What makes geoscience experts effective at interpreting seismic images?

....what makes a "good" expert and what factors affect interpretational ability?

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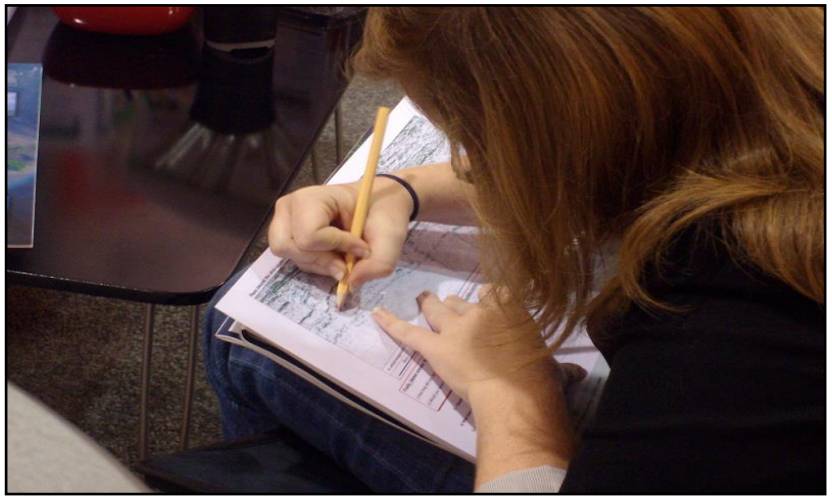


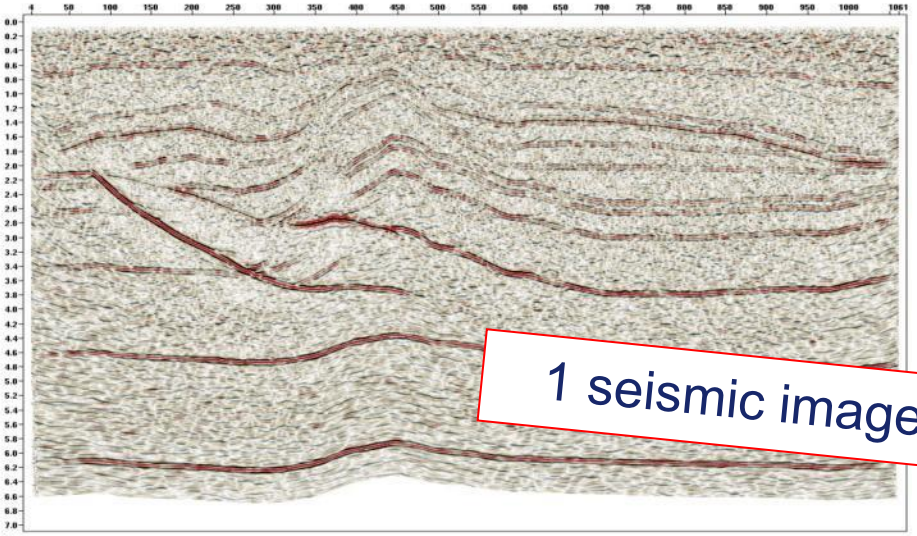
University of Strathclyde

midland valley

1495 UNIVERSITY OF ABERDEEN

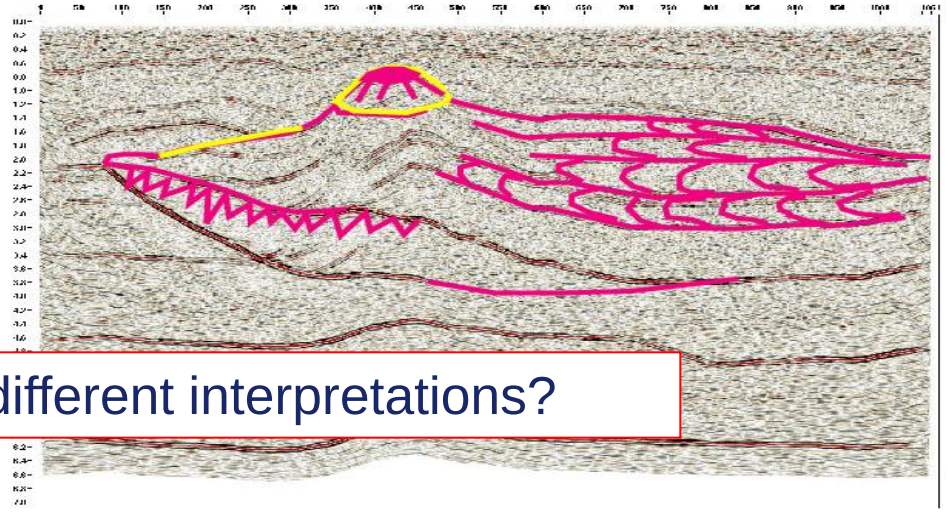
NATURAL ENVIRONMENT RESEARCH COUNCIL

Scottish Business Grants



1 seismic image

445 Geoscientists



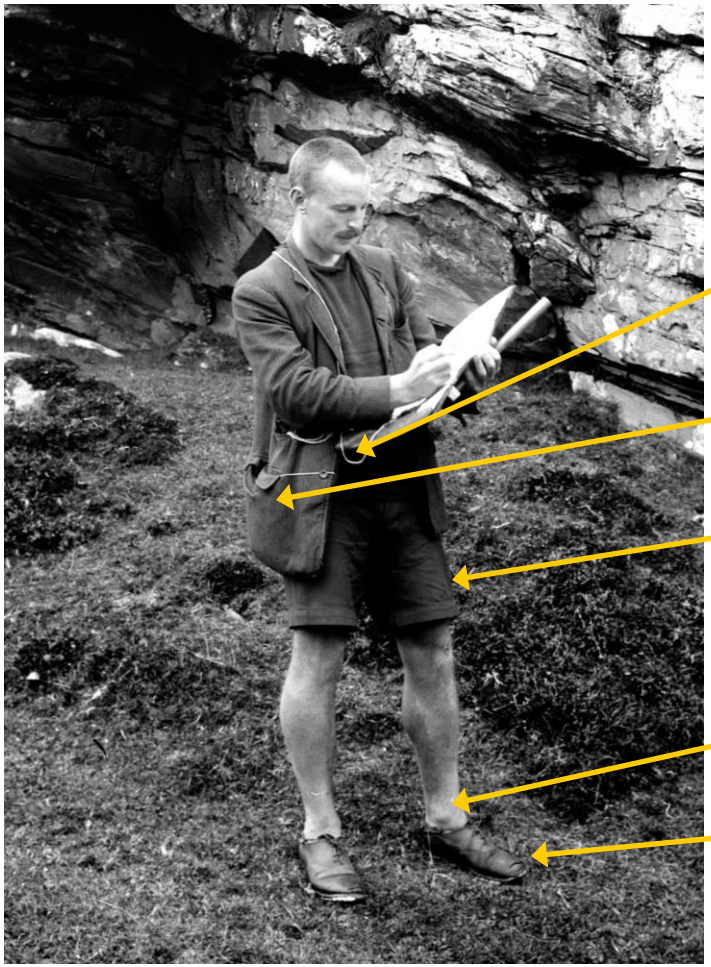
How many different interpretations?

What is an “expert”?

- Most elicitations conducted with a relatively small amount of experts
- How variable are expert opinions across a field?
- How variable are expert opinions of equivocal or sparse data?

How geologists collect data….in the field!

E.B. Bailey – summer (c. ?1912)



Equipment tied on with string

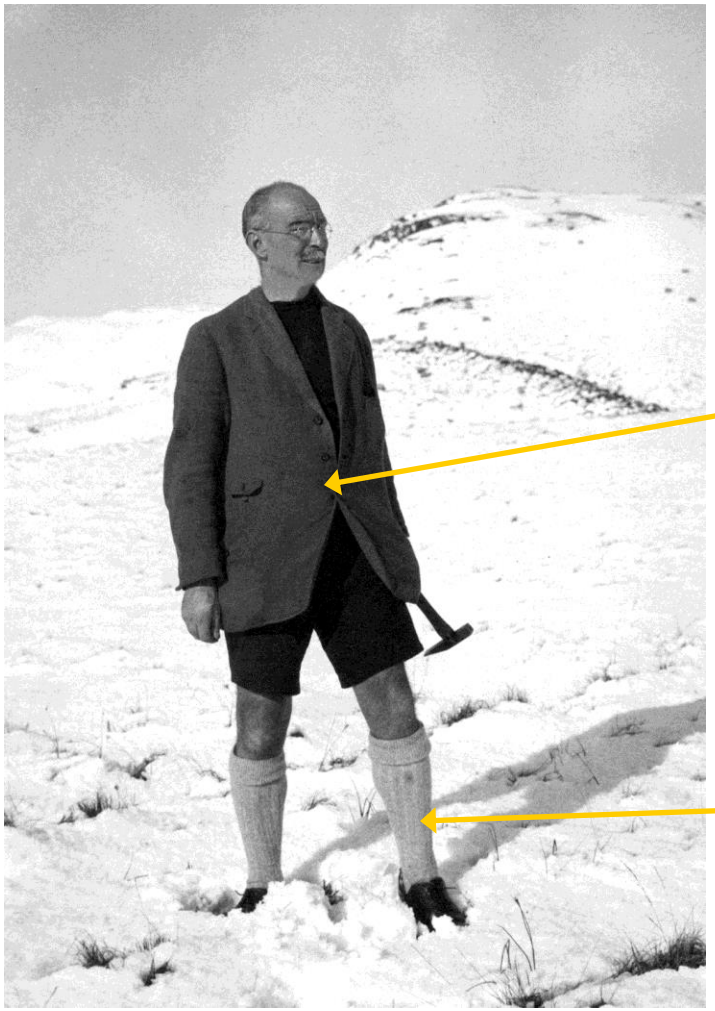
No lunch in pocket – already eaten

Shorts –
worn in all weathers and all seasons

No socks – they only get wet

Shoes (not boots) – holes in toes to let water out

E.B. Bailey – winter (and a little older)



Jacket – buttoned up

Thick socks

Geological surveyor - 2014

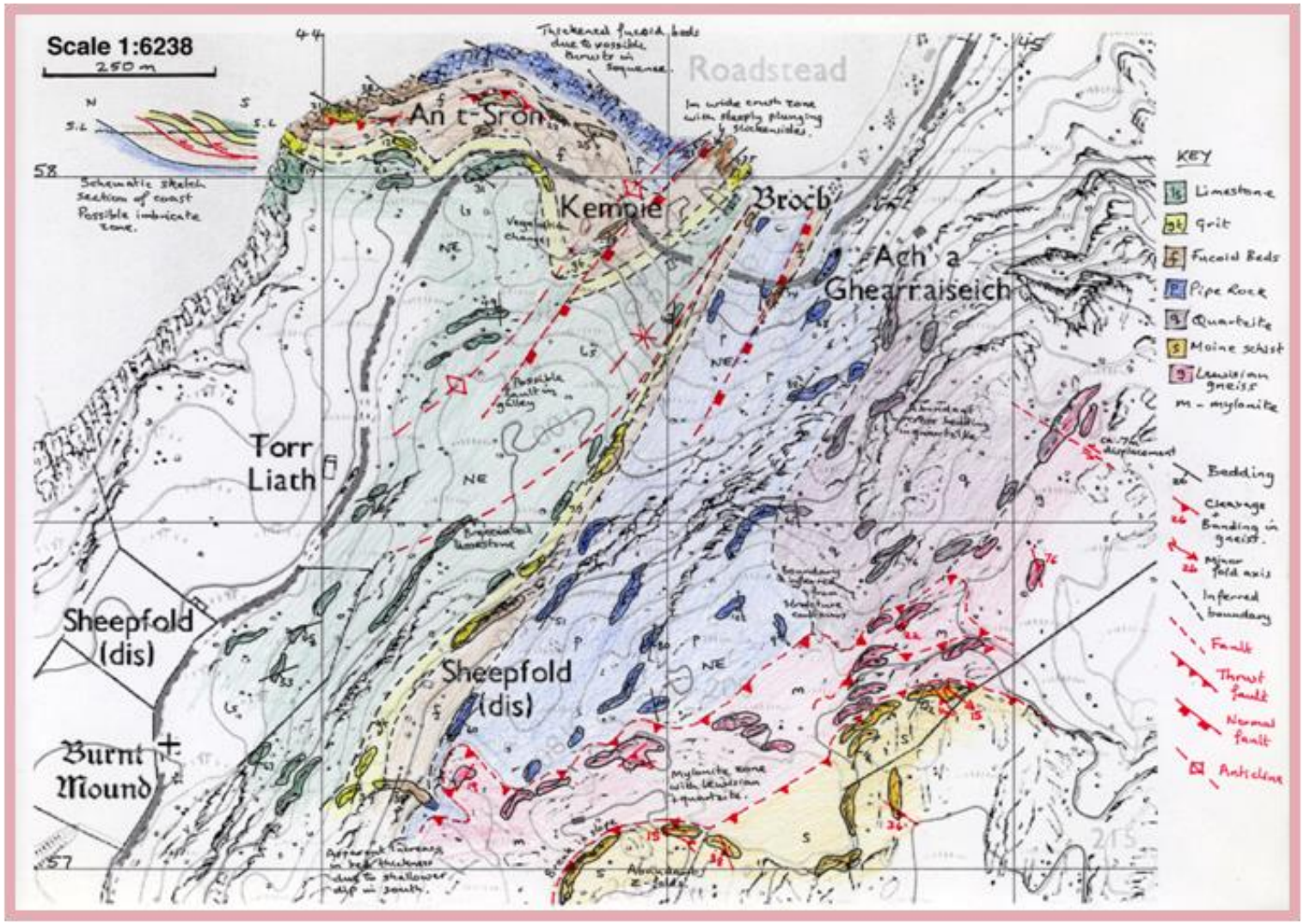
Lunch, emergency rations, survival kit, satellite phone, protective clothing etc.

Mobile Integrated Data Acquisition System, fully digital, includes:
maps – active and archive
Air photos
notebook
GPS

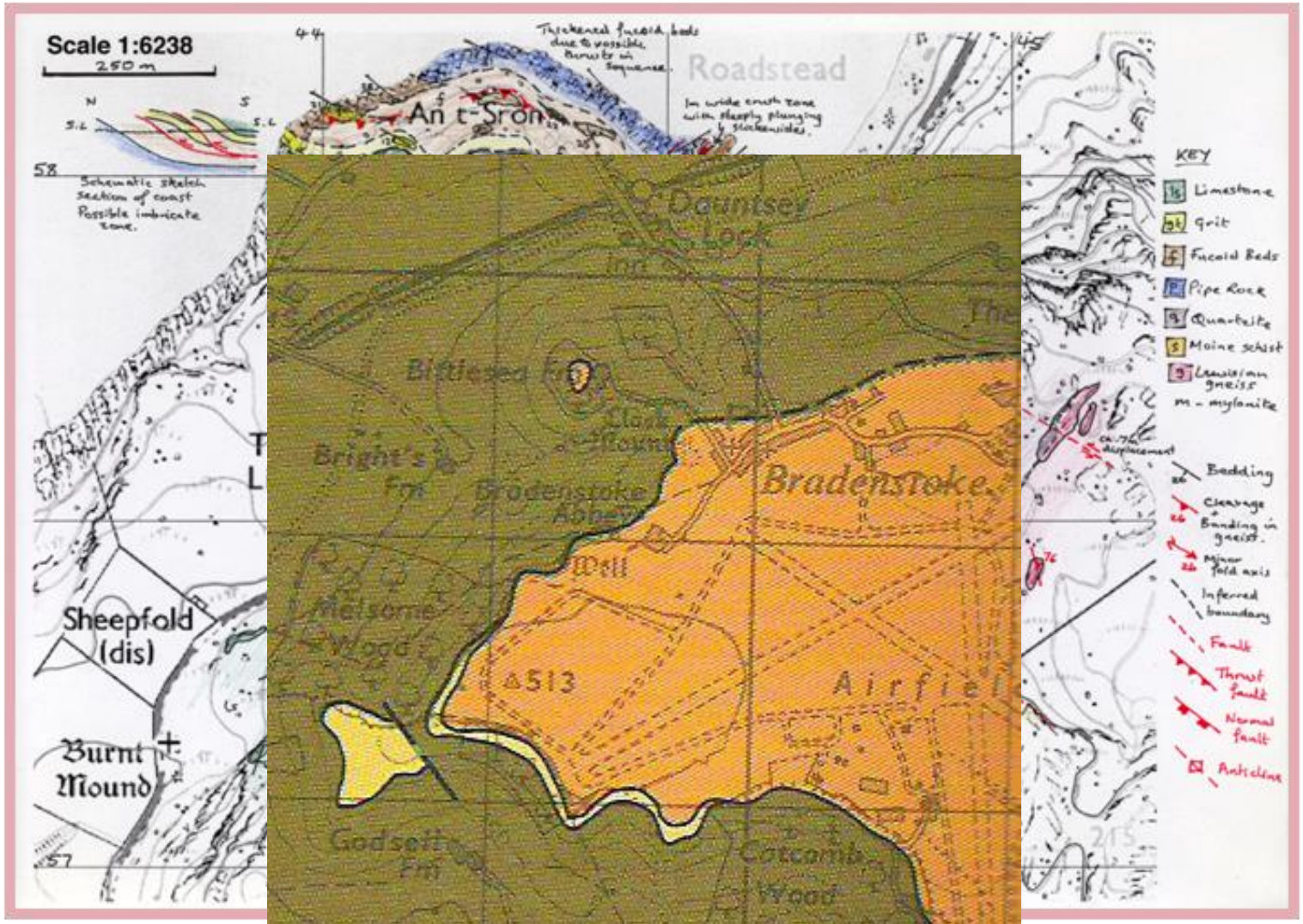
Long trousers to comply with health & safety regulations. Protect against:
UV radiation
hypothermia
midges
ticks

Boots – lightweight, goretex-lined

NB no hammer!

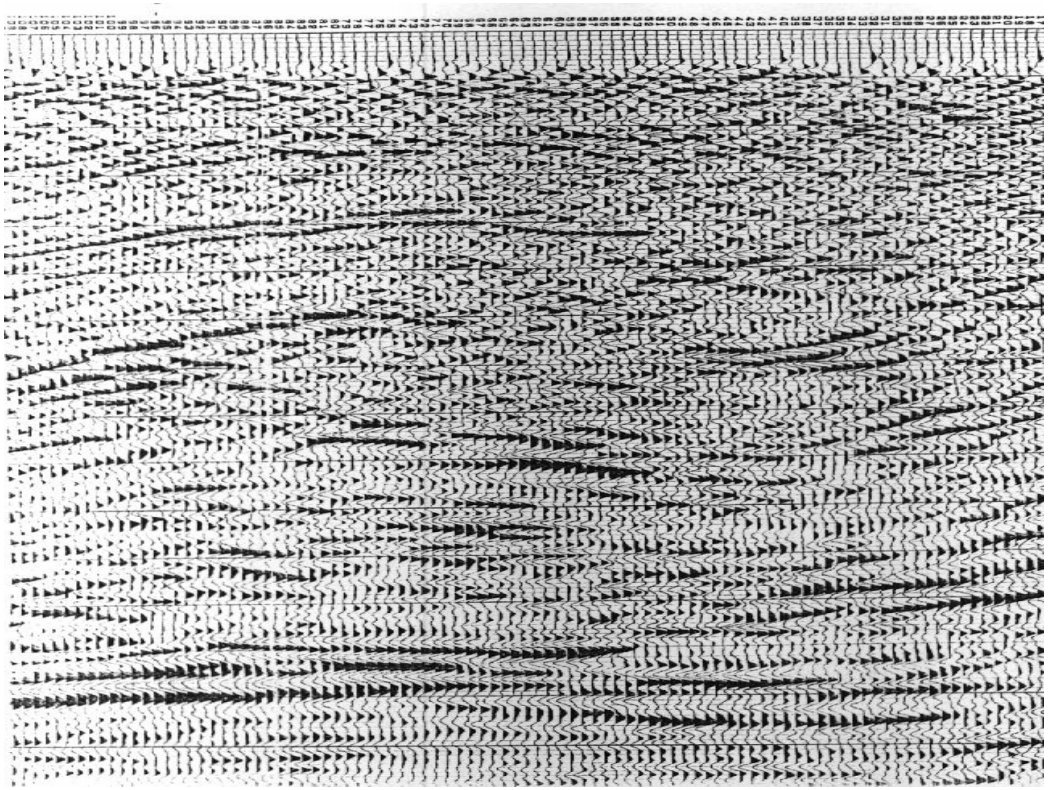


A map is a model of data – ALWAYS expect some deviation from predicted geology once you drill a borehole, cut a road cut, dig a foundation, build a dam, emplace radioactive waste…

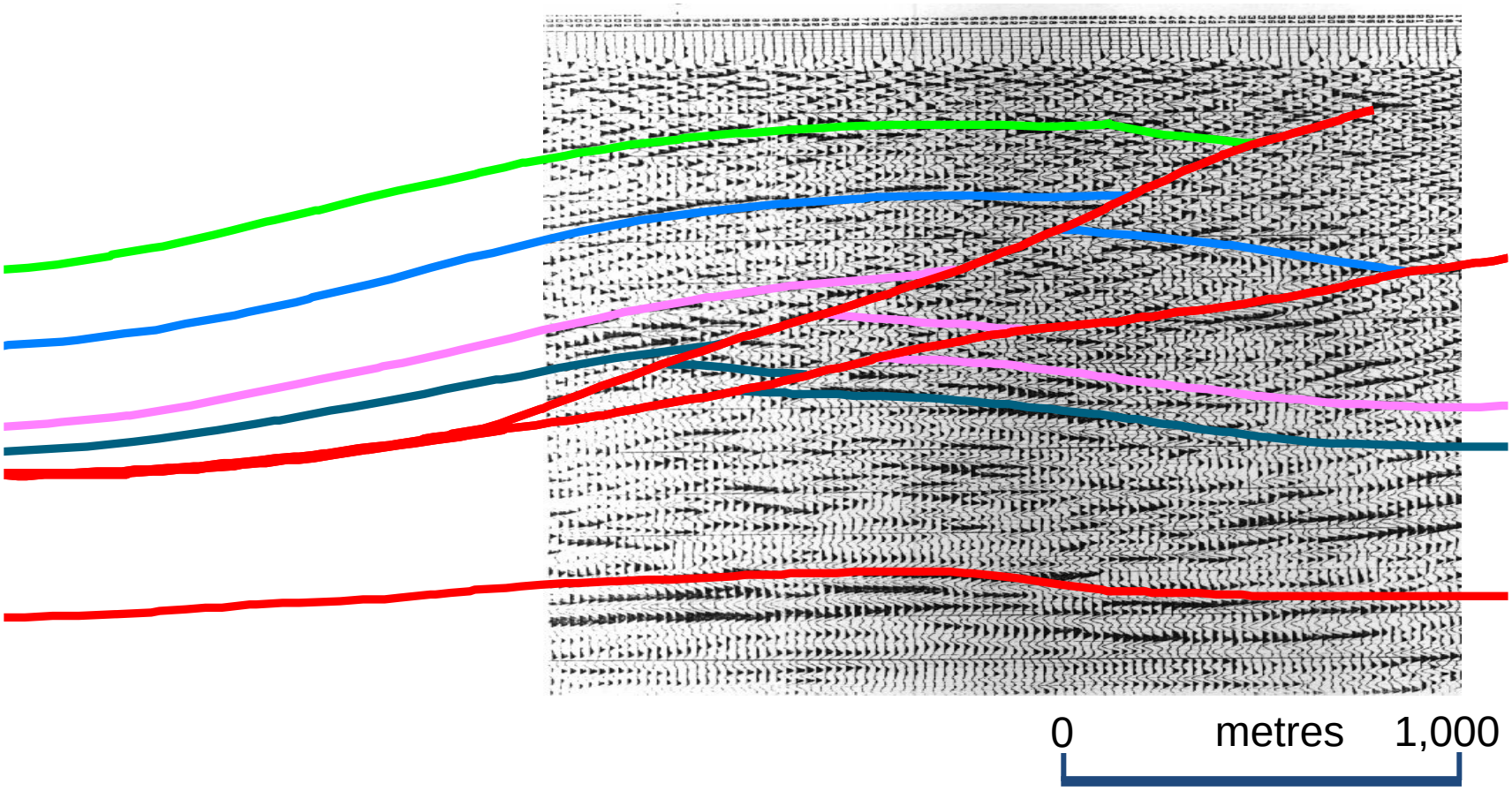


A map is a model of dat icted geology once you drill a borehole, cut a road c dioactive waste…

Geological data - subsurface



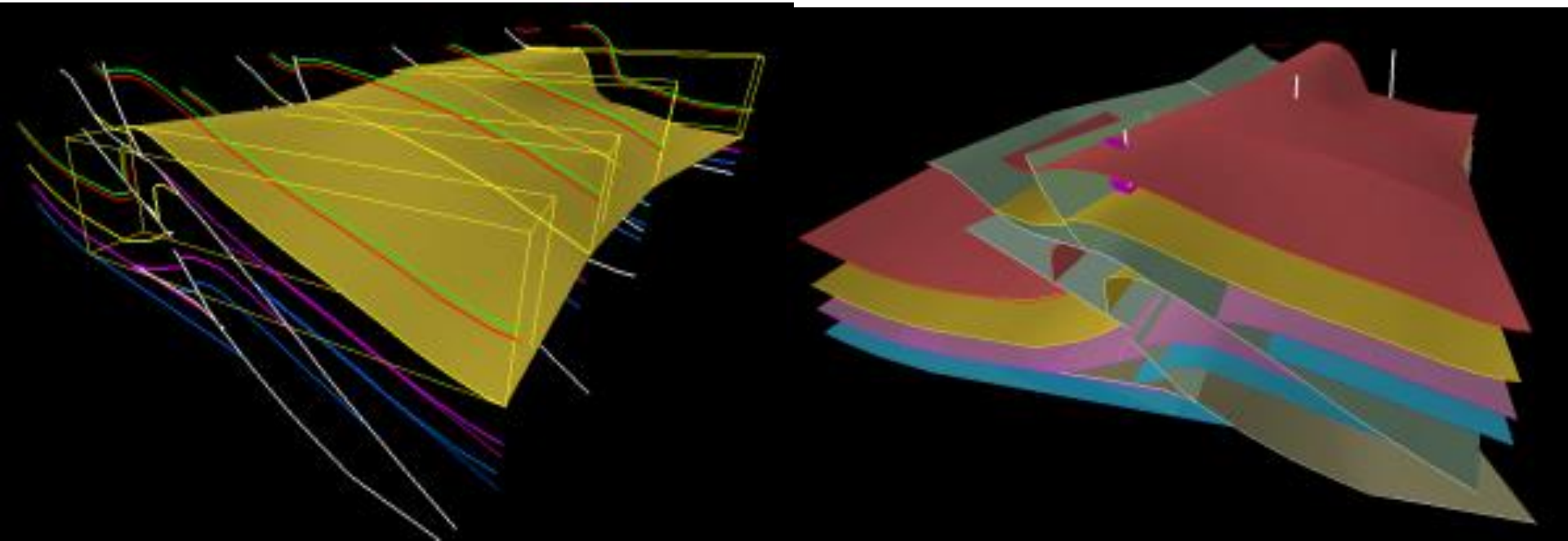
Model



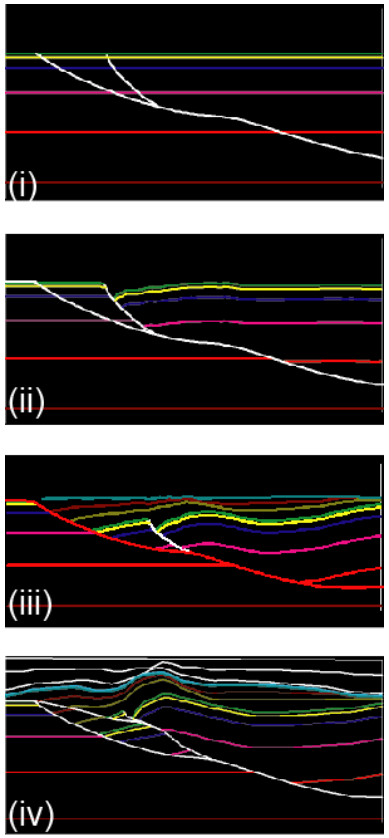
2D vs. 3D

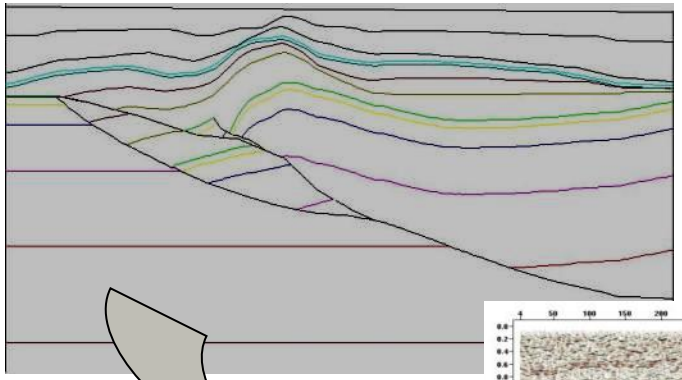
- 3D seismic basically a (VERY expensive) set of 2D slices that are interpreted and correlated

- The resulting models have an air of “truth”, which can be problematic to end-users (more later)

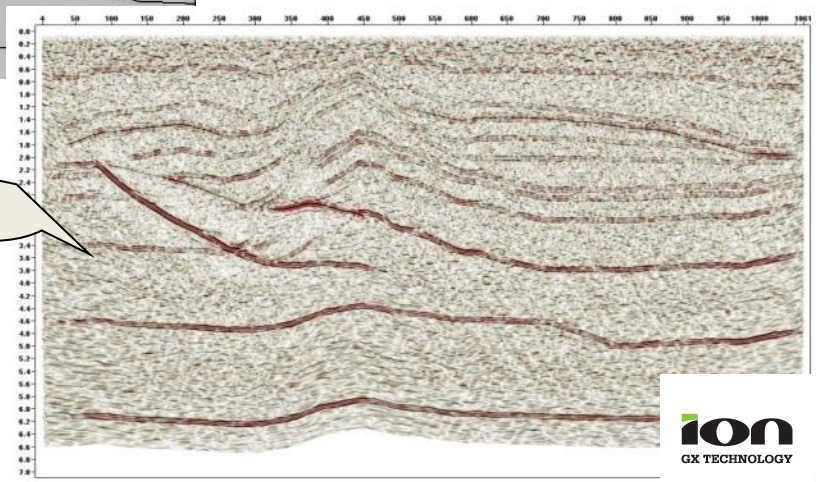


Part 1 - Odin





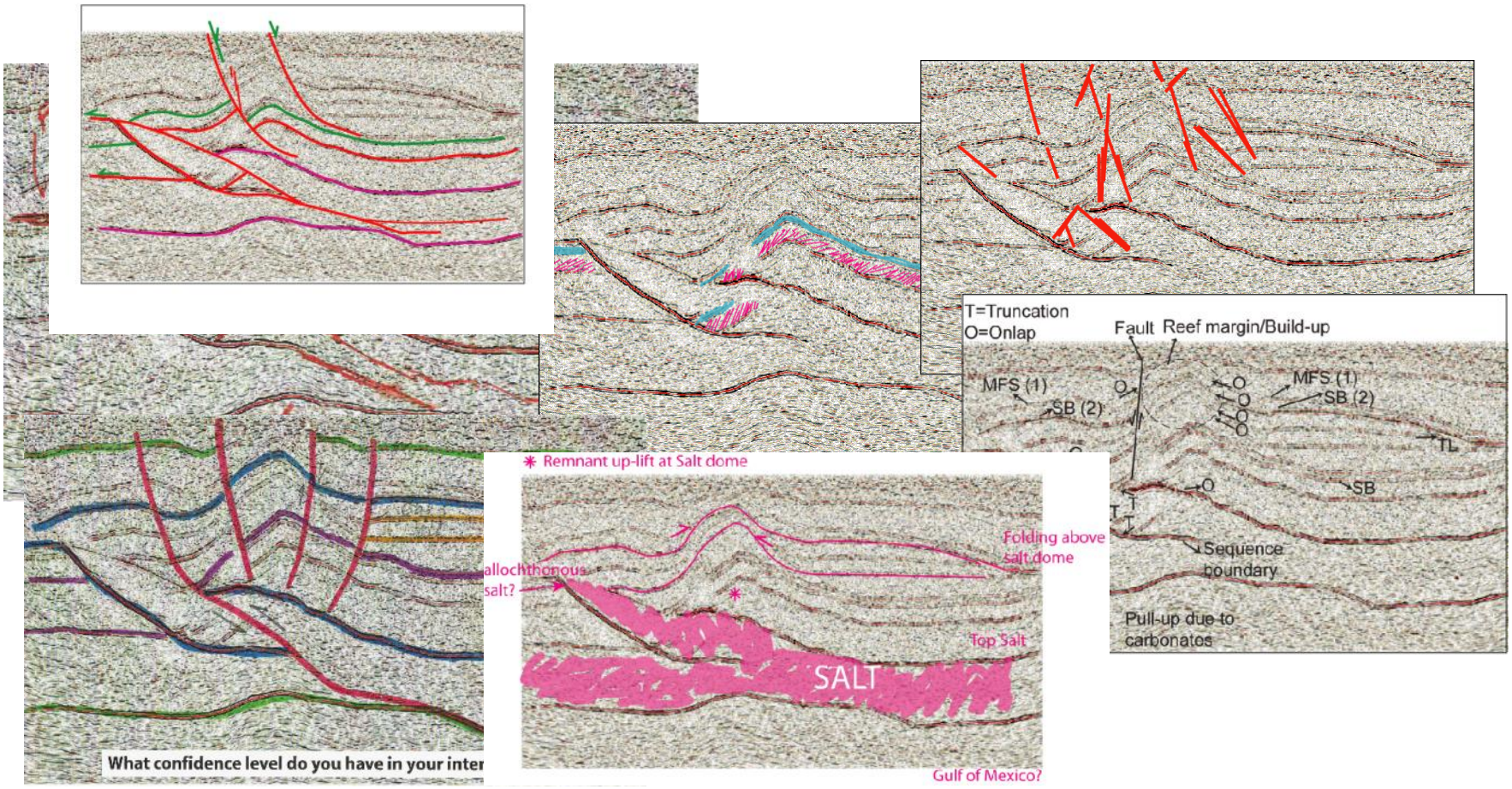
Experiment set-up



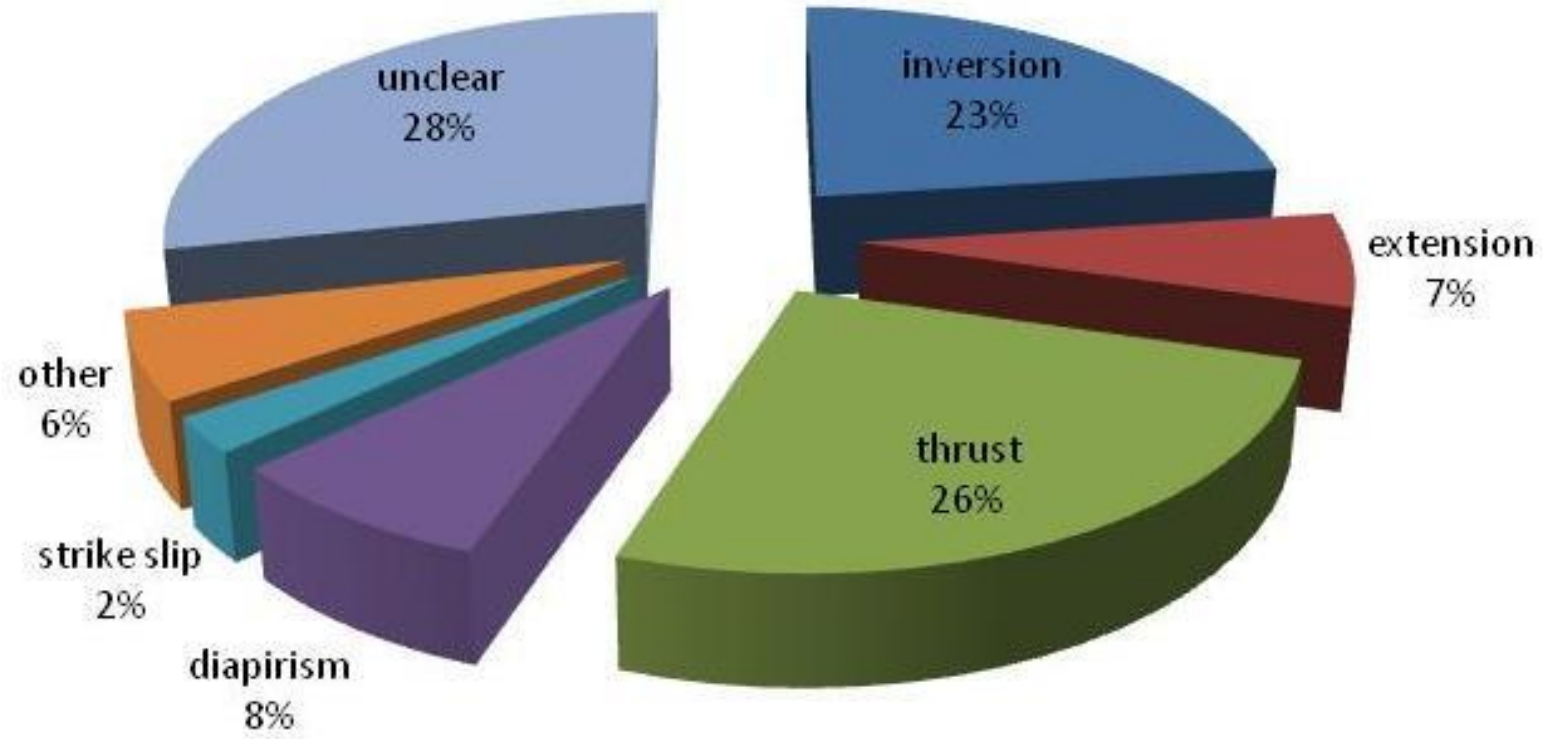
Synthetic seismic

Bond et al., 2007. GSA Today

One dataset – many concepts



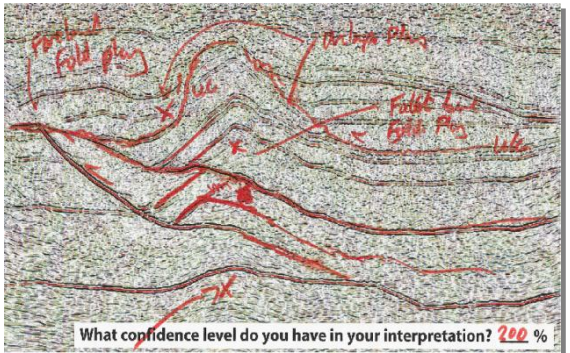
Many structural models



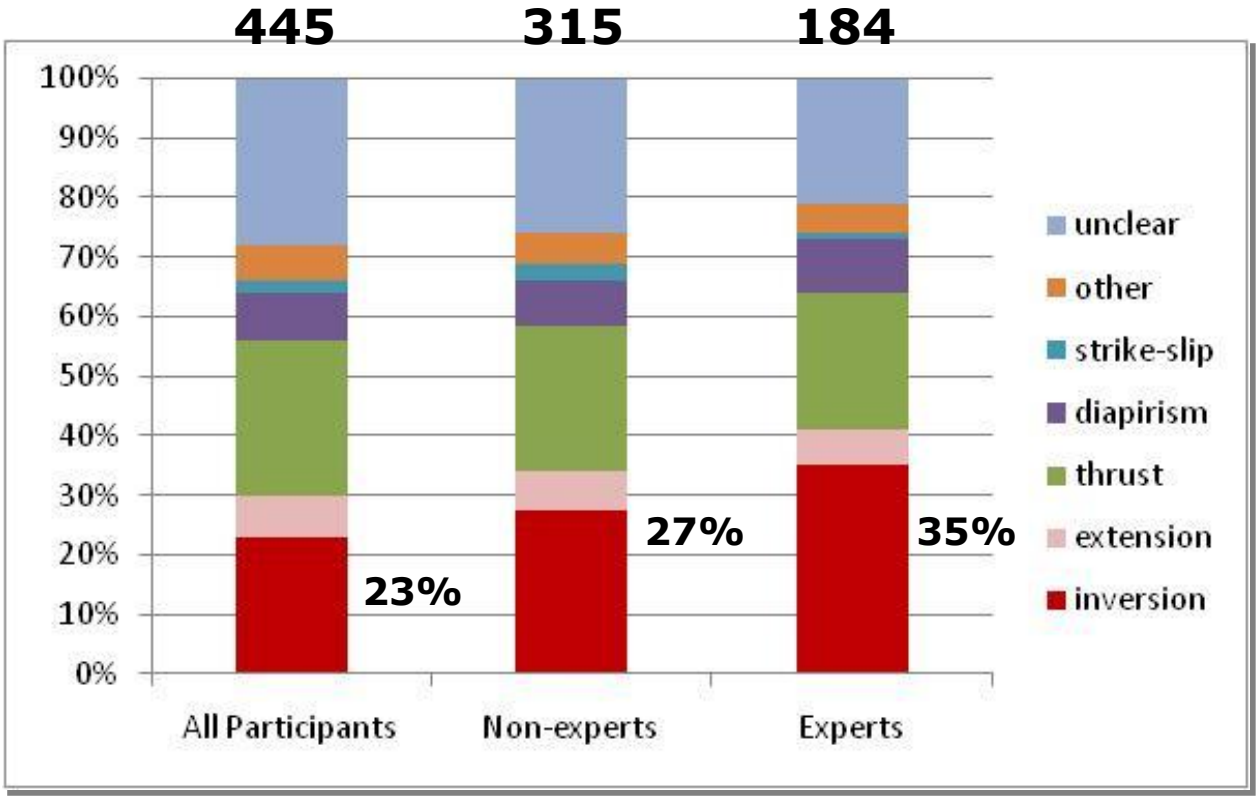
Effect of Prior Knowledge?

- **Dominant Tectonic Expertise - more likely than others to produce an interpretation based on this expertise (**i.e. dominant thrust tectonic experience - 29% produced a thrust interpretation, compared to 27% of participants with other expertise).
- **BUT not statistically significant.**

- **Length of Experience - had no obvious overall effect** (i.e. students were just as likely as those with 15+ years experience to produce an incorrect interpretation, 76%).



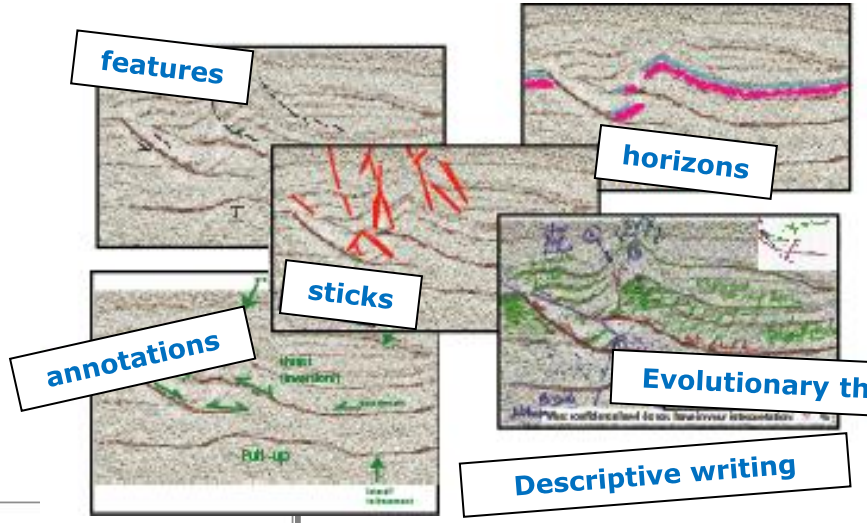
Self-defined *experts* in structural geology

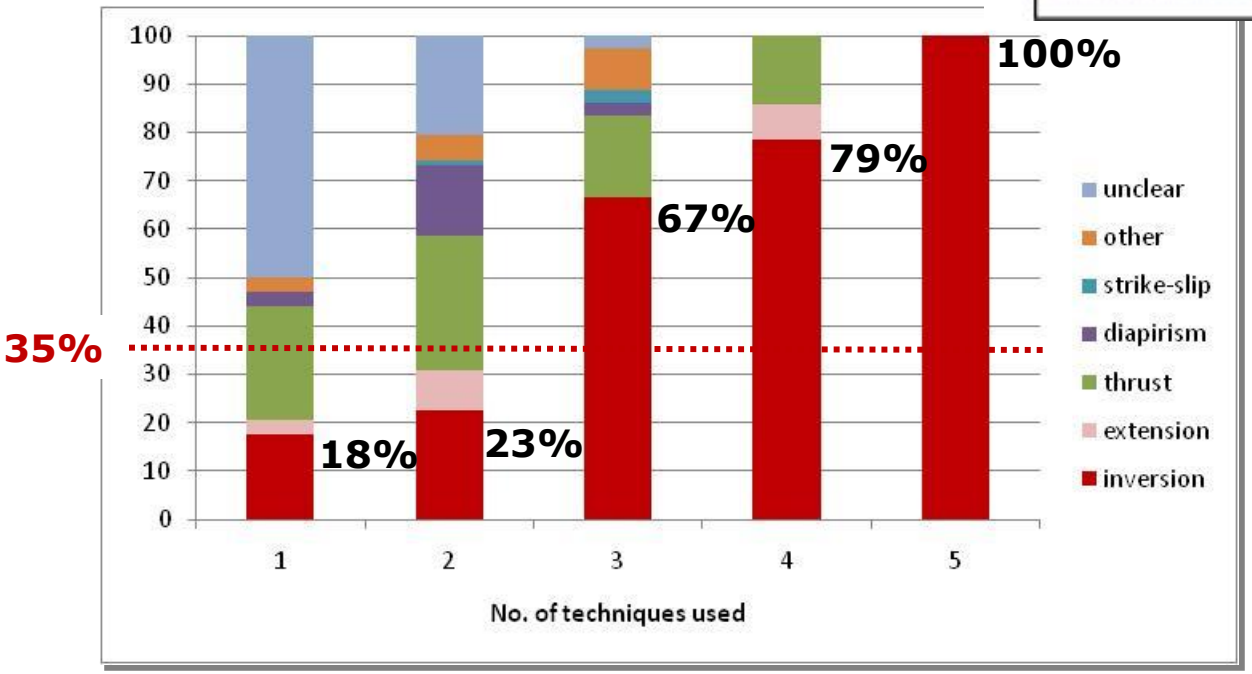


Techniques

Effective experts

use *lots* of techniques.

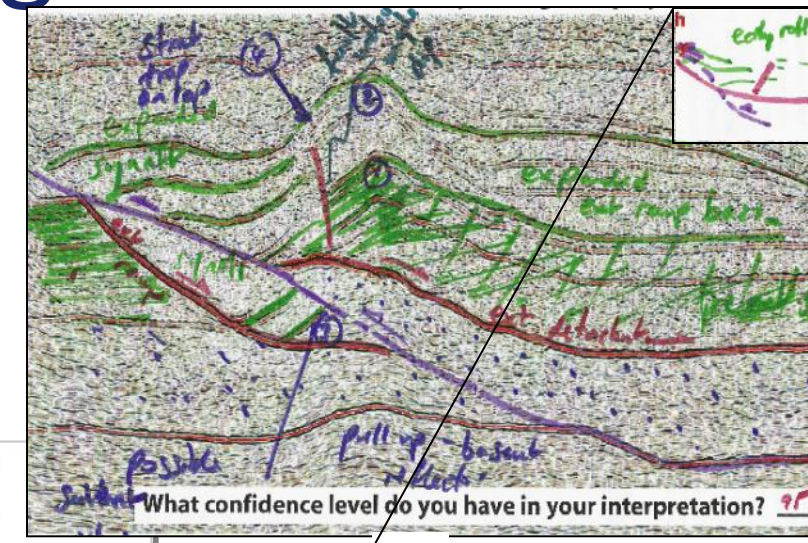


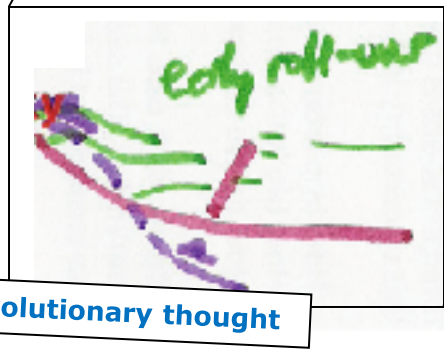


Specific Techniques

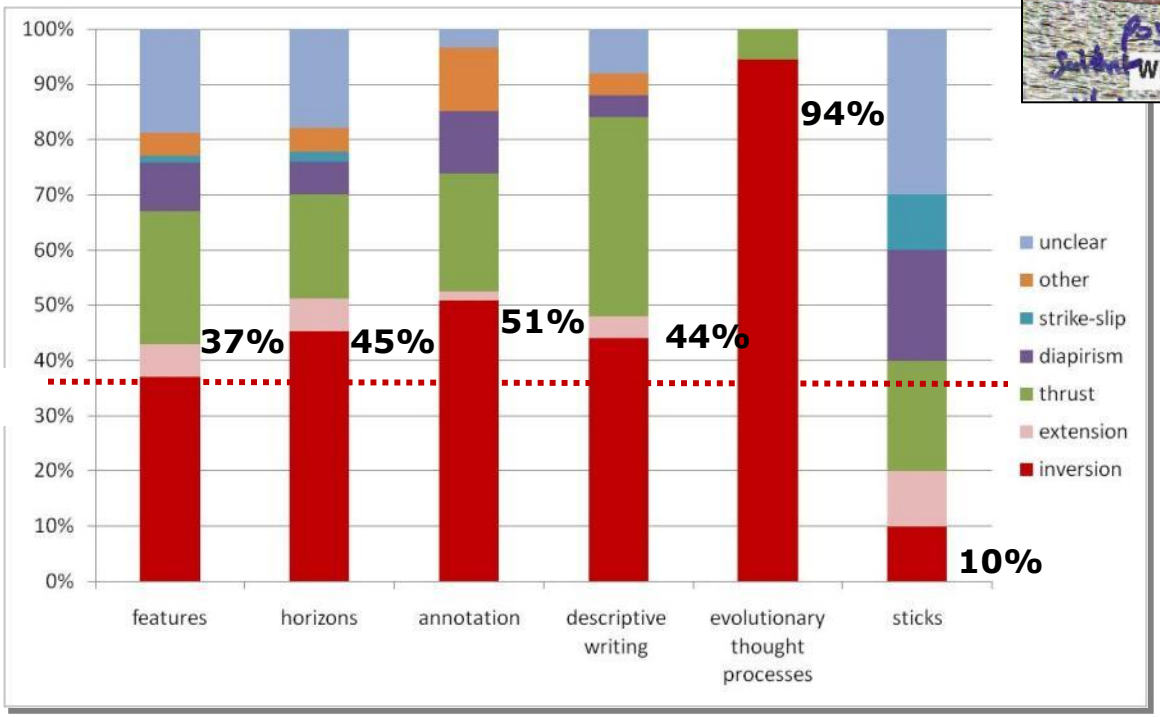
Effective experts

used *specific* techniques –notably thoughts about the geological evolution (reasoning).



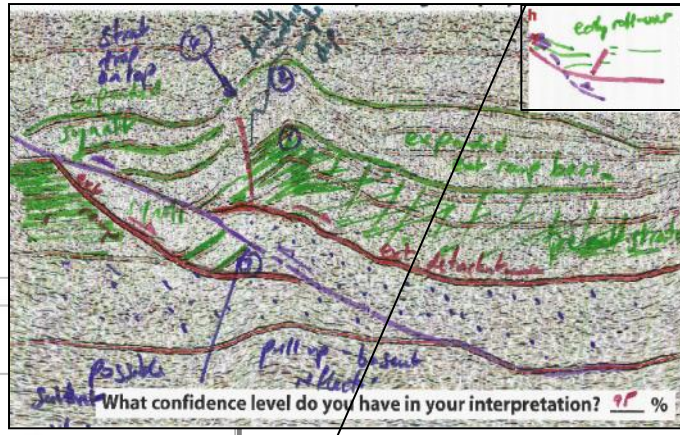


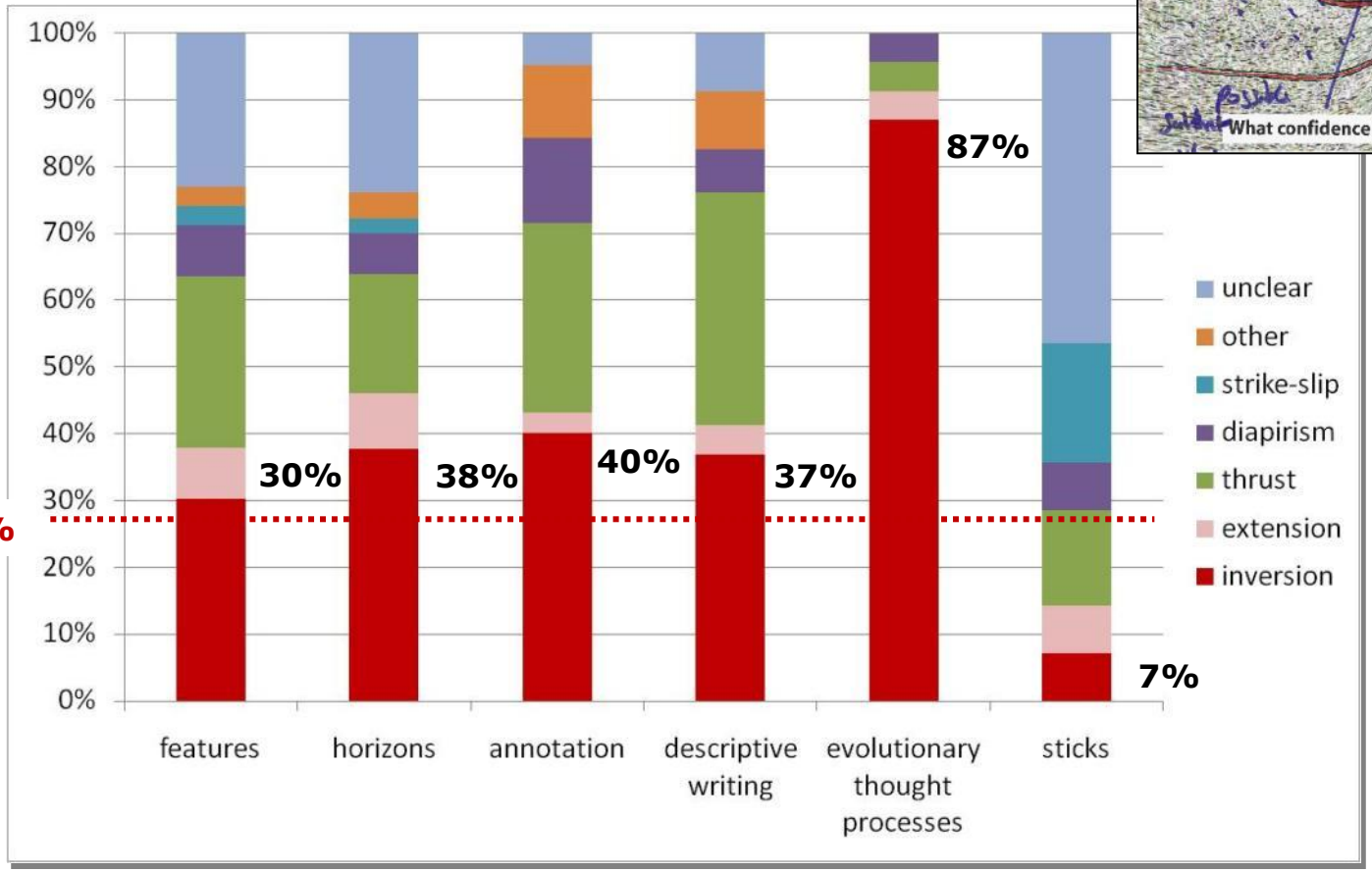
Evolutionary thought



Non-experts

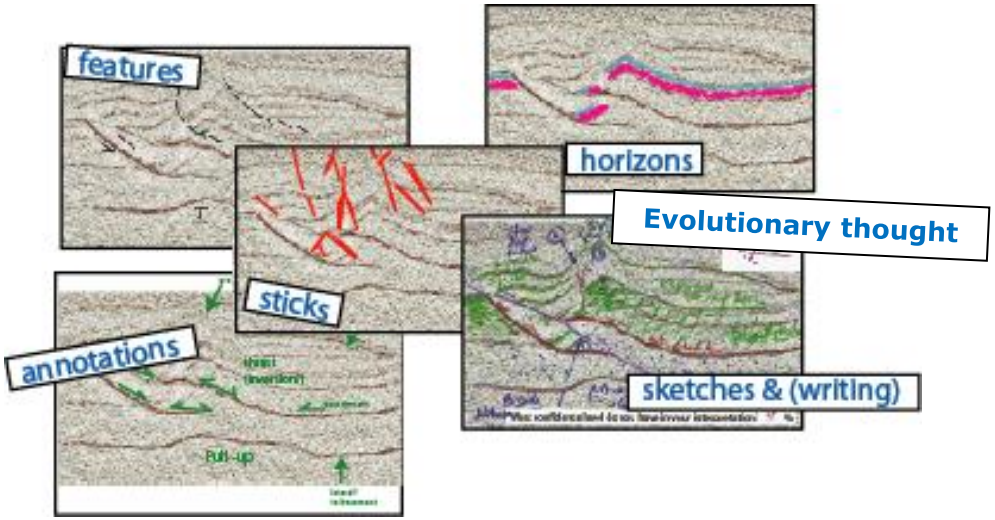
Everyone can be an expert?





Odin Experiment - Conclusions

Everyone *can* be effective by using multiple techniques to query the data and applying specific validation techniques (reasoning).

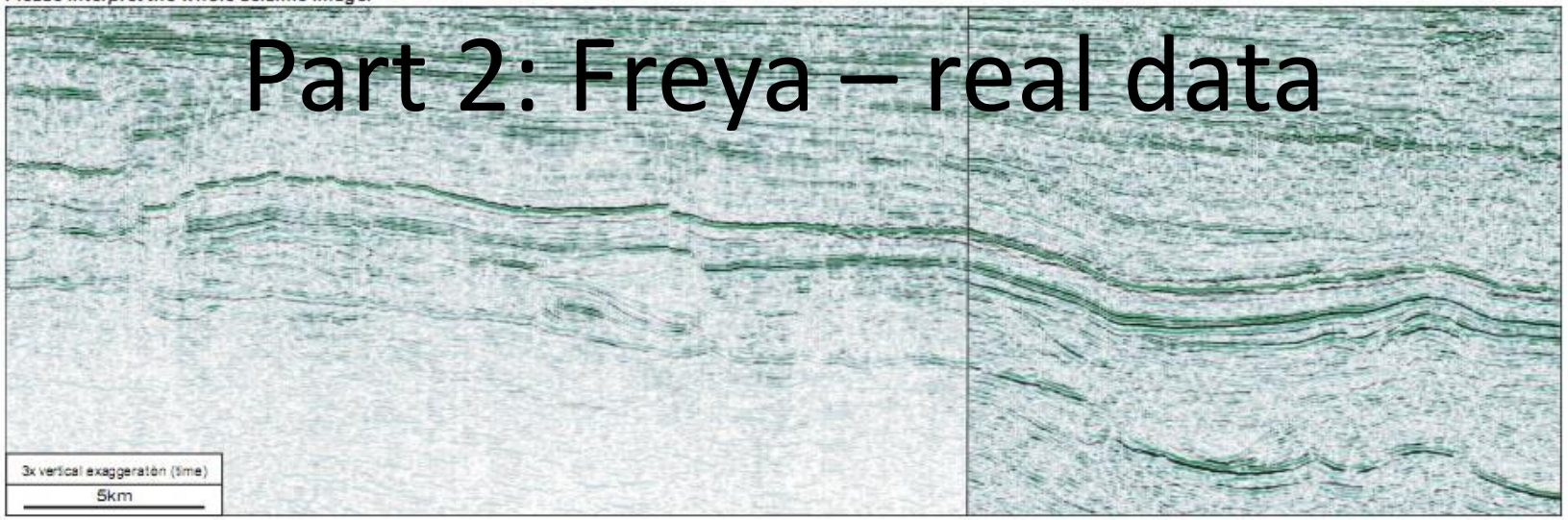


But not many people are:

of the 184 experts only 18 (c.10%) showed evidence of thinking about the geological evolution.

Part 2: Freya – real data

Please interpret the whole seismic image.



Finally, please answer the 3 questions below with regards to only the seismic interpretation exercise.

i) How long did you spend interpreting the seismic image? _____ minutes

ii) Would you have liked more time? Yes ○ No ○

ii) What is your confidence; in your interpretation?

Very Confident ○ *Confident* ○ *Satisfied* ○ *Doubtful* ○ *Totally unsure* ○

in the linkage of faults?

Very Confident ○ *Confident* ○ *Satisfied* ○ *Doubtful* ○ *Totally unsure* ○

II - *Geological Experience*

8) What best describes your experience in Structural Geology?

Specialist ○ Good Working Knowledge ○ Basic Knowledge ○ No Knowledge ○

9) What best describes your experience in Seismic Interpretation?

Specialist ○ Good Working Knowledge ○ Basic Knowledge ○ No Knowledge ○

10) How often do you interpret or use seismic images?

Daily ○ Weekly ○ Monthly ○ 6-Monthly ○ Yearly ○ Almost Never ○

In the following questions (Q11-13) please use rankings to indicate your answers.

Please note; you do not need to rank areas / geological settings where you have never worked - only rank options in which you actually have some experience.

Equal ranks are allowed.

In all questions, 1 = most active / worked there most, and lower rankings (2, 3, 4, etc...) = less active / worked there less.

11) Rank the following areas of geoscience to show which areas you have been most active in over the last 24 months.

Basin Modelling ☐ Geochemistry ☐ Geophysics ☐ Management ☐ Reservoir Engineering ☐

Reservoir Geology ☐ Sedimentology (carbonates) ☐ Sedimentology (clastic) ☐ Seismic Interpretation ☐

Stratigraphy ☐ Structural Geology ☐ Training ☐ Other? _____ ☐

12) Rank the following geological settings by duration to show where you have worked in the last 24 months.

Compressional tectonics ☐ Extensional tectonics ☐ Inversion tectonics ☐ Salt tectonics ☐

Shale tectonics ☐ Strike-slip tectonics ☐ Other? _____ ☐

13) Rank the following geological settings by duration to show where you have worked in your entire geoscience career.

Compressional tectonics ☐ Extensional tectonics ☐ Inversion tectonics ☐ Salt tectonics ☐

Shale tectonics ☐ Strike-slip tectonics ☐ Other? _____ ☐

Please turn over for Page 4...

III - *Geological Training*

14) Who was your first geoscience related employer after finishing your highest degree? _____

15) Have you completed an industry graduate training course/programme? Yes ○ No ○

16) If so, what was the duration of the course/programme, and what format did it take? Duration: _____

Course/Programme Format: _____

17) Have you been on a seismic interpretation course (not including University training)? Yes ○ No ○

18) If so, what was the duration of the course? _____

19) Have you been on a structural geology course (not including University training)? Yes ○ No ○

20) If so, what was the duration of the course? _____

21) Please mark geographical locations where you have investigated the geology for more than 2 weeks in your entire geoscience career.
(This should include everything; Ph.D. thesis, projects, scientific studies, fieldwork, etc...)

Acknowledgements

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The Virtual Seismic Atlas (VSA) is thanked for use of the seismic image.

Freyja

Uncertainty Analysis of Geological Interpretations

University of Strathclyde · Midland Valley · University of Glasgow · Natural Environment Research Council

Background

Freyja is a research project designed to quantify the uncertainty in the interpretation of data used to create geological models. This survey investigates the differences in how people interpret and understand geological data (such as seismic images). Completion of the survey will allow the investigators to quantify the differences between peoples' interpretations and to use this knowledge to devise workflows to minimise the effects of this uncertainty. To maximise the benefits of the survey a large sample size is needed; you are part of a skilled population that works with geological data and your participation is greatly appreciated. Freyja is part of Euan Macrae's Ph.D. work, if you would like more information about Euan's work contact Euan.J.Macrae@gmail.com or visit **www.gla.ac.uk/geologicaluncertainty**

Instructions

This exercise must be completed individually.

i) Complete the questionnaire (which continues over all 4 pages).
ii) Interpret the seismic image shown on the centre pages.
iii) Answer the final three questions under the seismic image.

The entire exercise is expected to take 15 - 25 minutes.

Your participation with Freyja is greatly appreciated - Thank you!

Please return completed questionnaires to:

Euan Macrae
Department of Civil Engineering
Graham Hills Building
University of Strathclyde
Glasgow, G1 1XP
Scotland, UK

Questionnaire

Unless otherwise stated please tick the circles to indicate your answers.

1) **Gender:** Male ○ Female ○

2) **Age:** < 21 ○ 21-30 ○ 31-40 ○ 41-50 ○ 51-60 ○ 61+ ○

I - *Education and Experience*

3) **What degrees have you completed?** None ○ Bachelors ○ Masters ○ PhD ○ (Tick all that apply.)

4) **What subject / topic area(s) were they in?**

Bachelors: _____

Masters: _____

PhD: _____

5) **Number of years of relevant experience (those relating to geoscience) since attaining your highest degree?**

_____ years

6) **Which of the below best describes where you have worked in the past 24 months?** (You may tick more than one circle.)

Academia ○ Consultancy ○ Service Company ○

Other _____ ○

Oil Company:
Super-major ○ Major ○ National ○ Medium-small Independent ○

And in what area? Exploration ○ Production ○ Other _____

7) **Which of the below best describes your background most accurately?** (You may tick more than one circle.)

Academia ○ Consultancy ○ Service Company ○

Other _____ ○

Oil Company:
Super-major ○ Major ○ National ○ Medium-small Independent ○

And in what area? Exploration ○ Production ○ Other _____

Data collection summary

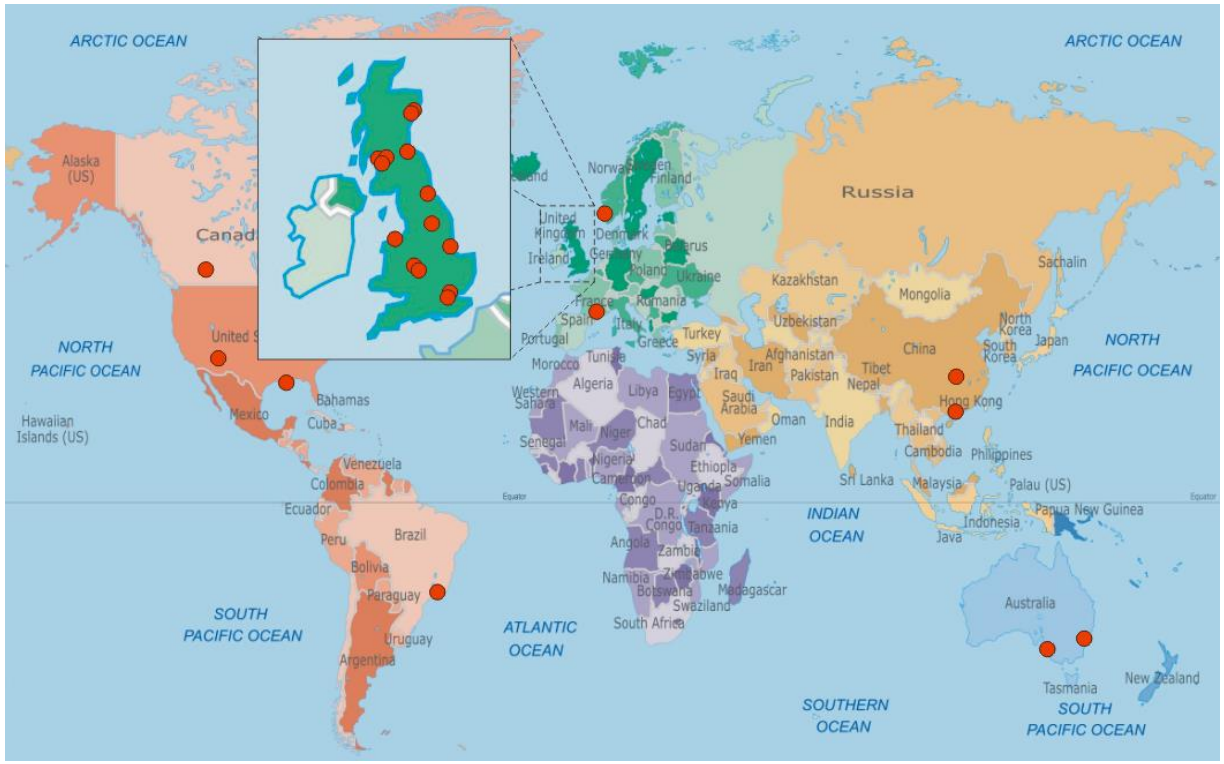
Total number of questionnaires collected during 2009 and 2010:

i) Universities: 279

ii) Energy Companies: 76

iii) Conferences: 312

$$\sum n = 667$$



AAPG ACE, New Orleans (USA)

12th April 2010

Sample validation

- To ensure a good sample, most of the least experienced respondents were excluded:

  Age < 21

  No University degree

  < 2 years experience (since completing highest degree)

  'No experience' in seismic interpretation

  'No experience' in structural geology

- Excluded respondents = 252; **therefore, 415 respondents were analysed**

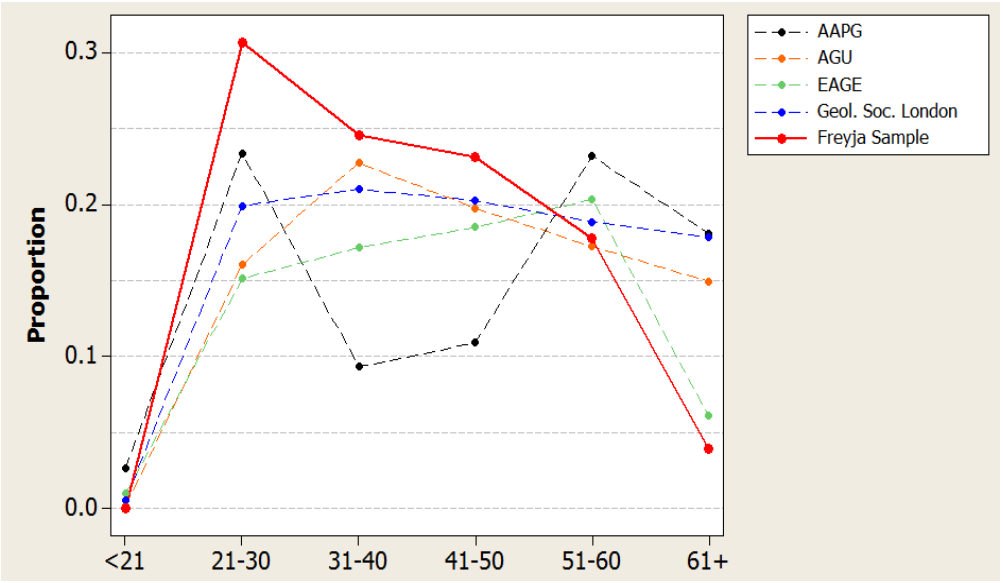
  i) Universities: 108 *(- 61%)*
  ii) Energy Companies: 66 *(- 13%)*
  iii) Conferences: 312 *(- 23%)*

$$\sum n = 415$$

Comparison against population?

Freyja Sample vs. Geoscientist Population

No. of Members:- AAPG = 35,627; AGU = 57,185; EAGE = 13,703; Geol. Soc. London = 9,930



Four large geoscientist organisations' membership lists used as proxy

$$\sum n = 415$$

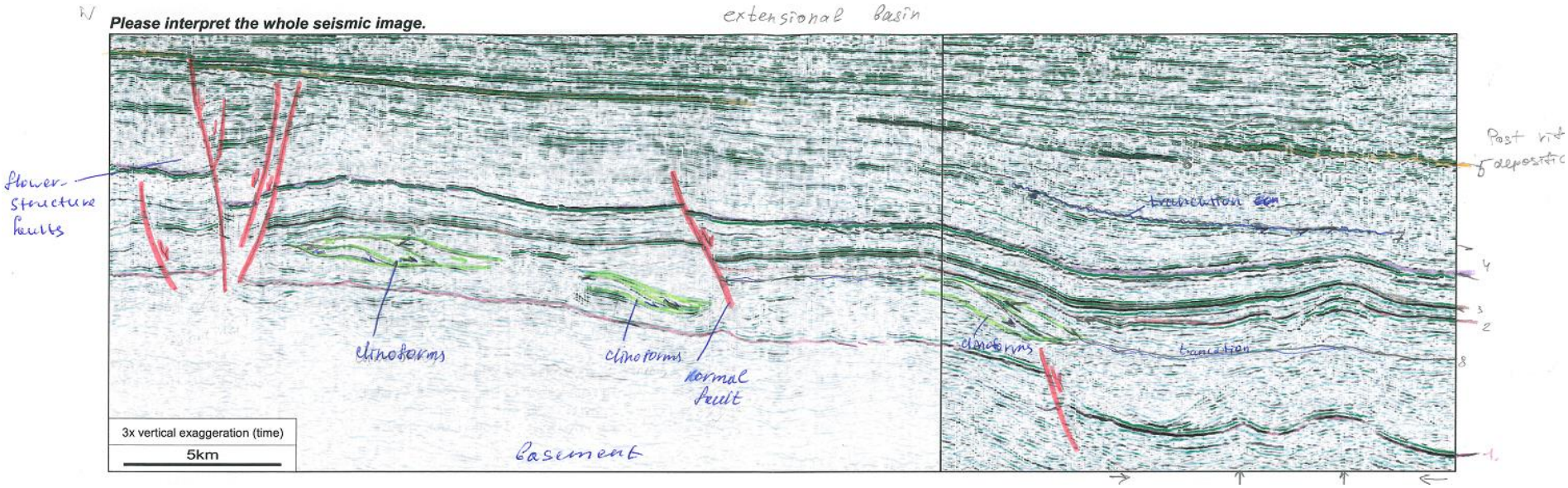
Organisation	Female (%)	Male (%)
AAPG	16.5	83.5
AGU	23.4	76.6
EAGE	16.1	83.9
GSL	19.5	80.5
Mean (%)	*18.9*	*81.1*
Freyja Sample	21.3	78.7

Demographics of the Freyja sample are a good match to geoscientist population

Freyja sample is a *good* sample

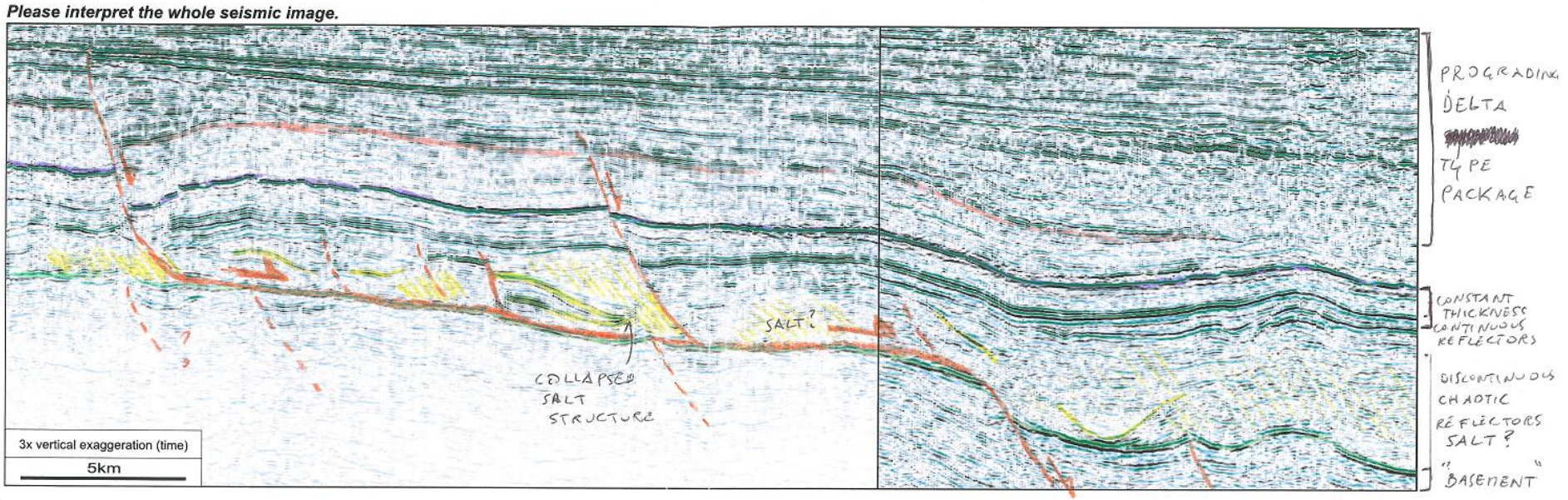
- The Freyja sample of 415 respondents:
  - ✓ is large – the error bound on estimates is <5% in most cases
  - ✓ has similar demographics (age and gender) to underlying geoscientist population
  - ✓ was collected internationally
  - ✓ was collected in a range of working environments
  - ✓ contains no non-experienced respondents (and many experienced respondents…)
- **We are therefore confident that the following results are representative of the underlying population**

Examples of interpretations



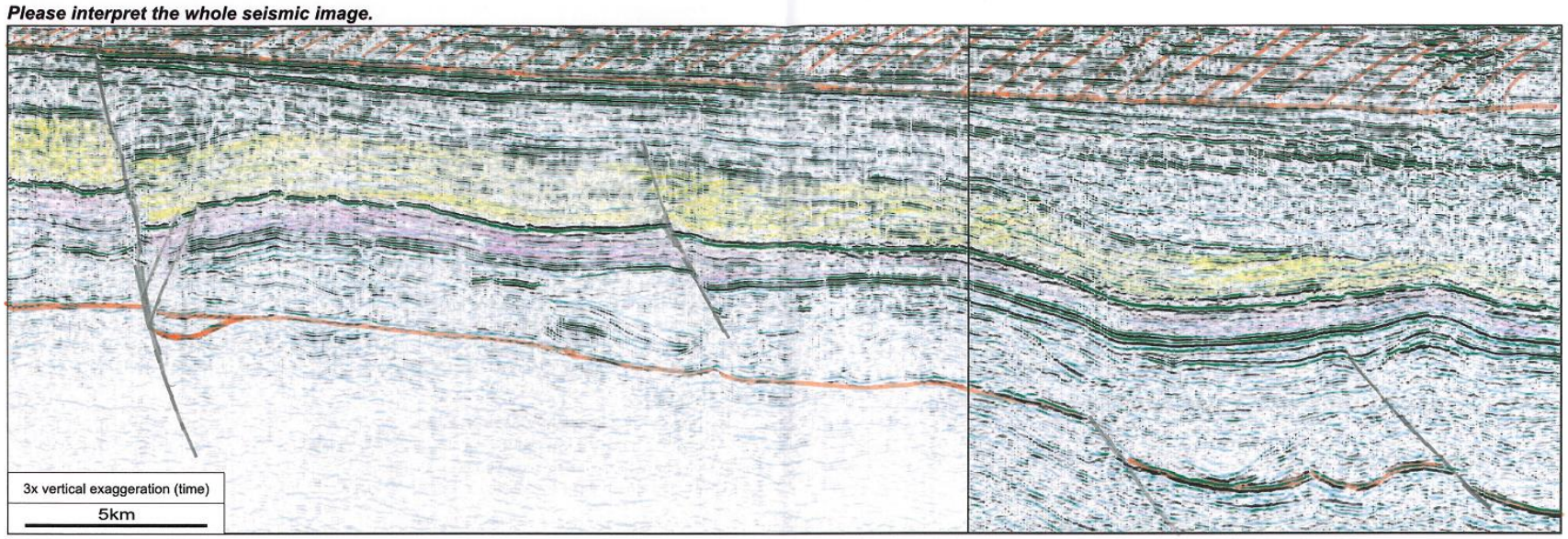
Respondent has interpreted strike-slip “flower structure” faults on the left-hand side and marked clinoforms in the middle area. The middle and right-hand side faults are both planar normal faults.

Examples of interpretations



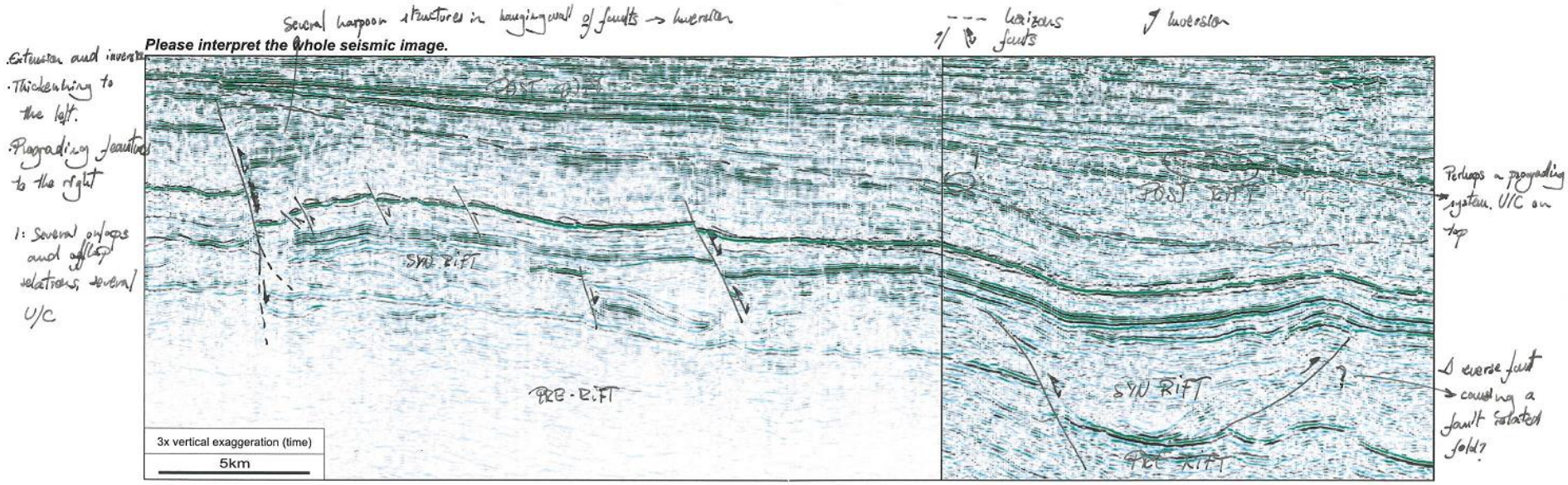
Respondent has interpreted a listric normal fault on the left-hand side which detaches onto a salt layer. The middle normal fault also looks listric and detaches onto the same salt horizon. The right-hand side planar normal fault cuts the basement.

Examples of interpretations



Respondent has interpreted a deeply cutting planar normal fault on the left-hand side, and planar normal faults in the middle and on the right-hand side.

Examples of interpretations



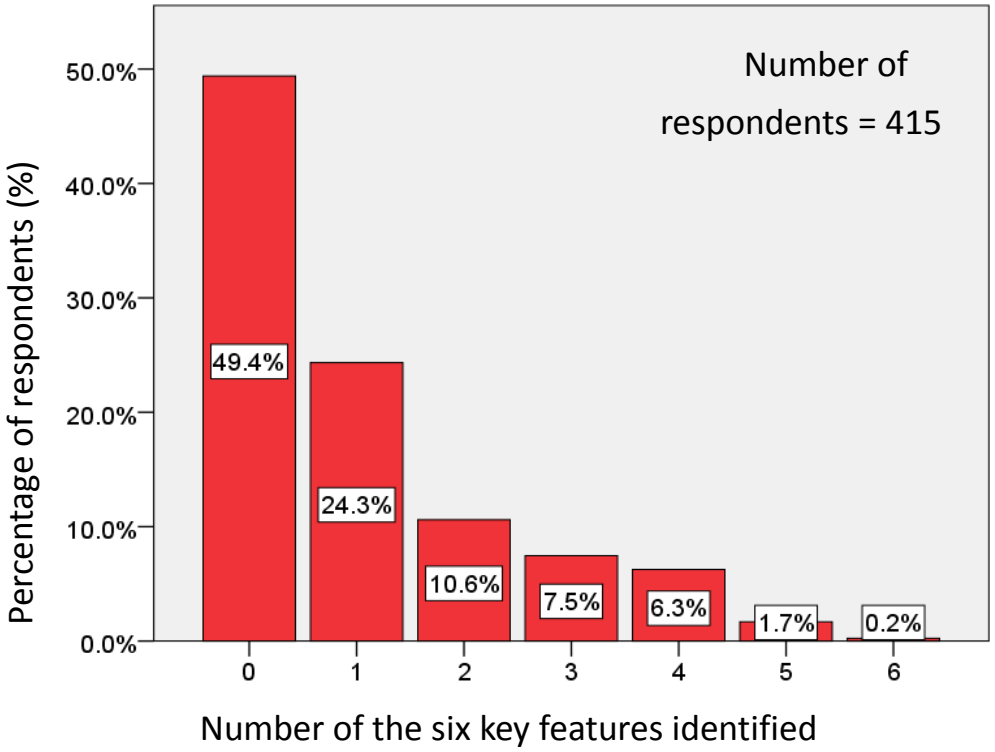
Respondent has interpreted inversion throughout their interpretation; noting “harpoon structures” on the left-hand side and annotating the faults with double-sided inversion arrows.

Data analysis: ‘reference expert’ vs. respondents

- As a validation process, respondents’ interpretations were compared to a reference expert’s interpretation
- The reference expert had access to additional time and data including; multiple seismic images, borehole data, geological papers and other geologists’ feedback
- We are therefore confident that the reference expert’s interpretation is valid and structurally ‘correct’

‘Reference expert’ vs. respondents

- Six ‘features’ in the seismic line were then said to be highly important to the tectonic story
- The number of the six features highlighted / interpreted was said to be the respondent’s *similarity score* (calculated via visual inspection)



- 49.4% of respondents highlighted zero of the six key features
- And, only 15.7% highlighted 3+ of the key features

Respondent information as captured by questionnaire	Percentage (%)	Total
Has a Bachelor's degree (Q3)	86.2	441
Has a Master's degree (Q3)	54.9	441
Has a Ph.D. degree (Q3)	37.4	441
Experience in an oil company	54.6	425
in exploration	80.6	216
in production	29.6	216
in academia	37.0	427
in a consultancy	15.7	427
in a service company	9.8	427
Minimum of a 'good working knowledge' of structural geology	65.5	441
Minimum of a 'good working knowledge' of seismic interpretation	59.6	441
Main experience in extensional geological settings	48.2	398
in compressional geological settings	20.1	398
in multiple geological settings	19.1	398

Factor name	P-value	Odds ratio (OR) with 95% CI
Written about geological time? *"Yes" to "No"*	<0.001	4.46 (2.48–8.00)
Cartoon drawn? *"Yes" to "No"*	0.022	3.76 (1.23–11.49)
Level of experience in structural geology? *"Specialist" to "Basic Working Knowledge"* *"Good Working Knowledge" to "Basic Working Knowledge"*	<0.001	3.25 (1.80–5.87) 1.20 (0.78–1.85)
Written about geological processes? *"Yes" to "No"*	<0.001	2.70 (1.55–4.72)
Concept explicitly stated? *"Yes" to "No"*	0.017	2.34 (1.17–4.69)
How often seismic images are interpreted or used? *"Daily / Weekly" to "Yearly / Never"* *"Monthly / 6-Monthly" to "Yearly / Never"*	0.004	2.33 (1.38–3.95) 2.24 (1.27–3.95)
Arrows drawn on faults? *"Yes" to "No"*	0.008	1.83 (1.17–2.87)
Background is mainly in super-major or major oil company? *"Yes" to "No"*	0.008	1.81 (1.17–2.79)
Number of global geological locations? *Per location, since a continuous factor*	0.022	1.04 (1.005–1.07)

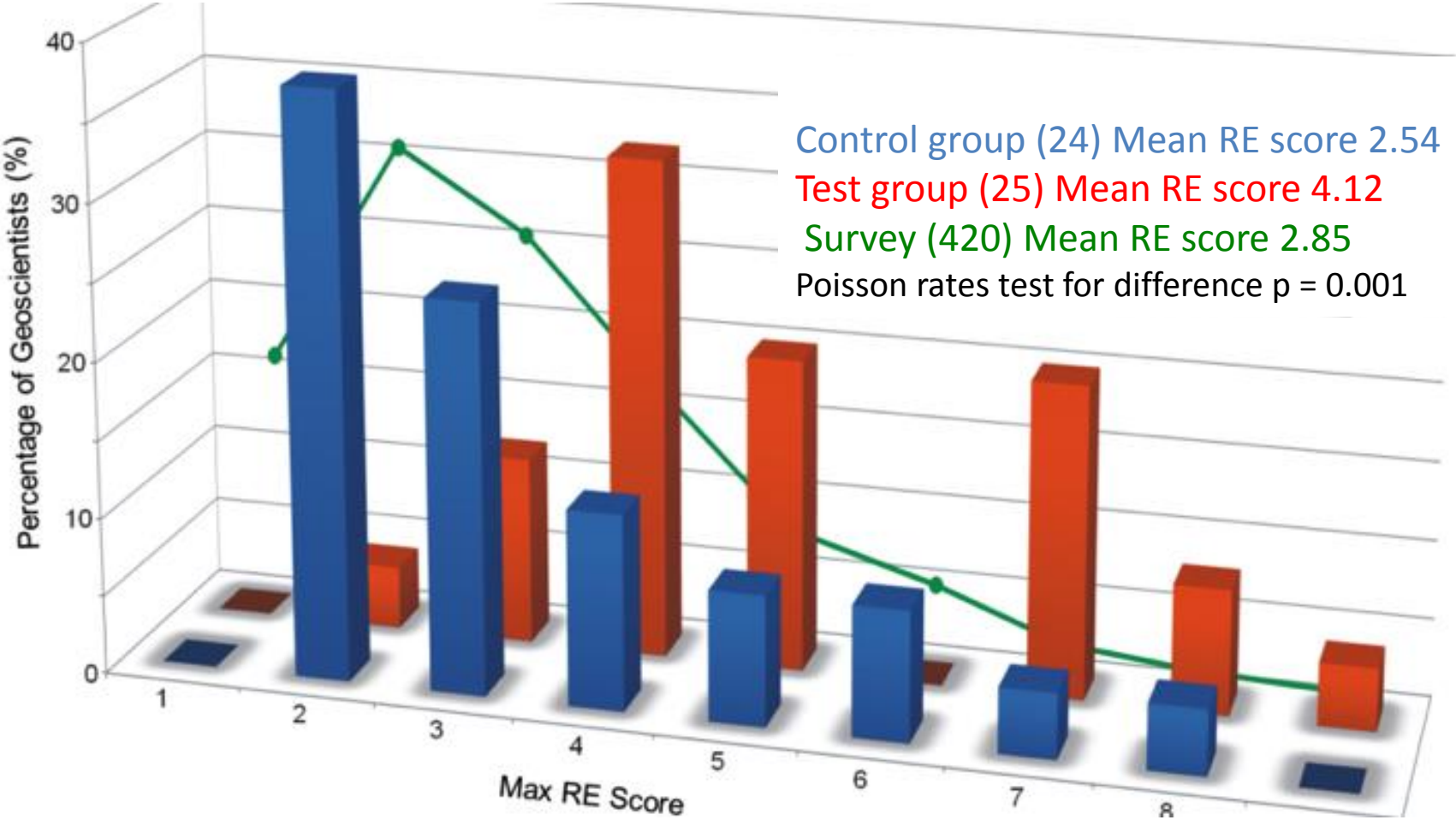
Results from multivariate analysis.

Factors ordered by decreasing odds ratio

Are positively and significantly associated to the Max RE Score

Techniques: 'writing about geological time' and 'drawing a cartoon' were both more significant than respondents' experience.

Confidence intervals (CI) for the odds ratios are noted.



Max RE Scores for test 62% higher than control geoscientists

causal link between ‘focussing on and stating’ the geological evolution and increased interpretational ability

What ‘type’ of respondents are best?

The *Education and Work Environment* variables were first analysed in a multivariate analysis then the *Experience* variables were added in…

•It was found that *“Experience in structural geology”*, *“Number of worldwide locations where the geology has been investigated”*, and *“Work for an oil company?”* were most significant ($p < 0.01$)

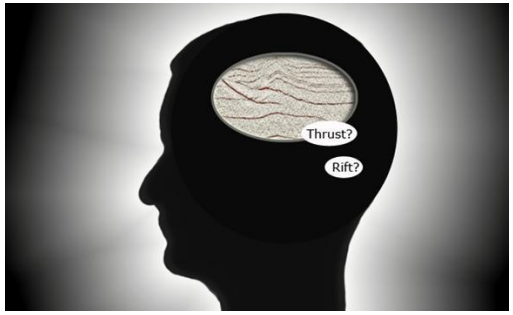
Meaning…

The likelihood of producing a better interpretation increases if you:

•Have a strong experience in structural geology

•Work at an oil company

•Have investigated the geology in many locations around the world



Interpreting uncertain geological data

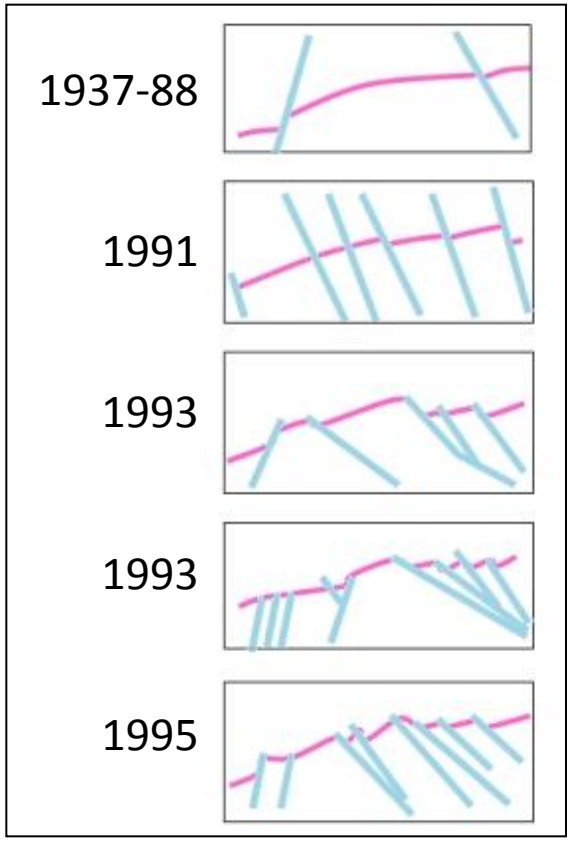
Midland Valley

Scottish Business Grants

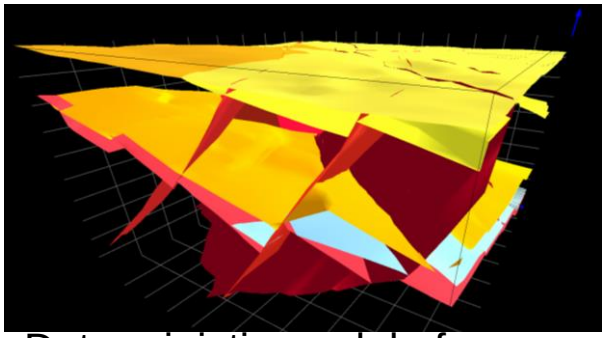
NATURAL ENVIRONMENT RESEARCH COUNCIL

Geological data inherently under-constrained and uncertain

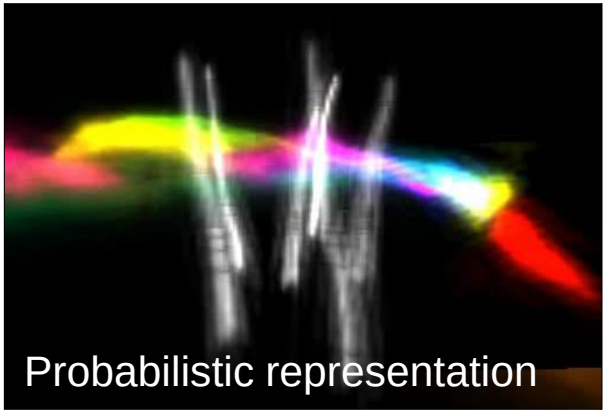
e.g. Changes in geological interpretation at Sellafield from 1937 to 1995 (investigations stopped 1997)



- Implications for
  - training,
  - industry practice
  - public engagement



Deterministic model of faulting at Sellafield



All models provided by Midland Valley Exploration (MVE)