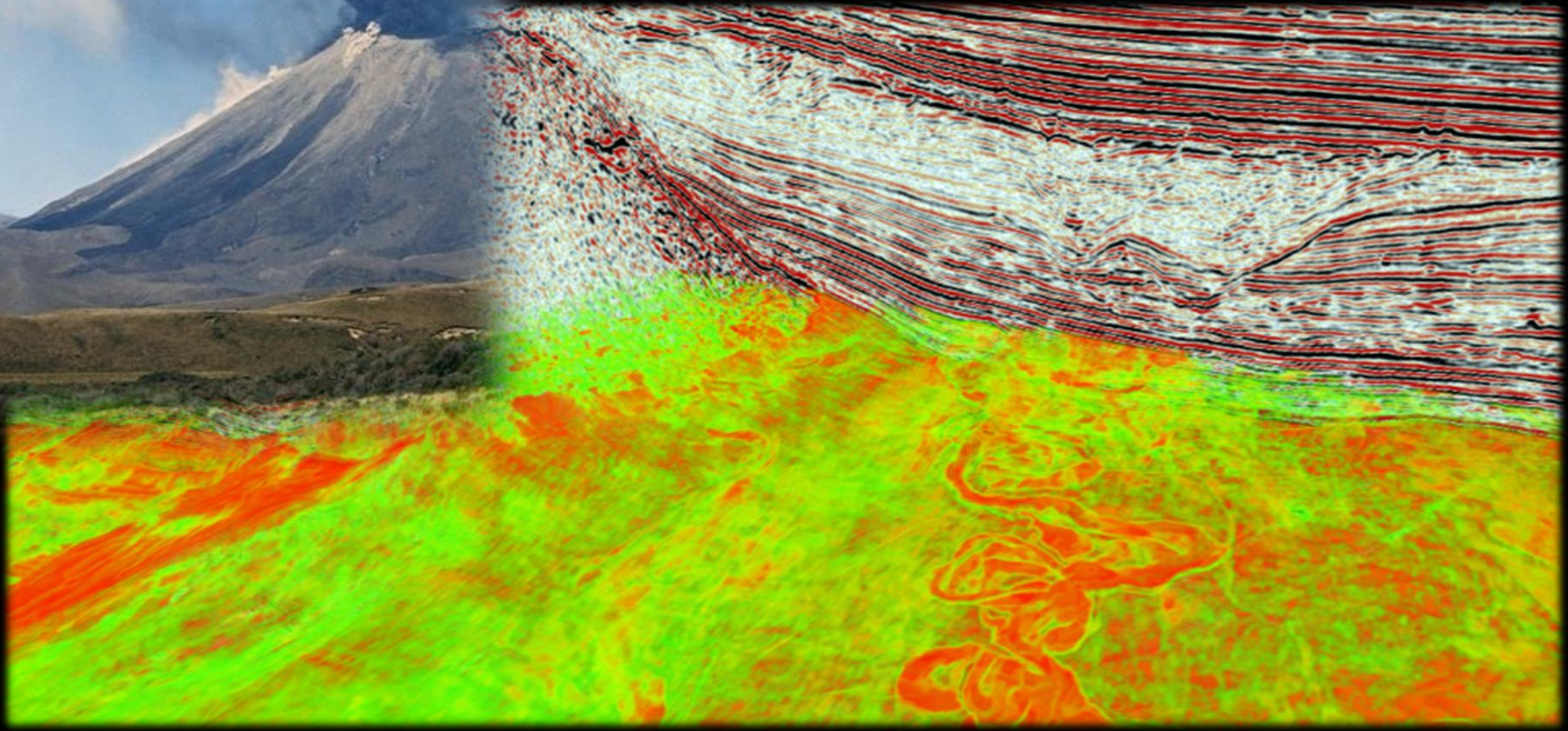
Volcanic rocks as petroleum reservoirs and their role in the emerging renewable energy industry

Dr Alan Bischoff
University of Canterbury, New Zealand

2020 Summer Academic Lecture activity for Graduate Students
China University of Petroleum



Presentation Outline

1

Igneous rocks and magmatic processes

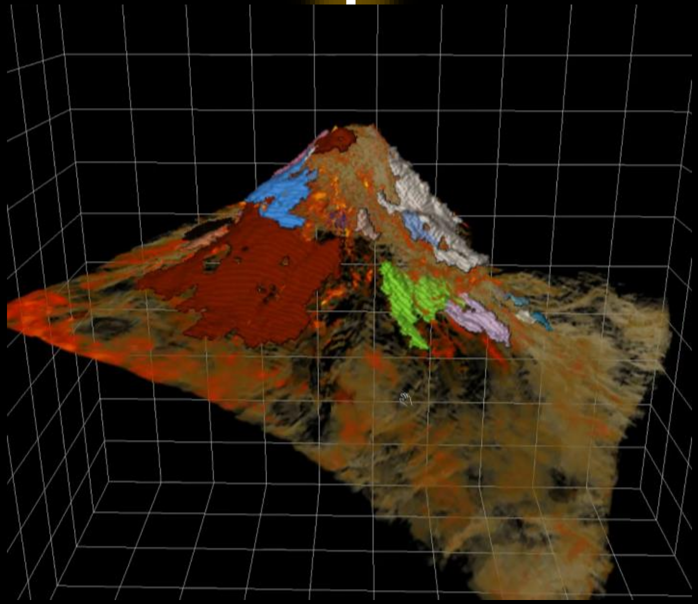
2

Volcanic rocks as petroleum reservoirs

Pyroclastic rock. ϕ: 47%. k: 798 mD

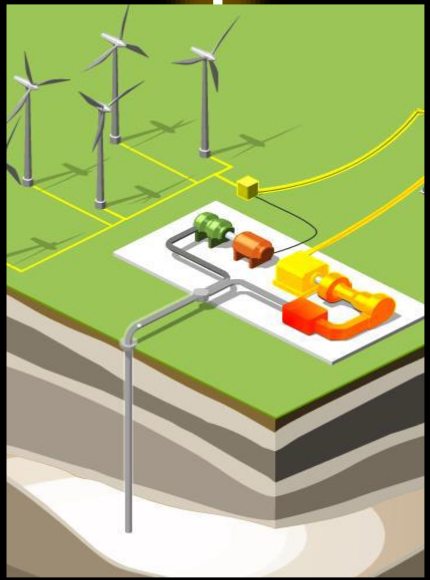
3

Modern interpretation of buried volcanic systems



4

Emerging renewable energy industry



Part 1
Igneous rocks and magmatic processes

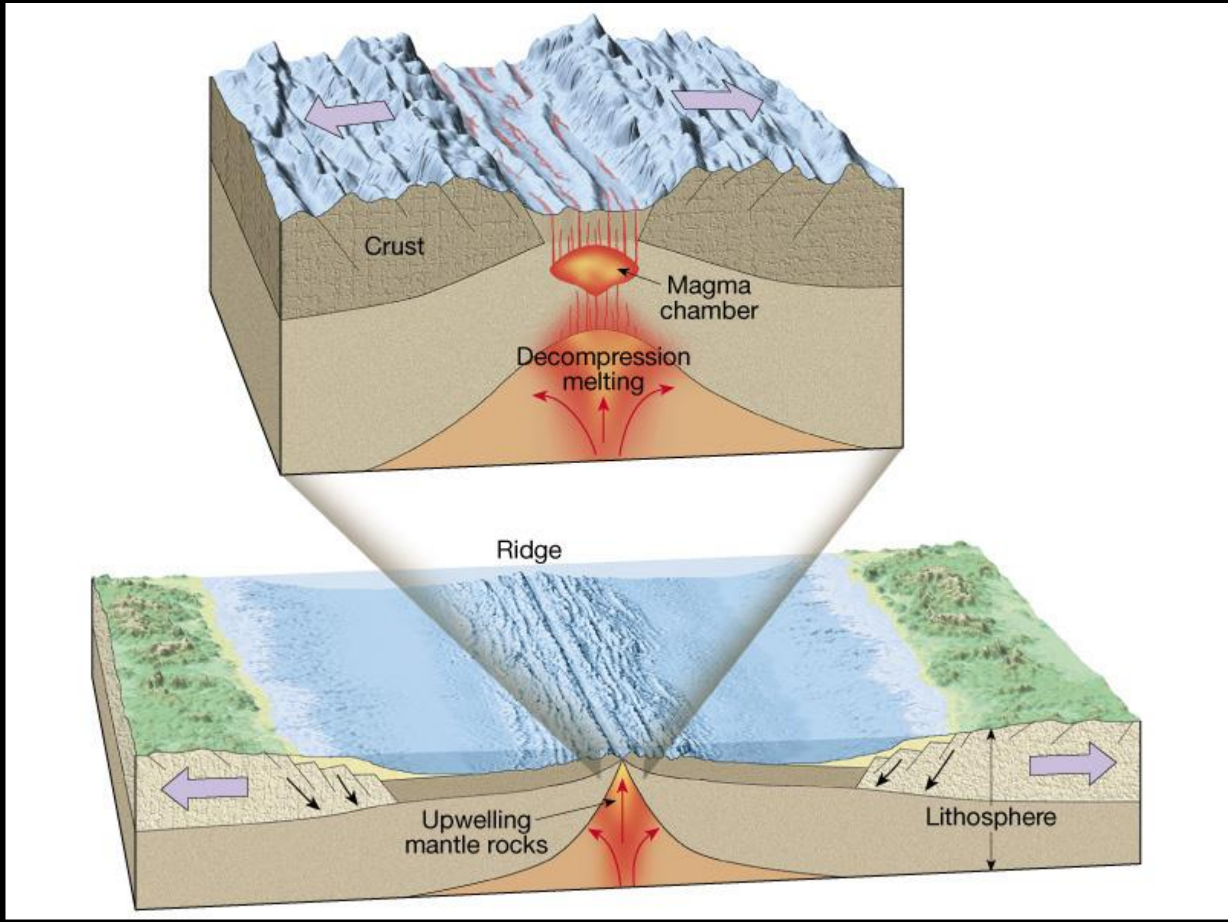
1- Genesis of igneous rocks

2- Volcanic and sub-volcanic environments

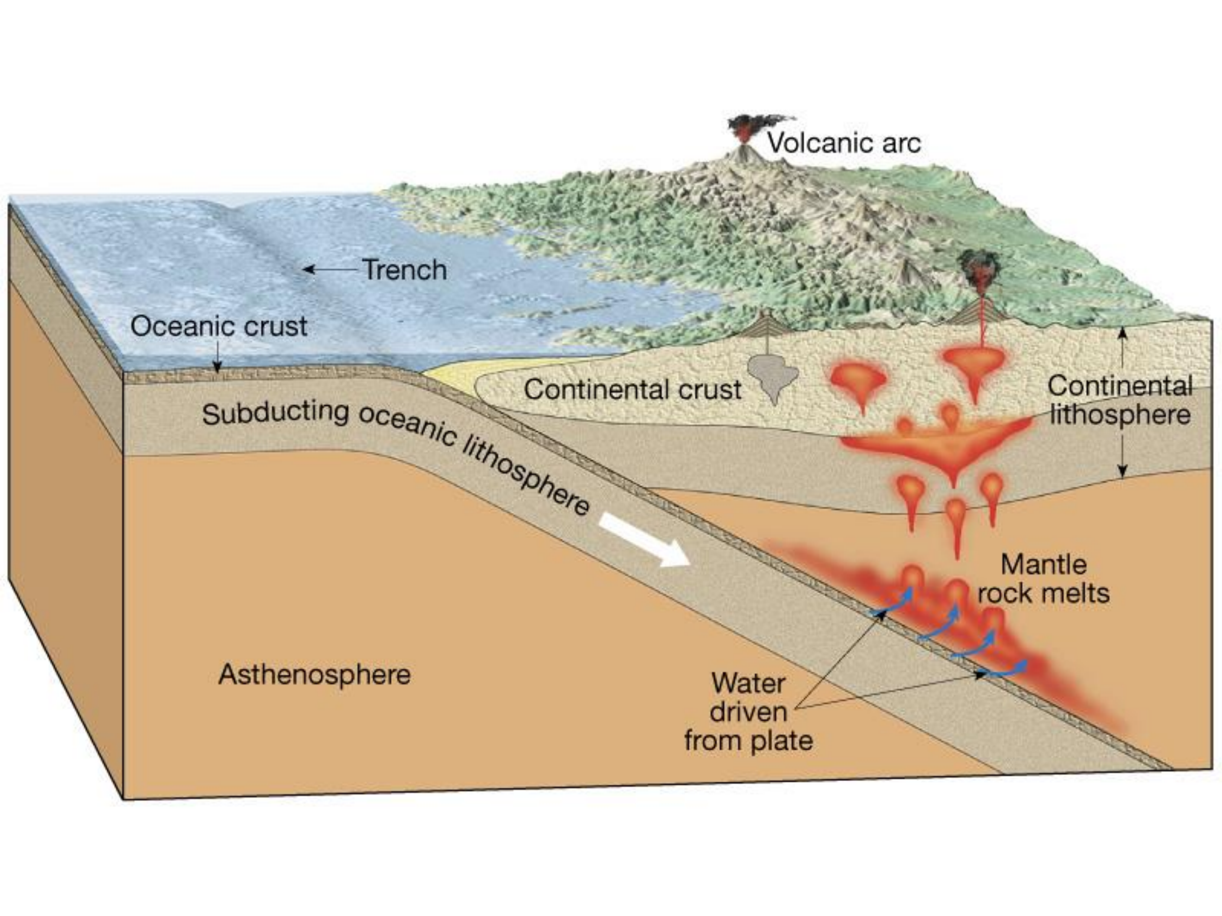
3- Classification of igneous rocks

Partial melting of the lower crust and upper mantle

decompression melting

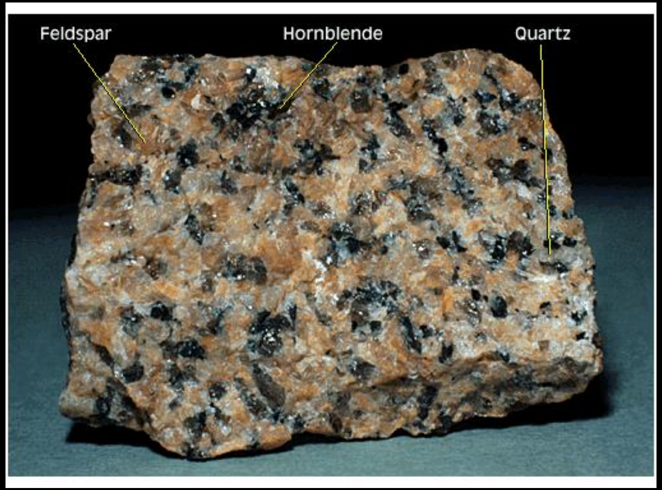


fluid-induced melting



1- Genesis of igneous rocks

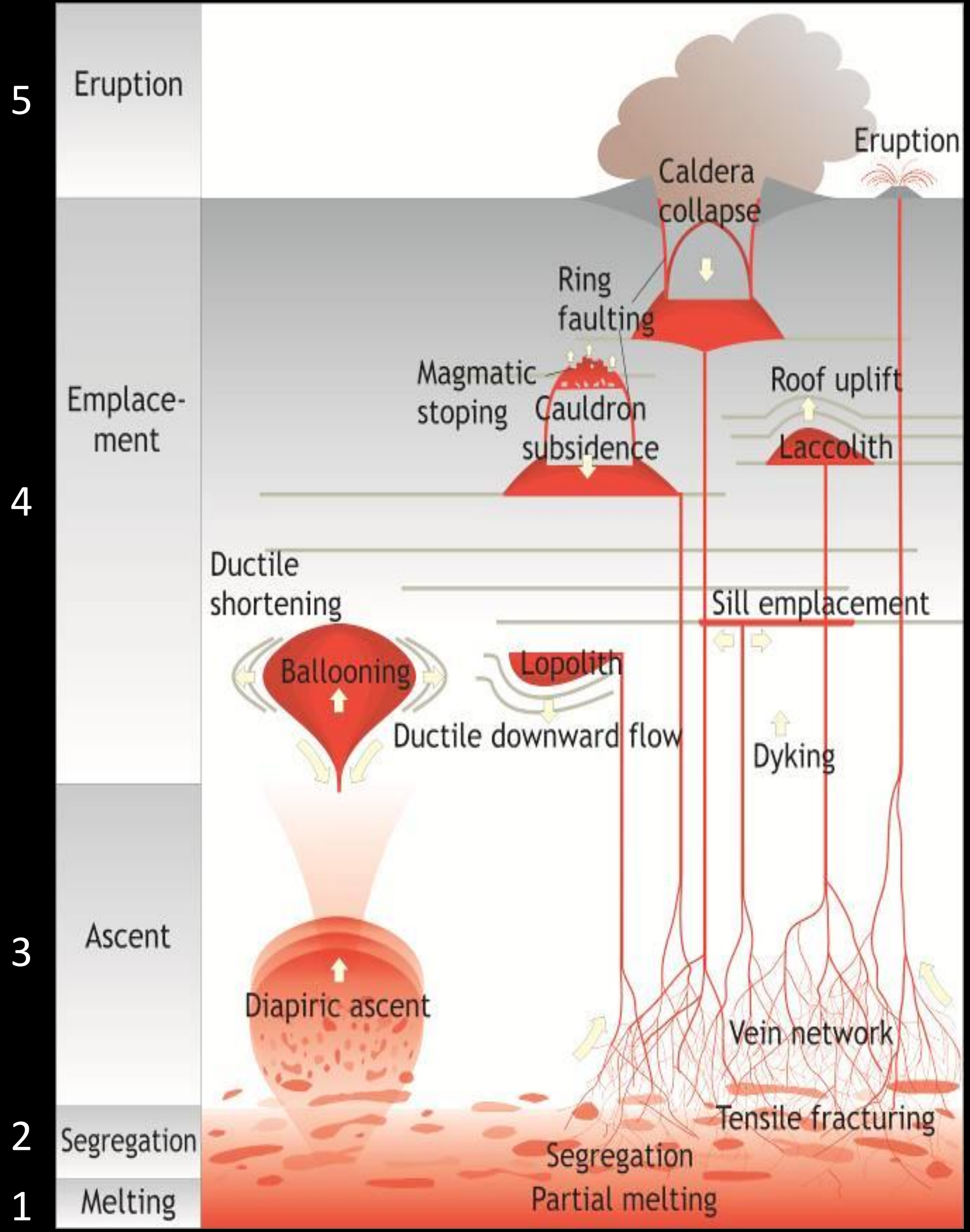
Eruption



Granite: batholiths, large plutons

Diabase: dikes and sills

Migmatite: partial melting



Burchardt, 2009

Viscosity: resistance to flow. Mainly controlled by the chemical composition of the magma.

Mafic magmas, lower silica (basalt).
Low viscosity (runny)

Felsic magmas, high silica (rhyolite).
High viscosity (sticky)

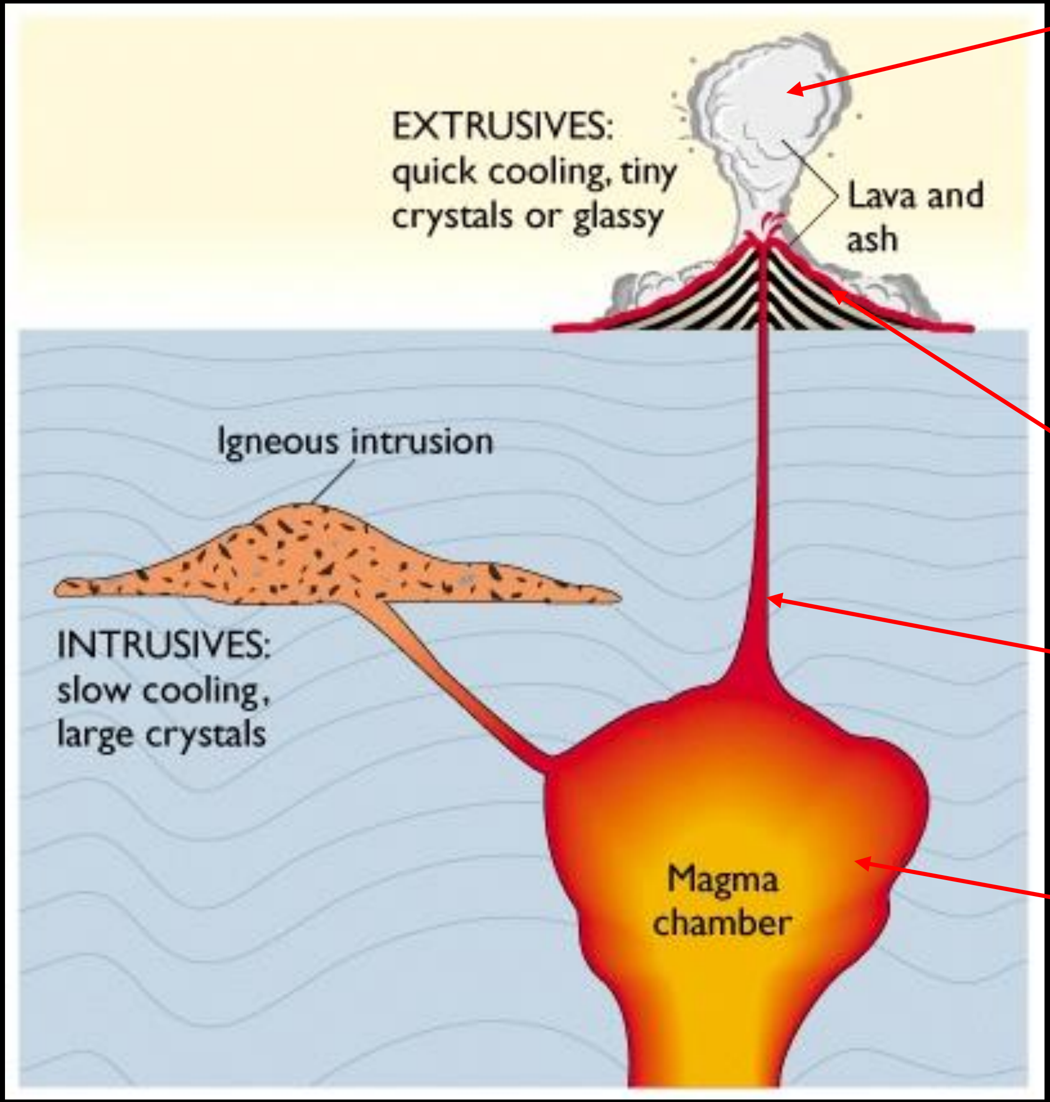
1- Genesis of igneous rocks

Explosivity: Magmas with low viscosity allow gas to escape more easily = less explosive

low gas content +
fluidal lava
quiet eruptions

high gas content +
sticky lava
explosive
eruptions

2- Volcanic and sub-volcanic environments



Explosive eruption

Pyroclastic

Effusive eruption

Aphanitic, coherent

Autoclastic

Medium-grained phaneritic

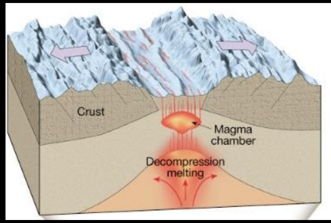
Coarse-grained phaneritic

Heaven Lake, Changbaishan volcano, China.

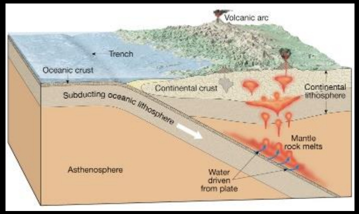
1 and 2 - Genesis and environments of igneous rocks: TAKE-HOME MESSAGE

Igneous rocks form by PARTIAL MELTING

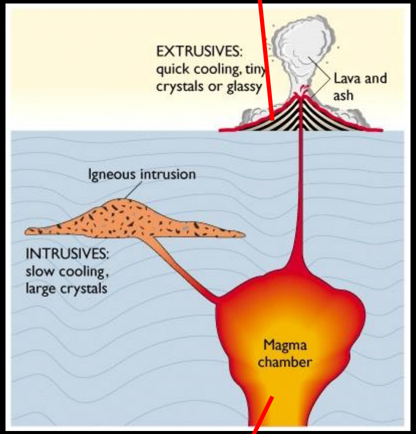
decompression



fluid-induced



Magma that crystalizes above the surface form aphanitic extrusive rocks



Magma that crystalizes below the surface form phaneritic intrusive rocks

Eruptions can be

Explosive

Effusive

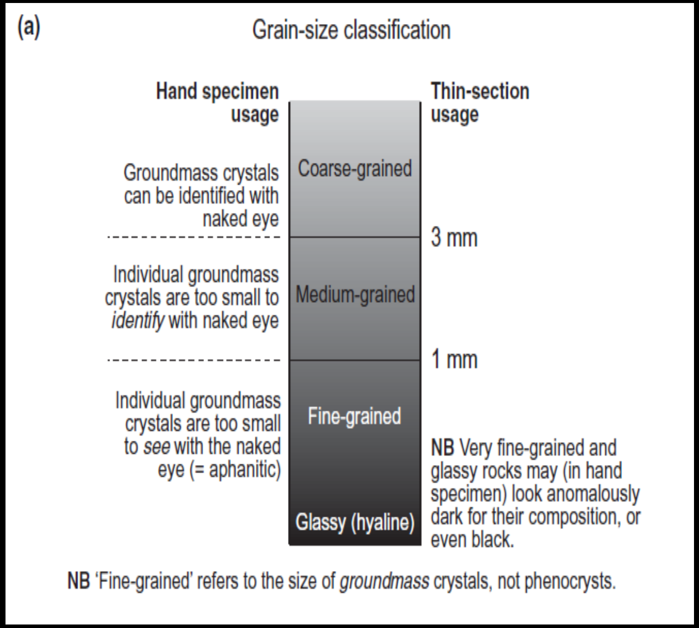
Pyroclastic

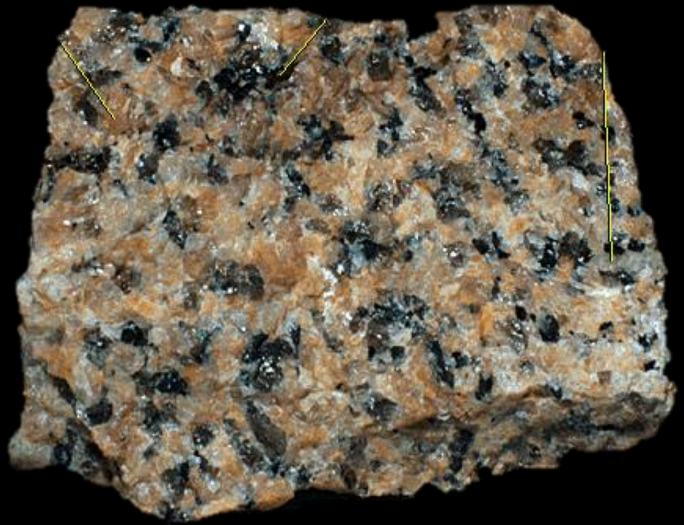
Coherent lava

autoclastic lava

3- Classification of igneous rocks

Textural: grain-size





Coarse-grained phaneritic

Glassy

Aphanitic

Porphyritic

3- Classification of igneous rocks

Textural: particle fragmentation

Coherent

a unified whole solidified product of magma

Clastic

Autoclastic fragments form by mechanical friction during movement of lava and breakage of cool brittle outer margins

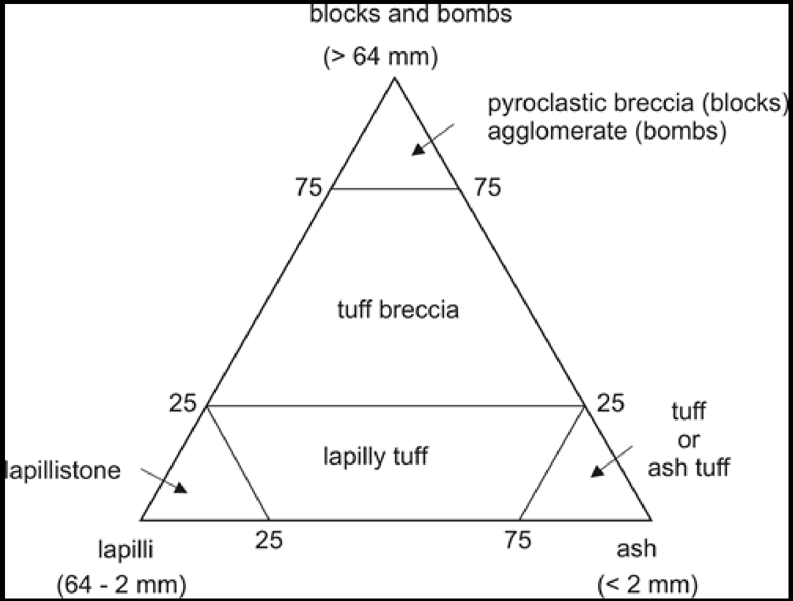
Hydroclasts form by steam explosions from magma-water interactions

Pyroclastic form by fragmentation of magma and country rocks, as gases are released by decompression and then ejected from a volcanic vent

Epiclasts are sediments derived from erosion of volcanoes or ancient volcanic terrains

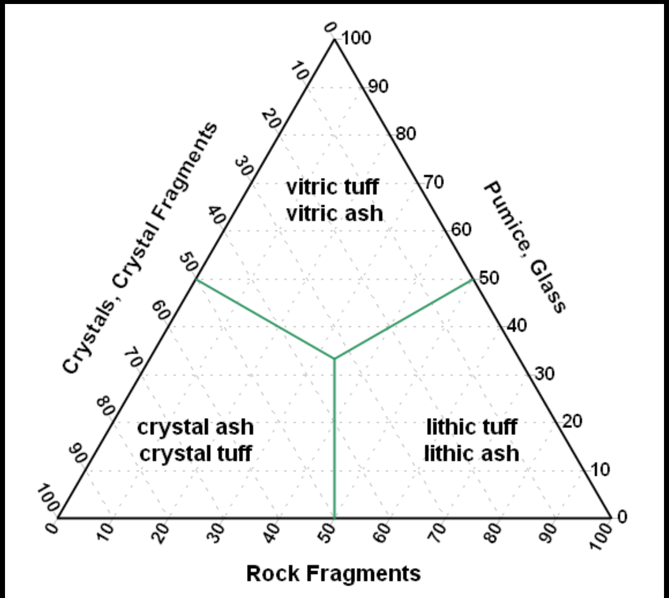
3- Classification of igneous rocks

Classification of pyroclastic rocks using size abundances



Fisher, 1966

Classification of pyroclastic rocks using fragment composition



Pettijohn, 1975

Cinder or tephra: volcanic fragments, typically of pyroclastic material

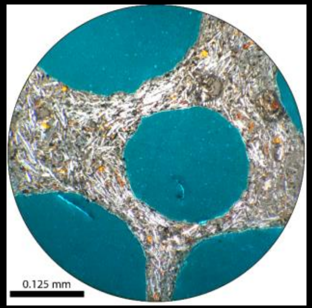
Spatter: blobs of lava thrown into the air and deposited near a vent

Welded pyroclastic

Unwelded pyroclastic

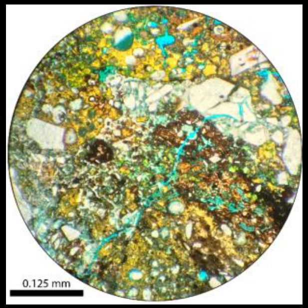
Textural: vesicularity, result of gas trapped in the melt at the time of solidification

Vesicular volcanic rock



Massive volcanic rock

Clastic volcanic rock



3- Classification of igneous rocks

Structural: massive, fractured, banded, layered

Massive volcanic rock

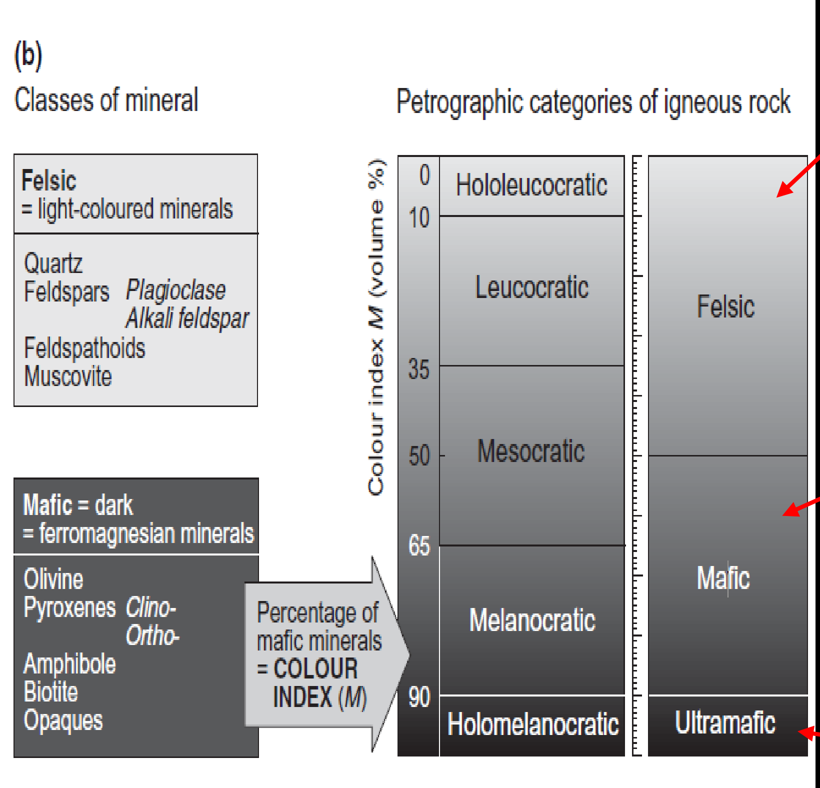
Banded volcanic rock

Fractured volcanic rock

Layered volcanic rock

3- Classification of igneous rocks

Colour index: volume proportions of light (felsic) and dark (mafic)



Leucocratic, felsic, phaneritic.
Typically granites

Leucocratic, felsic, aphanitic
Typically rhyolites

Melanocratic, mafic, phaneritic.
Typically gabbros

Melanocratic, mafic, aphanitic.
Typically basalts

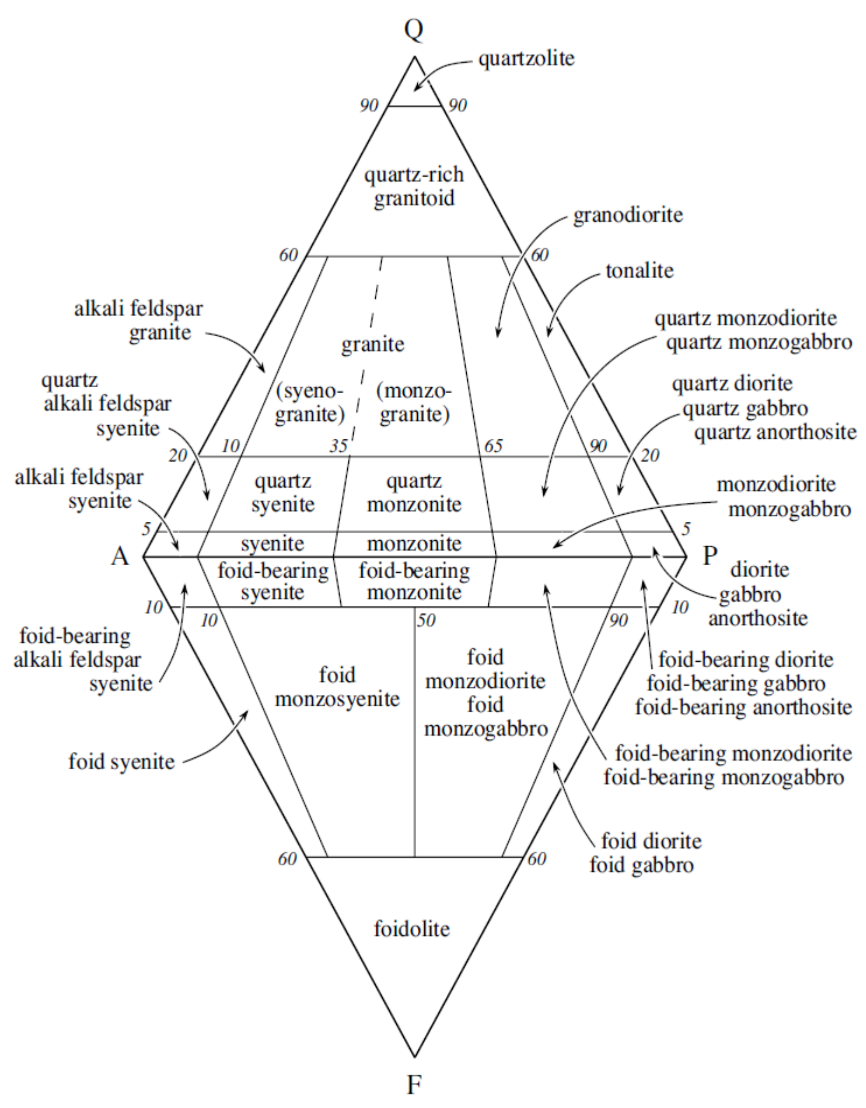
Holomelanocratic, ultramafic, phaneritic.
Typically peridotites

Holomelanocratic, ultramafic, aphanitic.
Typically Komatiites

3- Classification of igneous rocks

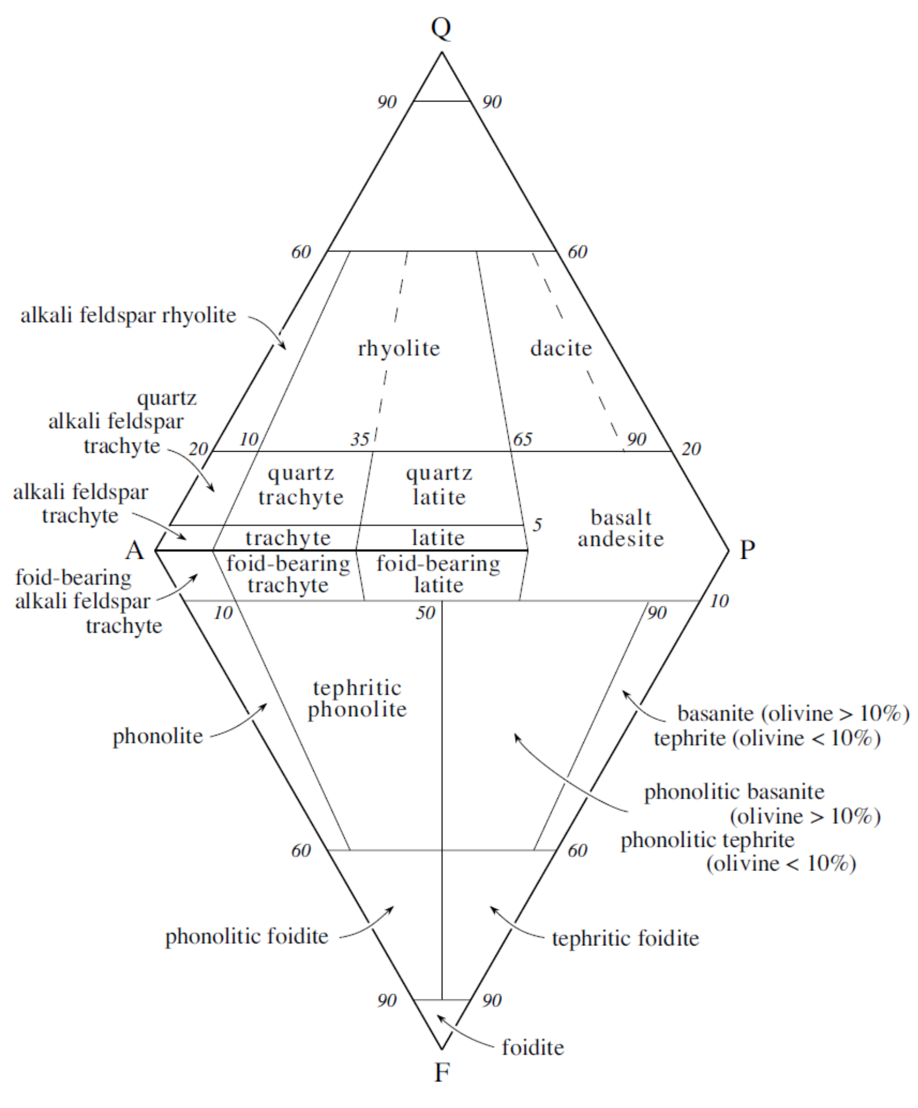
QAPF modal classification. Perceptual of quartz, plagioclase, k-feldspar and feldspathoid minerals

Plutonic or intrusive rocks



Streckeisen, 1976

Volcanic or extrusive rocks

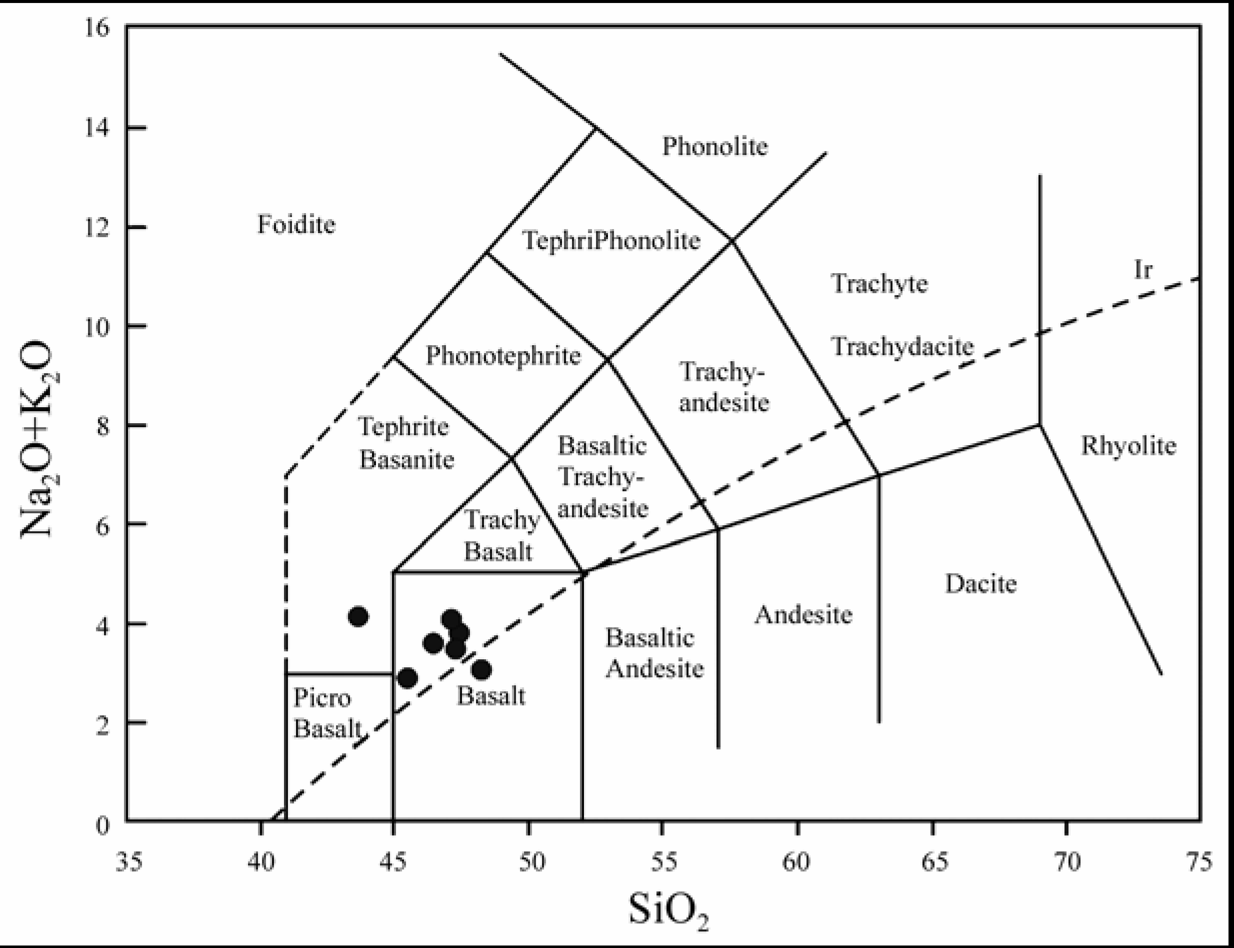


Streckeisen, 1976

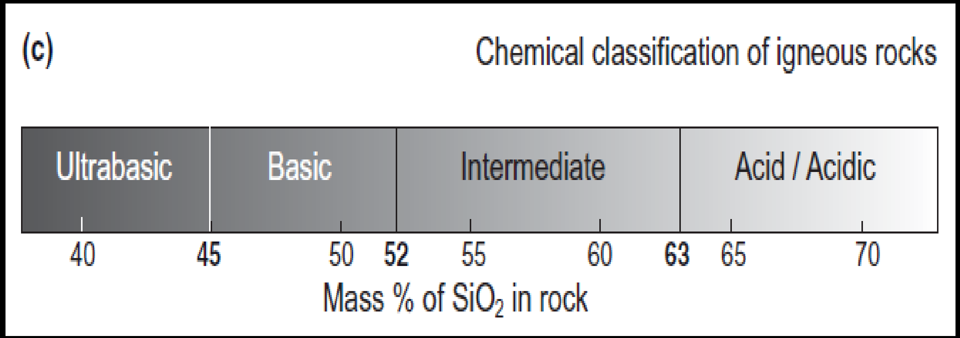
3- Classification of igneous rocks

Chemical

TAS diagram: Stands for Total Alkali vs Silica

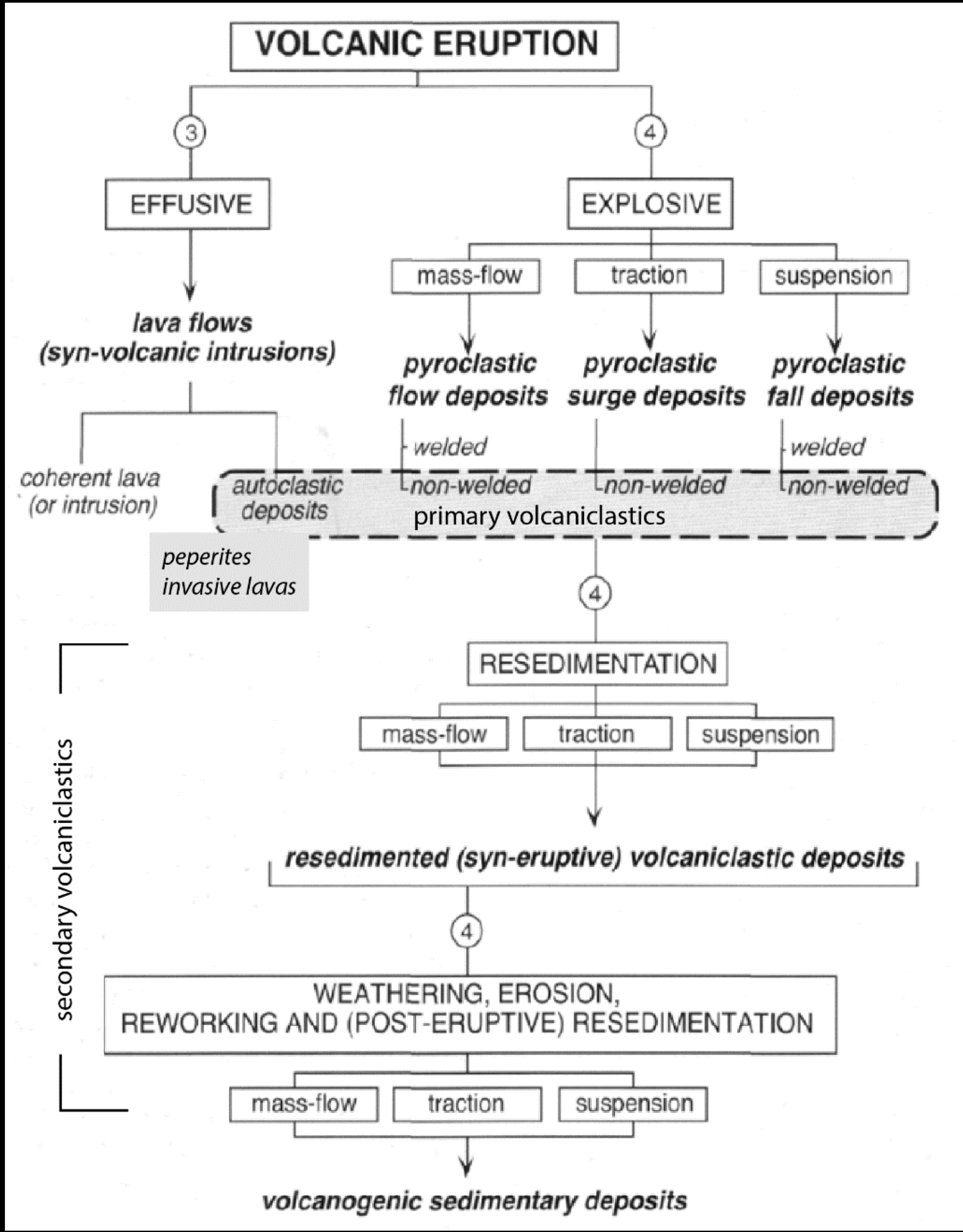


Le Maitre et al., 2002



3- Classification of igneous rocks

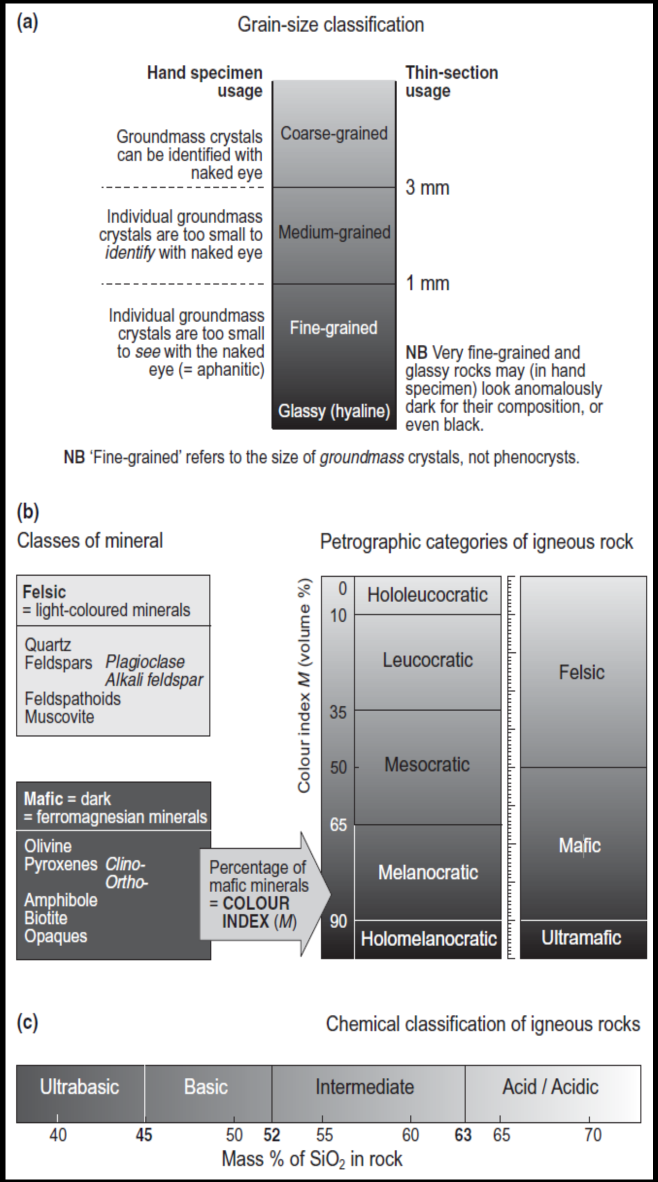
Genetic classification of volcanic rocks

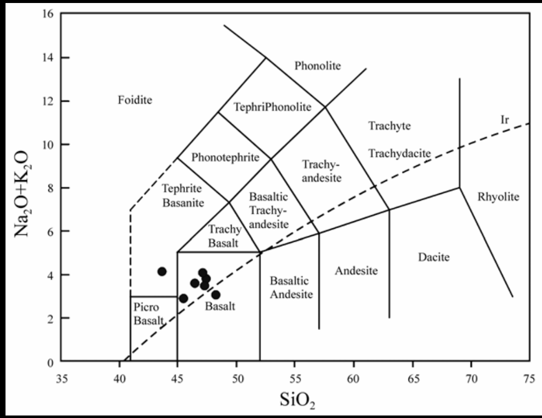


Modified from McPhie et al. (1993).

Epiclastic

3- Classification of igneous rocks: TAKE-HOME MESSAGE





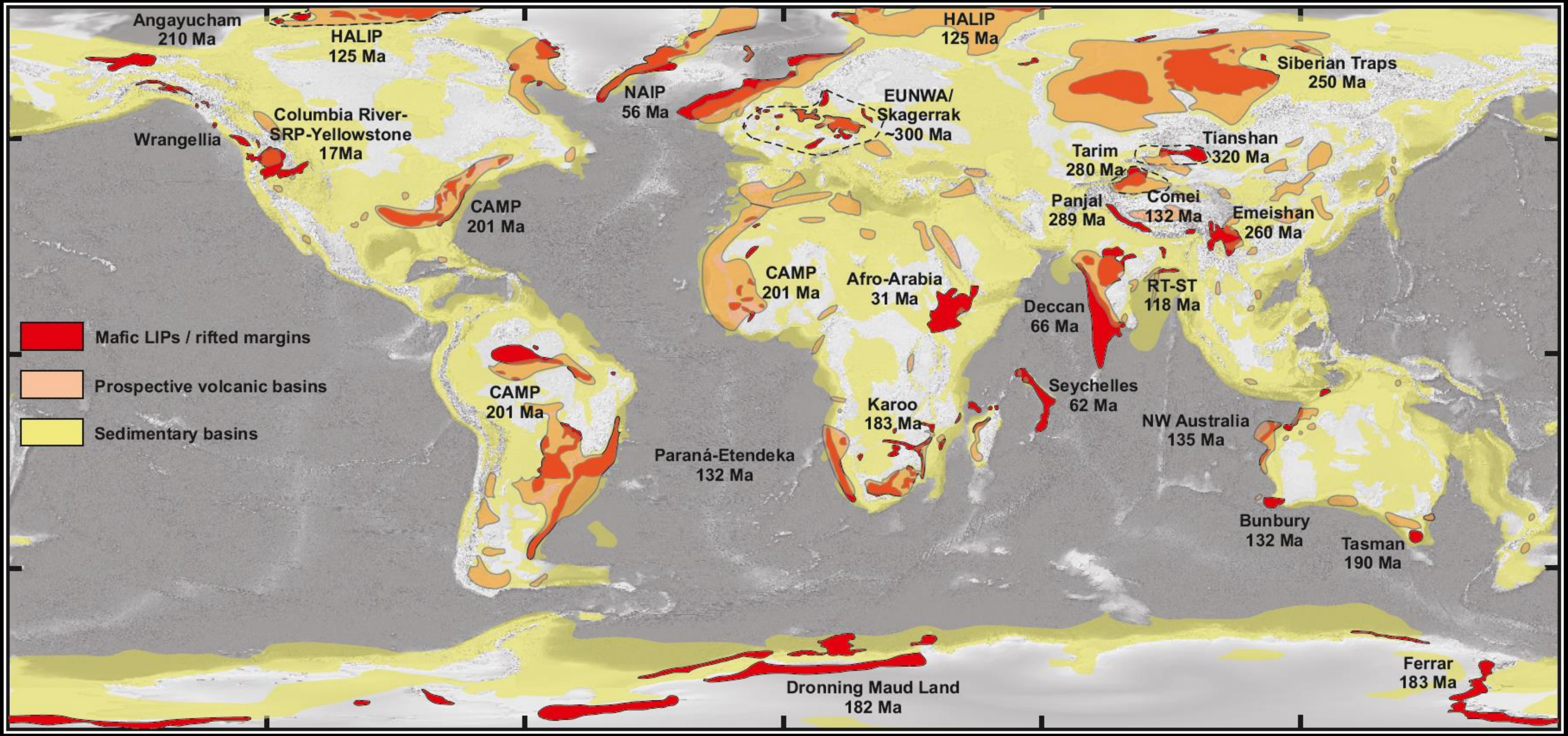
Part 2
Volcanic rocks as petroleum reservoirs

1- Global distribution

2- Types of volcanic reservoirs

3- Petrophysical controls

Global distribution of igneous rocks in sedimentary basins



Senger et al., 2017

Examples of O&G fields associated with volcanoes

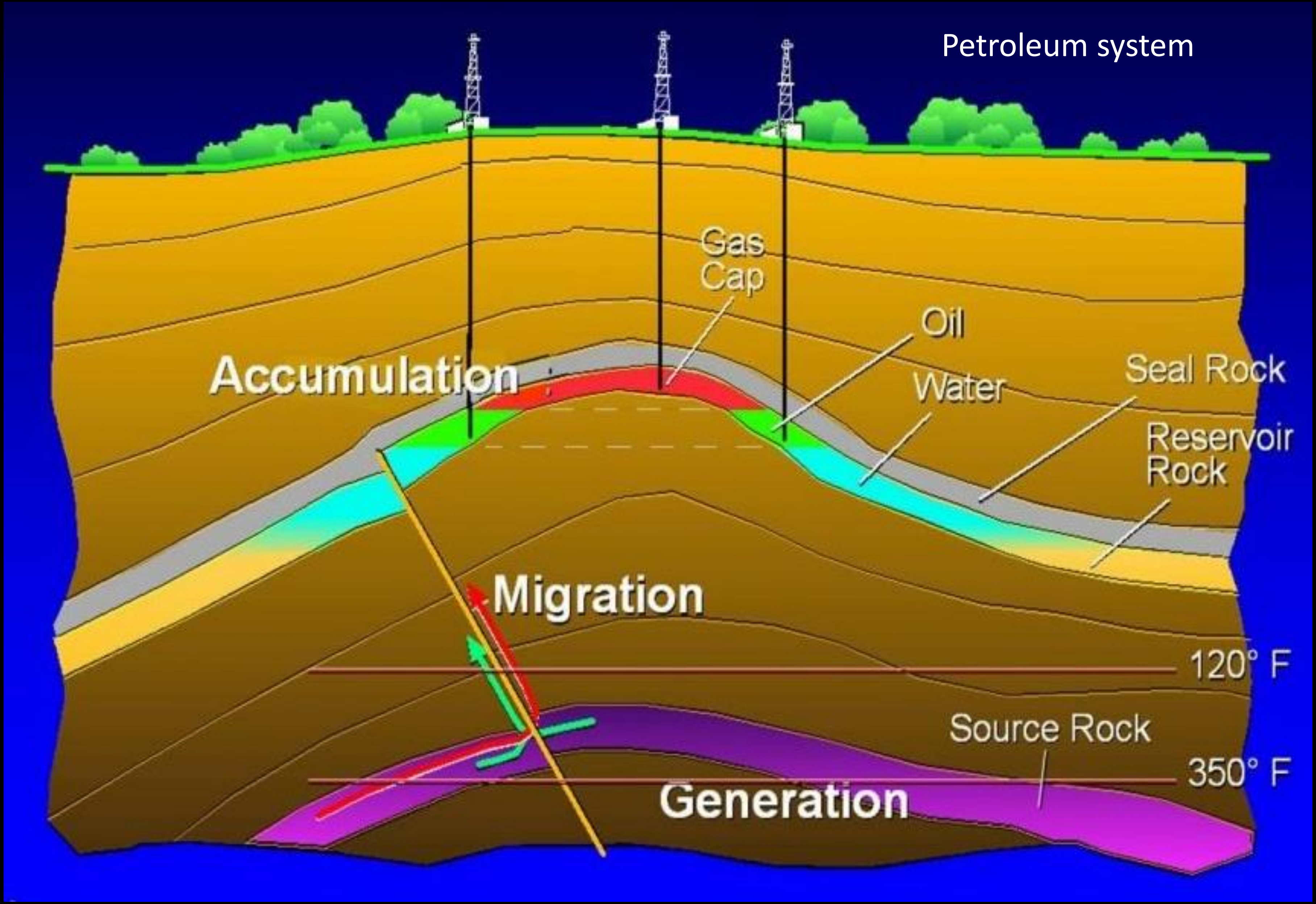
Location	Basin/Field	O&G volume	Reservoirs
USA	Sheep Basin	100 Kbbl	pyroclastic rocks
Greenland	Nussauq Basin	50 Mbbl	vesicular basalts
Indonesia	Krishna Field	200 Mbbl	limestone draping volcano
Algeria	Ilizi Basin	400 Mbbl	sandstone over intrusion
Myanmar	Yadana Field	5 tcf	limestone draping volcano
Brazil	Pão de Açúcar Field	700 Mbbl and 3 tcf	limestone draping volcano and pillow-lavas
Indonesia	Jatibarang Field	1.2 Gbbl and 2.7 tcf	fractured basalts
China	Songliao Basin	14 tcf	volcanic reservoirs
Brazil	Lula and Mero fields	> 10 Gbbl	limestone associated with volcanic rocks and hydrothermal activity

Note: oil volumes follow the International System of Units (SI)

K: thousand
M: million
G: billion
Tcf: trillion cubic feet

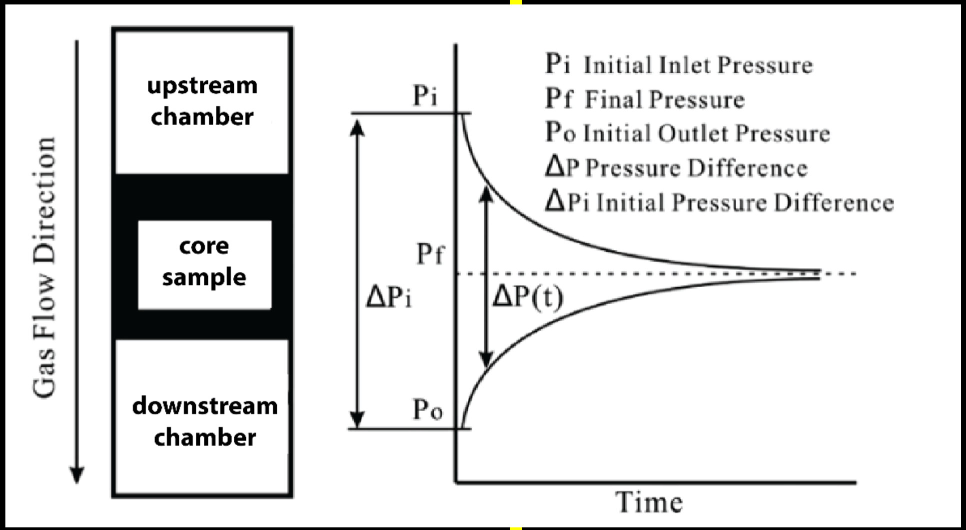
Pyroclastic rock exhuming oil, Kora Volcano, New Zealand

Concepts: volcanic reservoirs, seals, traps



Measuring porosity and permeability

Pulse Decay Permeameter

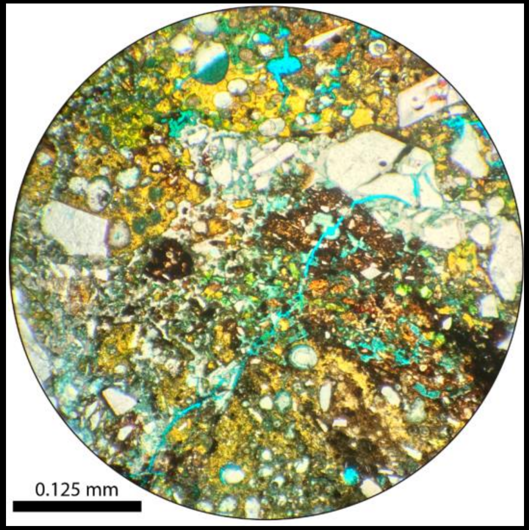


$$kgas = \left(\frac{2nL}{A}\right)\left(\frac{V_{up}}{P_{up}^2 - P_{down}^2}\right)\left(\frac{\Delta P_{up}}{\Delta t}\right)$$

ϕ and k result

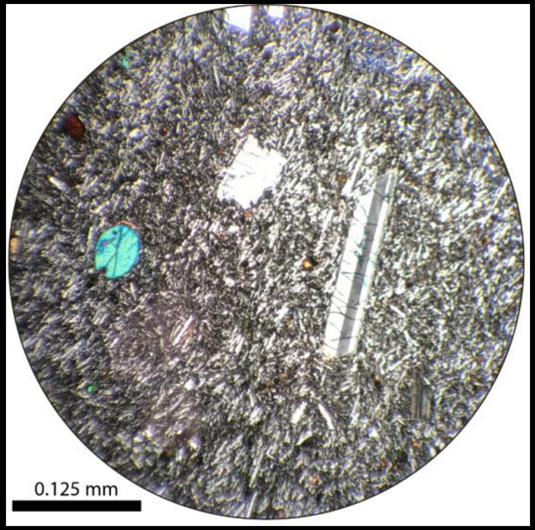
Concepts: Porosity and permeability

Pyroclastic volcanic reservoir



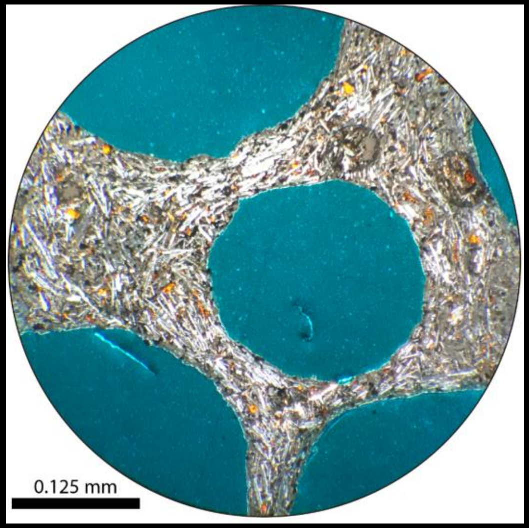
ϕ: 46.97 %
k: 798 mD

Effusive volcanic seal



ϕ: 3.42 %
K: 0.006 mD

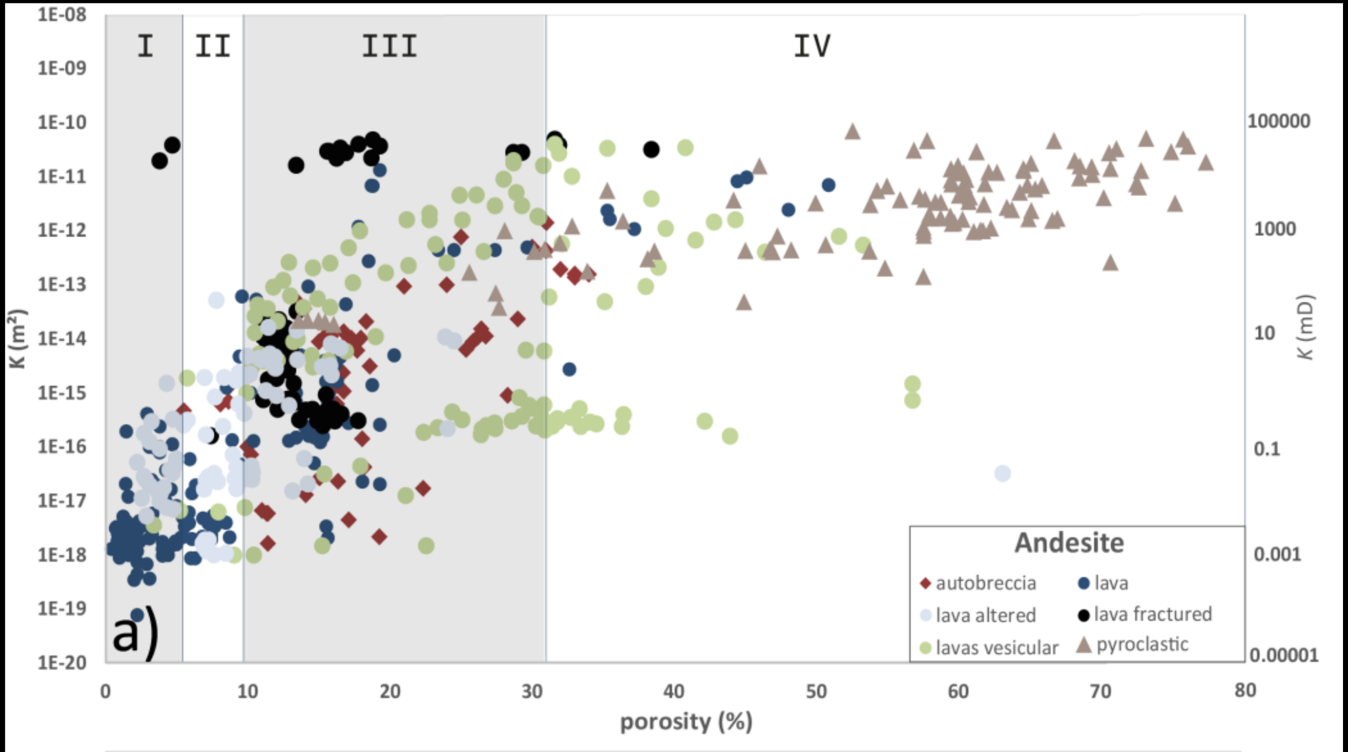
Pyroclastic volcanic seal

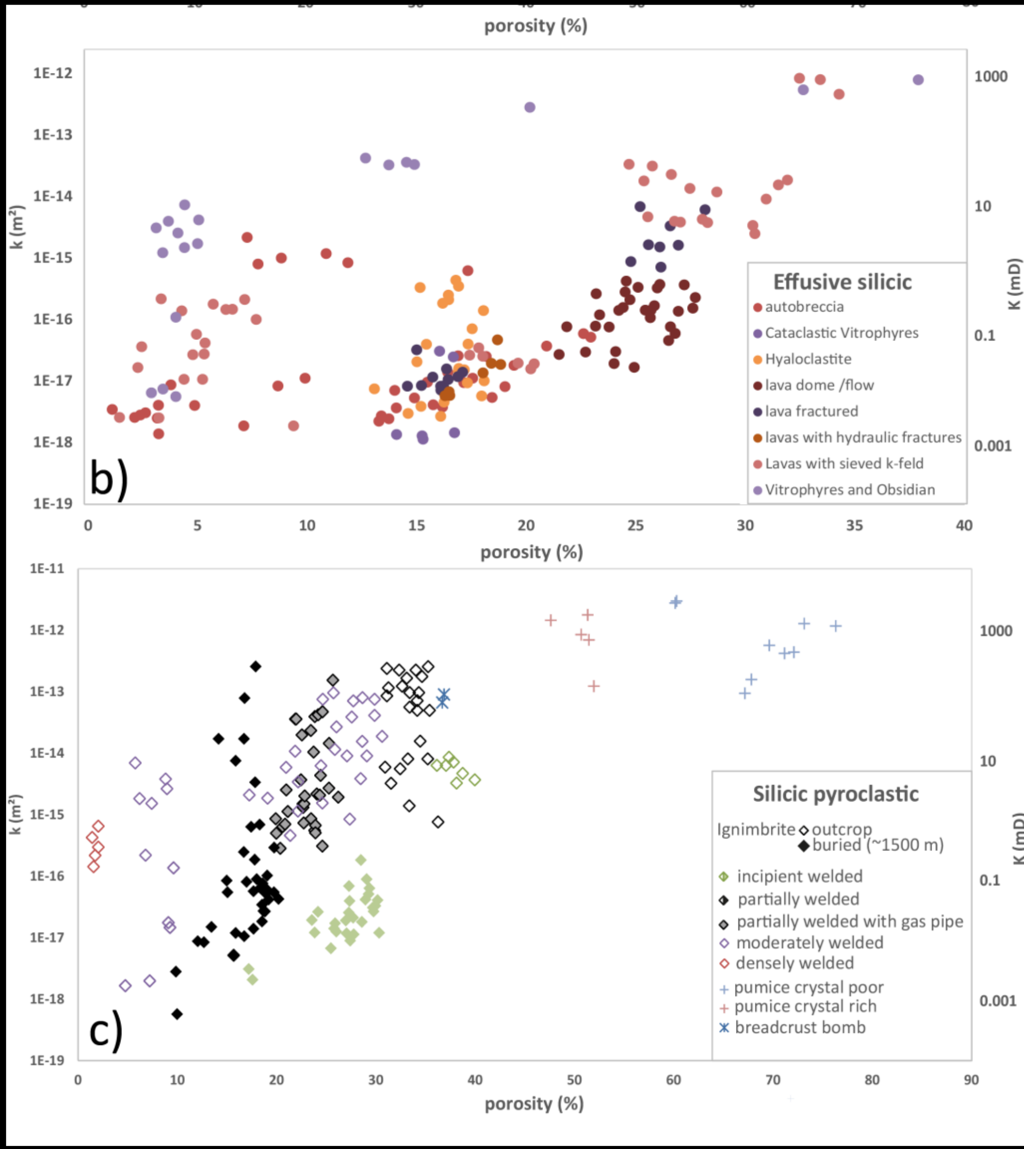


ϕ: 57.44 %
k: 0.11 mD

Petrophysical global databank

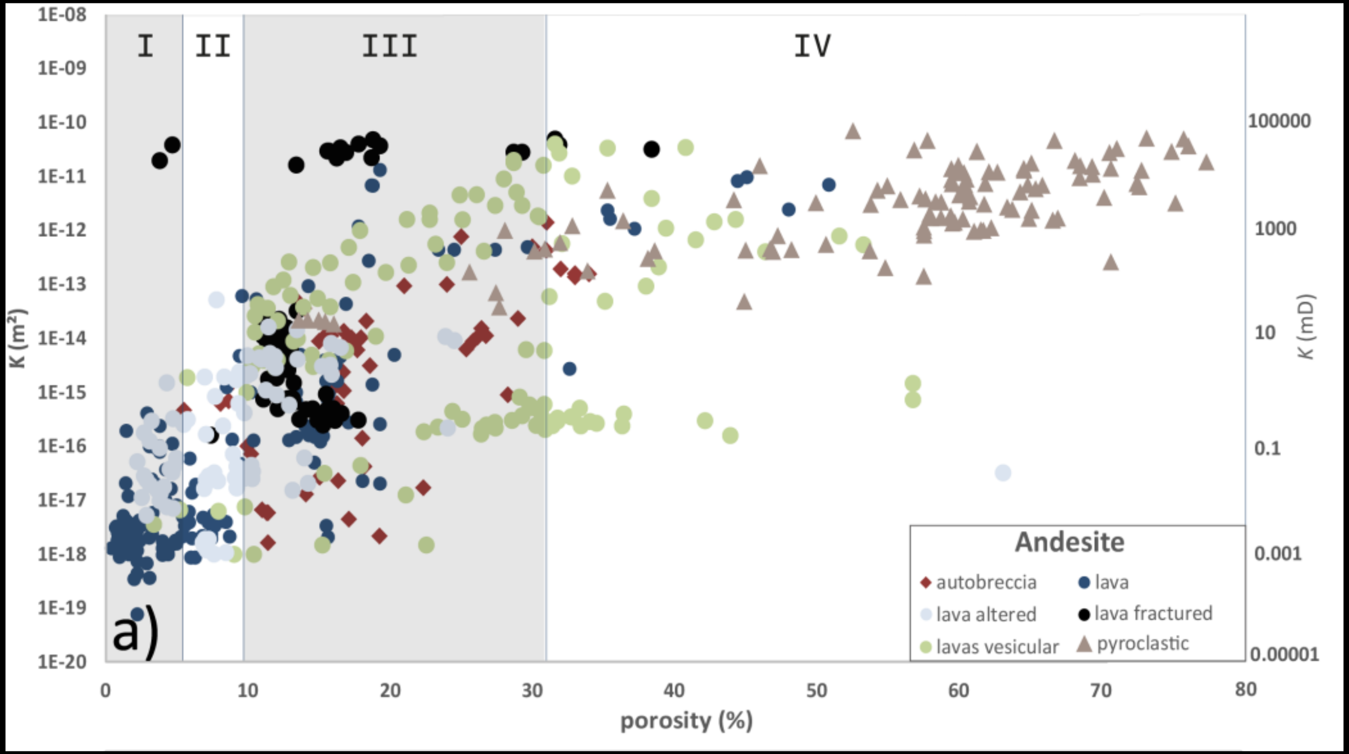
ϕ and k from 3811 samples of volcanic rocks globally distribute and from a range of depths





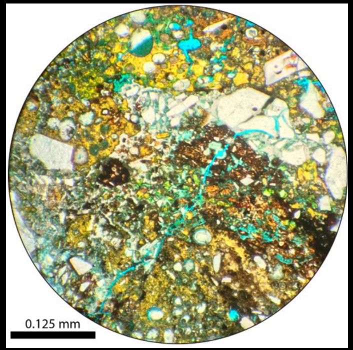
Primary controls in the porosity and permeability of volcanic rocks

Material fragmentation



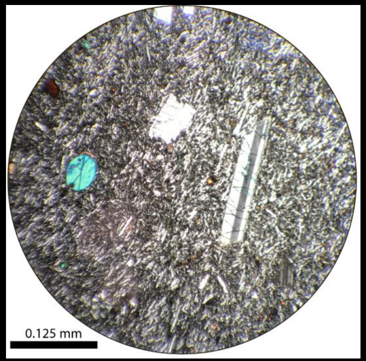
Pyroclastic andesite

ϕ: 46.97 %
k: 798 mD



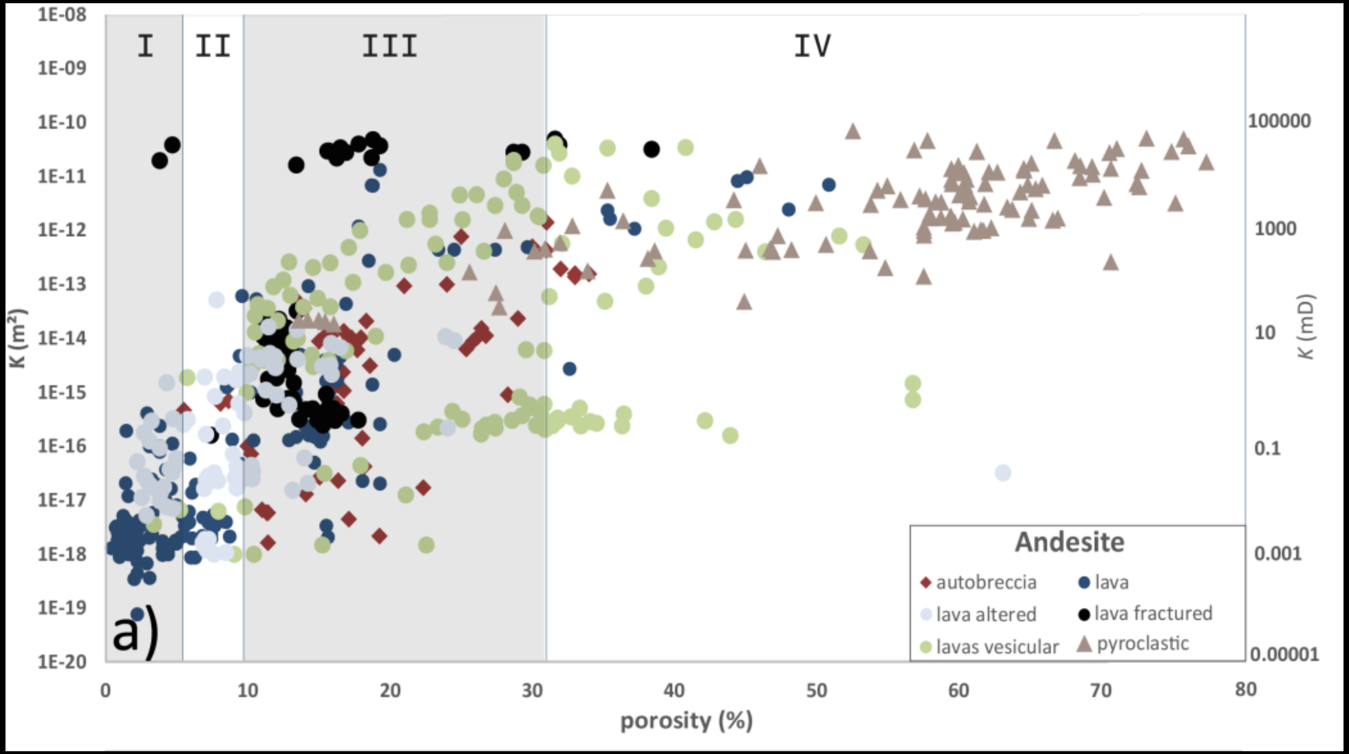
Coherent lava andesite

ϕ: 3.42 %
K: 0.006 mD



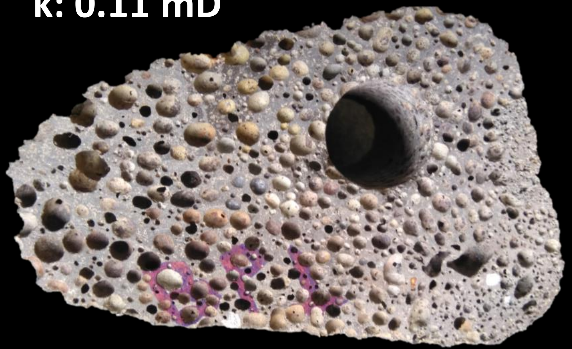
Primary controls in the porosity and permeability of volcanic rocks

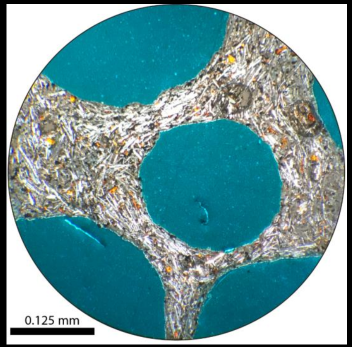
Vesicles



Vesicular pyroclastic rock

ϕ: 57.44 %
k: 0.11 mD





Vesicular lavas

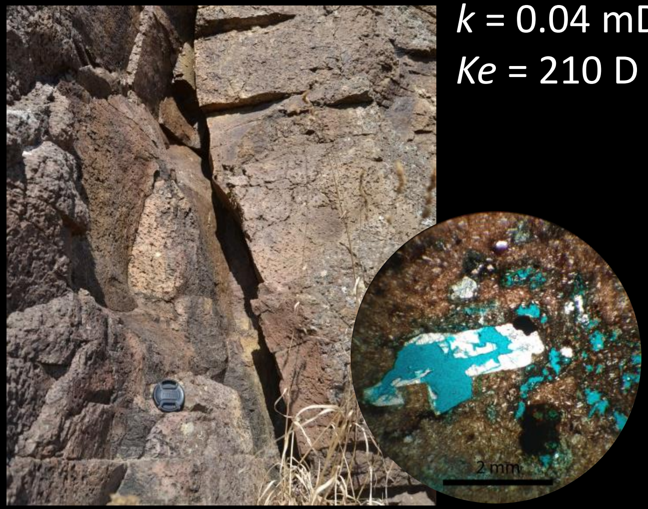
Planke et al., 2019

Primary controls in the porosity and permeability of volcanic rocks

Fracturing

PhD student Marcos Rossetti

ϕ = 25.05%
k = 0.24 mD
Ke = 10.5 D

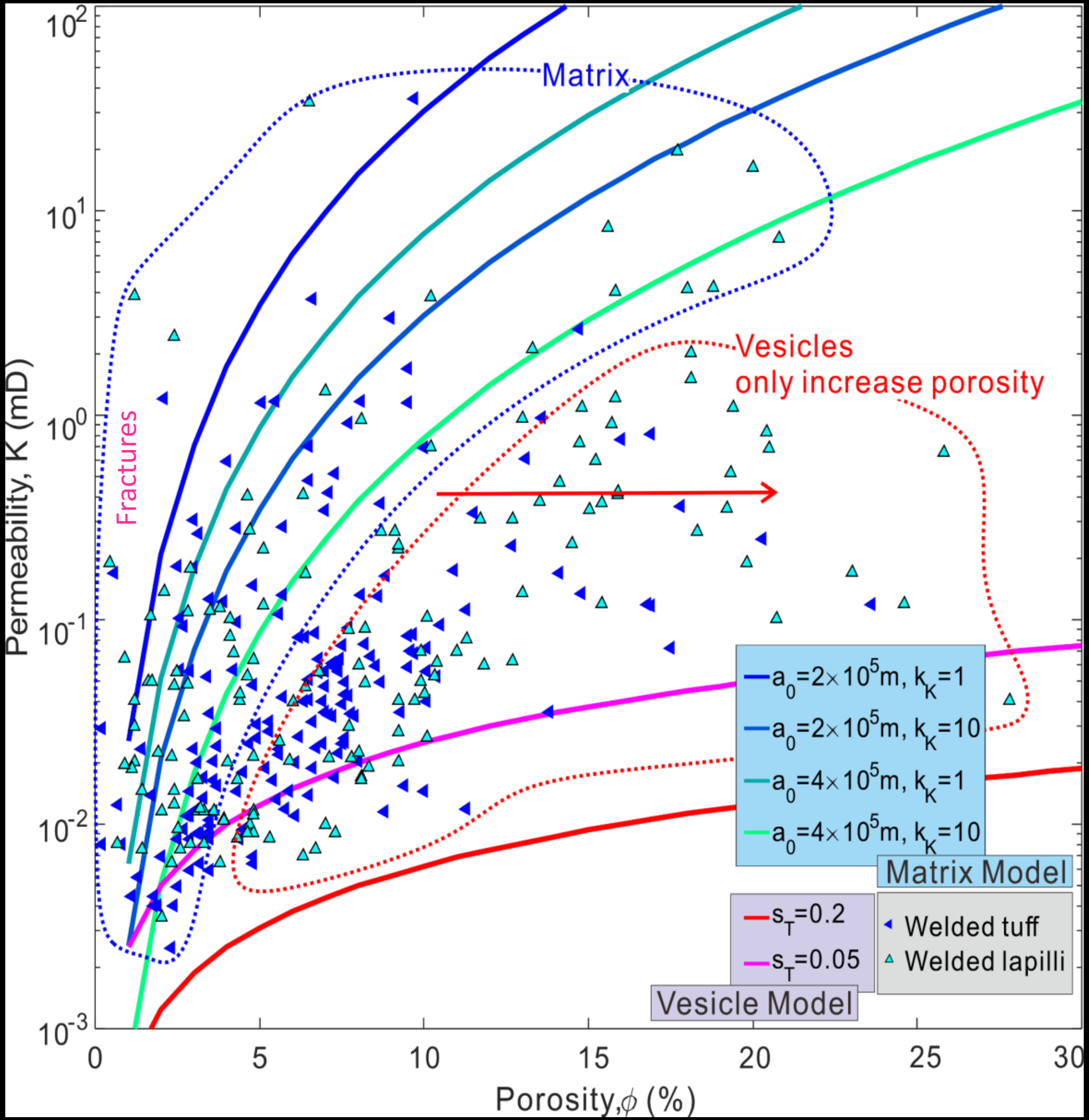


ϕ = 15.89 %
k = 0.04 mD
Ke = 210 D

ϕ = 15.5 %
k = 3.58 mD
Ke = 63.1 D

Primary controls in the porosity and permeability of volcanic rocks

Pore type and shape



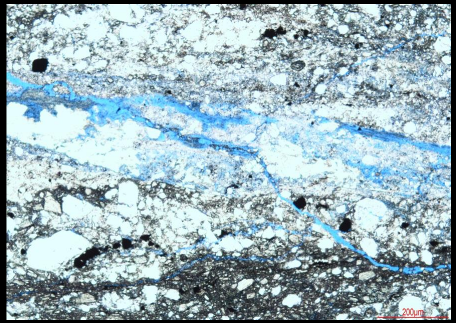
ϕ and k of pyroclastic rocks

PhD student Hanfei Wang

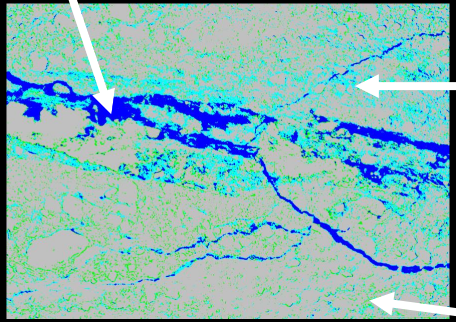
Machine

Learning

Algorithms



Fracture porosity: 7.3 %



Mineral dissolution: 14.8 %

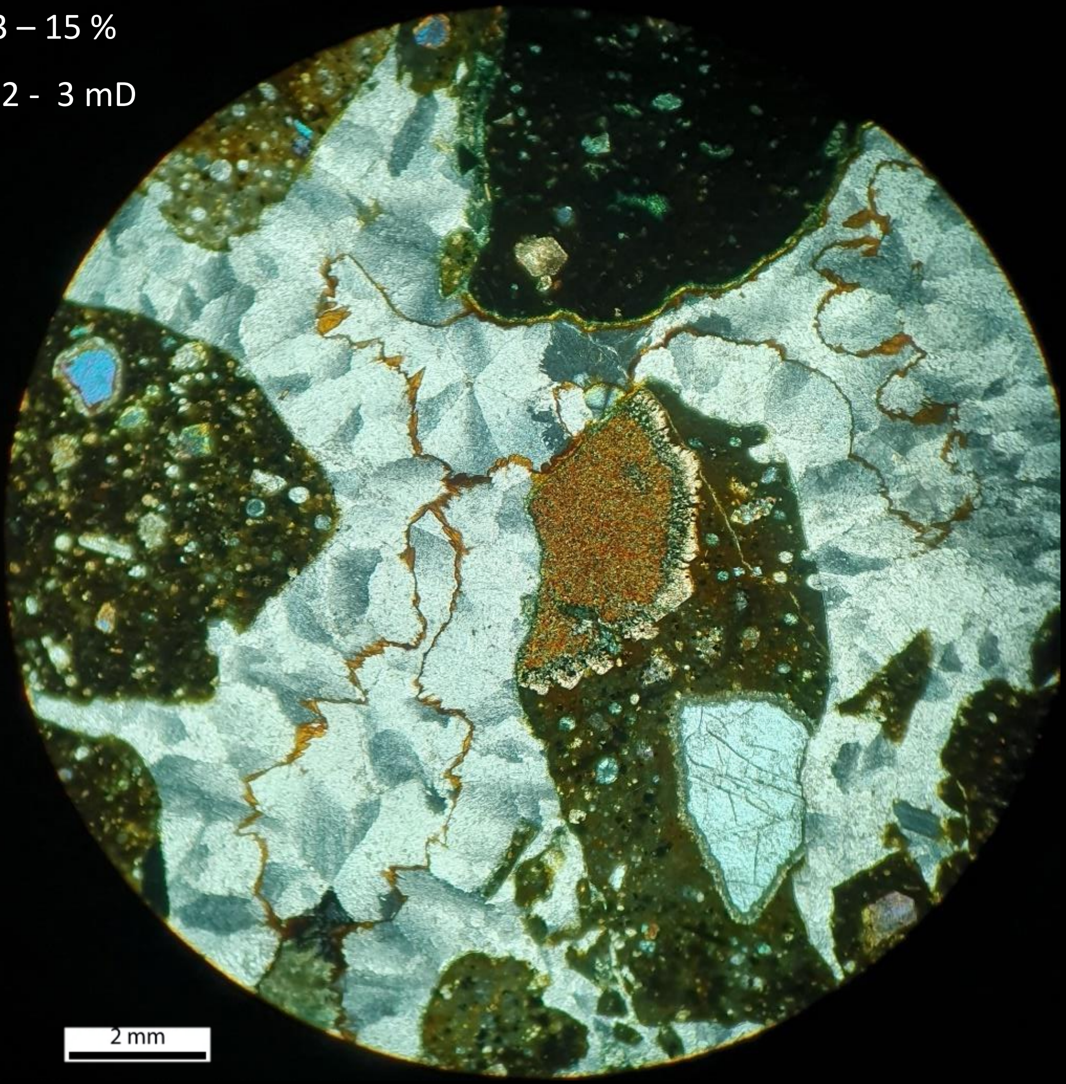
Matrix porosity: 7%

Secondary controls in the porosity and permeability of volcanic rocks

Cementation and mineral alteration

ϕ: 0.3 – 15 %

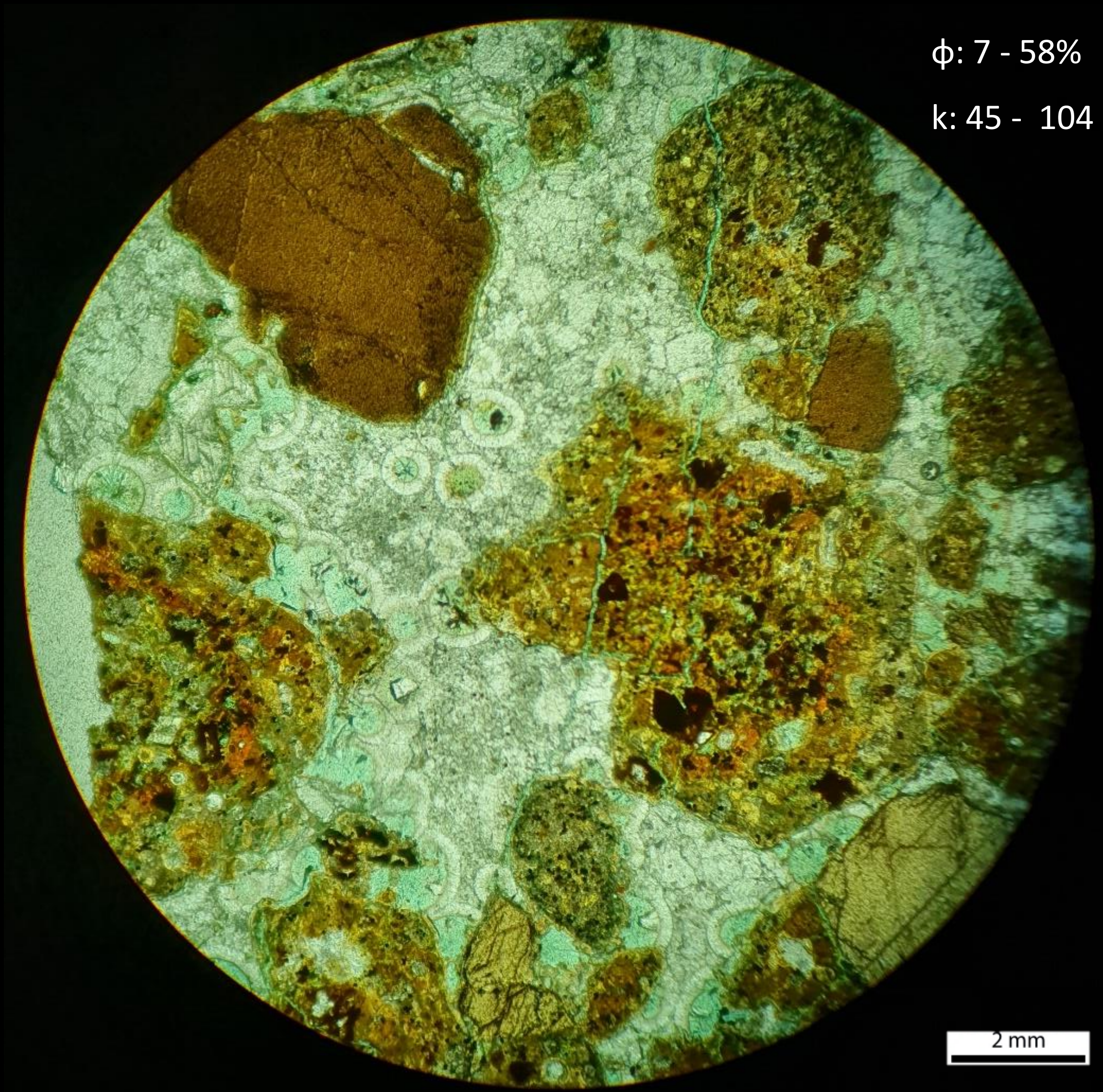
k: 0.02 - 3 mD



Cemented lapilli tuff

ϕ: 7 - 58%

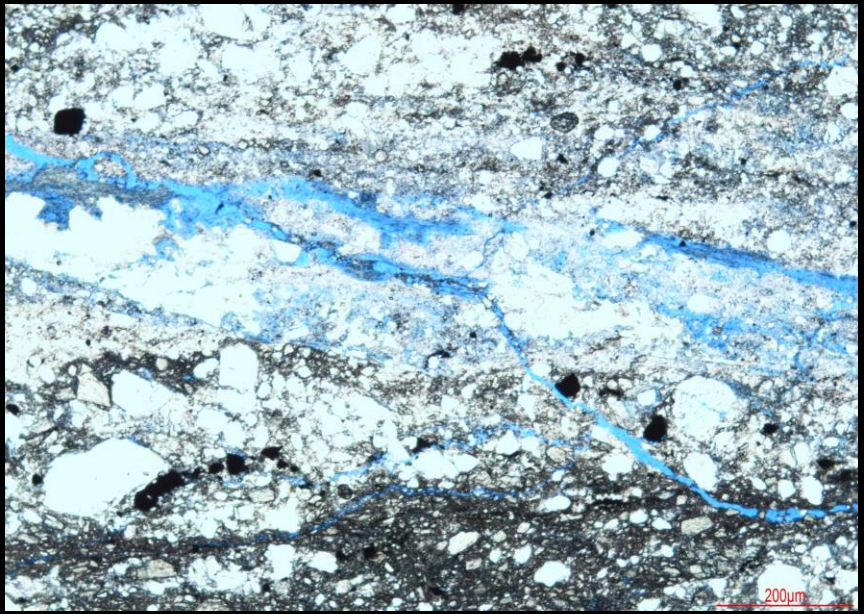
k: 45 - 104 mD



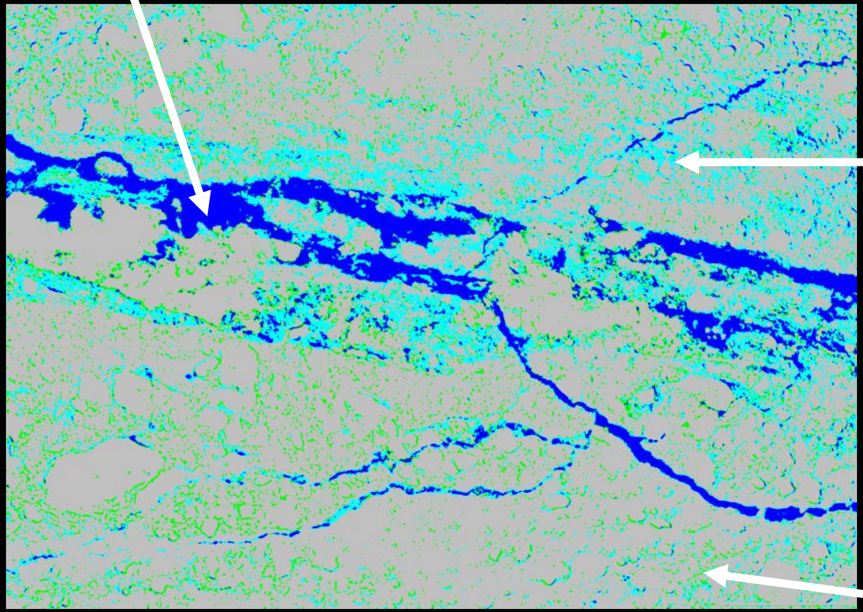
Altered lapilli tuff

Primary and secondary controls are equally important in the porosity and permeability of volcanic rocks

Kora 1a – 1905.44 m



Fracture porosity: 7.3 %



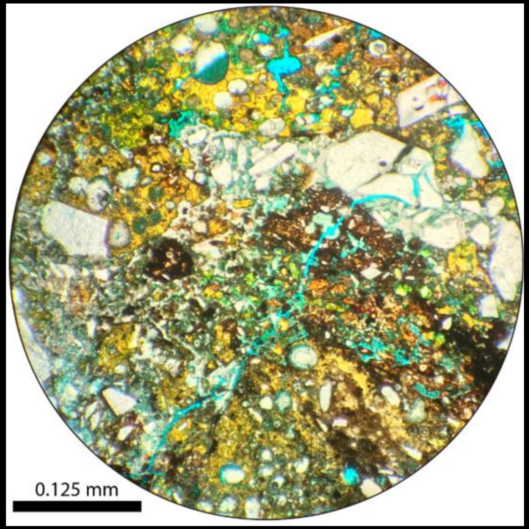
Mineral dissolution: 14.8 %

Matrix porosity: 7%

Machine Learning Algorithms

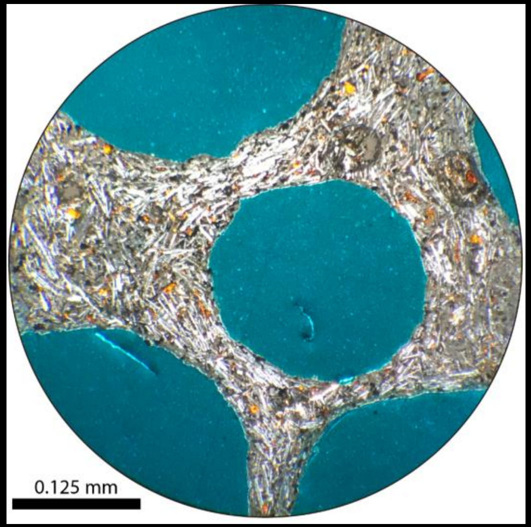
Volcanic reservoirs: TAKE-HOME MESSAGE

Pyroclastic volcanic reservoir



ϕ: 46.97 %
k: 798 mD

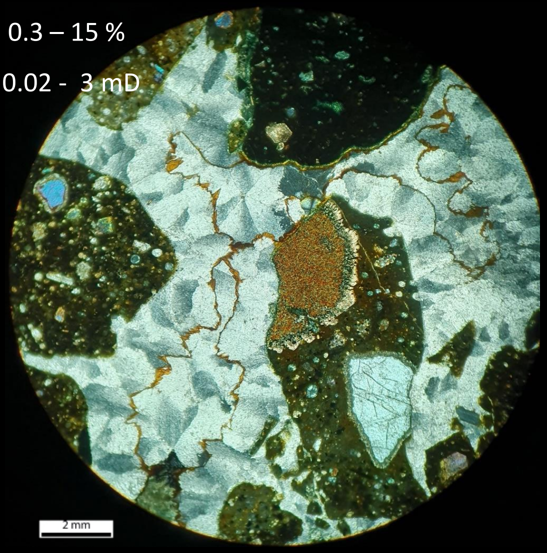
Pyroclastic volcanic seal



ϕ: 57.44 %
k: 0.11 mD

ϕ: 0.3 – 15 %

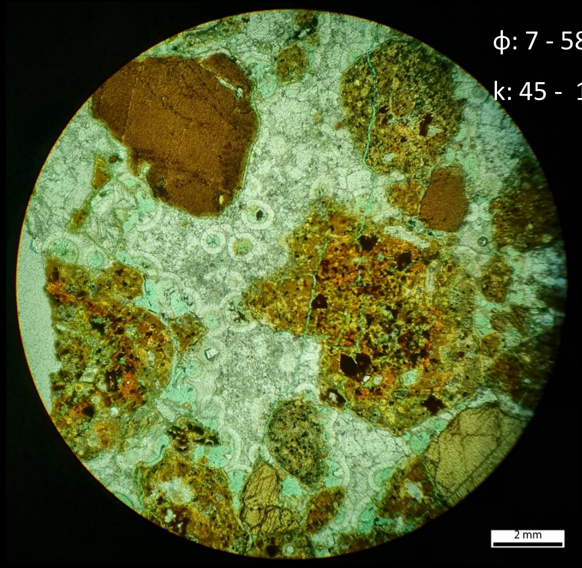
k: 0.02 - 3 mD



Cemented lapilli tuff

ϕ: 7 - 58%

k: 45 - 104 mD



Altered lapilli tuff

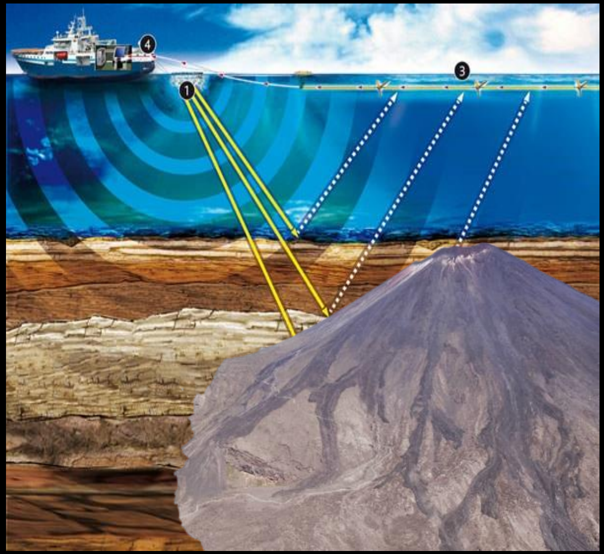
Part 3

Modern interpretation of buried volcanic systems

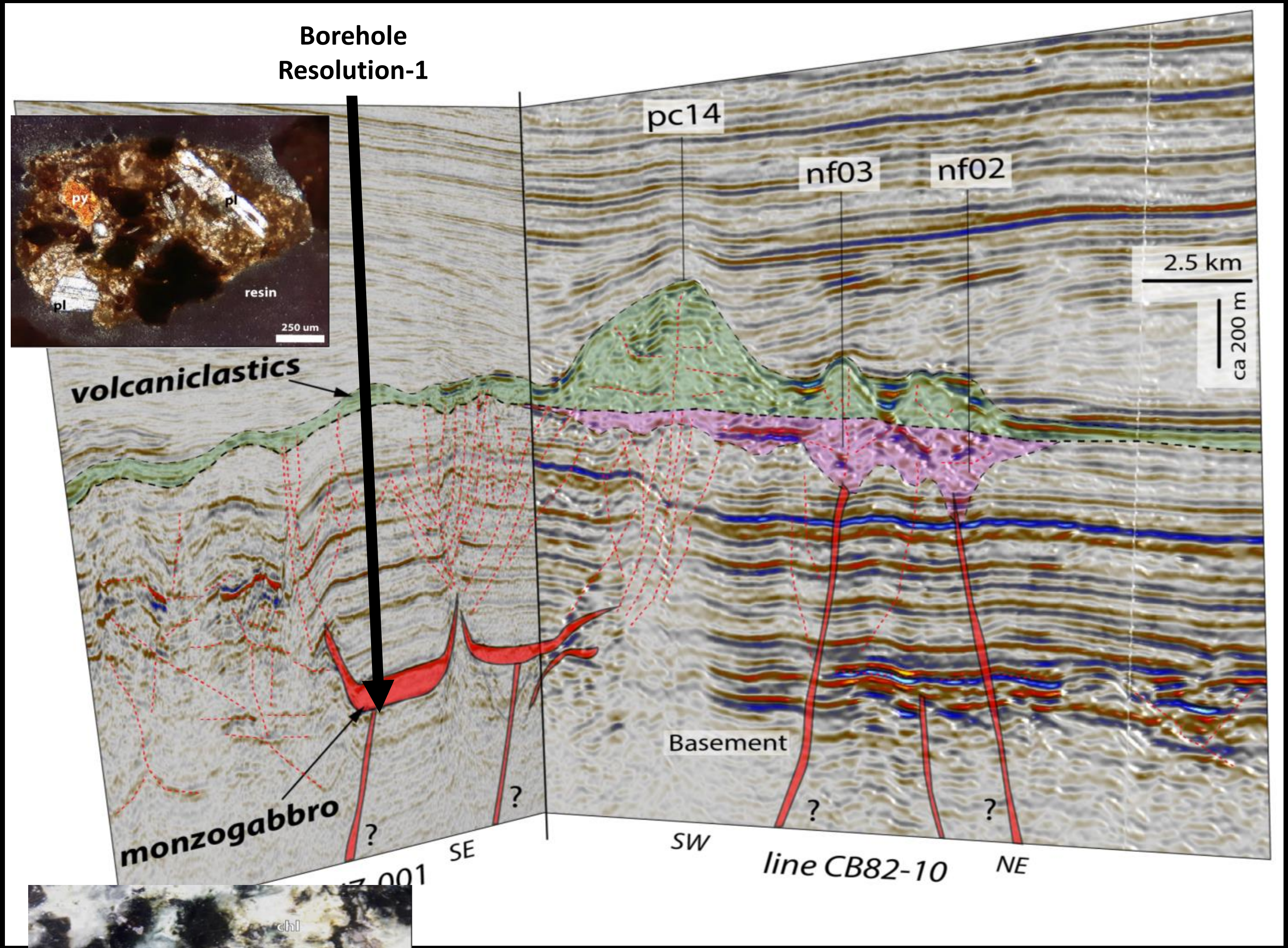
1- Seismic reflection interpretation

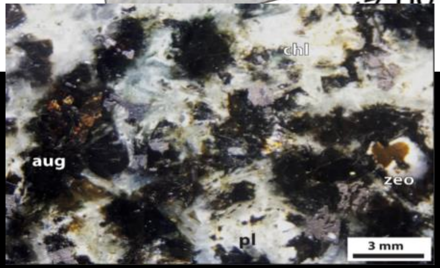
Volcanoes buried in sedimentary basins

Seismic reflection



Drilling operations



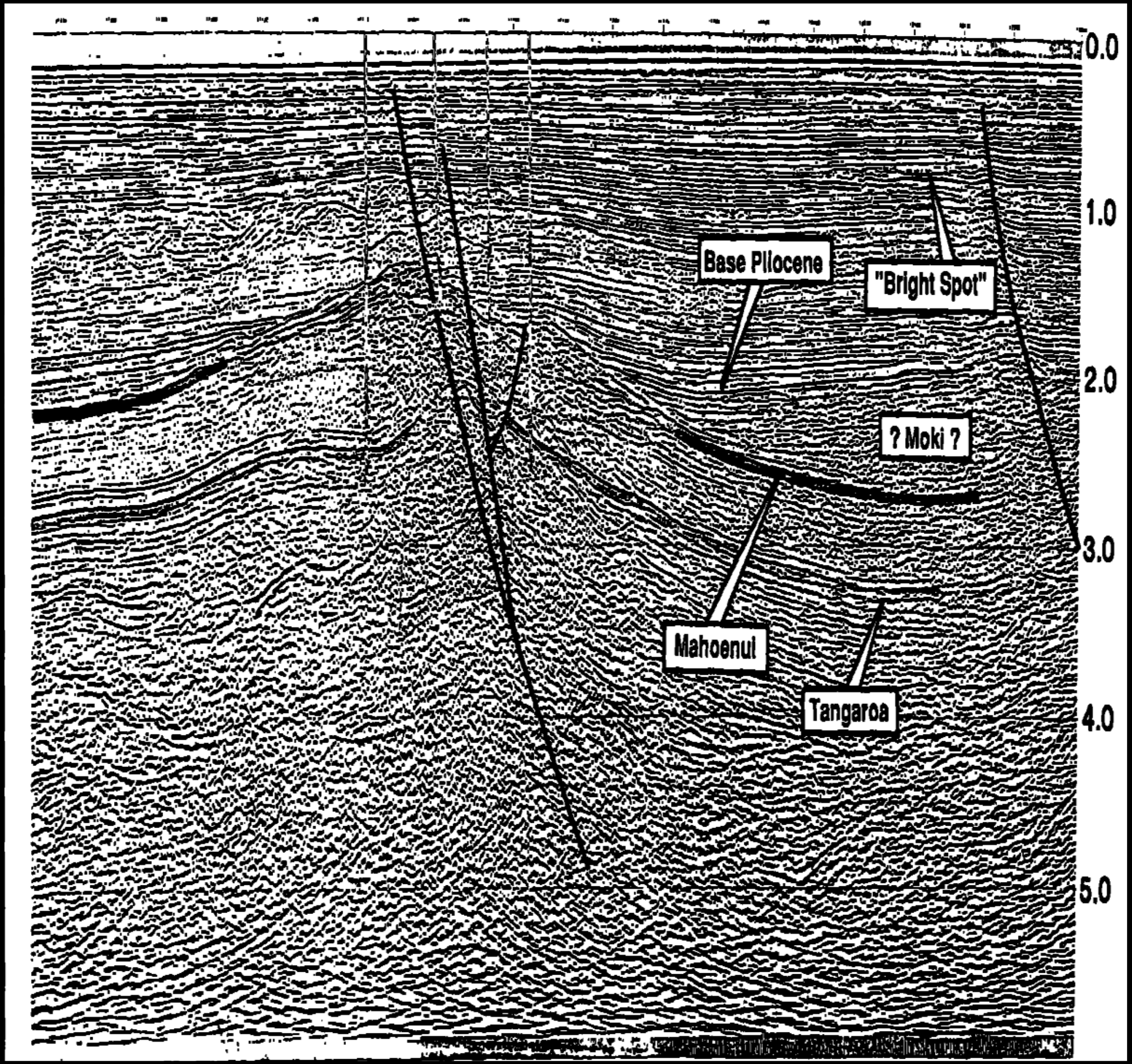


2D seismic line offshore Canterbury Basin, NZ

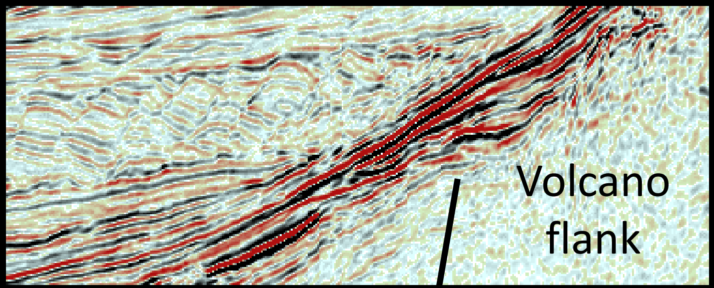
Bischoff et al. 2019

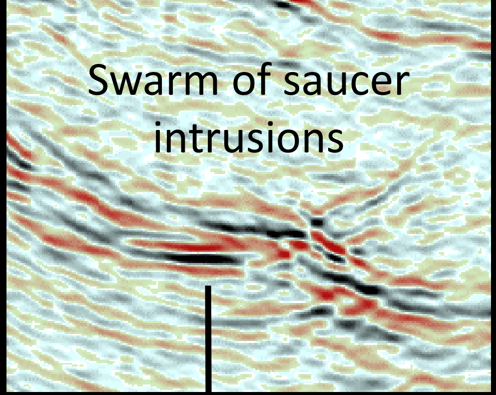
Modern seismic: from 2D to 3D visualization

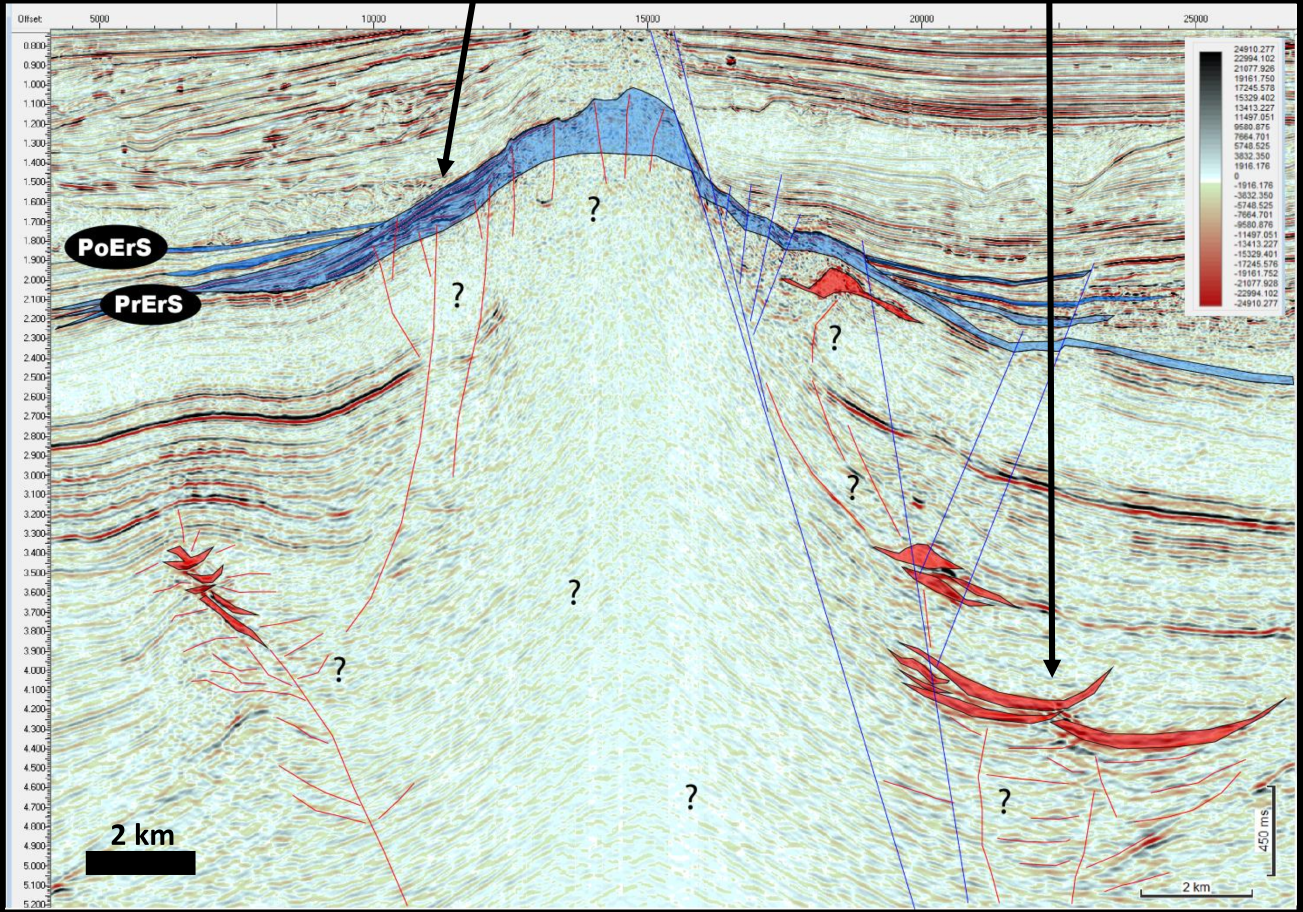
Kora Volcanic Edifice, Taranaki Basin



Excellent quality 2D seismic line from the early 1980’s



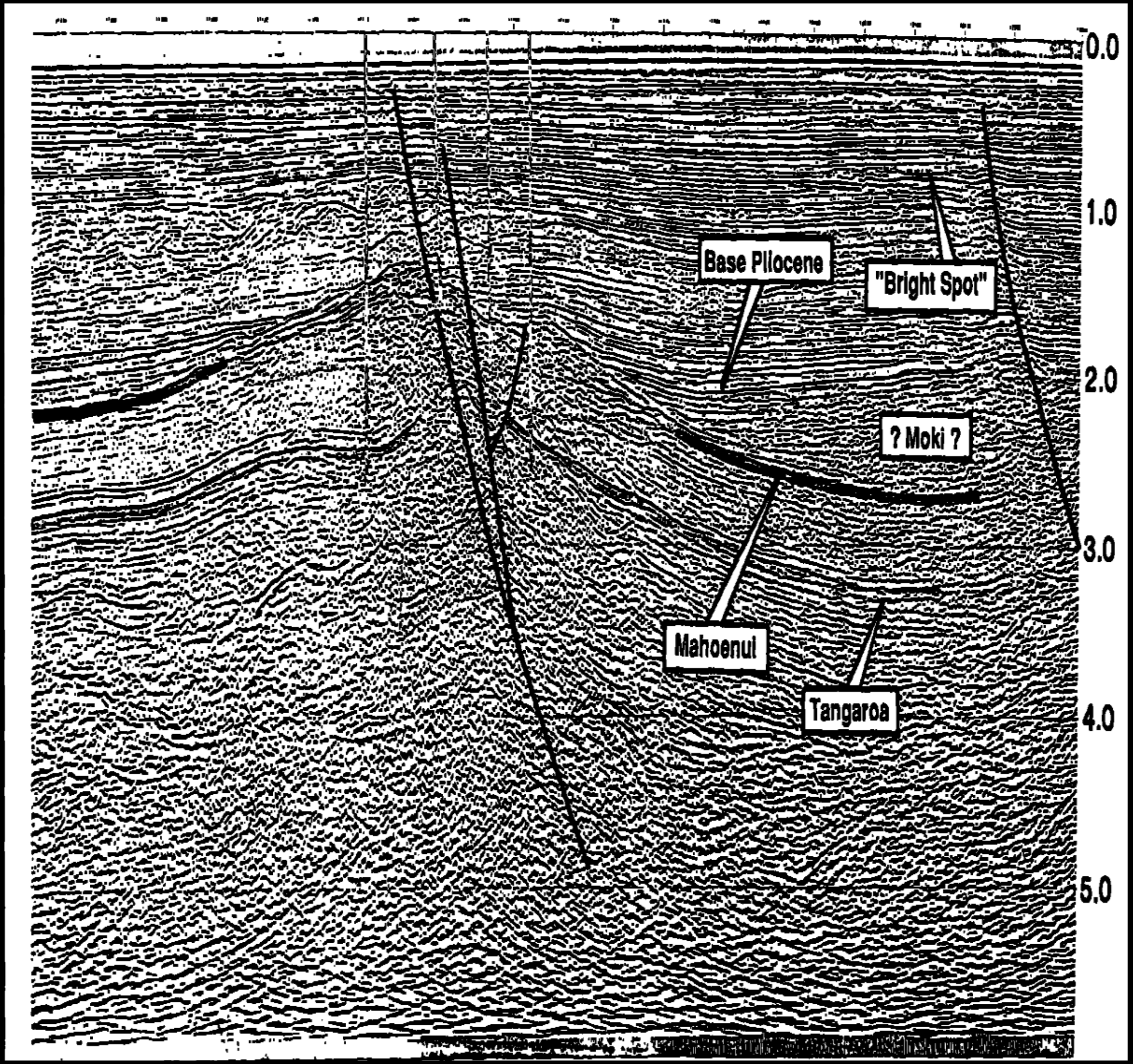




Average quality 2D seismic line from the 2000’s

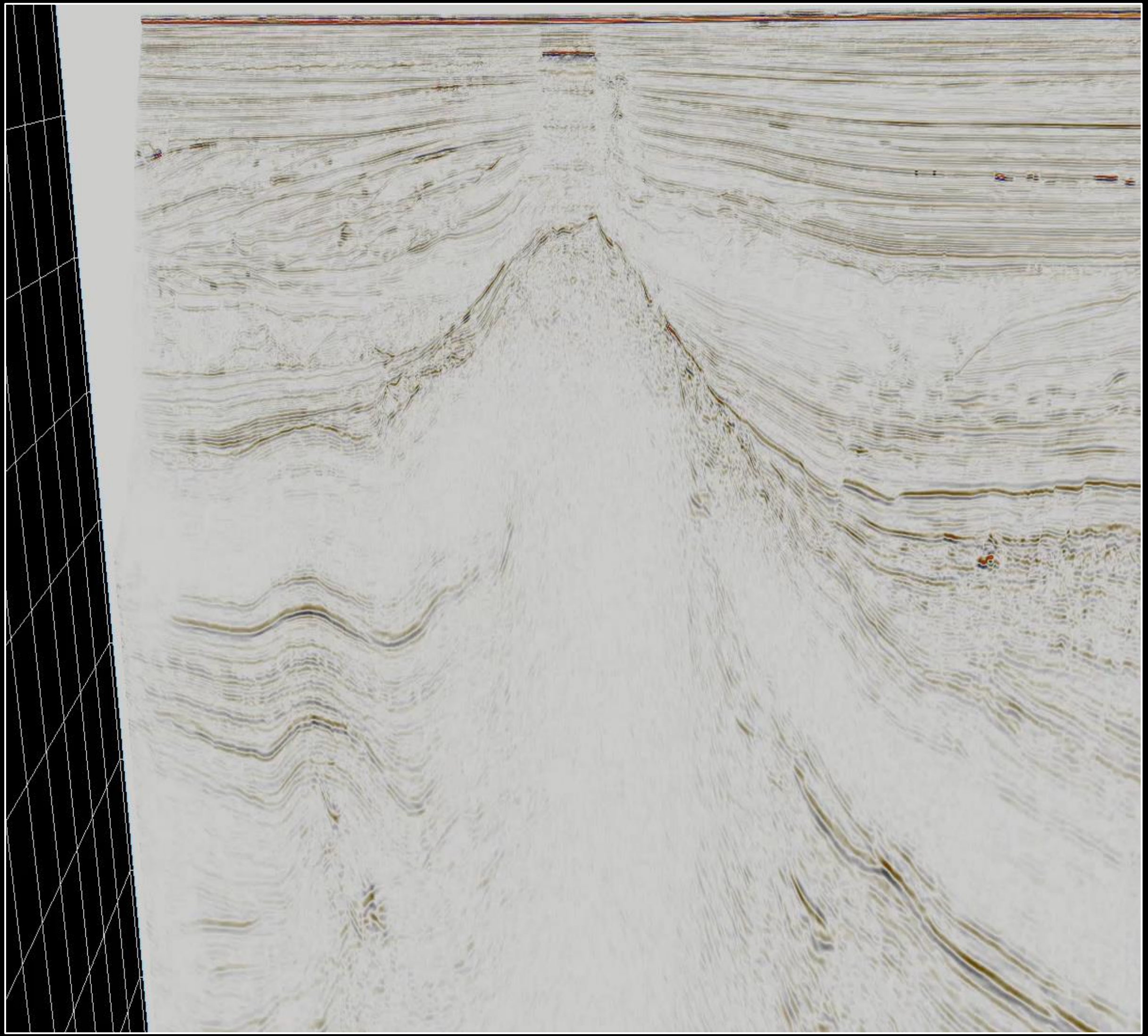
Modern seismic: from 2D to 3D visualization

Kora Volcanic Edifice, Taranaki Basin



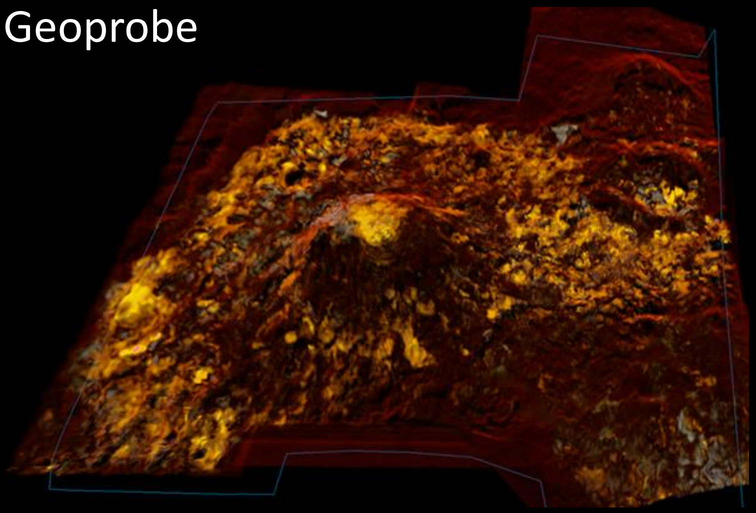
Excellent quality 2D seismic line from the early 1980's

Geobody extraction

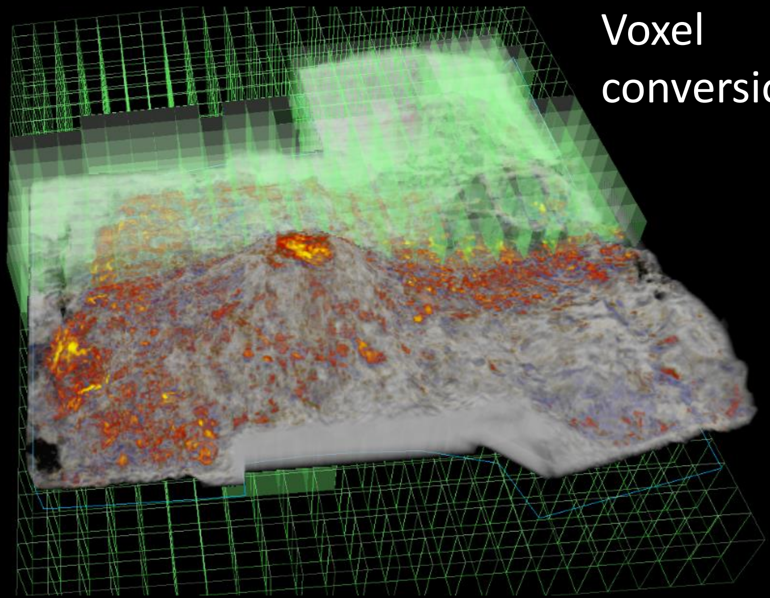


Geobody extraction

Geoprobe

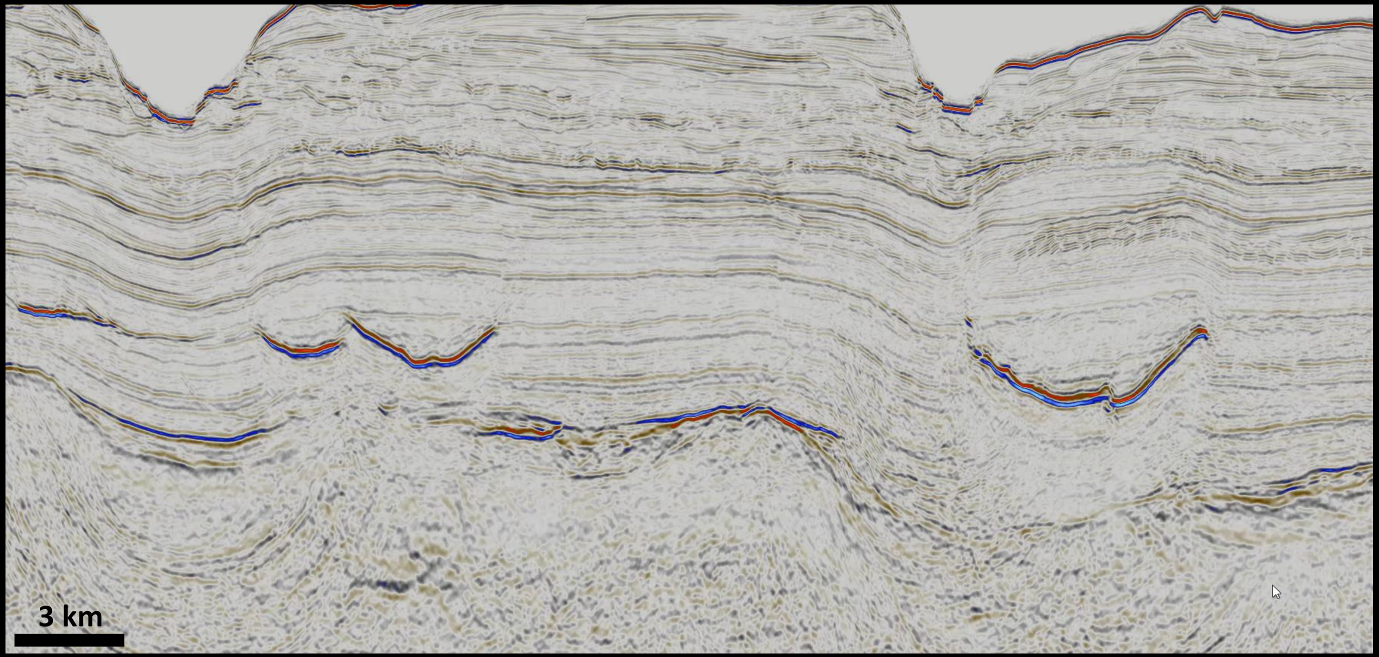


Taranaki Basin

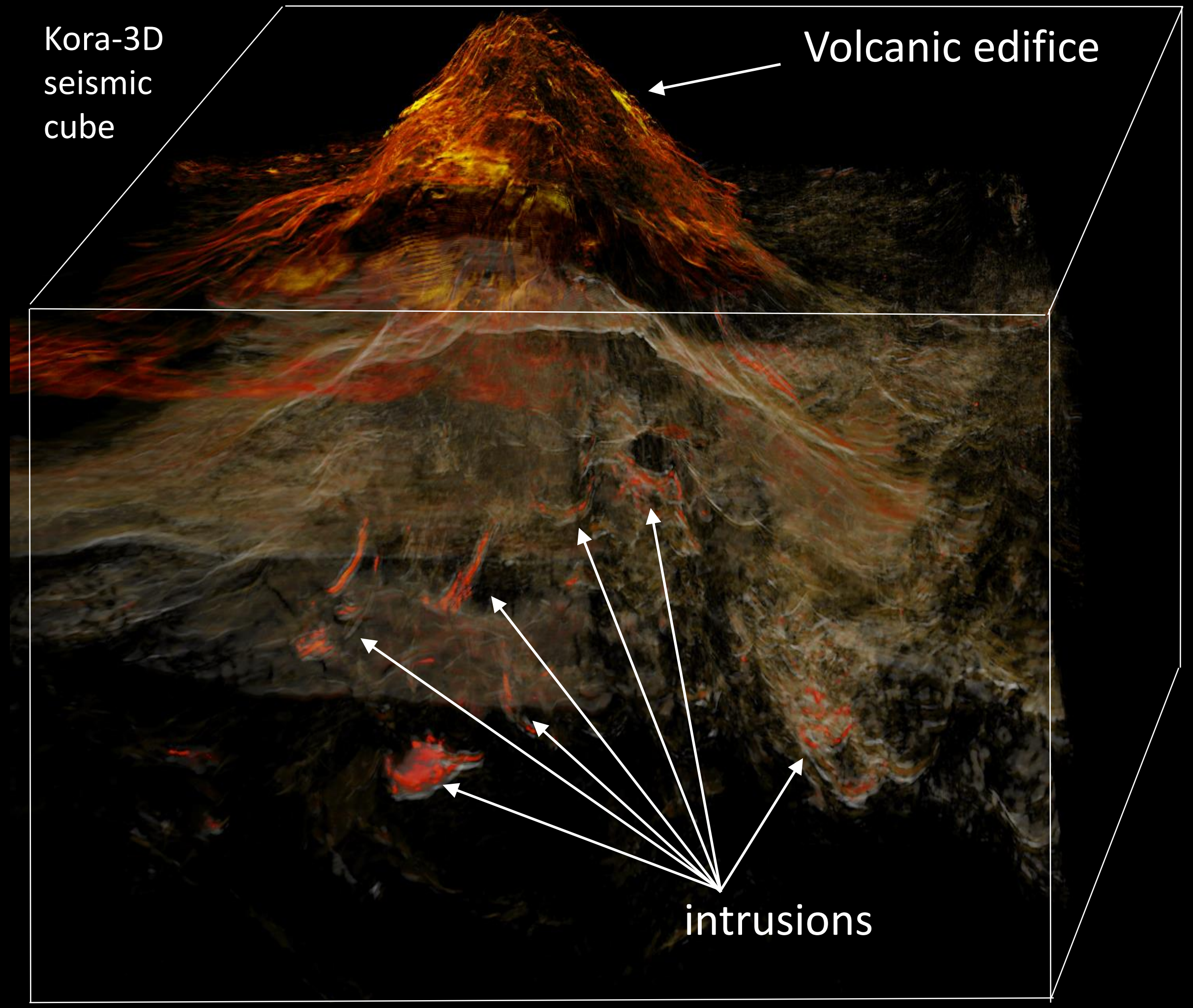


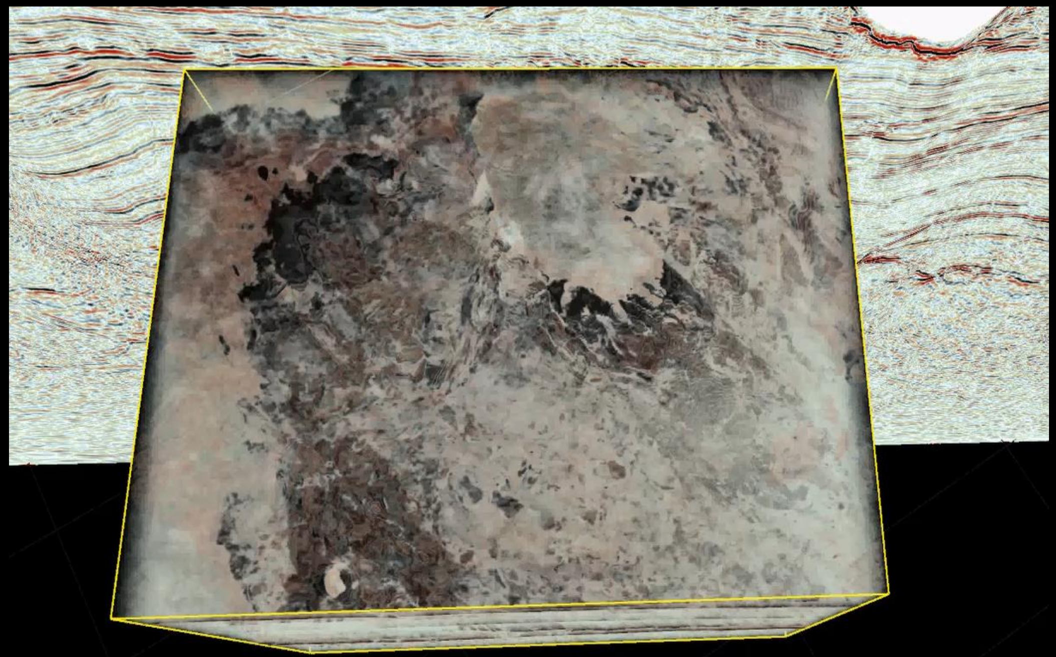
Voxel conversion

Saucers sills in the Canterbury Basin



Seismic reflection interpretation of buried volcanic systems: TAKE-HOME MESSAGE





Part 4
Emerging renewable energy industry

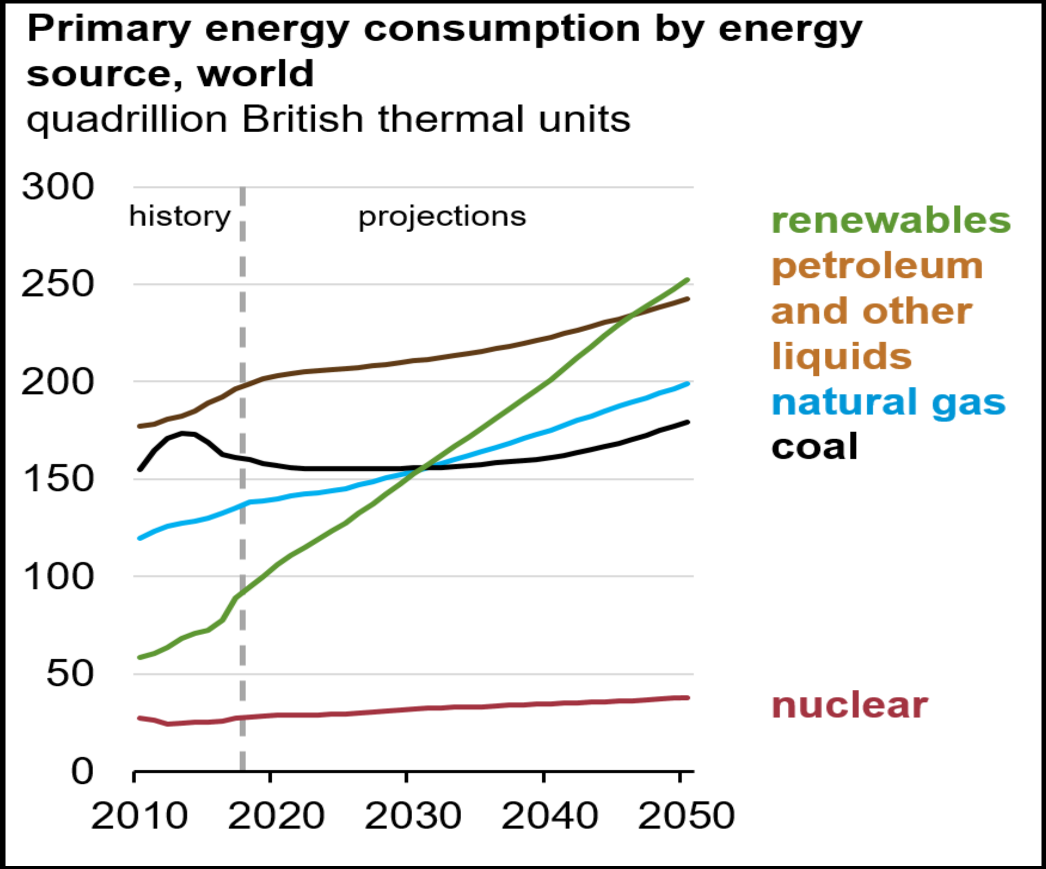
1- Global energy scenario

2- Geoenergy

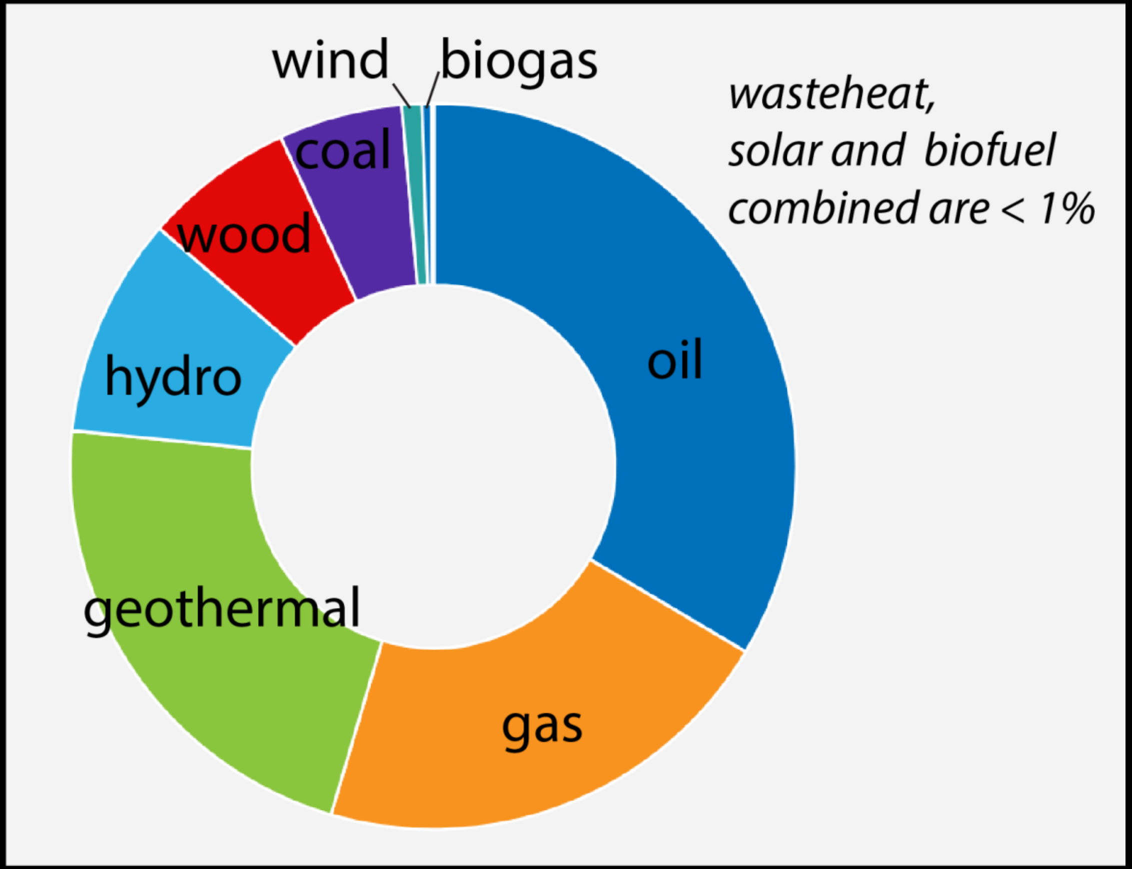
3- Types of geoenergy resources related with volcanic systems

Rationale

International Energy Outlook 2019



Present energy consumption in New Zealand by source type



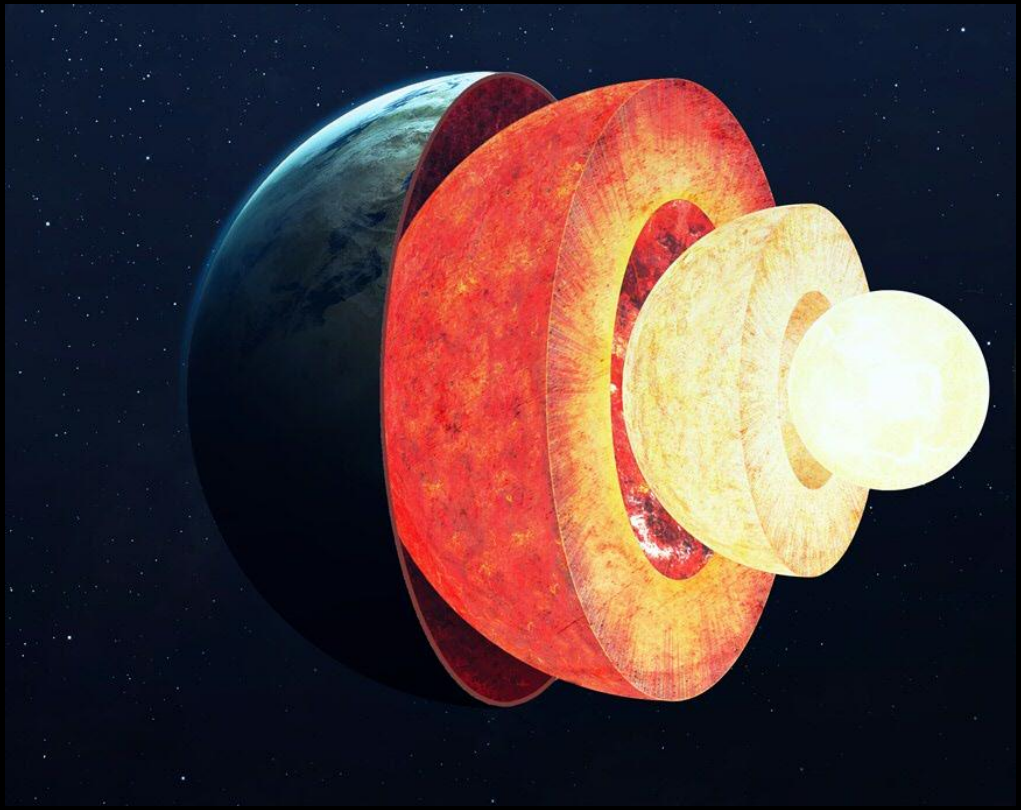
What is Geoenergy?

Geoenergy is energy derived from, or storage in, the earth.

Fossil fuels: coal, peat, oil and gas.

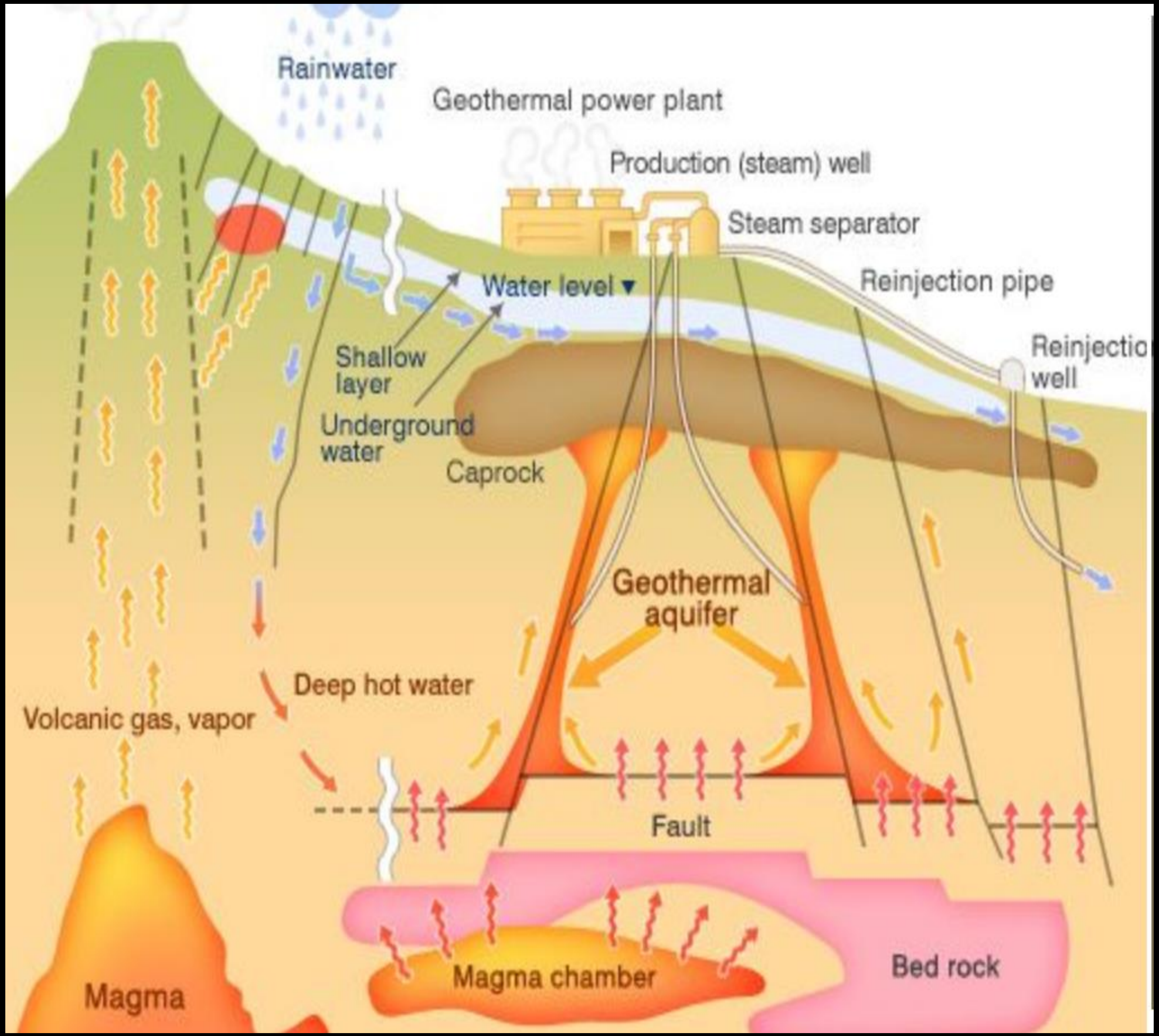
Geothermal energy. Heat generated by radioactive decay or at volcanic regions.

Energy technologies that interact with the subsurface: Carbon Capture, Utilization and Storage (CCUS), Compressed Air Energy Storage (CAES), Underground Hydrogen Storage (UHS).

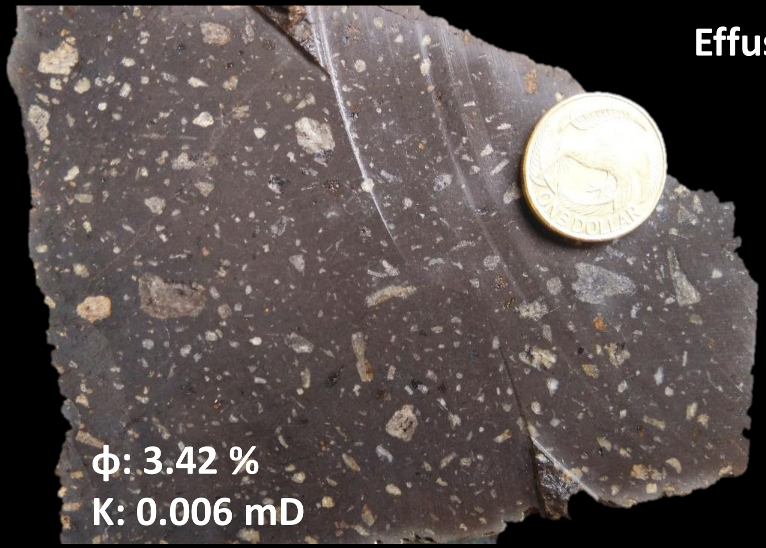


In other words, is the energy that depends of the geological conditions to be produced.

Geothermal Energy



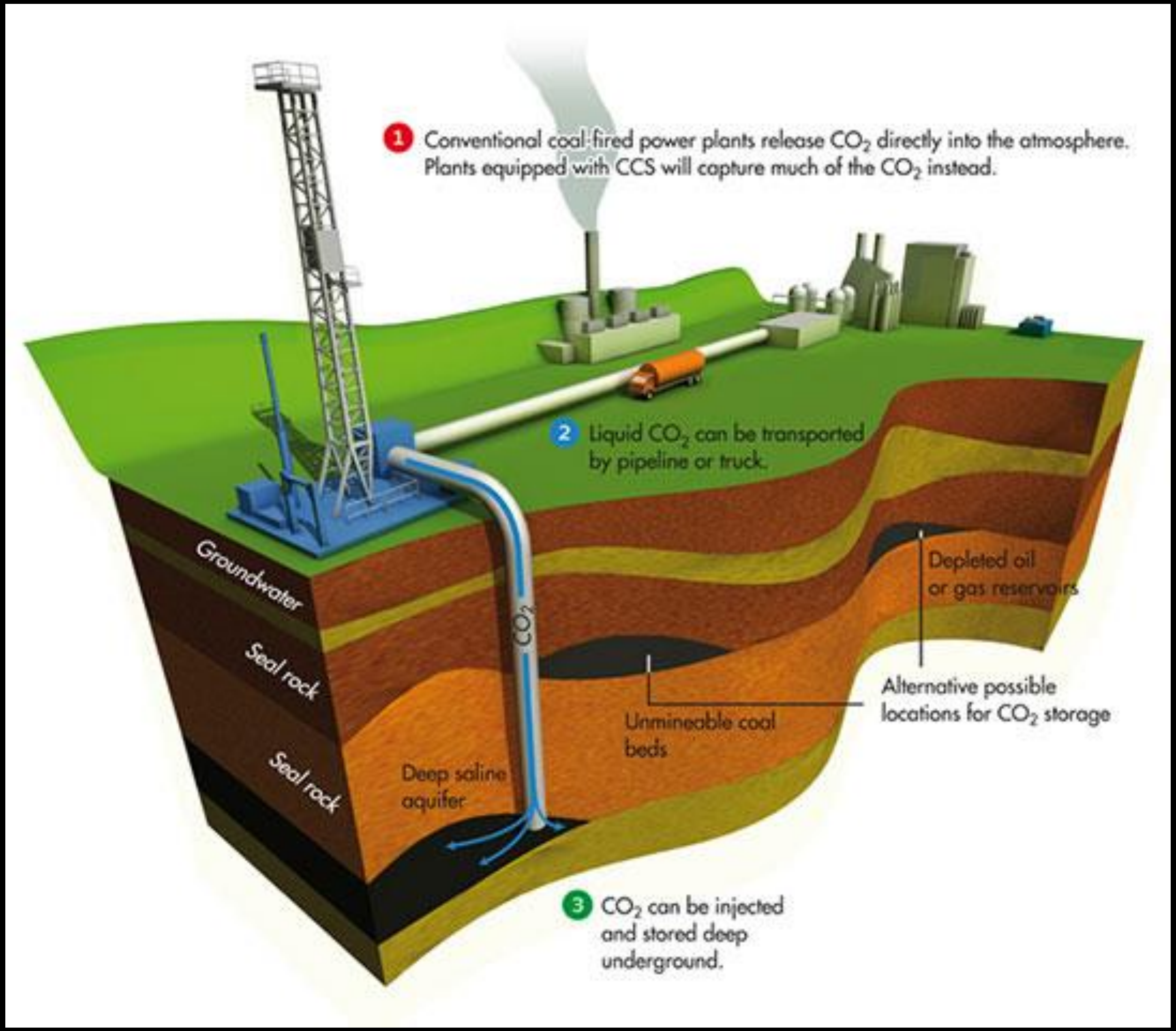
Pyroclastic volcanic reservoir

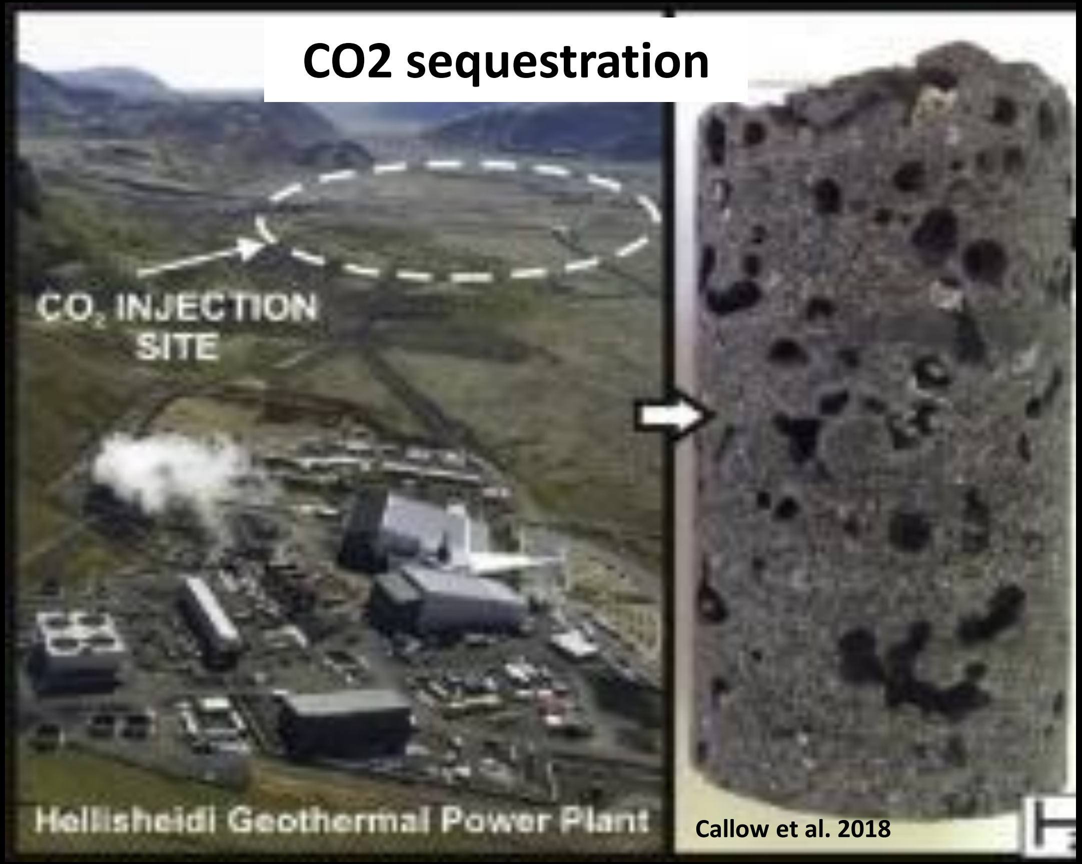


Effusive volcanic seal

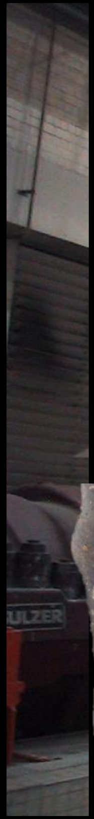
Carbon capture, utilisation and storage (CCUS)

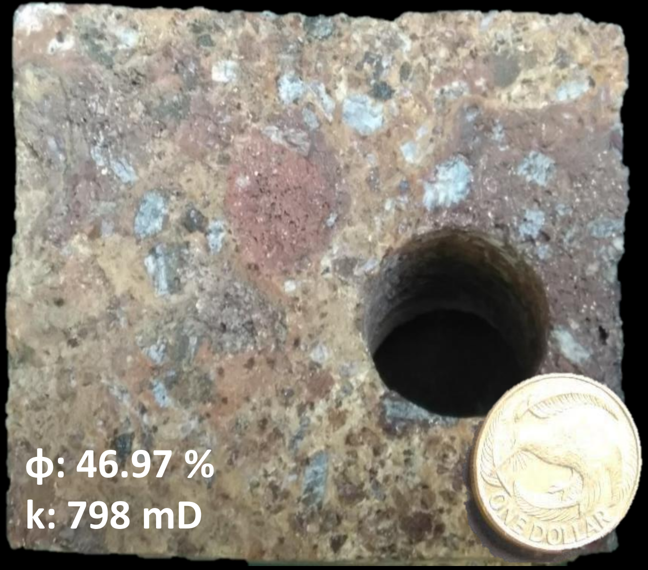
CO2 can be converted back to energy!





Compressed Air Energy Storage (CAES)

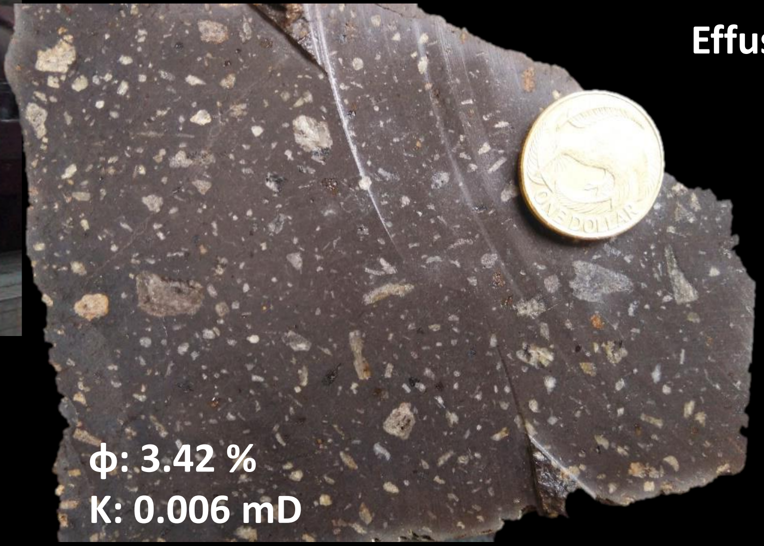




Pyroclastic volcanic reservoir

?

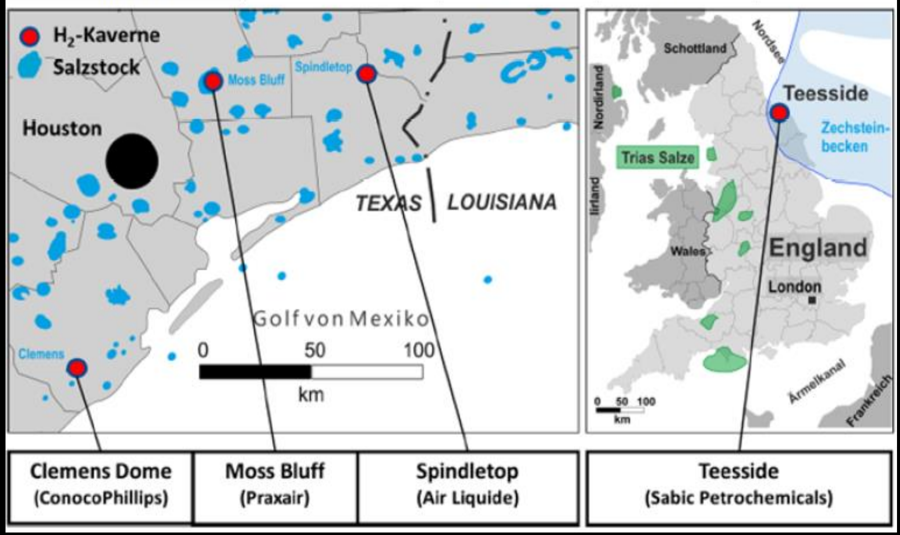
Effusive volcanic seal



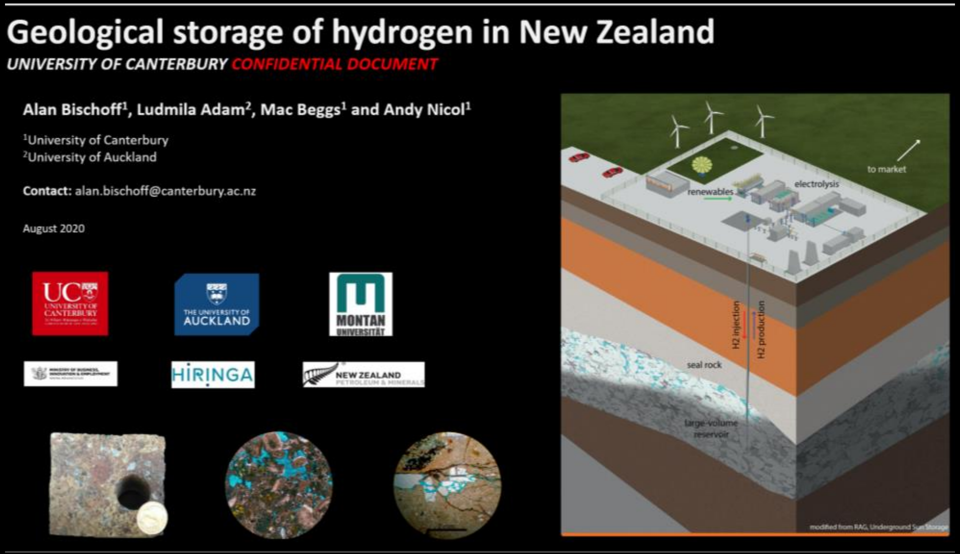
Geological storage of hydrogen

Four underground hydrogen sites in UK and USA.

Localisation	Clemens Dome (US)	Moss Bluff (US)	Spindletop (US)	Teeside (UK)
Operator	Conoco Philips	Praxair	Air Liquide	Sabic
Start	1983	2007	2014	1972
Volume (10^3 m^3)	580	566	>580	3*70
Pressure (bar)	70-135	55-152	Confidential	45
Energy (GWh)	92	120	>120	25



Hydrogen storage in volcanic rocks?



Geological storage of hydrogen in New Zealand

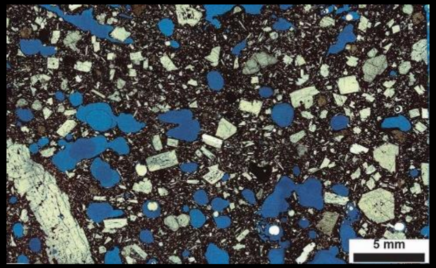
UNIVERSITY OF CANTERBURY CONFIDENTIAL DOCUMENT

Alan Bischoff[1], Ludmila Adam[2], Mac Beggs[1] and Andy Nicol[1]

[1]University of Canterbury
[2]University of Auckland

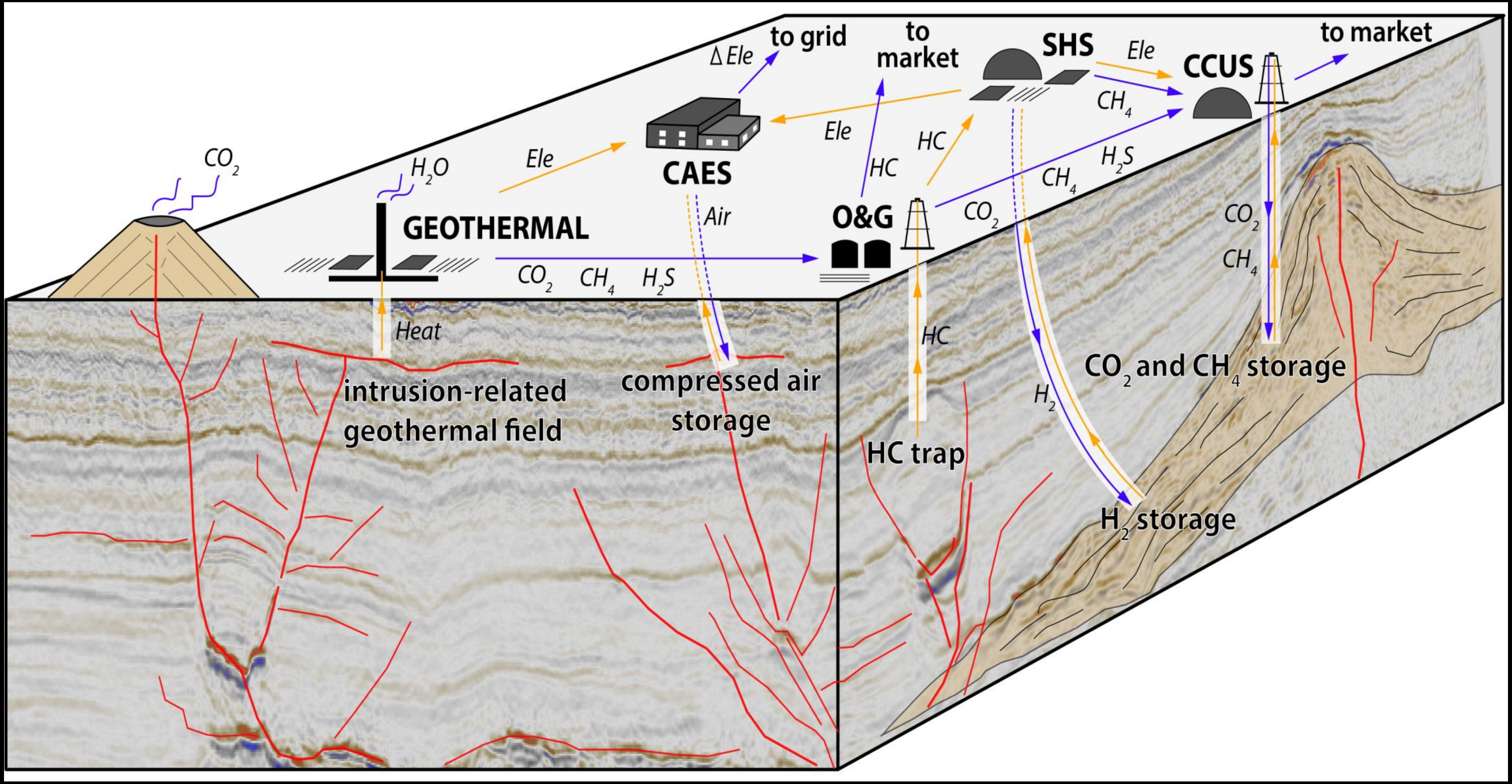
Contact: alan.bischoff@canterbury.ac.nz

August 2020



Geoenergy: TAKE-HOME MESSAGE

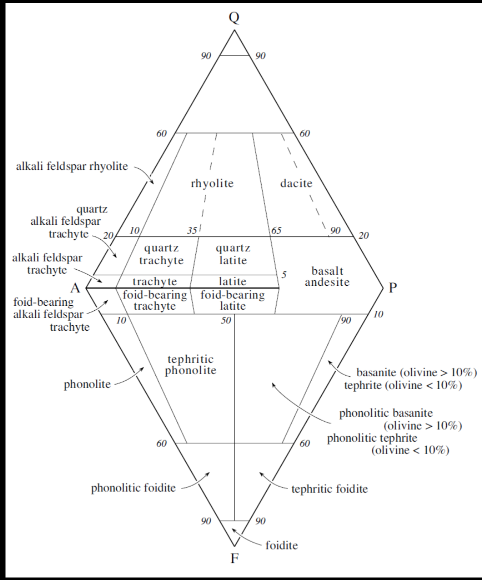
Combined systems will play important role to supply affordable, clean and reliable energy systems in the future. Volcanoes and volcanic rocks can provide ideal conditions for many of these systems.



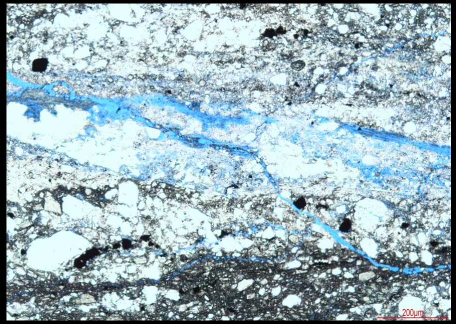
Wrapping-up

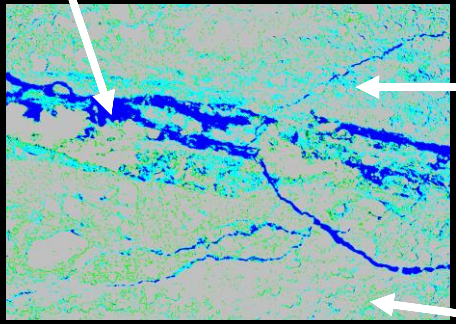
genesis

classification

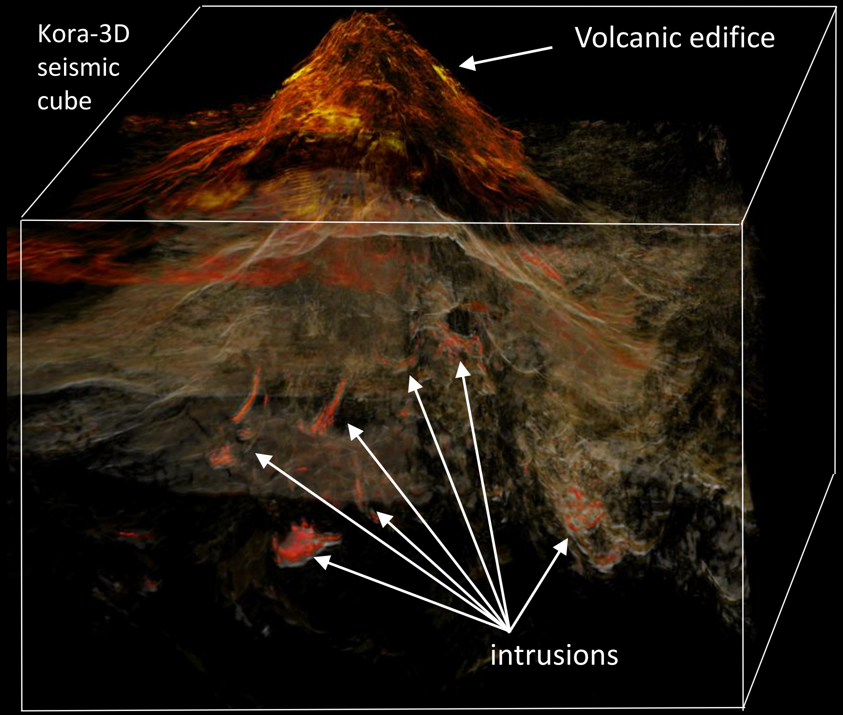


Volcanic reservoirs

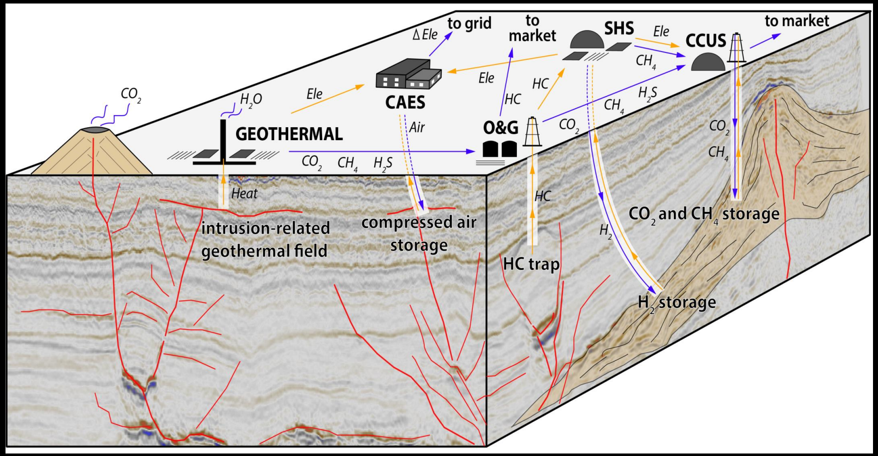




Seismic reflection



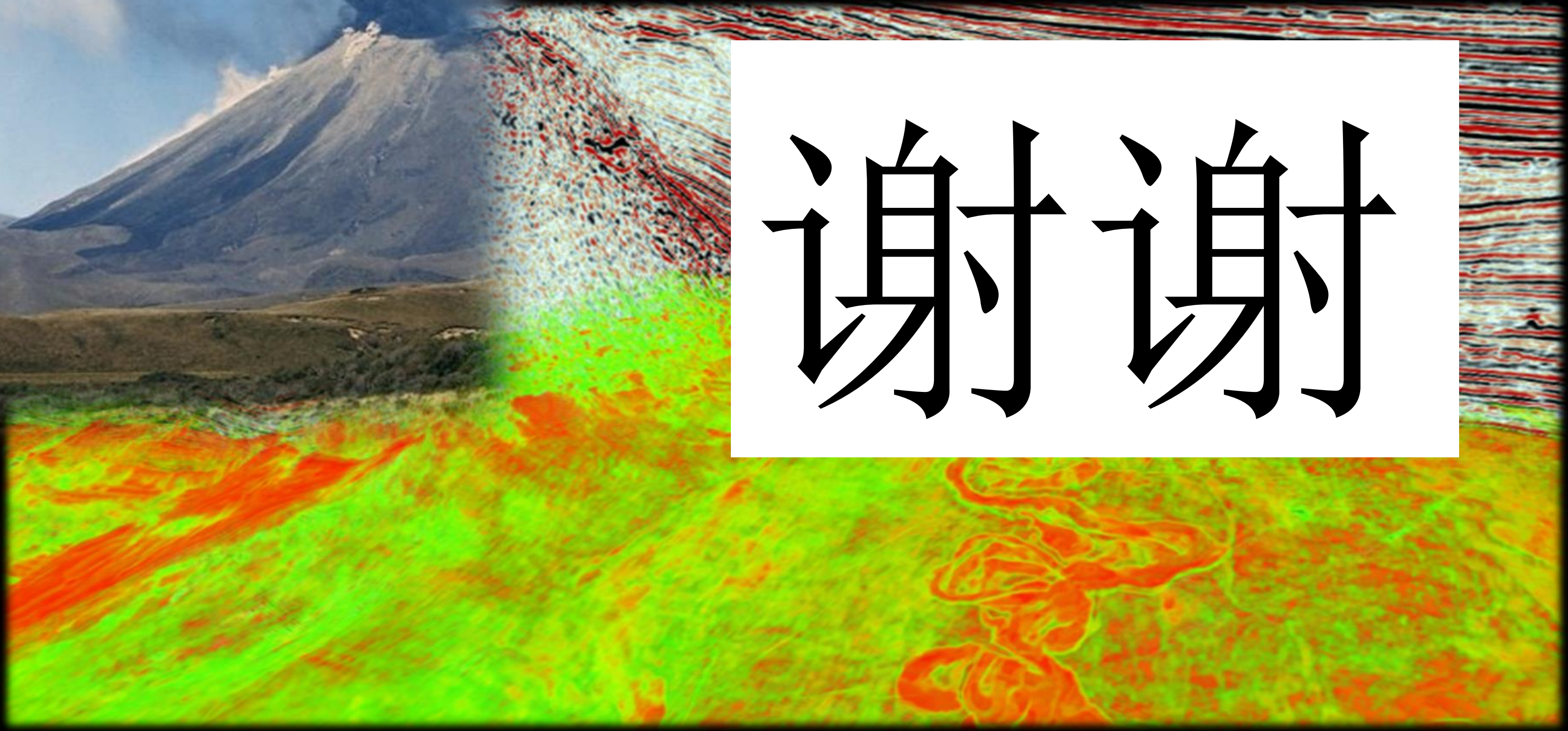
Geoenergy



Volcanic rocks as petroleum reservoirs and their role in the emerging renewable energy industry

Dr Alan Bischoff
University of Canterbury, New Zealand

2020 Summer Academic Lecture activity for Graduate Students
China University of Petroleum



谢谢