Petrophysics and Exploration Targeting: Best Practice and Applications

Mike Dentith, Cameron Adams
The University of Western Australia

Barry Bourne
Terra Resources

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Petrophysics – rock physical properties

- Links the geologist's view of the world with the geophysicist's view

  Chemistry → mineralogy → lithology

  Density/magnetism/conductivity etc → geophysical response

- Significance – what is the geophysics telling us?

  Mineral system concept has suggested many new geophysical targets: fluid/metal sources, fluid pathways, fluid reservoirs

  Exploration under cover will use more geophysics but its interpretation will have less geological control

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Petrophysics – a way forward?

- Datasets are often too small and lack adequate geological context

  Lithology is not the primary control in many cases → geology ≠ geophysics

  Petrophysical consequences of alteration

- Predictive capability is generally poor
- Particular need to understand seismic and electrical conductivity

  Magnetotellurics, passive seismics

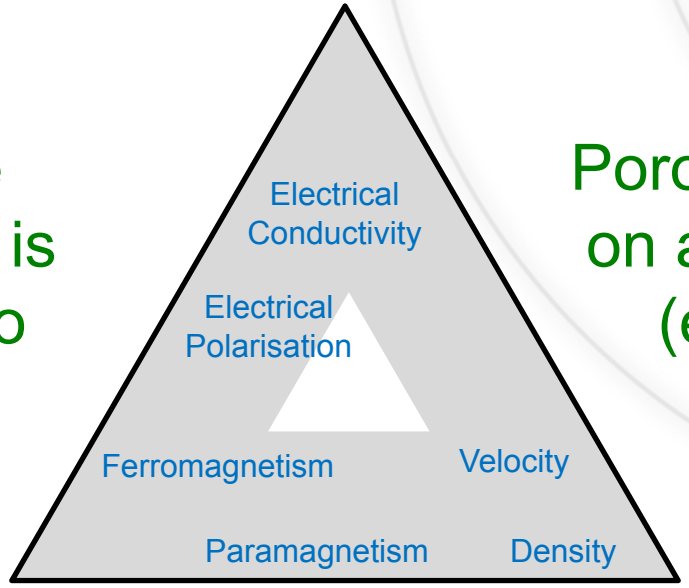
THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Petrophysics – a conceptual framework

Texture
(Geometric Relationships Between Grains)

Lithology can be important, but this is not necessarily so



Porosity is a major control on all physical properties (except magnetism)

Grain
(Amount, Size, Shape of Particular Mineral Species)

Bulk
(Overall Mineralogy)

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Carbonate-hosted base metals -

- Mississippi valley-type, Irish style
- Traditionally considered a poor geophysical target
  - Mineralisation is poorly conductive and non-magnetic and does not contain radio-elements
  - Gravity and seismic responses are of low amplitude and must be recognised against a noisy background
  - May be an alteration halo of Fe-sulphides

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

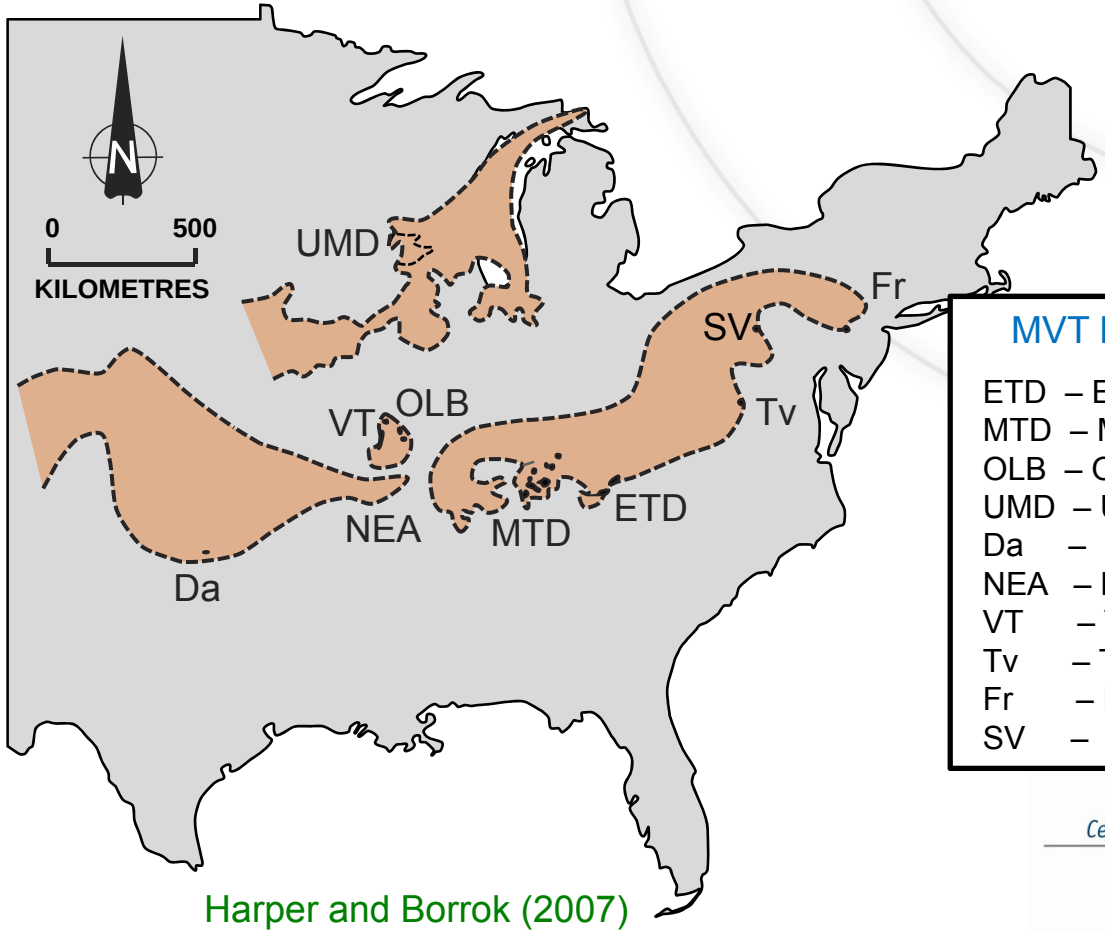
Carbonate-hosted base metals

- Map prospectivity indicators undercover using velocity (passive seismic) and/or conductivity (magnetotellurics)?

  N America: deposits associated with a regional dolomitisation front

  Ireland: deposits associated with 'hydrothermal' dolomite

Dolomitised rock behind dolomitisation front



Harper and Borrok (2007)

MVT Deposits/Districts

ETD – East Tennessee District
MTD – Middle Tennessee District
OLB – Old Lead Belt
UMD – Upper Mississippi District
Da – Davis
NEA – NE Arkansas
VT – Viburnum Trend
Tv – Timberville
Fr – Freidensville
SV – Sinking Valley

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Carbonate physical properties

- Simple mineralogy

  Calcite, dolomite (anhydrite, aragonite)

- But chemically very reactive

  Dolomitisation (calcite ↔ dolomite)

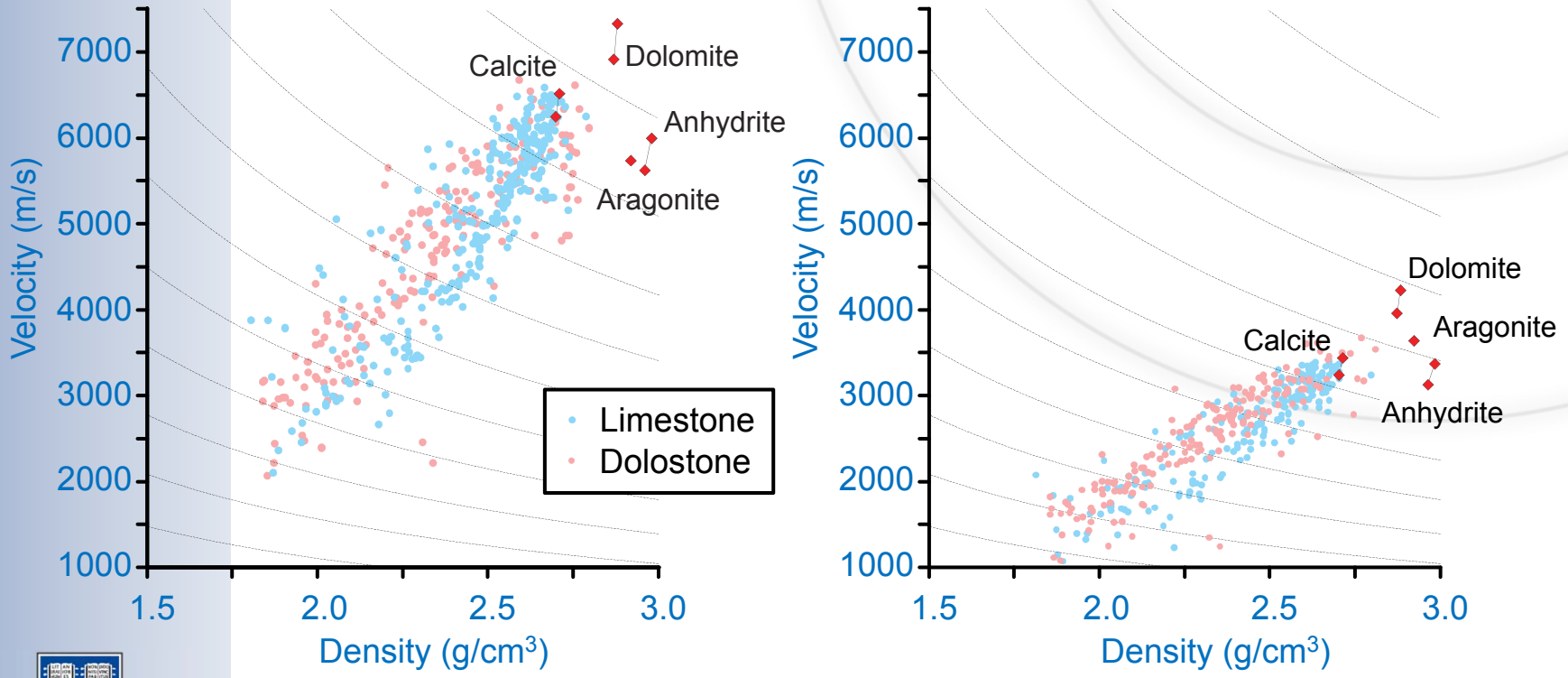
  Prone to dissolution and cementation

- Very complex porosity-permeability characteristics

  Porosity is a major control on all physical properties (except magnetism)

Carbonate seismic properties

- What are the key controls on the distribution?



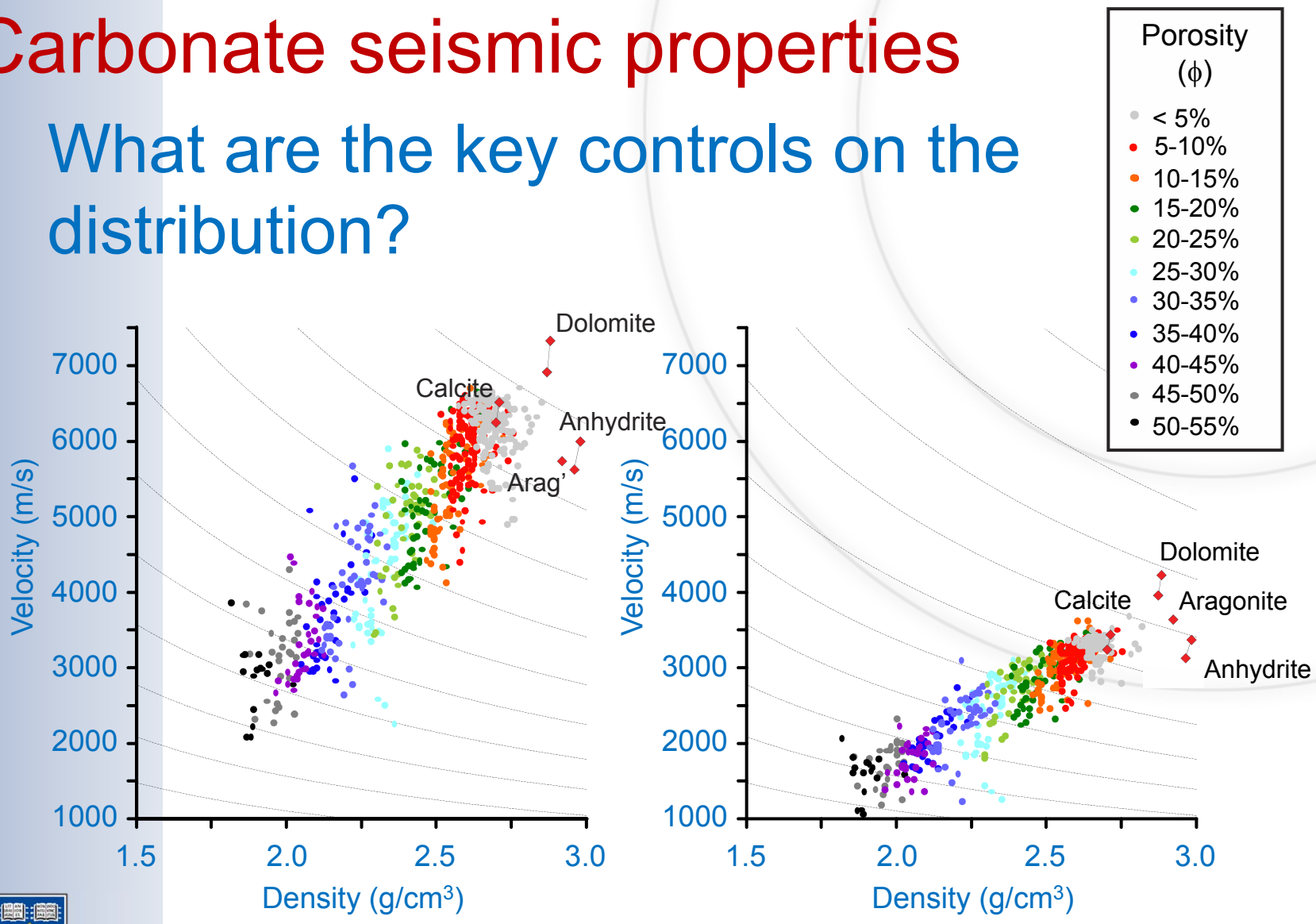
THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Data from 7 published sources

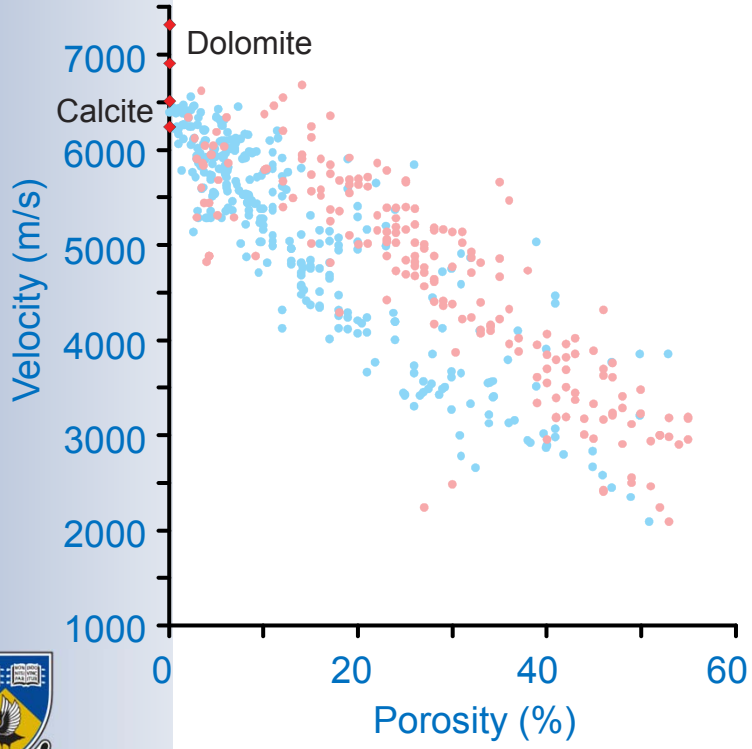
Carbonate seismic properties

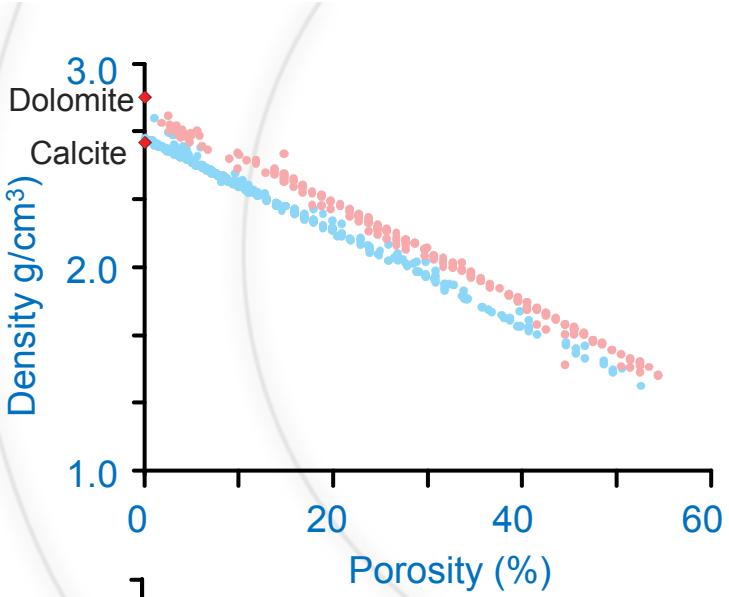
- What are the key controls on the distribution?

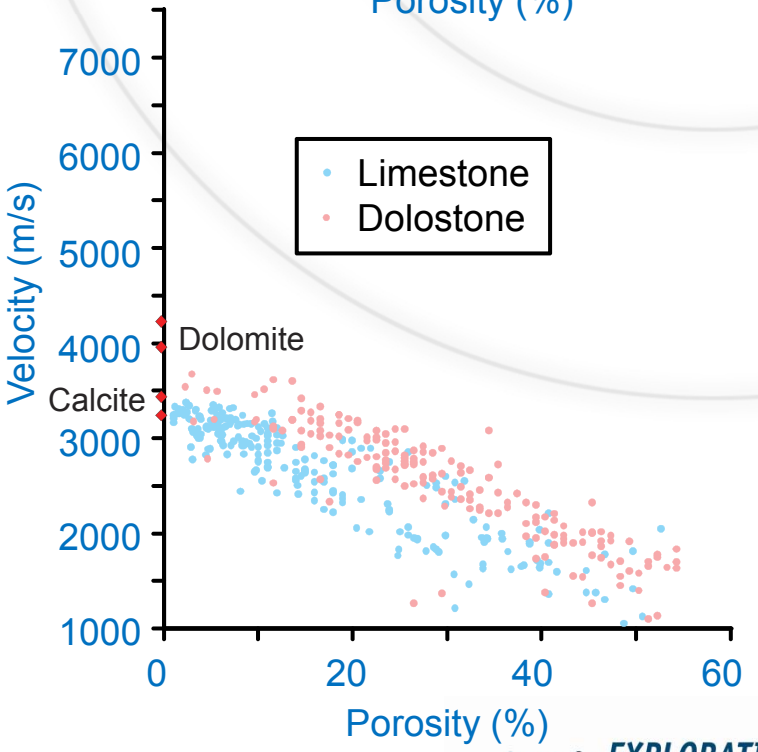


Carbonate seismic properties

- What are the key controls on the distribution?





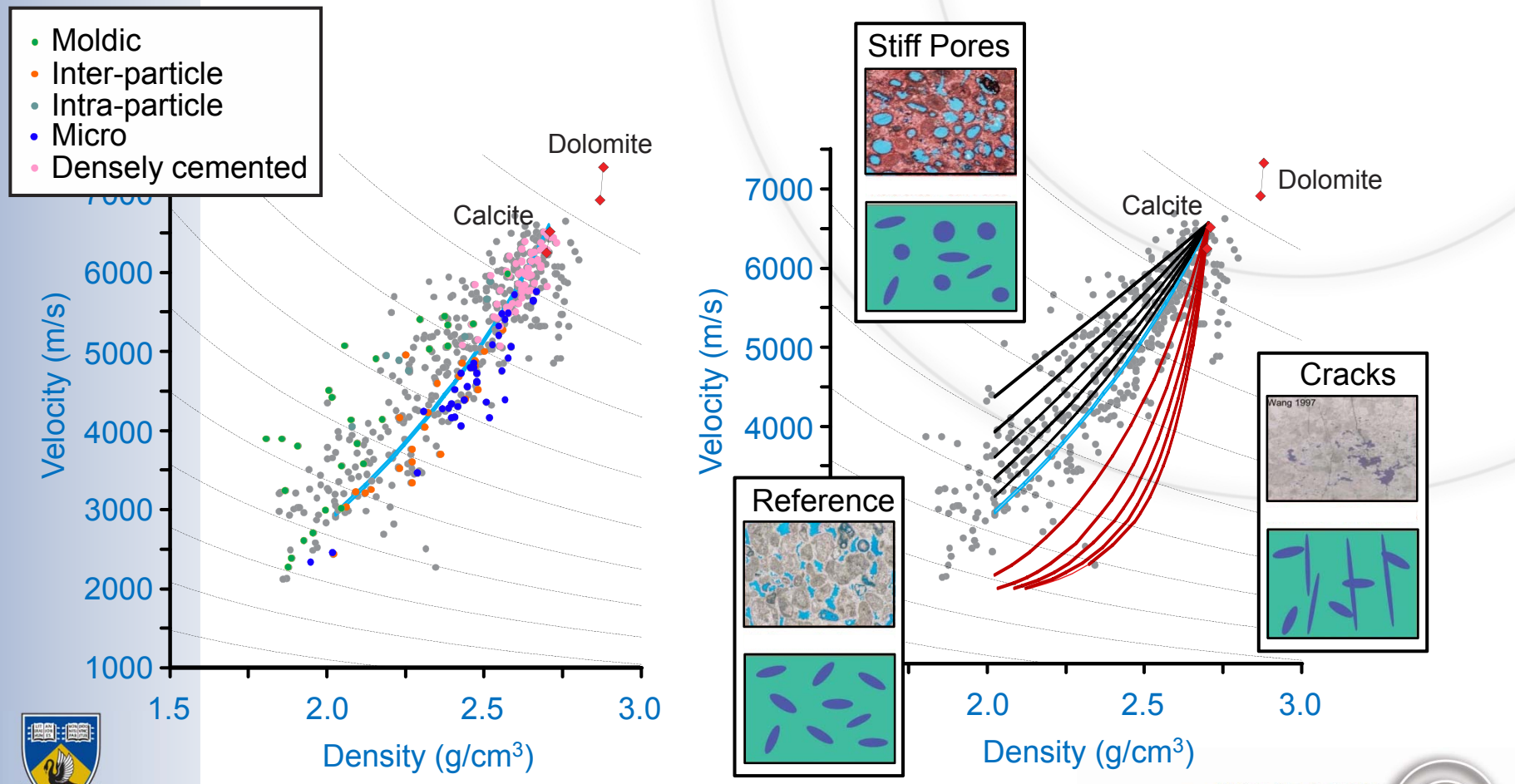


THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Carbonate seismic properties

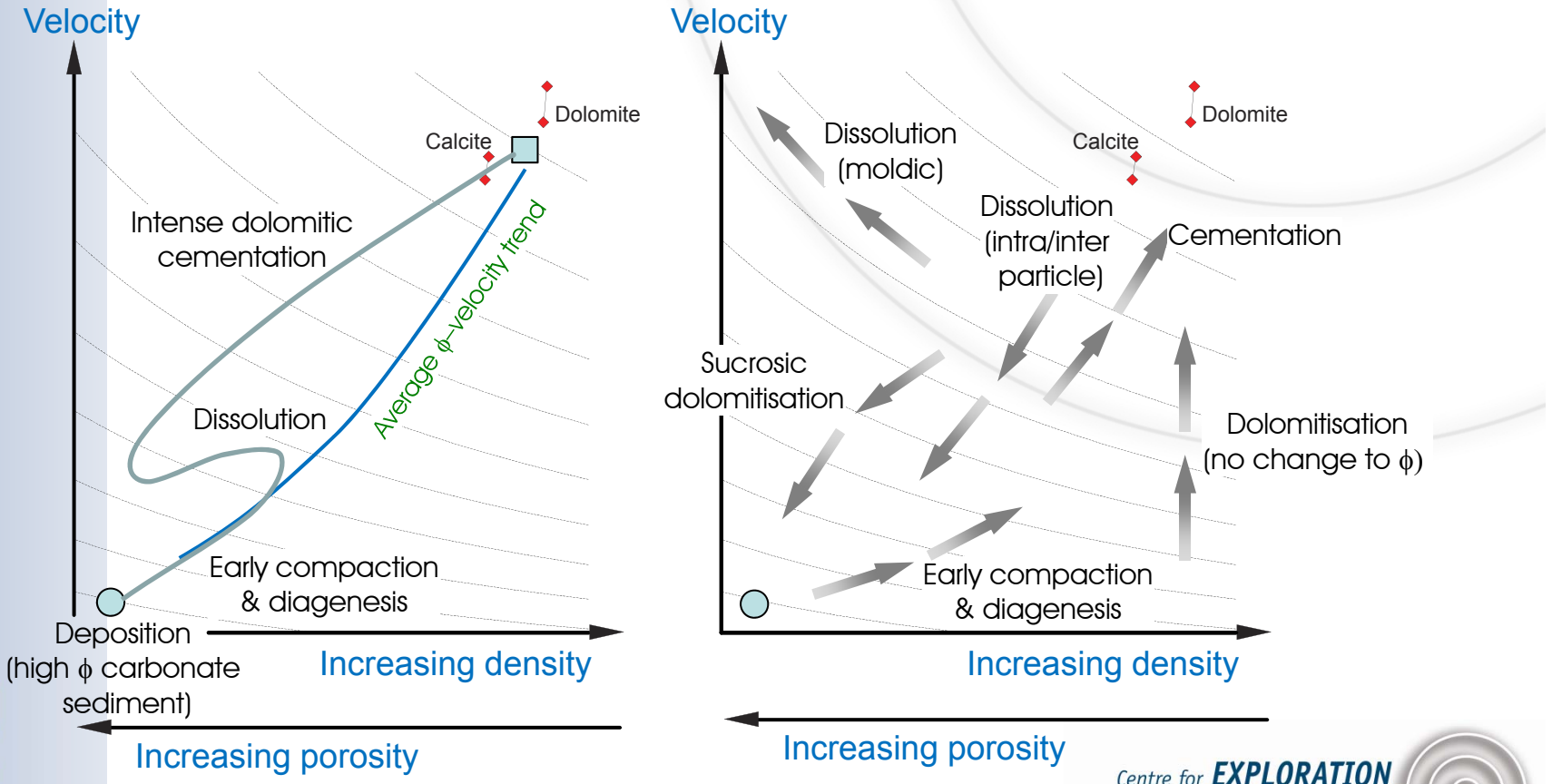
- What are the key controls on the distribution?



Developed from diagrams in Anselmetti & Eberli (1997) and Xu & Payne (2009)

Carbonate seismic properties

- What are the key controls on the distribution – predictive capability?



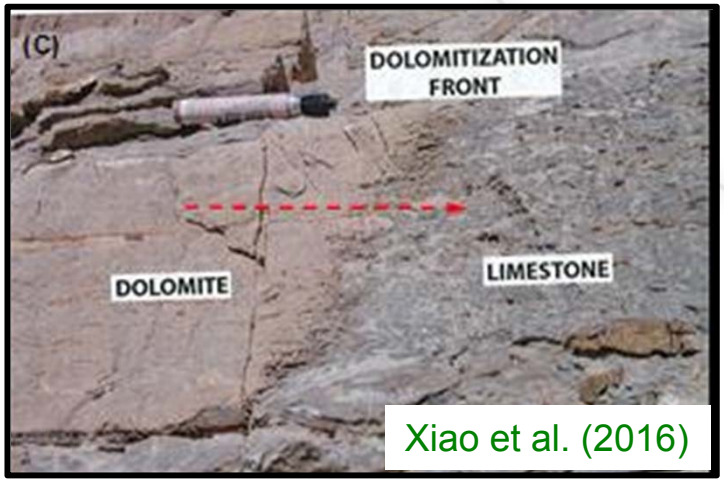
Developed from diagrams in Anselmetti & Eberli (1997)

Carbonate seismic properties

- Theoretically you can map dolomitisation fronts using seismic methods

  Acoustic impedance – seismic attributes

  Velocity – passive or tomographic seismic



Xiao et al. (2016)

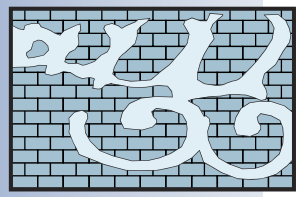
- Other options?

Carbonate electrical properties

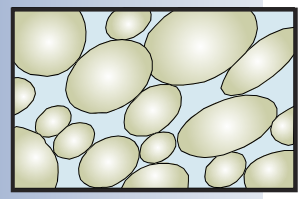
- Formation factor and the Archie equation

$$F = \frac{\rho \text{ Saturated rock}}{\rho \text{ Pore-fluid}} = \frac{a}{\phi^m}$$

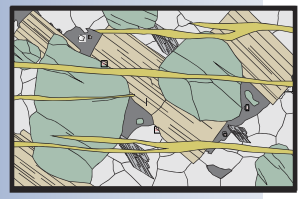
a, m - empirical parameters
ϕ - fractional porosity



Conductive Pore Fluid in Secondary Porosity



Conductive Pore Fluid in Intergranular Porosity

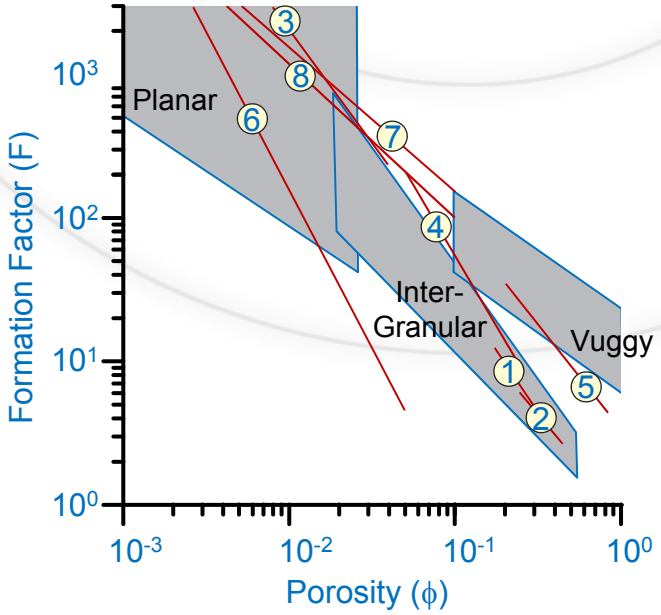


Pore Fluid or Conductive Minerals in Fractures

High Formation Factor

Increasing Complexity of Current Flow Path

Low Formation Factor



THE UNIVERSITY OF WESTERN AUSTRALIA

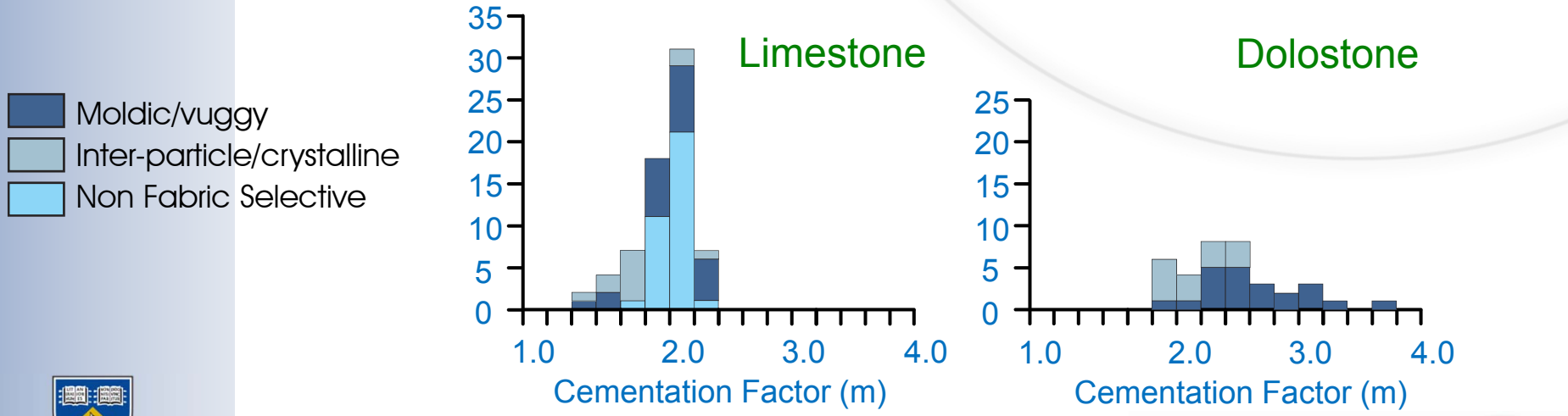
Centre for EXPLORATION TARGETING

Carbonate electrical properties

- Matrix plays no part
- Electrical properties correlated with the type of porosity/permeability

  Different values for different types of porosity

  Recognisably different populations for dolostone and limestone – because of their different types of porosity



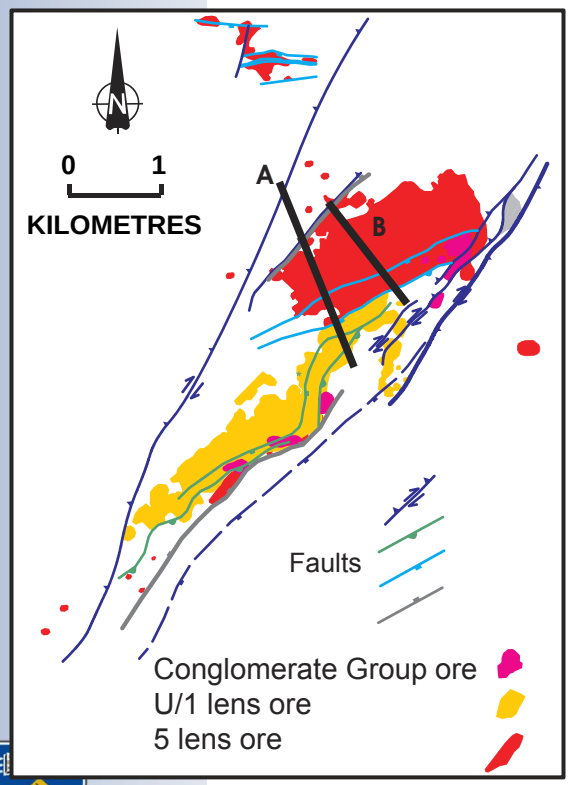
Data replotted from Ragland (2002)

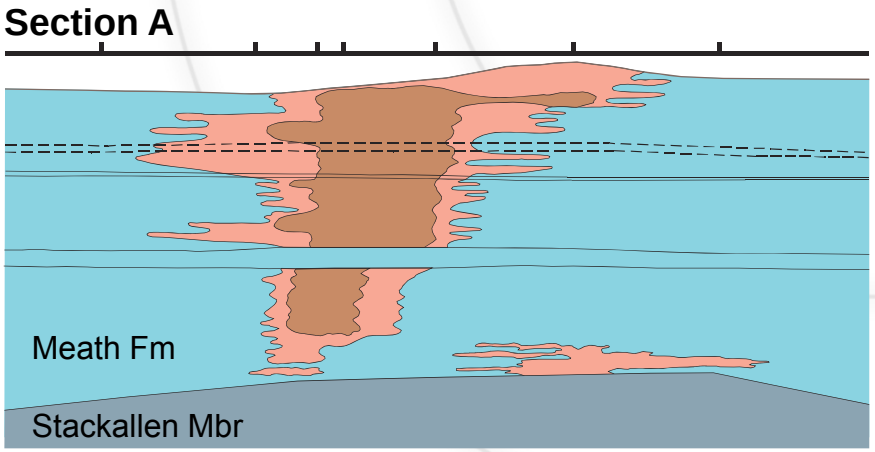
THE UNIVERSITY OF WESTERN AUSTRALIA

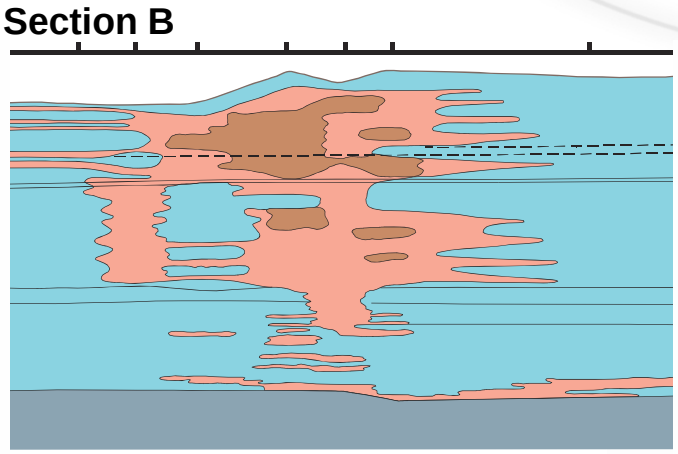
Centre for EXPLORATION TARGETING

Carbonate electrical properties

- Navan deposit, Ireland
- Halo of hydrothermal dolomite reaches 20% ϕ







Vuggy porosity
Limits of dolomitisation

0 500
KILOMETRES

VE 20:1

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING

Ashton et al., (2015); Braithwaite & Rizzi (1997)

Conclusion

- Petrophysical data are potentially very useful for both testing and generating ideas about exploration strategy
  - More than just a guide for modelling geophysical responses
- Uncover and mineral systems: a need to understand what controls physical properties and develop a predictive capability
  - Think beyond lithology - consider alteration and porosity
  - Need plenty of data and of the right kind - scanners

THE UNIVERSITY OF WESTERN AUSTRALIA

Centre for EXPLORATION TARGETING