_4	Ref.
Dunedin area														
Mitchell (16)	−45.11345	170.80433	w	900517	26	3.75	72	3.76	47.2	1.3100	190	780	2	b
Kingan (17)	−45.00000	170.64865	s	900517	—	0.38	4.2	0.33	4.1	0.0650	940	120	1	b
Wairongoa (18)	−45.80090	170.35400	s	980212	13	6.97	33.04	7.03	88.2	0.0510	992	7	0.08	a
Wairongoa (18)			s	980212	12	6.69	0.88	6.69*	83.9	0.0507	809	141	5.37	a
Wairongoa (18)			s	871101	18	6.64	104	6.66	83.5	0.0950	965	30	3	b
Wairobgoa (18)			s	900210	13	6.81	37	6.86	86.1	0.1300	960	32	4	b
Sailsbury Tunnel/N (19)	−45.77690	170.32840	s	980212	—	3.89	0.94	3.89*	48.8	0.0024	984	14	n.a.	a

[a] This work.
[b] Giggenbach et al., 1993.

tion of helium, and CO_2 and CH_4 contents in gases produced along the New Zealand part of a convergent plate boundary. *Geochim. Cosmochimi. Acta* **57**, 3427–3455.

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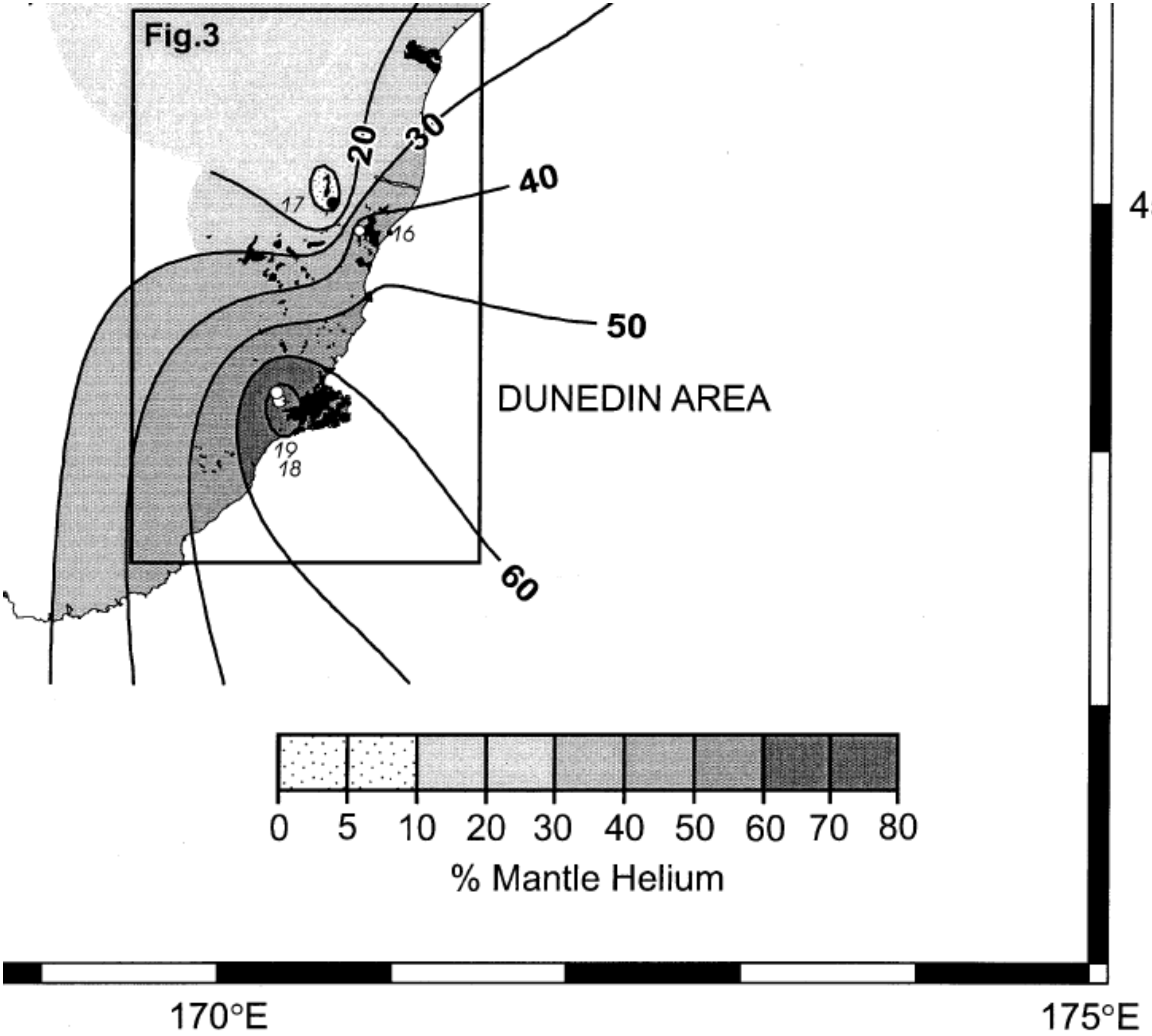


Fig.3
20
30
40
50
60
17
16
19
18
DUNEDIN AREA
45°S
0
5
10
20
30
40
50
60
70
80
% Mantle Helium
170°E
175°E

An order-of-magnitude calculation indicates that the still hot igneous rock lies about 20 km deep.

Conductive heat transport

$$L = (\alpha t)^{1/2}$$

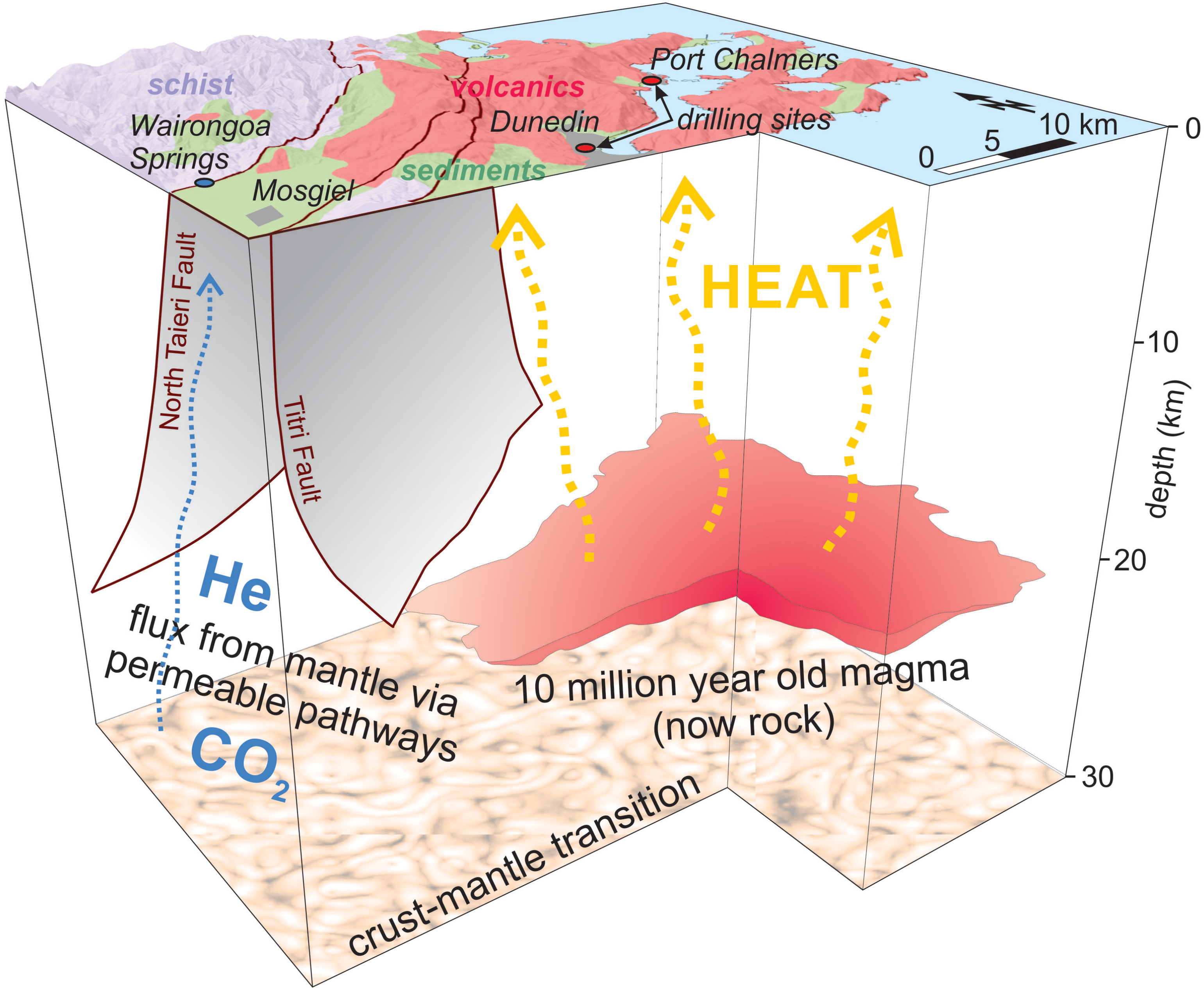
for

$$\alpha = 10^{-6}\ m^2\ s^{-1}$$

$$t = 11\text{-}16\ \text{Myr}\ (3.5\text{-}5 \times 10^{14}\ s)$$

then

$$L = 19\text{-}22\ \text{km}$$


schist
volcanics
Port Chalmers
Wairongoa
Springs
Dunedin
drilling sites
Mosgiel
sediments
10 km
5
0
0
10
20
30
depth (km)
North Taieri Fault
Titri Fault
HEAT
He
flux from mantle via
permeable pathways
CO2
10 million year old magma
(now rock)
crust-mantle transition