Queen's University Belfast

GSI
Geological Survey of Ireland
Suirbhéireacht Gheolaíochta Éireann

SSTI
Funded as part of the Strategy for Science, Technology and Innovation

NDP
National Development Plan
Transforming Ireland

Department of Enterprise, Trade and Investment
www.detini.gov.uk
Geological Survey of Northern Ireland

# Investigations multidisciplinaires au sein d'aquifères de socle faiblement productifs en Irlande : typologie, propriétés et importance pour le cycle de l'eau irlandais

# Multidisciplinary investigations of poorly productive hard rock aquifers in Ireland: typologies, properties and significance in the Irish water cycle

*U. Ofterdinger, **J.-C. Comte**, R. Cassidy, J. Caulfield, K. Pilatova, J. Nitsche, C. Wilson, Z. Cai, R. Flynn*

**International Conference Hard-Rock Aquifers: Up-to-date Concepts and Practical Applications, La Roche sur Yon 2015**

# Research Activities

## Overview of Research Activities completed as part of Griffith Geoscience Project:

- Geophysics – borehole geophysics, ground based surveys (ERT, seismic, EM, GPR), airborne geophysics (AEM);
- Hydraulic Testing – Integral Borehole Pump Testing and Packer Testing;
- Tracer Testing – Borehole Injection and Dilution Tests;
- Structural Geology Mapping – outcrop mapping and borehole imaging;
- Hydrodynamic Monitoring – long-term groundwater & surface water level monitoring;
- Hydrochemical Analysis – major and trace element analysis;
- Geochemical Analysis – Rock-water interaction studies;
- Isotope Analysis ($^{2}H$, $^{3}H$, $^{18}O$, $^{13}C$, $^{14}C$) in precipitation, groundwater & surface water;
- Geochemical Modelling (NetPath).

# Research Activities

## Overview of Research Activities completed as part of Griffith Geoscience Project:

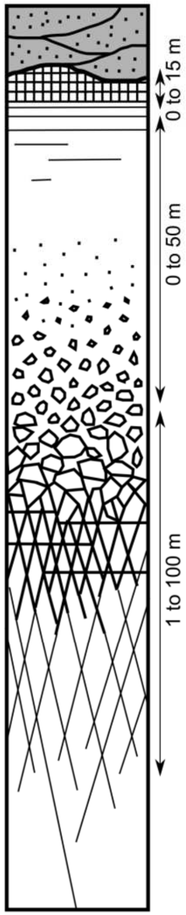
- Geophysics – borehole geophysics, ground based surveys (ERT, seismic, EM, GPR), airborne geophysics (AEM);
- Hydraulic Testing – Integral Borehole Pump Testing and Packer Testing;
- Tracer Testing – Borehole Injection and Dilution Tests;
- Structural Geology Mapping – outcrop mapping and borehole imaging;
- Hydrodynamic Monitoring – long-term groundwater & surface water level monitoring;
- Hydrochemical Analysis – major and trace element analysis;
- Geochemical Analysis – Rock-water interaction studies;
- Isotope Analysis ($^{2}H$, $^{3}H$, $^{18}O$, $^{13}C$, $^{14}C$) in precipitation, groundwater & surface water;
- Geochemical Modelling (NetPath).

# Terminology

REGOLITH

SAPROLITE

SAPROCK

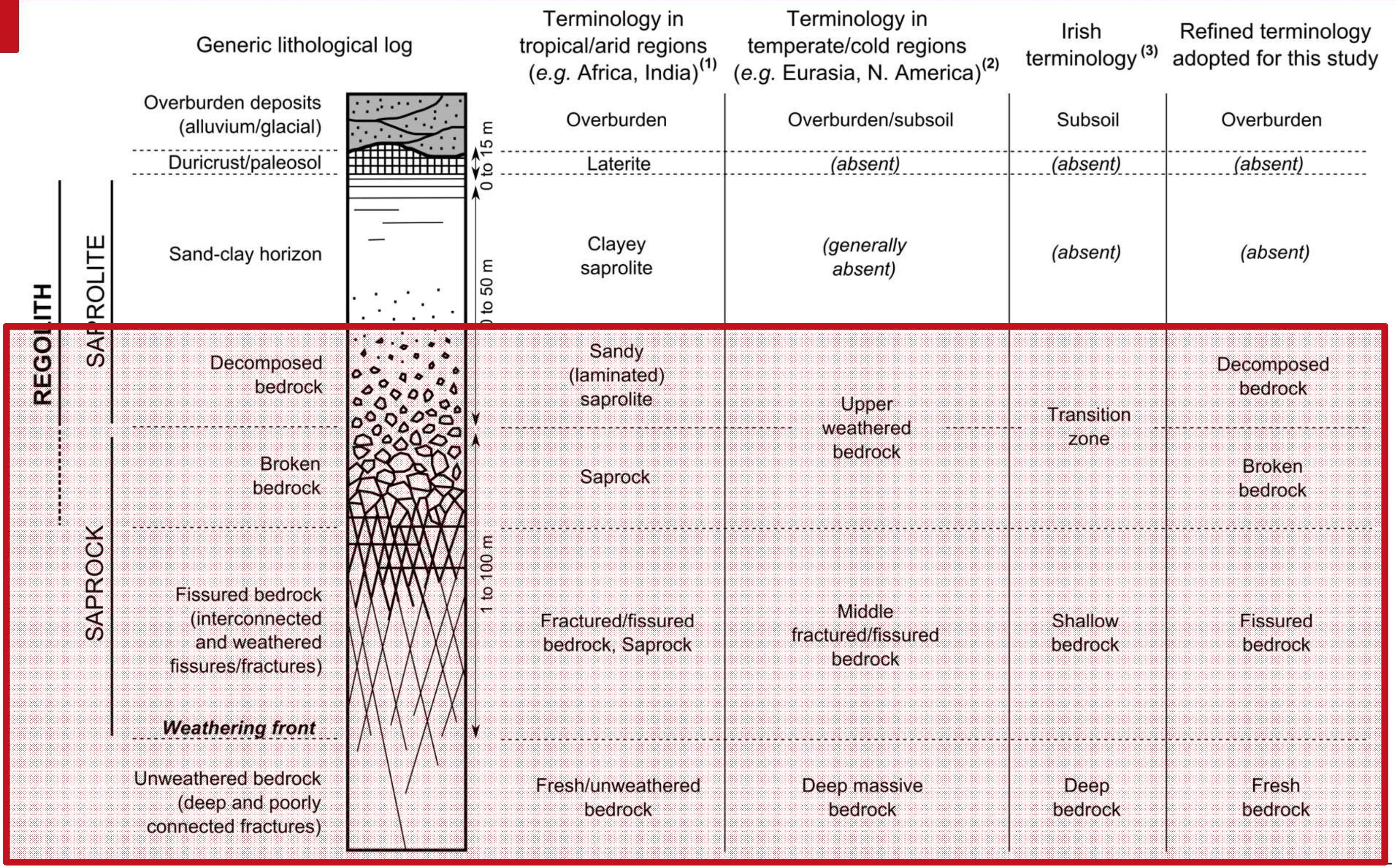



| Generic lithological log | Terminology in tropical/arid regions (*e.g.* Africa, India)[(1)] | Terminology in temperate/cold regions (*e.g.* Eurasia, N. America)[(2)] | Irish terminology[(3)] | Refined terminology adopted for this study |
|---|---|---|---|---|
| Overburden deposits (alluvium/glacial) | Overburden | Overburden/subsoil | Subsoil | Overburden |
| Duricrust/paleosol | Laterite | *(absent)* | *(absent)* | *(absent)* |
| Sand-clay horizon | Clayey saprolite | *(generally absent)* | *(absent)* | *(absent)* |
| Decomposed bedrock | Sandy (laminated) saprolite | Upper weathered bedrock | Transition zone | Decomposed bedrock |
| Broken bedrock | Saprock | | | Broken bedrock |
| Fissured bedrock (interconnected and weathered fissures/fractures) ***Weathering front*** | Fractured/fissured bedrock, Saprock | Middle fractured/fissured bedrock | Shallow bedrock | Fissured bedrock |
| Unweathered bedrock (deep and poorly connected fractures) | Fresh/unweathered bedrock | Deep massive bedrock | Deep bedrock | Fresh bedrock |

(1) After Foster (1984), Acworth (1987), Wright and Burgess (1992), Chilton and Foster (1995), Dewandel *et al.* (2006), Lachassagne *et al.* (2011)
(2) After Krasny (1996), Durand *et al.* (2006), Krasny and Sharp (2007)
(3) After Moe *et al.* (2010)

Comte et al. 2012

# Terminology




(1) After Foster (1984), Acworth (1987), Wright and Burgess (1992), Chilton and Foster (1995), Dewandel *et al.* (2006), Lachassagne *et al.* (2011)
(2) After Krasny (1996), Durand *et al.* (2006), Krasny and Sharp (2007)
(3) After Moe *et al.* (2010)

Comte et al. 2012

# Terminology

| Generic lithological log | Terminology in tropical/arid regions (*e.g.* Africa, India)[1] | Terminology in temperate/cold regions (*e.g.* Eurasia, N. America)[2] | Irish terminology[3] | Refined terminology adopted for this study |
|---|---|---|---|---|
| Overburden deposits (alluvium/glacial) | Overburden | Overburden/subsoil | Subsoil | Overburden |
| Duricrust/paleosol | Laterite | *(absent)* | *(absent)* | *(absent)* |
| Sand-clay horizon | Clayey saprolite | *(generally absent)* | *(absent)* | *(absent)* |
| | | er ered ck | Transition zone | Decomposed bedrock |
| | | | | Broken bedrock |
| | | le issured ck | Shallow bedrock | Fissured bedrock |
| | | ssive ck | Deep bedrock | Fresh bedrock |

ITH ROLITE 0 to 15 m 0 to 50 m


), Lachassagne *et al.* (2011)

(3) After Moe *et al.* (2010)

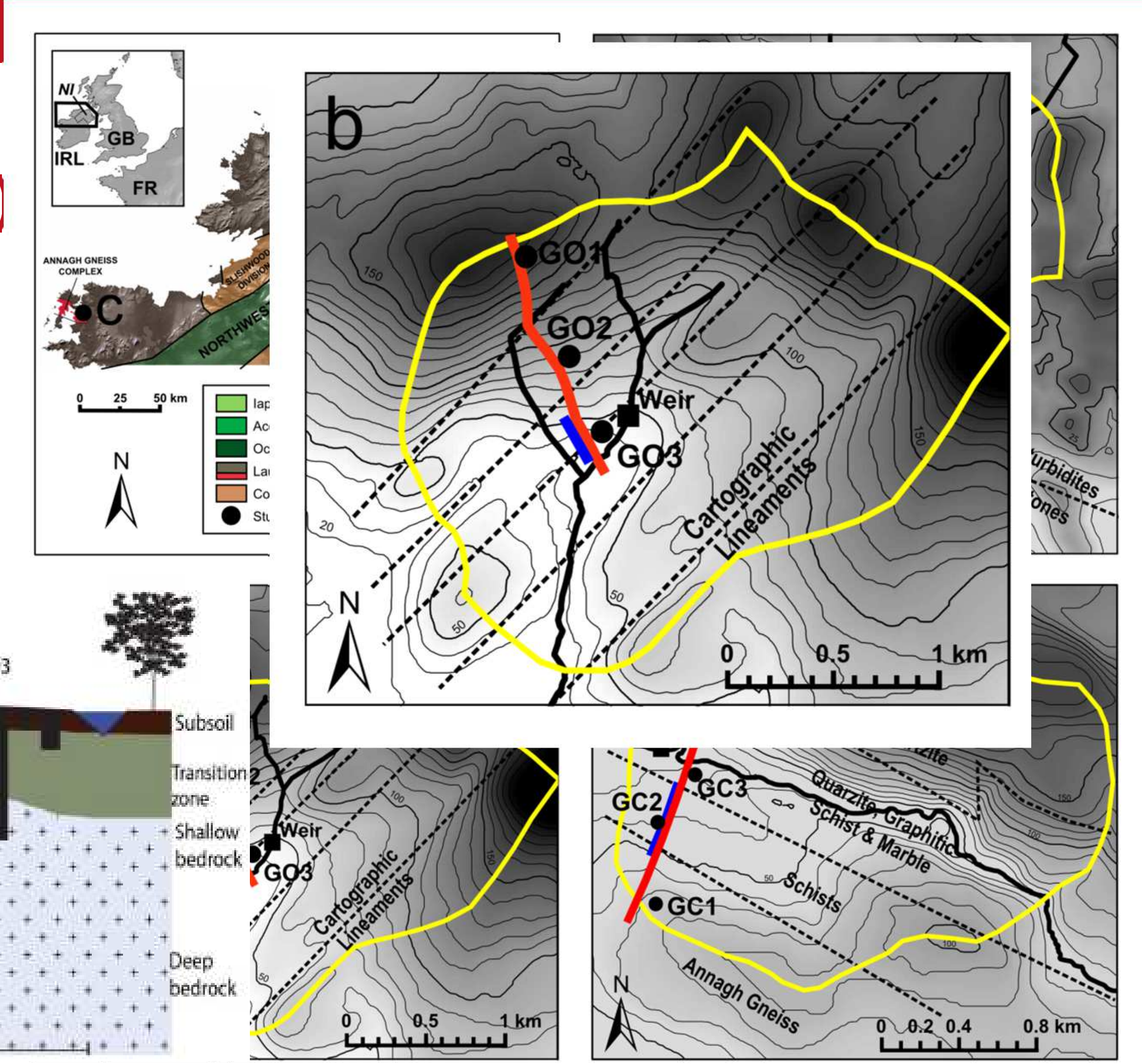
Comte et al. 2012

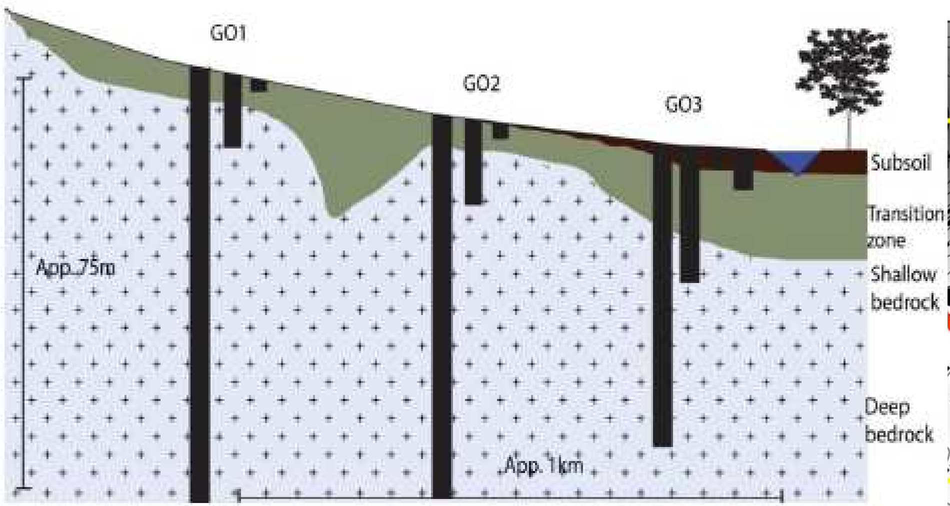
# Study Sites

a) Mount Stewart (MS)

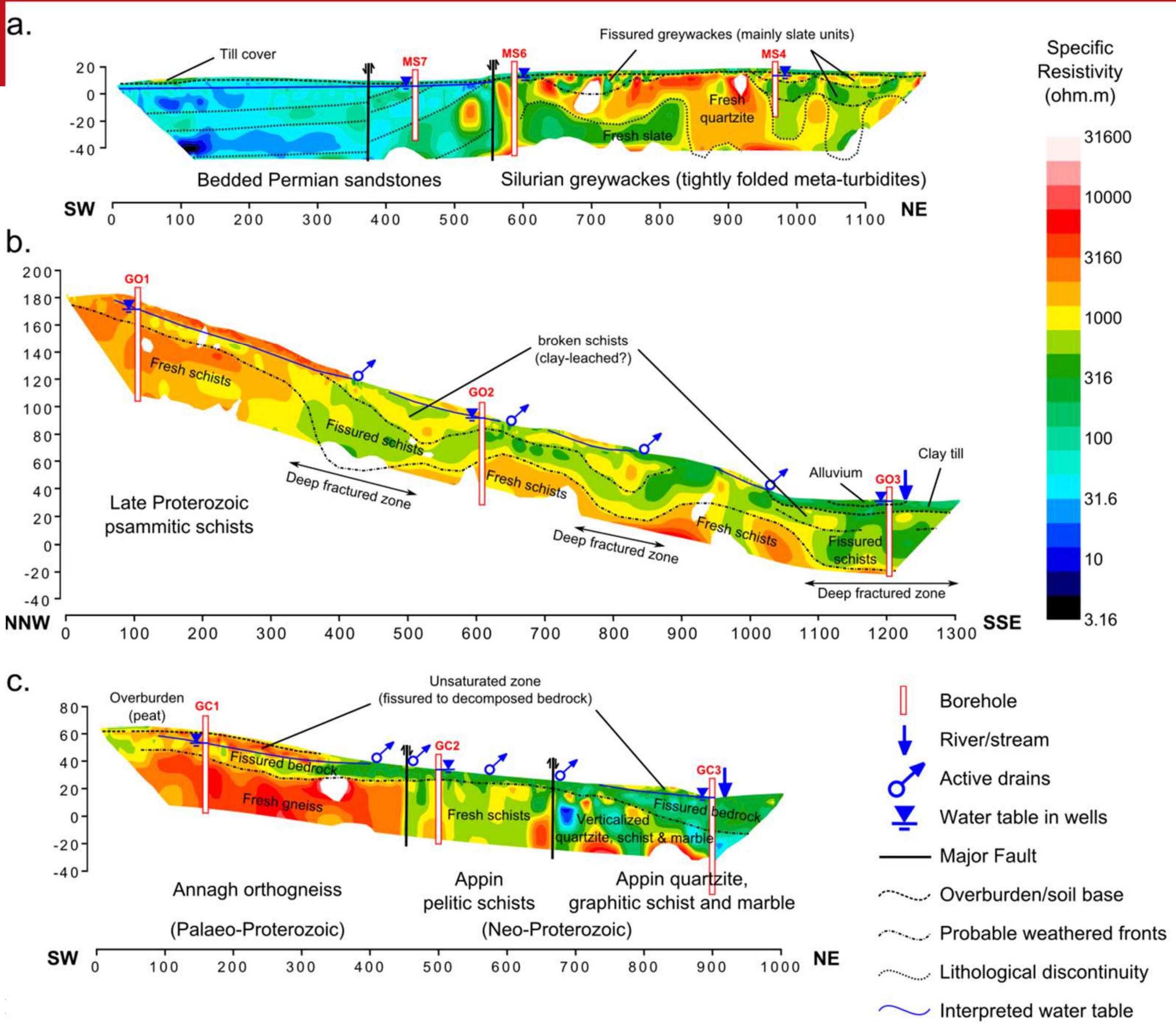
b) Gortinlieve (GO)

c) Glencastle (GC)



# Surface Geophysics / ERT




Comte et al. 2012

# Structural Geology

**At BH/outcrop scale:**

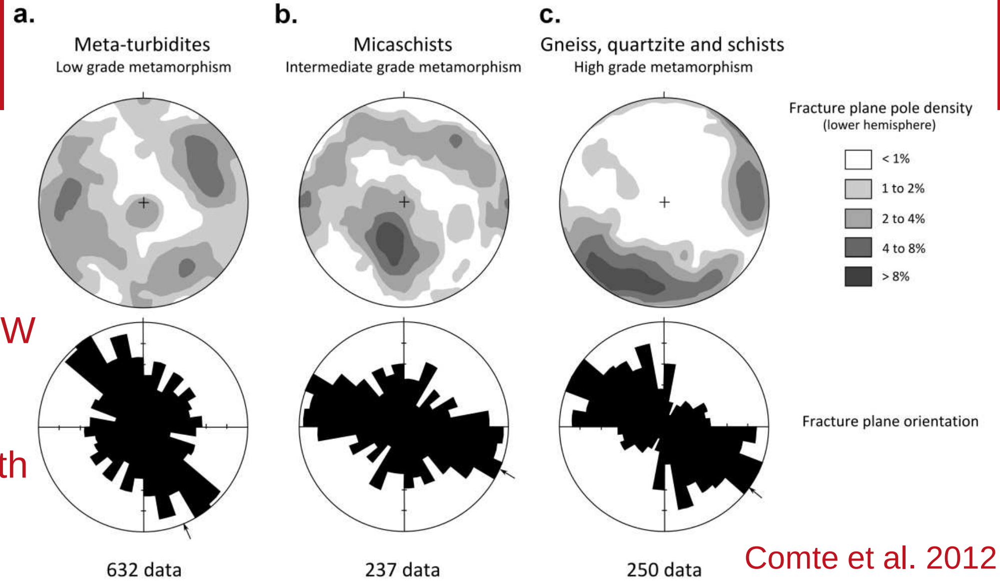
- 2 dominant fracture sets:
  -WNW-ESE with dip angles 35°NNE and 60-70° SSW
  -NE-SW/NNE-SSW with dip angle 60-70 deg ESE

- at this meso-scale influenced by Alpine tectonics with Caledonian as secondary control

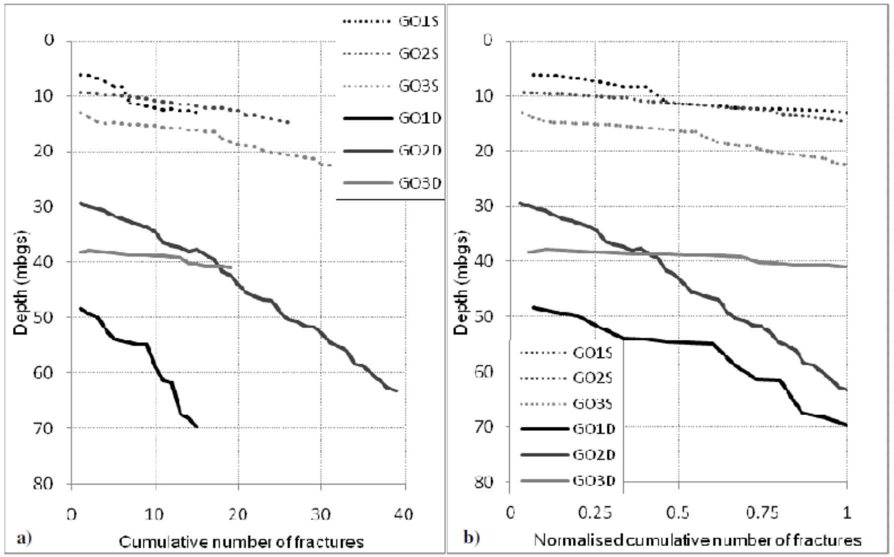
- at macro-scale (catchment/regional scale); lineaments typically associated with pre-alpine NE-SW trend

- cumulative distribution plots of fracture occurrence with depth bgl (actual & normalised) indicate steeper slope / larger fracture spacing in deeper bedrock boreholes (except GO3)

  - GO3 affected by deeper weathering

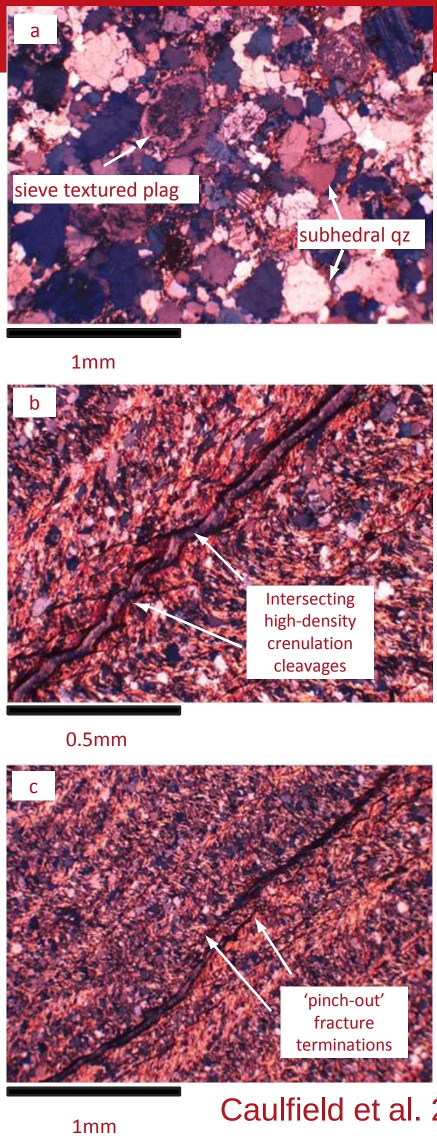



Comte et al. 2012




Nitsche 2015

# Structural Geology / Geochemistry




Caulfield et al. 2014

**Orientated rock samples:**

- Foliation planes with WNW-ESE strike dip angle 26° NNE

- In thin sections 2 sets of interconnected micro-fractures:
  - both WNW-ESE strike
  - Set 1 dipping 25-32° NNE; Set 2 dipping 65-72° SSW
  - commonly lined by Fe-oxides

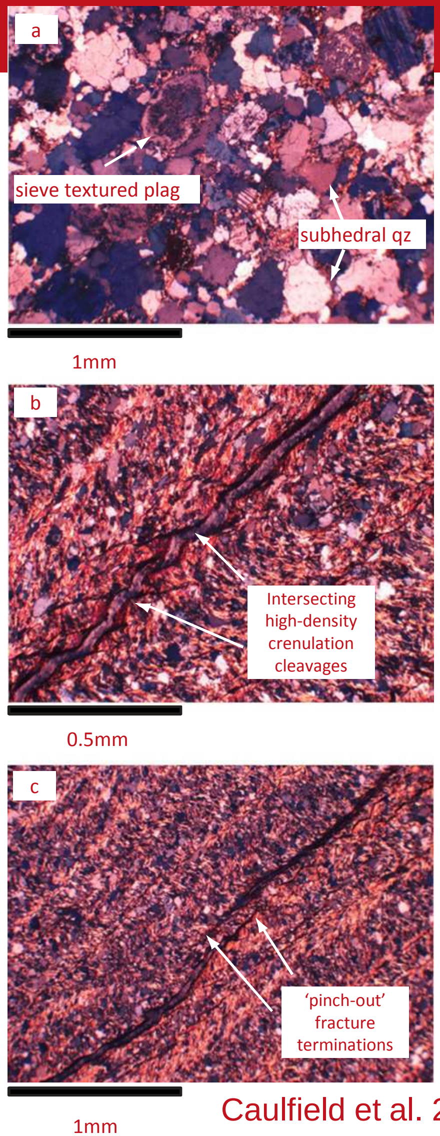
- Lining reduces secondary porosity

- 'Pinch-out' terminations indicate discontinuous nature

- These structures span micro to meso-scale (also visible in BH/outcrop)

- Seen to act as micro/meso-scale pathways for weathering solutions and subsequent transport of dissolved species away from sites of mineral breakdown

# Structural Geology / Geochemistry



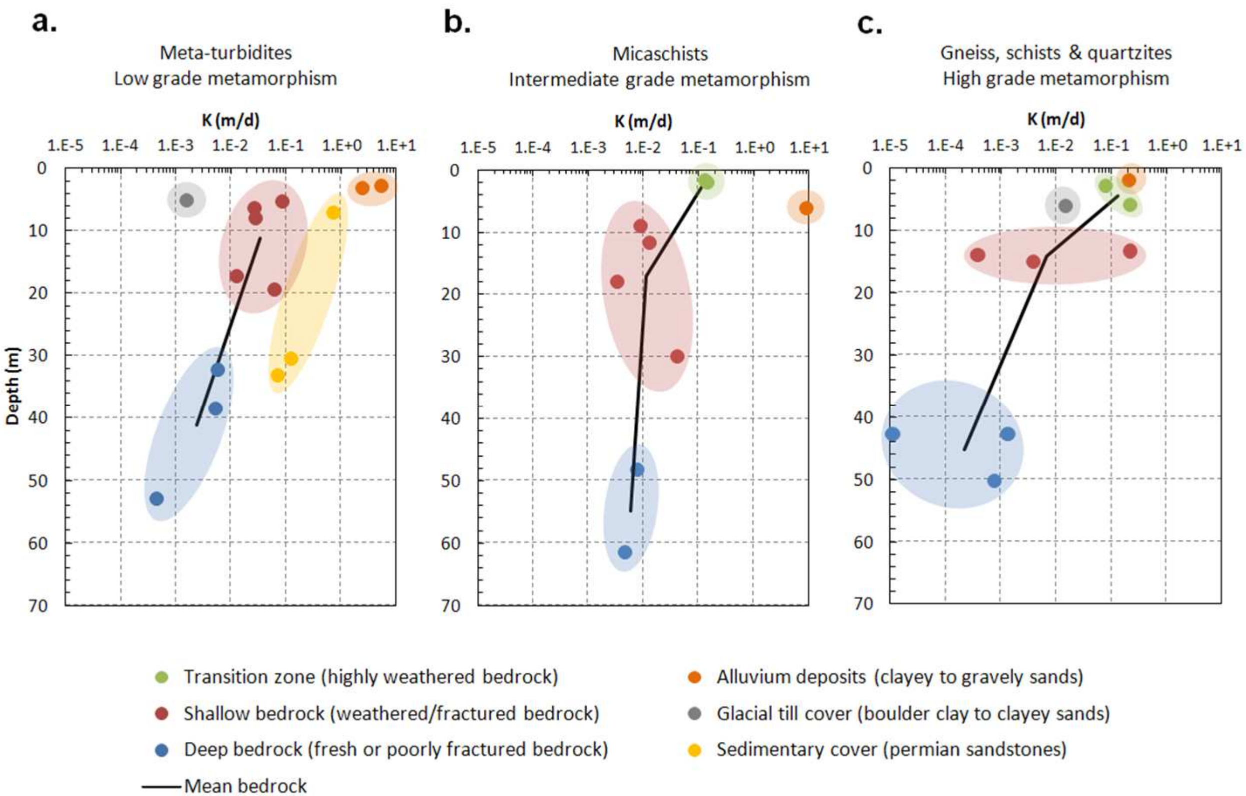
Caulfield et al. 2014

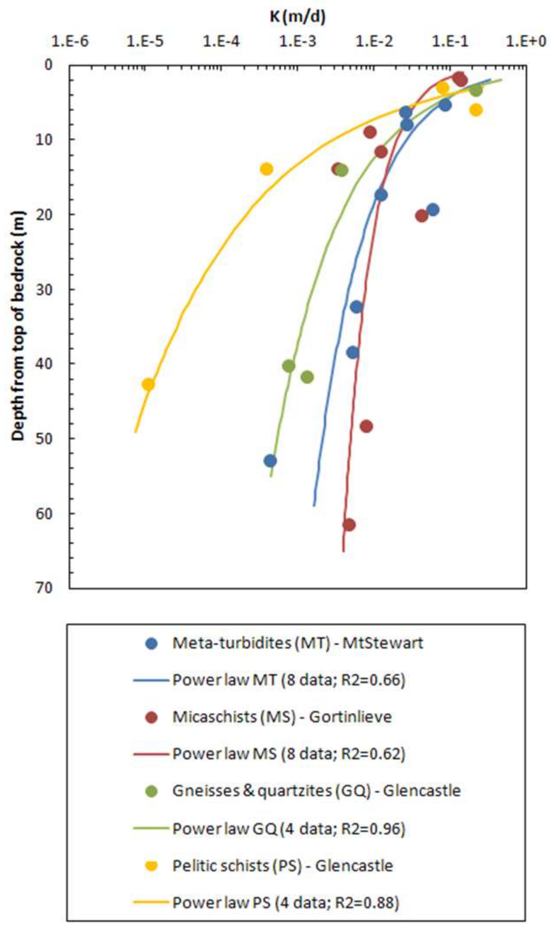
## Weathering:

- Qtz most resistant mineral present in bedrock; samples from highly fractured/fissured zones contain higher % of strained grains / weathered rinds
  - weakened crystal structure and proximity to micro-fractures makes them vulnerable to weathering
- Alteration of Na-feldspars main source of Na release
- Ubiquitous sieve-textured feldspar grains reflect preferential dissolution of more Ca-rich grain cores and replacement with sericite
- Secondary weathering products dominated by illite & montmorillonite
- Samples show variation in clay content across transition zone; clay-poor upper layer and clay-enriched lower horizon (*see ERT*)
  - reflects eluviation of secondary clay weathering products from upper weathering profile and accumulation in basal part as illuvial layer as fracture density decreases with depth
  - driven by meteoric recharge transporting clays as a suspension

# Hydrodynamic Parameters

| | Geometric mean | Range | No. data |
|---|---|---|---|
| Hydraulic conductivity $K$ (m d$^{-1}$) | | | |
| Transition (broken/decomposed) zone | $0.9\times10^{-1}$ | $1.5\times10^{-2}-2.2\times10^{-1}$ | 4 |
| Shallow (fissured) bedrock | $1.6\times10^{-2}$ | $3.8\times10^{-4}-2.2\times10^{-1}$ | 12 |
| Deep (massive) bedrock | $1.2\times10^{-3}$ | $1.1\times10^{-5}-7.8\times10^{-3}$ | 8 |
| Storativity $S$ (–) | | | |
| Transition (broken/decomposed) zone | $3.7\times10^{-2}$ | $2.8\times10^{-2}-4.9\times10^{-2}$ | 4 |
| Shallow (fissured) bedrock | $1.7\times10^{-3}$ | $1.0\times10^{-4}-2.8\times10^{-2}$ | 12 |
| Deep (massive) bedrock | $3.8\times10^{-5}$ | $1.2\times10^{-8}-5.2\times10^{-3}$ | 8 |



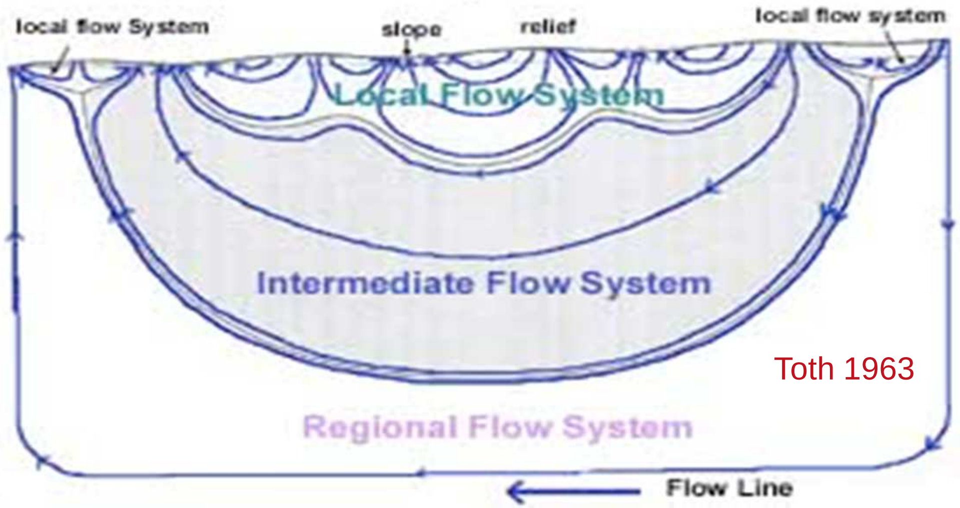

Comte et al. 2014

# Hydrochemistry

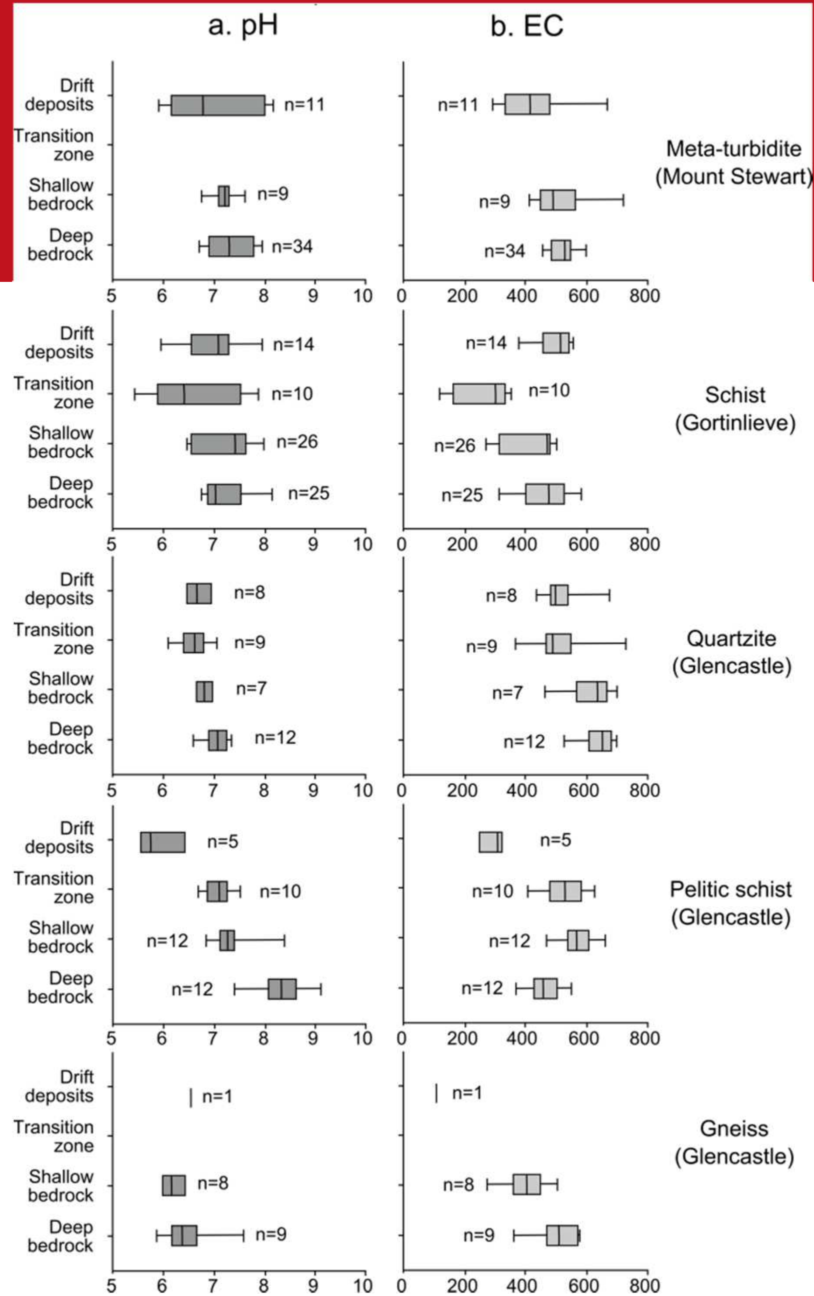
- Subtle differences in the median values of pH and EC across the individual aquifer typologies at the 3 sites

- Variation within individual bedrock units noteworthy; associated with the varying residence times as a result of aquifer properties.
  - Gortinlieve with wider variations.

- Degree of weathering major influence on absolute values of pH and EC; presence of deep weathered zones and considerably faster flows result in decrease of both pH and EC (e.g. at GO3)




Toth 1963




Pilatova 2015

# Summary

- ERT highlights weathering profile – governed by lithology and faults
- ERT highlights varying clay content in transition zone – also seen in geochemistry
- Across scales dominant fracture sets; sets spanning micro- to meso-scale provide pathways for weathering process
- Depth-dependancy of hydrodynamic parameters (generalised for aquifer typologies)
- Hydrochemistry reflect dynamics of flow systems (broadly consistent with Toth's model)

# Acknowledgments

We wish to thank our colleagues at:

- Irish Environmental Protection Agency (EPA)
- Northern Ireland Environment Agency (NIEA)
- Geological Survey of Ireland (GSI)
- Geological Survey of Northern Ireland (GSNI)

*This work is based on research grant-aided by the Irish Department of Communications, Energy and Natural Resources under the National Geoscience Programme 2007–2013. The views expressed are the authors' own and do not necessarily reflect the views and opinions of the Minister for Communications, Energy and Natural Resources.*