New paleointensity results from rapidly cooled Icelandic lavas: Implications for Arctic geomagnetic field strength

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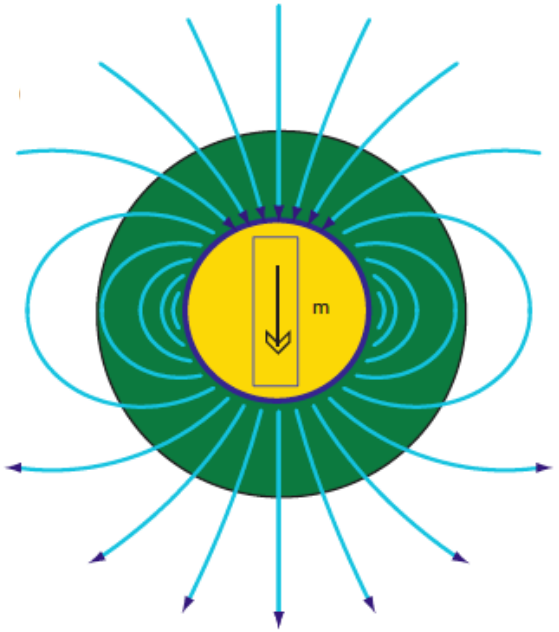
Understanding the Geomagnetic Field

Geocentric Axial Dipole Hypothesis (GAD)

- Declination: 0° everywhere
- Inclination and Intensity: Latitude dependent
- Symmetry

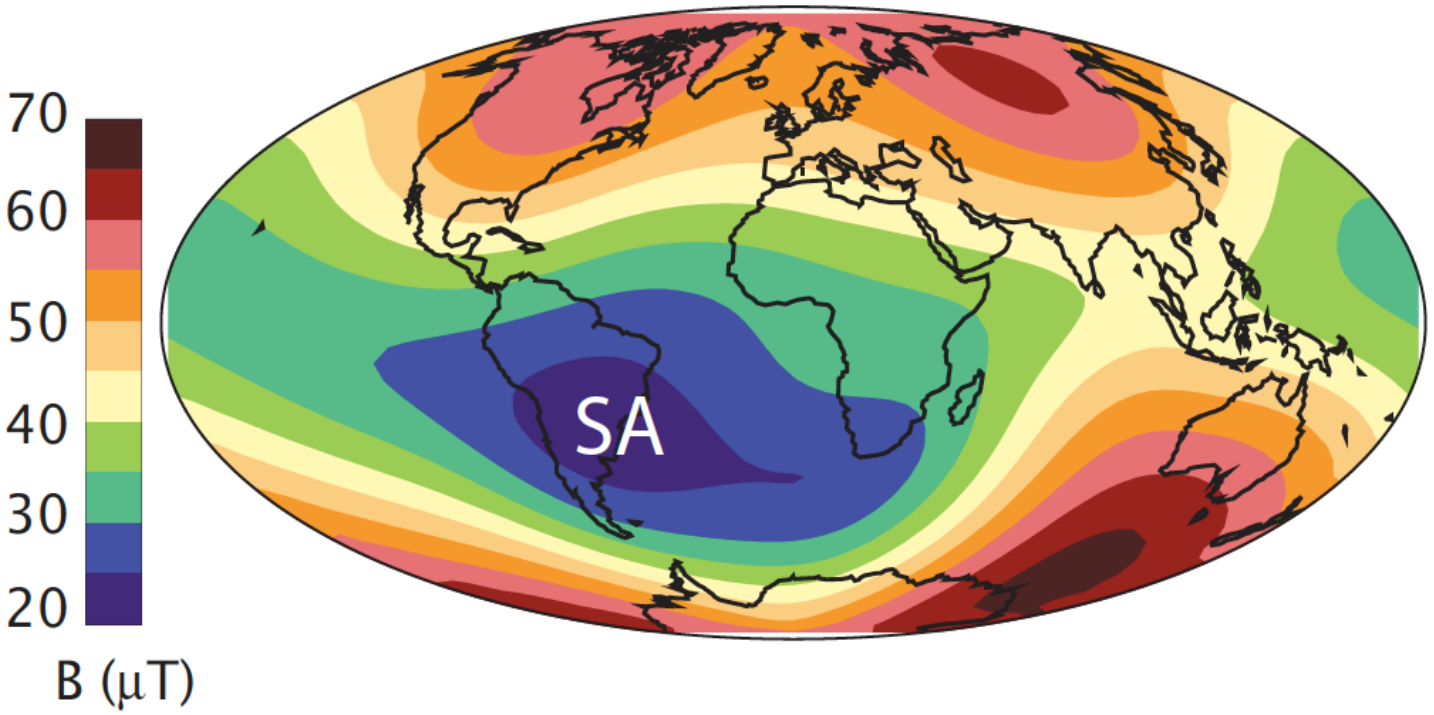


Earth=Bar Magnet

Tauxe, 2010

Present Field (2005)

Surface Field Intensity

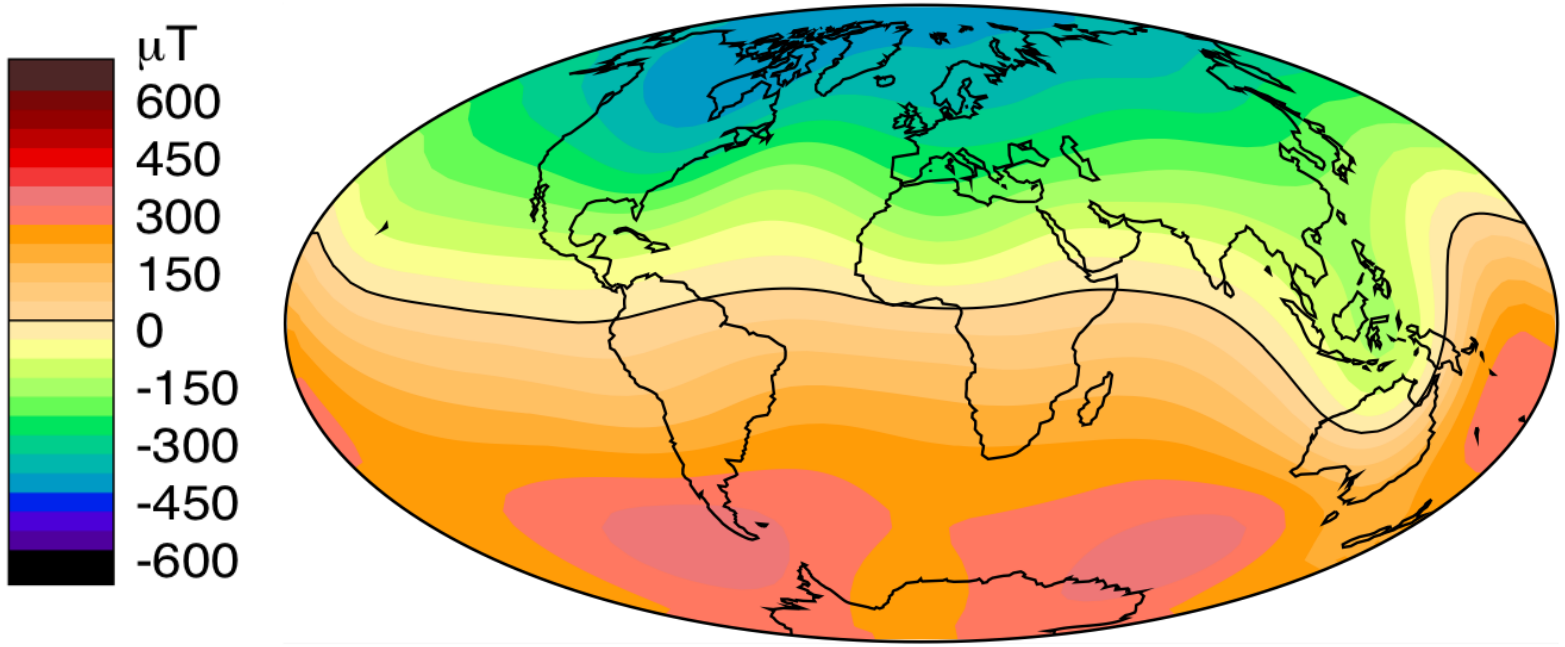


SA = South Atlantic Anomaly

Cromwell et al., 2013a

Recent Field (0-10 ka)

Core/Mantle Intensity

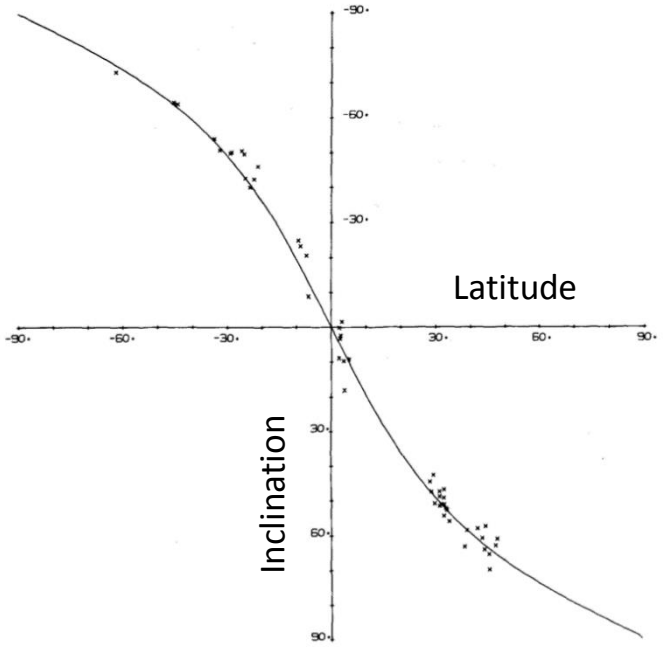


Korte et al., 2011

Ancient Field (0-5 Ma)

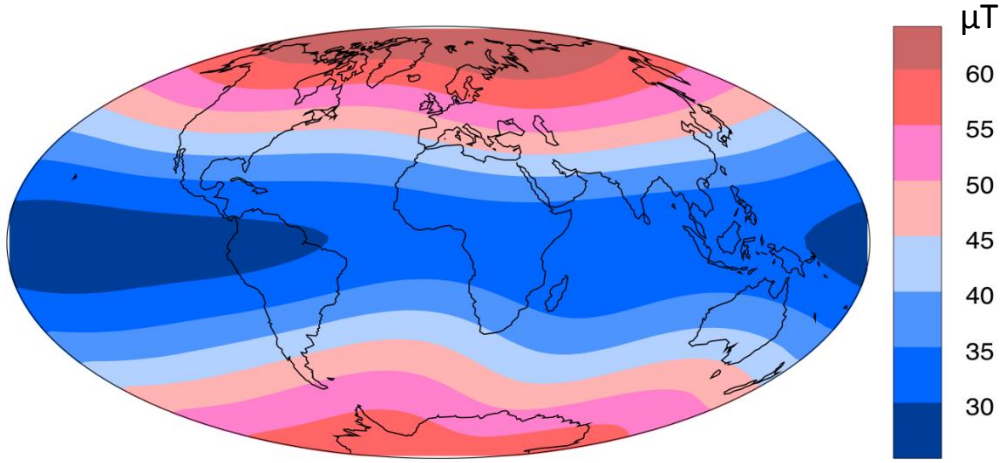
- Geomagnetic field **should** average to GAD

Inclination



Opdyke and Henry, 1969

Surface Field Intensity



Hatakeyama and Kono, 2002
(Fig: Tauxe, 2010)

Is the field GAD?

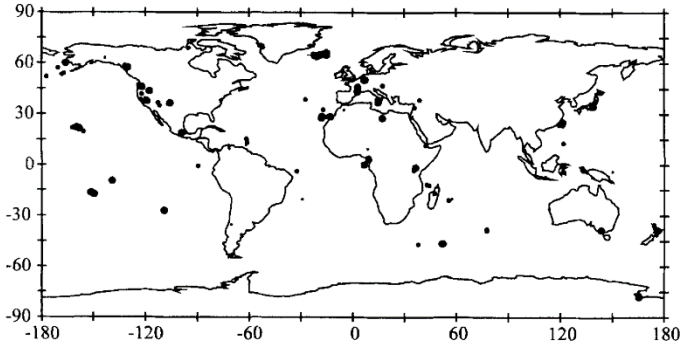
- Geomagnetic field is dipole dominated
    - 90% (e.g. Johnson and Constable, 1995)

- Contains non-dipole components
    - Dipole offset (Wilson, 1971)
    - Quadrupole
        - 4-5% (e.g. McElhinny et al., 1996)
    - Octupole
        - ~1% (e.g Hatakeyama and Kono, 2002)

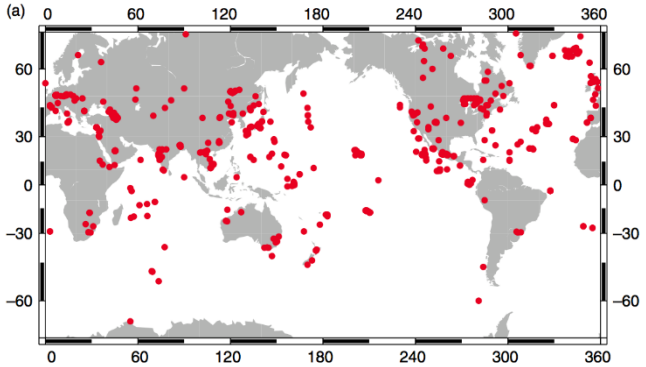
Limitations

Geographic
- S. Hem.
- High Latitudes

Direction Sites



Intensity Sites



McElhinny and McFadden, 1997; Tauxe and Yamazaki, 2007; Tauxe, 2010

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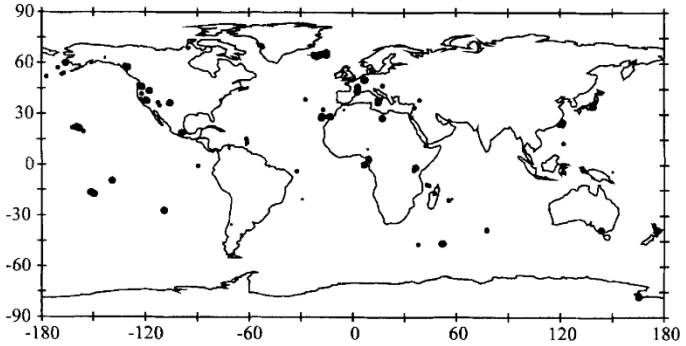

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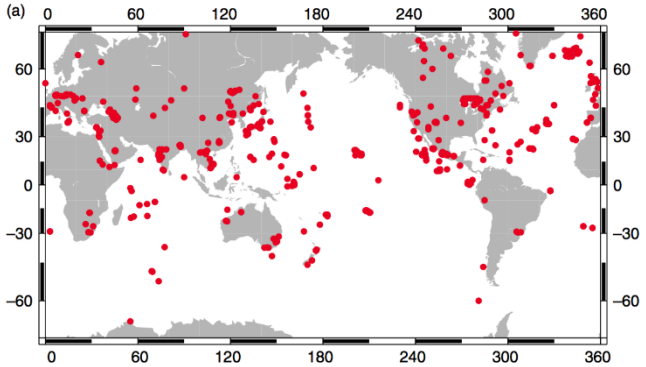
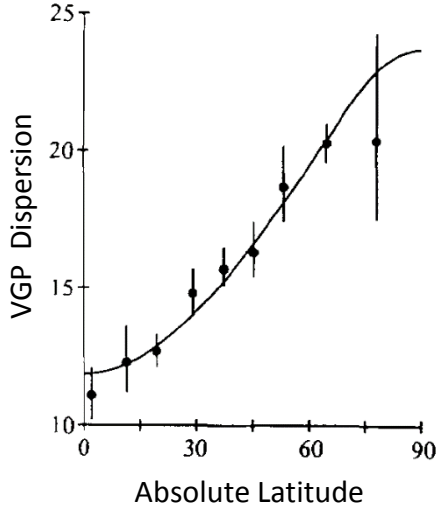
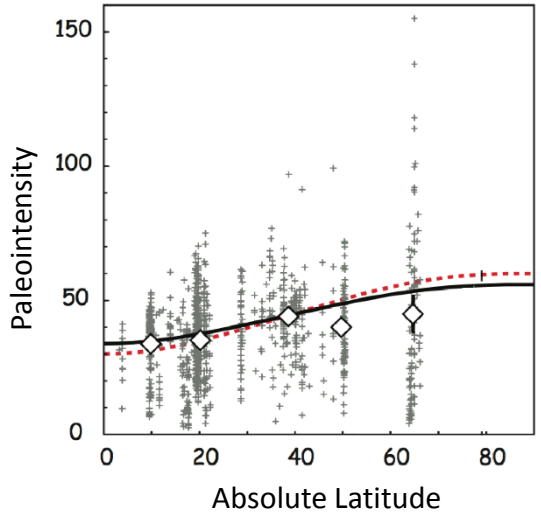


Analytic

- Symmetry
- Data Quality





McElhinny and McFadden, 1997; Tauxe and Yamazaki, 2007; Tauxe, 2010

Research Motivations

- Fill in the gaps in geographic data coverage
  - Arctic
  - Intensity and directions

- New evaluation of field behavior
  - Accurate intensity and directional data
  - Do we see a GAD field?

Outline

- New Methodology
  - Global paleointensity observations
  - New analytical method from Hawaiian lava flows
- Intensity results from Iceland
- Synthesis
  - Arctic vs. Antarctic field behavior
  - Long-Term Field Estimates

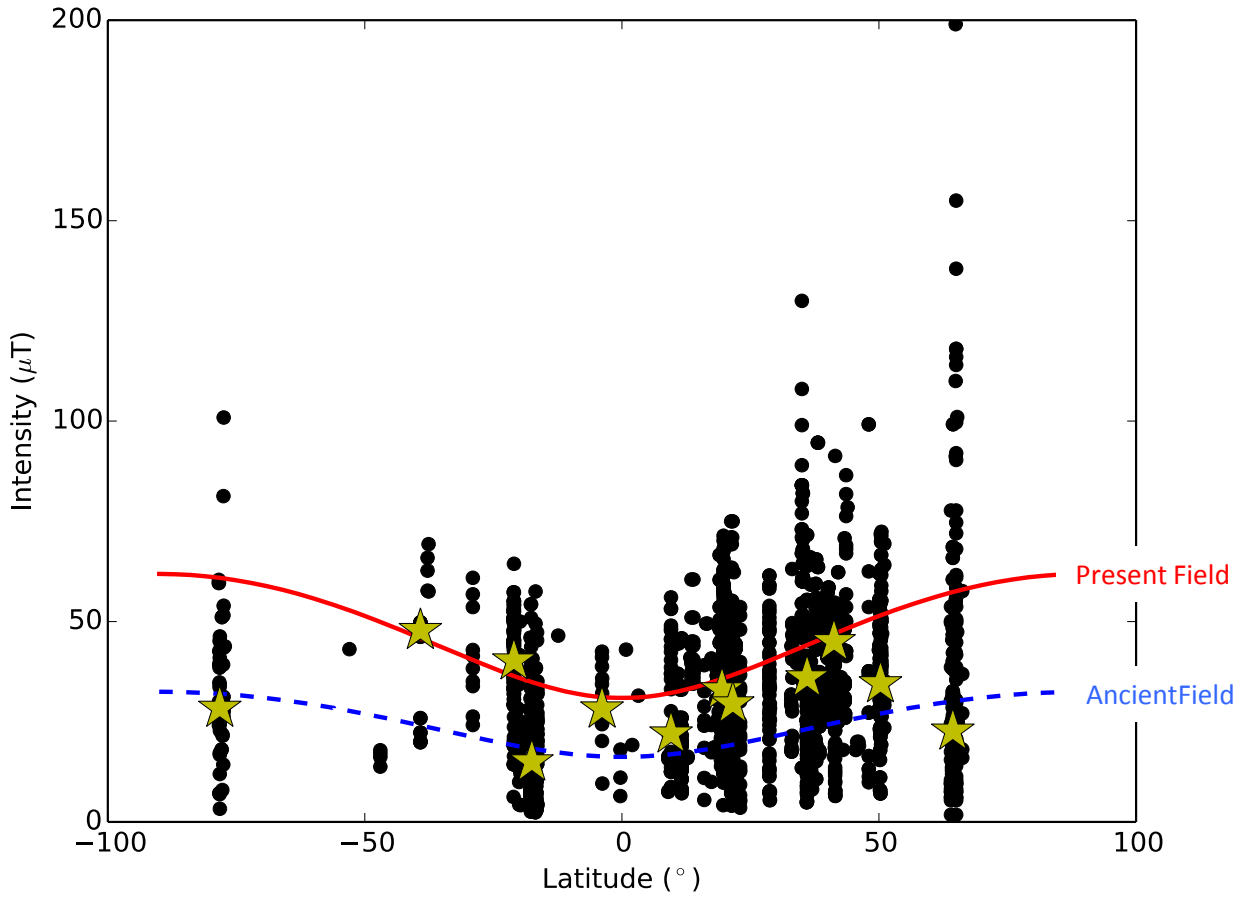
Global View-Paleointensity

Most latitude bins agree with present field strength

Polar regions (some others) are half as strong

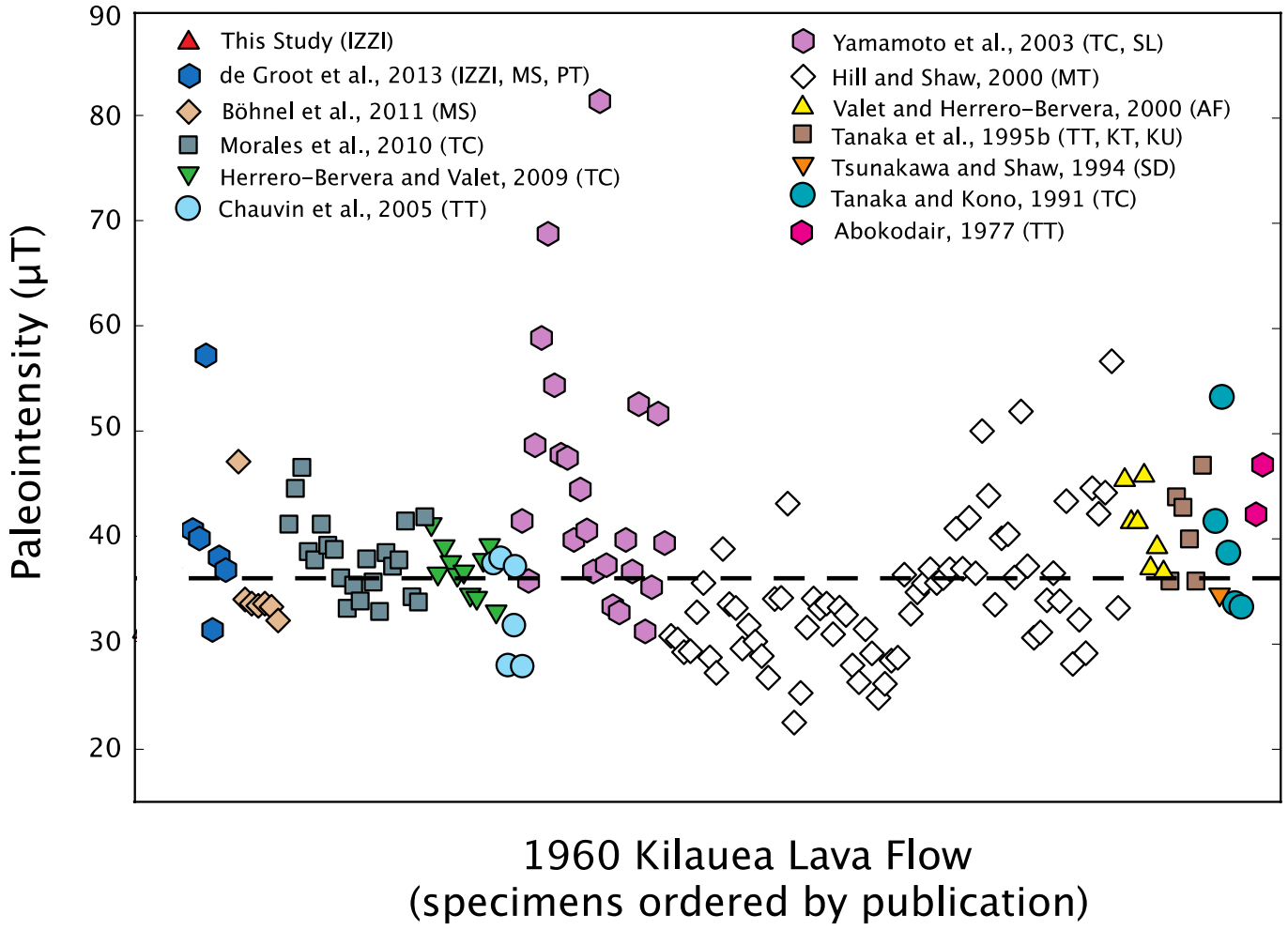
Dipole field?

Data quality is a concern



Cromwell et al., submitted

Paleointensity Data Quality

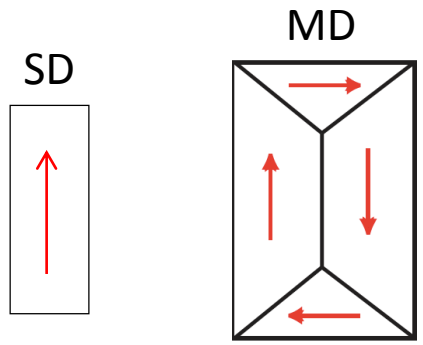


Differences between studies:

- Variable selection requirements
- Experimental types

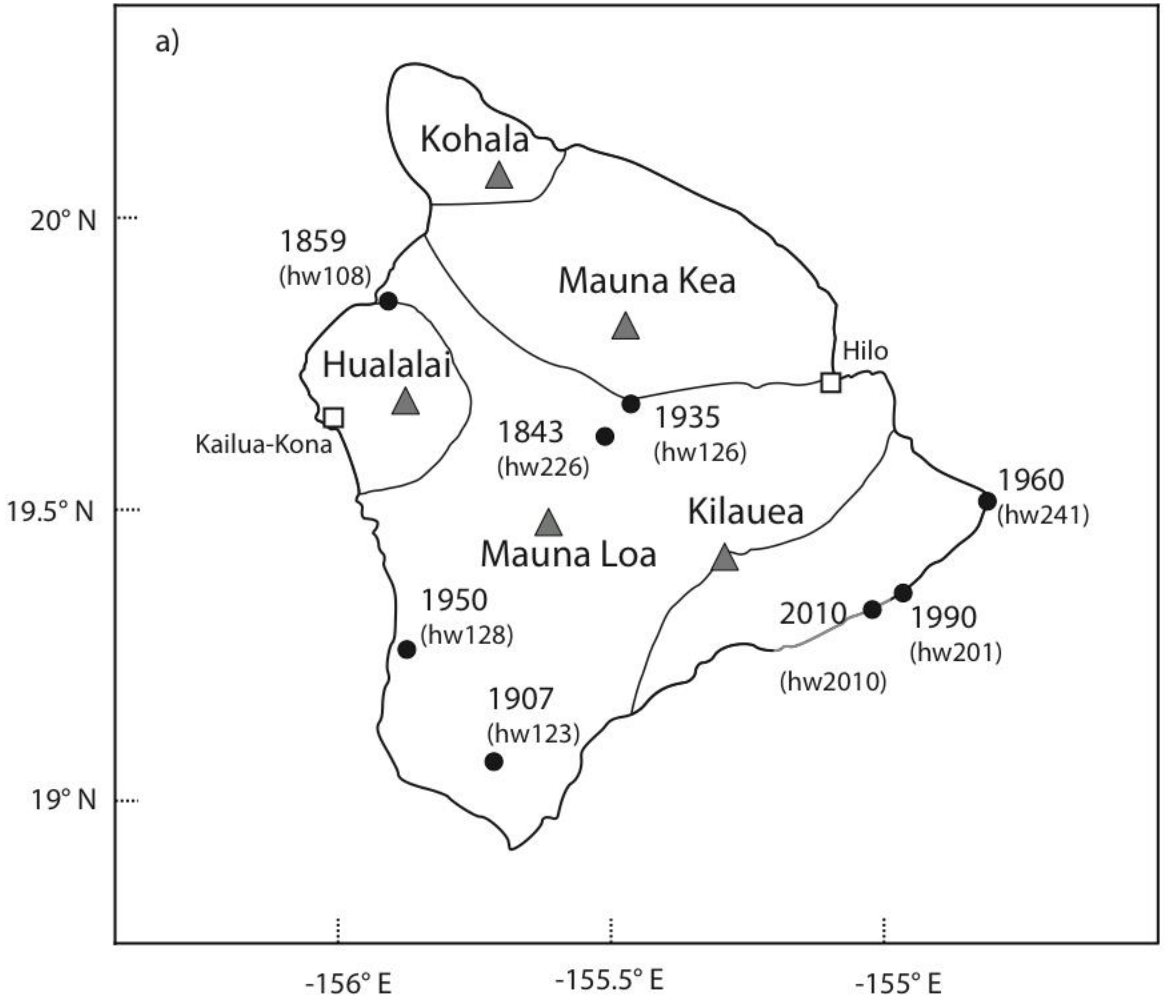
All use:

- Crystalline lava samples
  - Slowly cooled
  - Likely multi-domain
  - Subjective interpretations
  - Alteration



Cromwell et al., 2015

Volcanic Glass from Hawaii

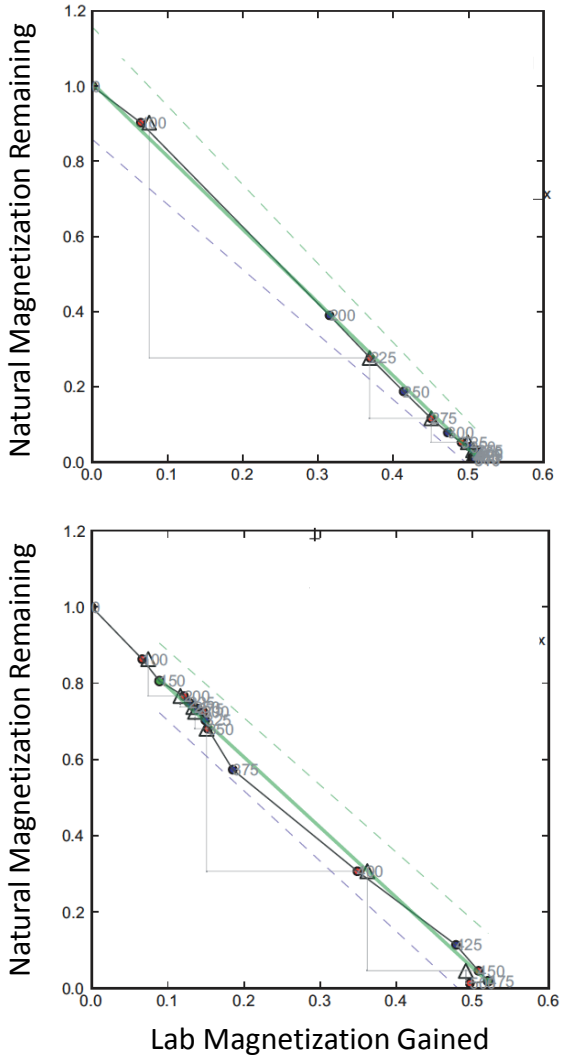


Cromwell et al., 2015

Strict Selection Criteria

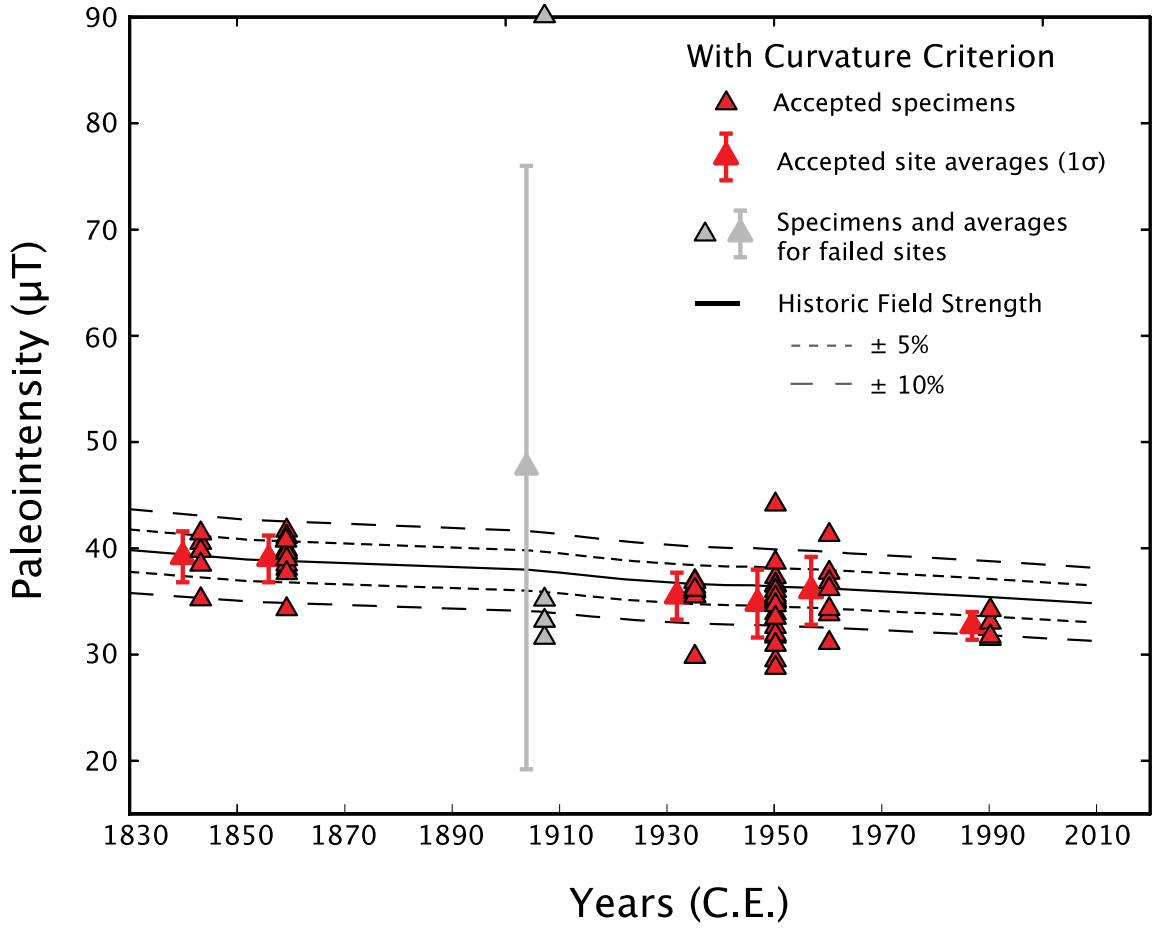
Specimen Level	
SCAT	-
FRAC	≥ 0.78
Gap Max	≥ 0.60
B	≤ 0.10
MAD	≤ 5°
DANG	≤ 10°
$\|k'\|$	≤ 0.164

Site Level	
nn	≥ 3
B_σ	≤ 4 μT
B_σ %	≤ 10%

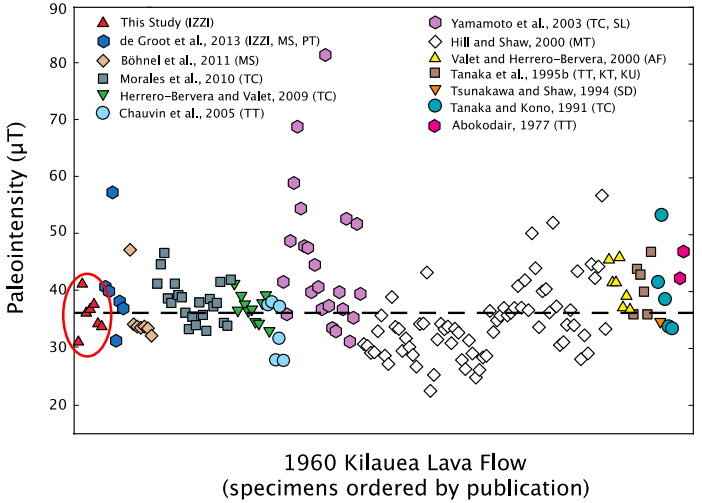


Selection Statistics: Paterson et al., 2014. Figures: Cromwell et al., 2015

Strict Selection Criteria =Accurate Results



- Avg. Intensities within 5% of expected field
- Accurate to 1-sigma uncertainty

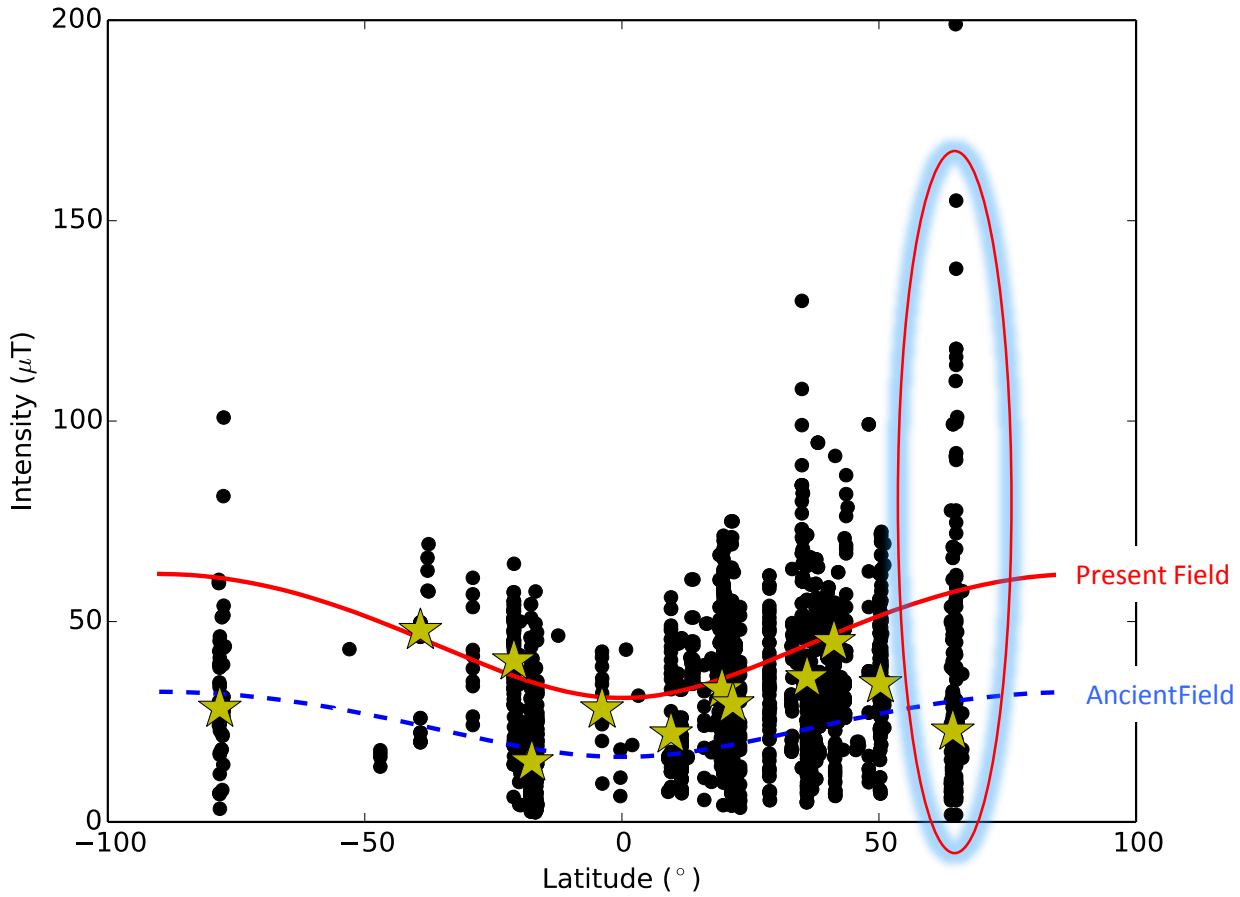


1960 Kilauea Lava Flow
(specimens ordered by publication)

Cromwell et al., 2015

Global View-Paleointensity

Iceland?



Cromwell et al., submitted

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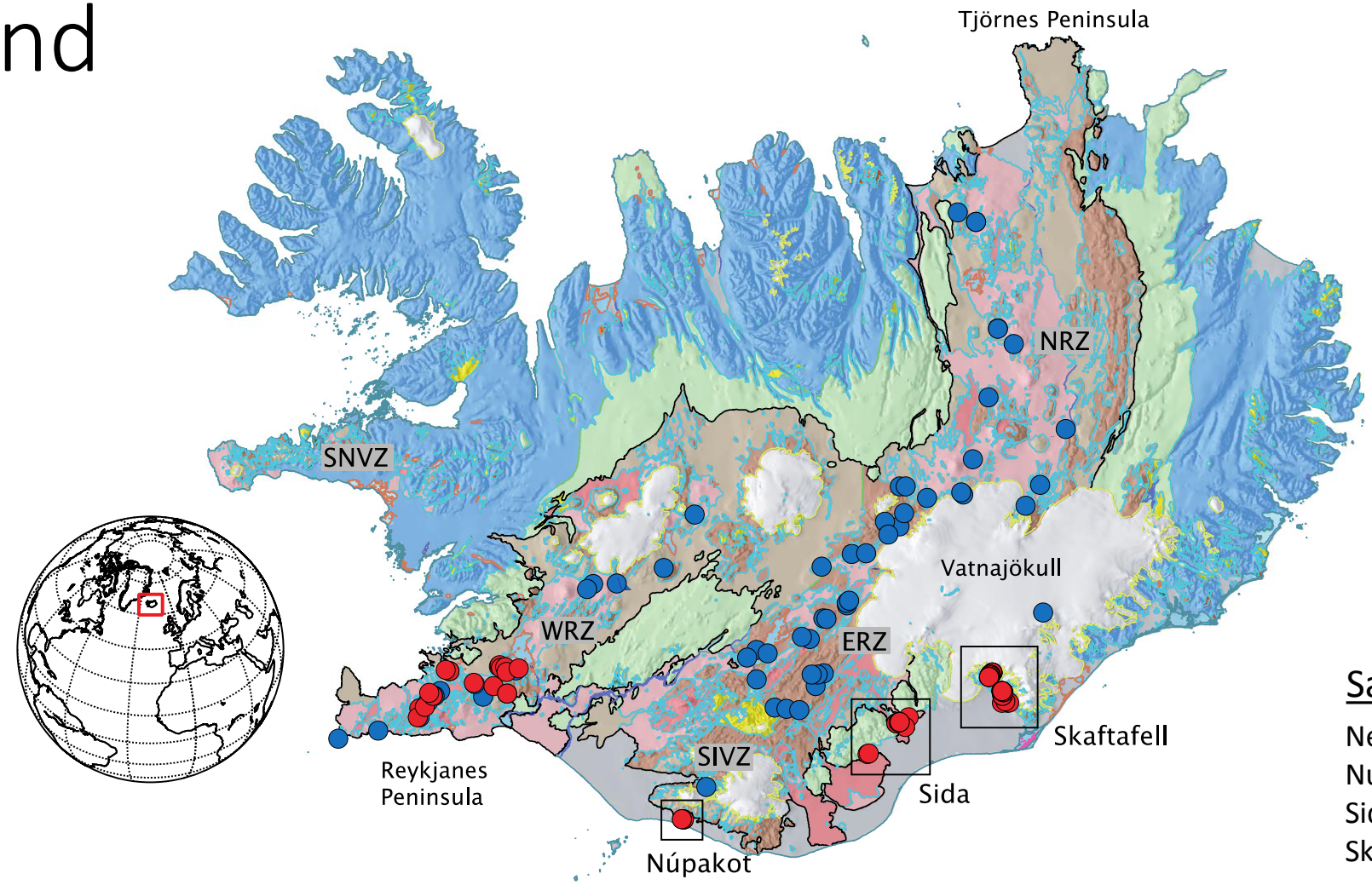
Iceland



Field Seasons

- pre-2008
- 2012

129 Total Sites

Sampling Areas (age)

Neovolcanic Zone (0-780 ka)
Núpakot (~ 780 ka)
Sida (0-10 ka, ~ 2.58 Ma)
Skaftafell (0-4 Ma)

- Holocene sediments
- Postglacial lavas: Historic, < 1100 yrs
- Postglacial lavas: Prehistoric, > 1100 yrs
- Acidic postglacial lavas: Historic, < 1100 yrs
- Acidic postglacial lavas: Prehistoric, > 1100 yrs
- Acidic extrusive rocks: Tertiary and Pleistocene, > 11 ka
- Hyaloclastites, pillow lavas and sediments: Late Pleistocene, < 0.78 Ma
- Interglacial and supraglacial lavas and sediments: Late Pleistocene, < 0.78 Ma
- Extrusive volcanics and sediments: Pleistocene, 0.78–3.3 Ma
- Extrusive volcanics and sediments: Tertiary, > 3.3 Ma
- Intrusive rocks, gabbro, dolerite, diorite
- Acidic intrusive rocks, rhyolite, granophyre, granite
- Lakes, reservoirs, rivers
- Glaciers

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Pillow Basalts

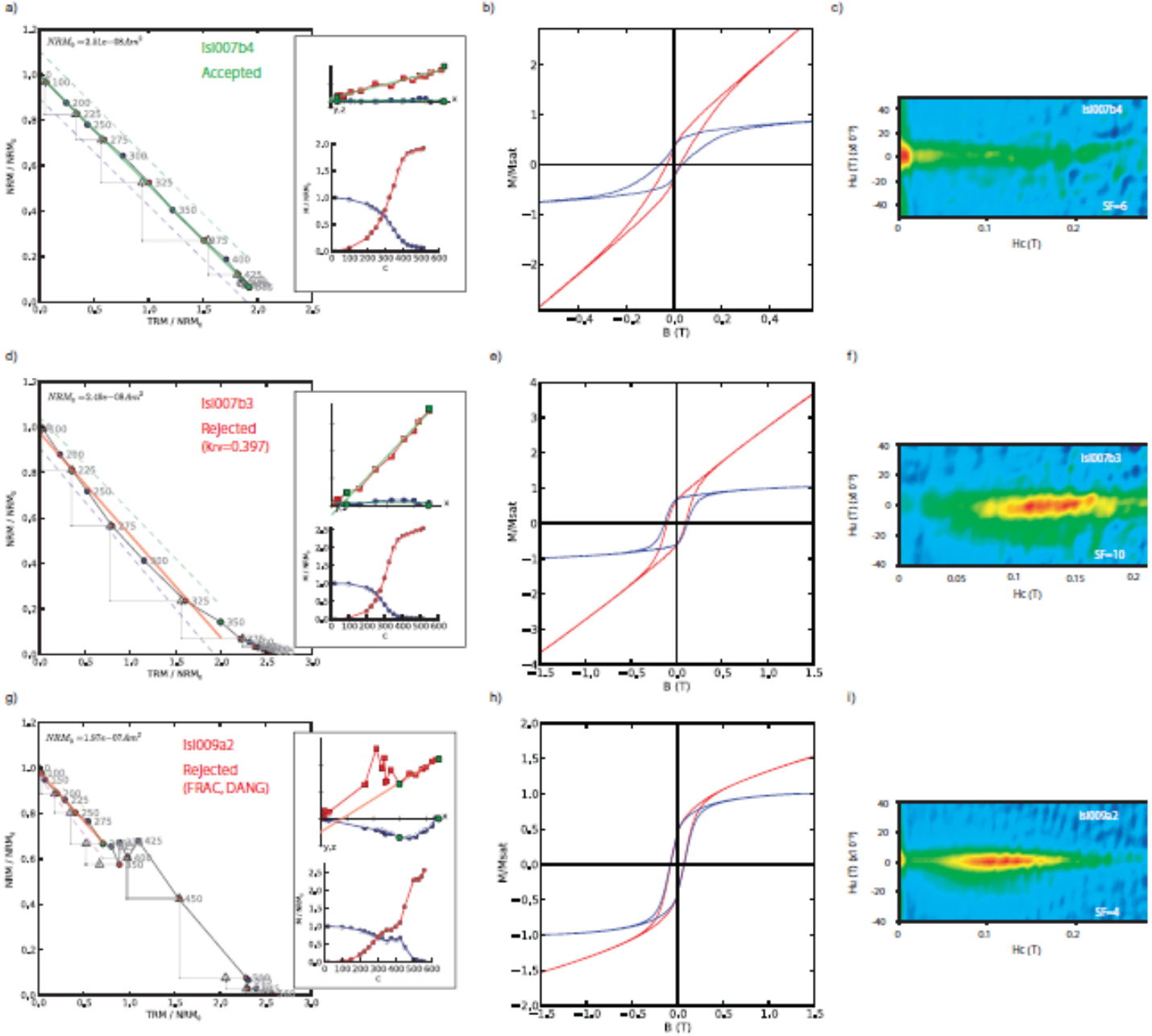
Hyaloclastites

Sub-aerial flows
-Pahoehoe

Sub-aerial flows

Typical Results

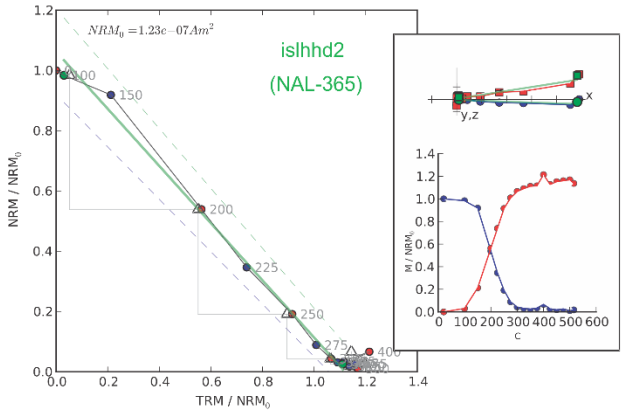
- Successful sites have straight Arai plots through the entire experiment
- Single-domain-like behavior found in a range of studies



More Results

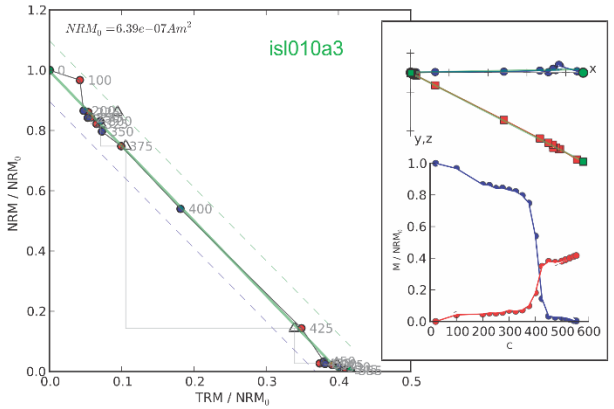
Low-T magnetic grains

a)



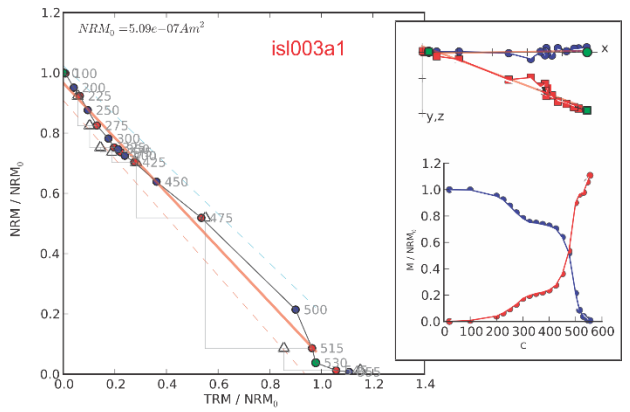
Low/high-T grains

b)

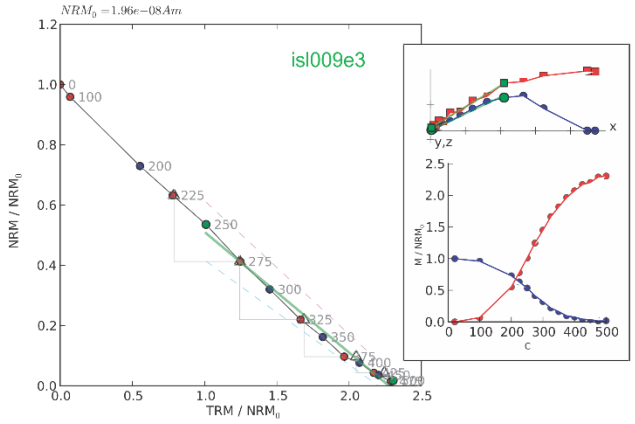


Med/high-T grains
-Fails curvature statistic

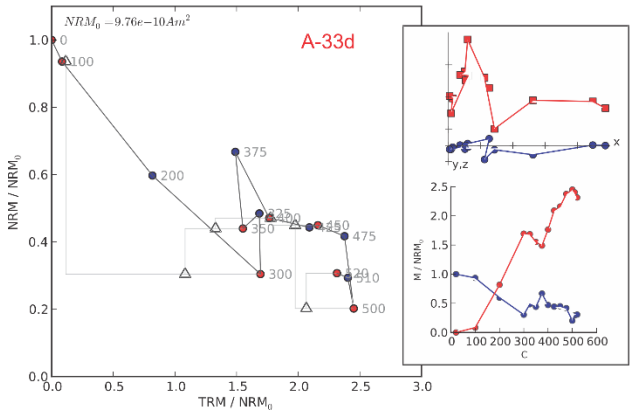
c)



d)



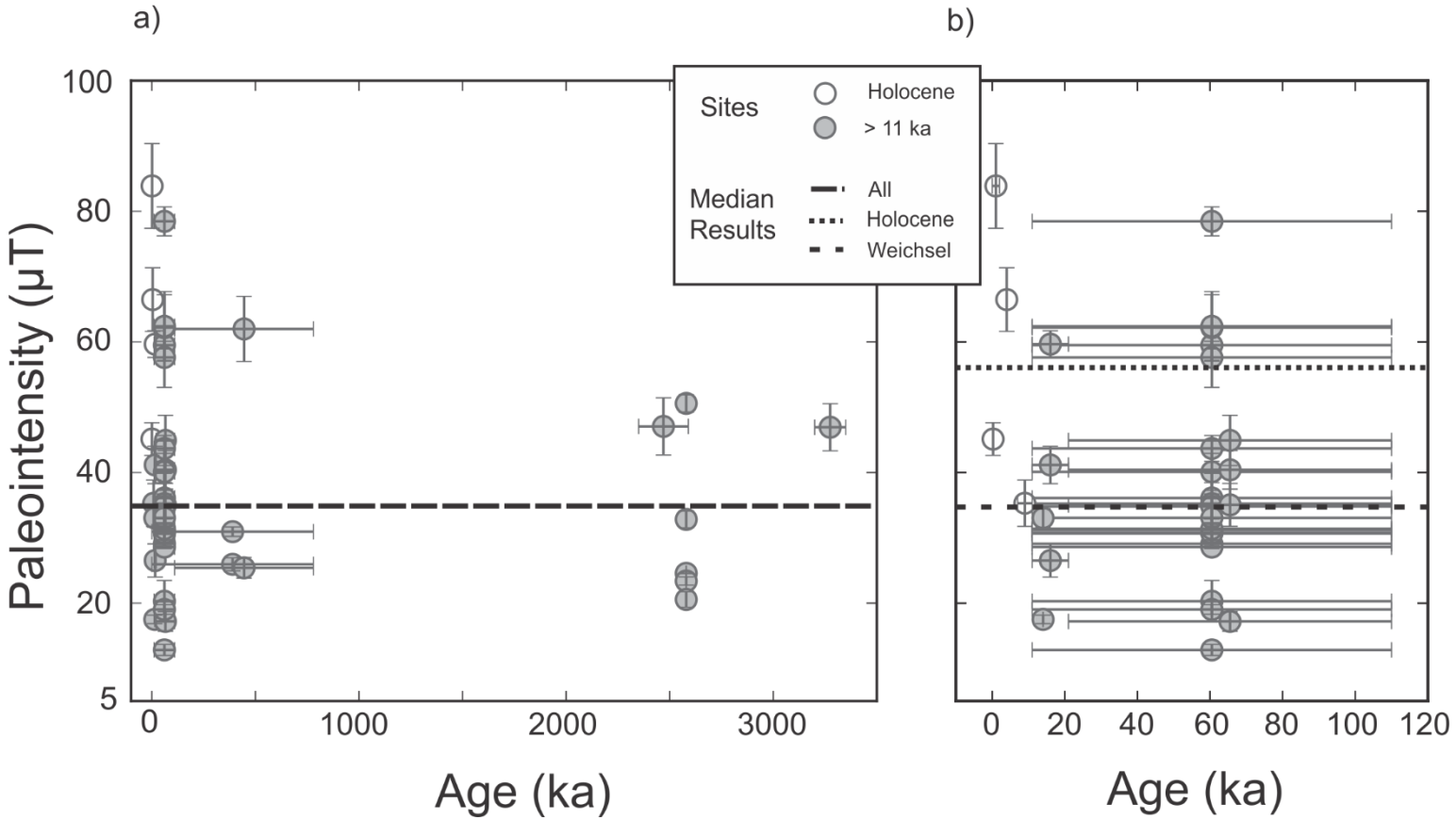
e)



Physical rotation during cooling

Alteration

Iceland Paleointensity



Age	Paleointensity
All Sites: n=44	*34.9 ± 9.8 μT*
Holocene (N=4):	55.8 ± 15.6 μT
Weichsel (N=29):	34.8 ± 6.4 μT
Brunhes (N=4):	28.4 ± 2.8 μT
Mat/Gss (N=6):	28.7 ± 6.7 μT
Gauss (N=1)	46.9 ± 3.6 μT

Cromwell et al., submitted

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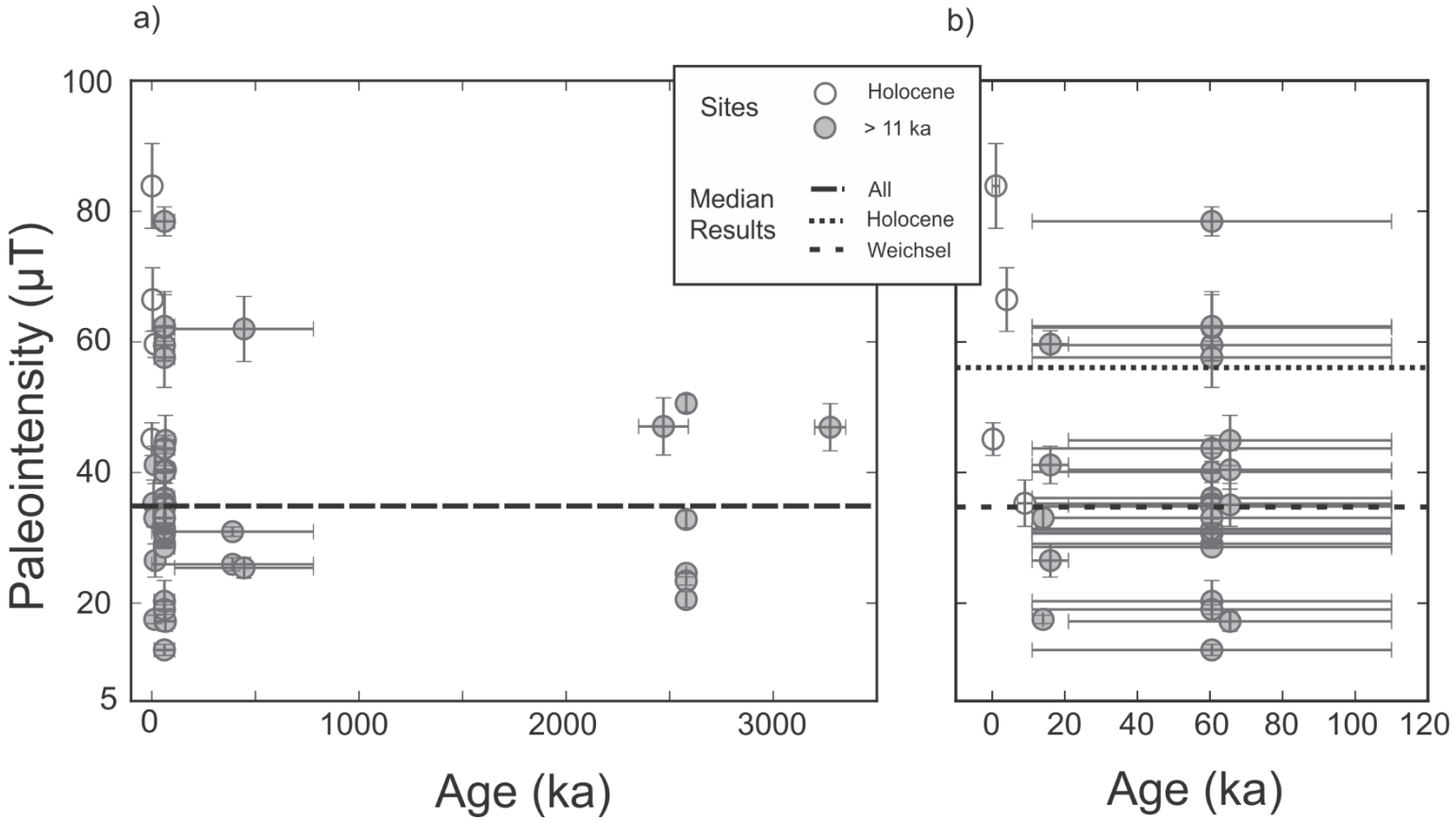

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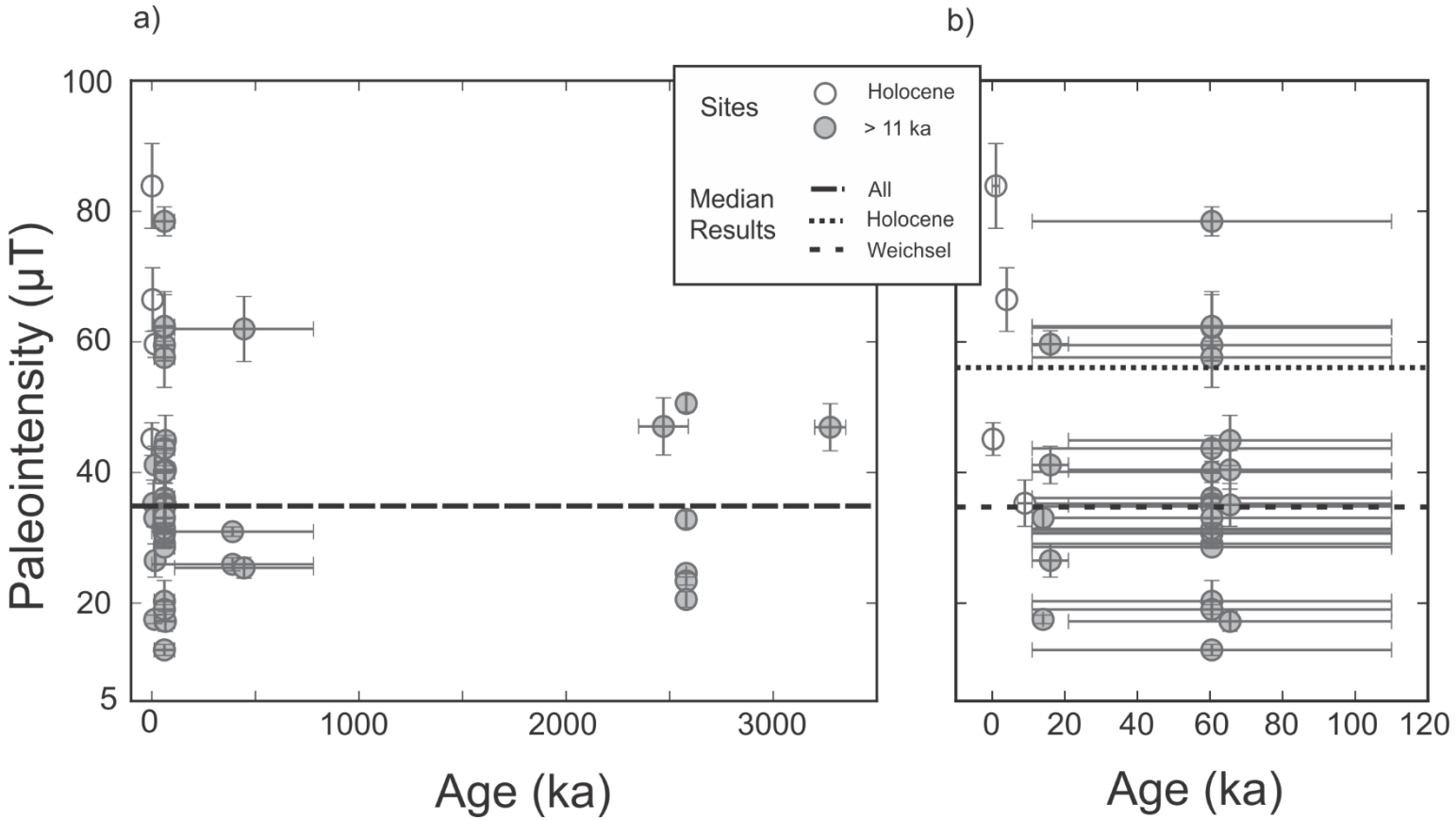


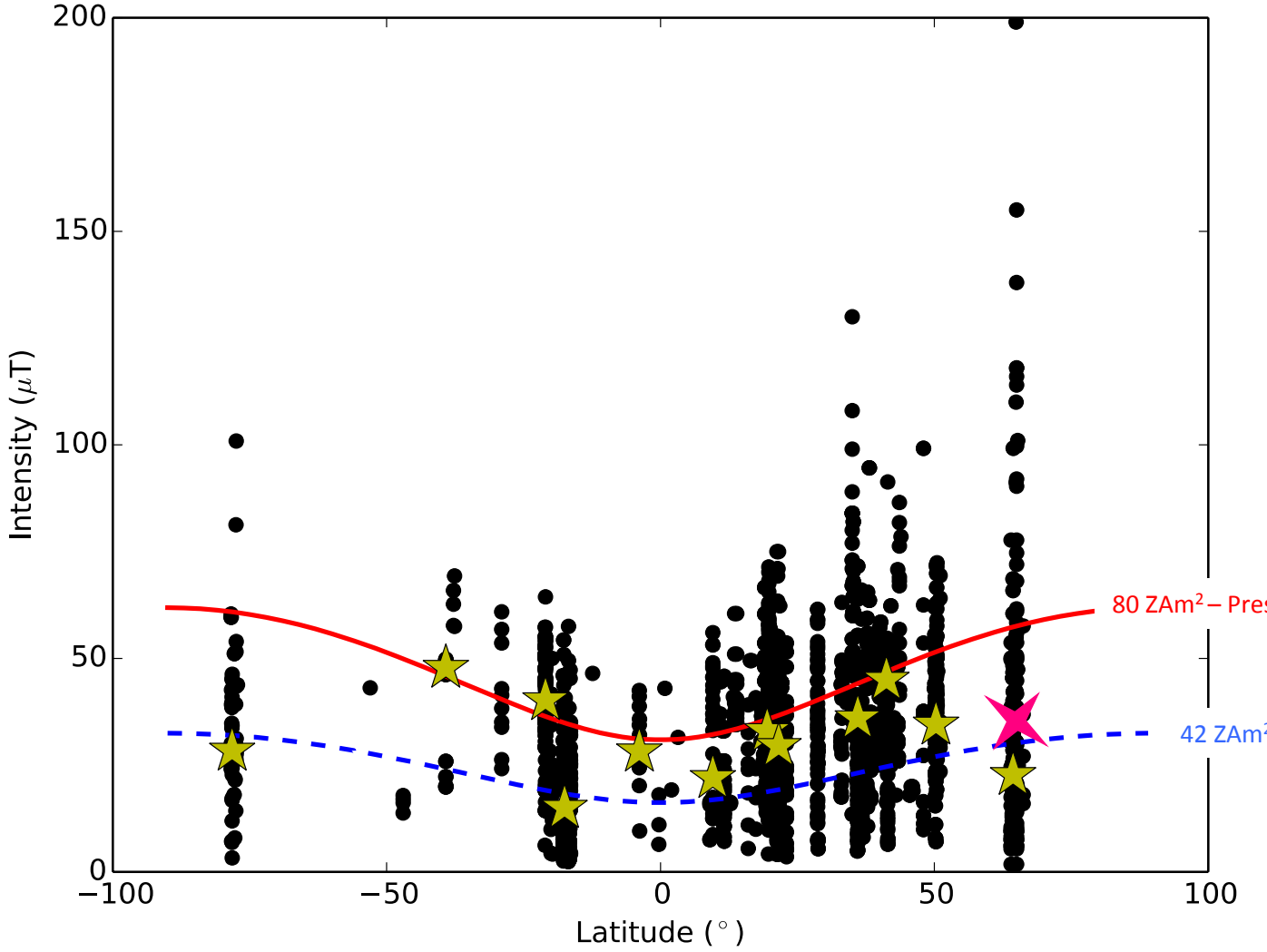
Non-Holocene sites about 2/3 present day field strength (52.5 μT)

Undifferentiated Weichsel sites consistent with “Late” and “Early”

Possible Laschamp excursion record (Weichsel sites)

Cromwell et al., submitted

Iceland Results:



Median VADM (All > 11 ka) = 47.0 ± 11.6 ZAm^2

Cromwell et al., submitted

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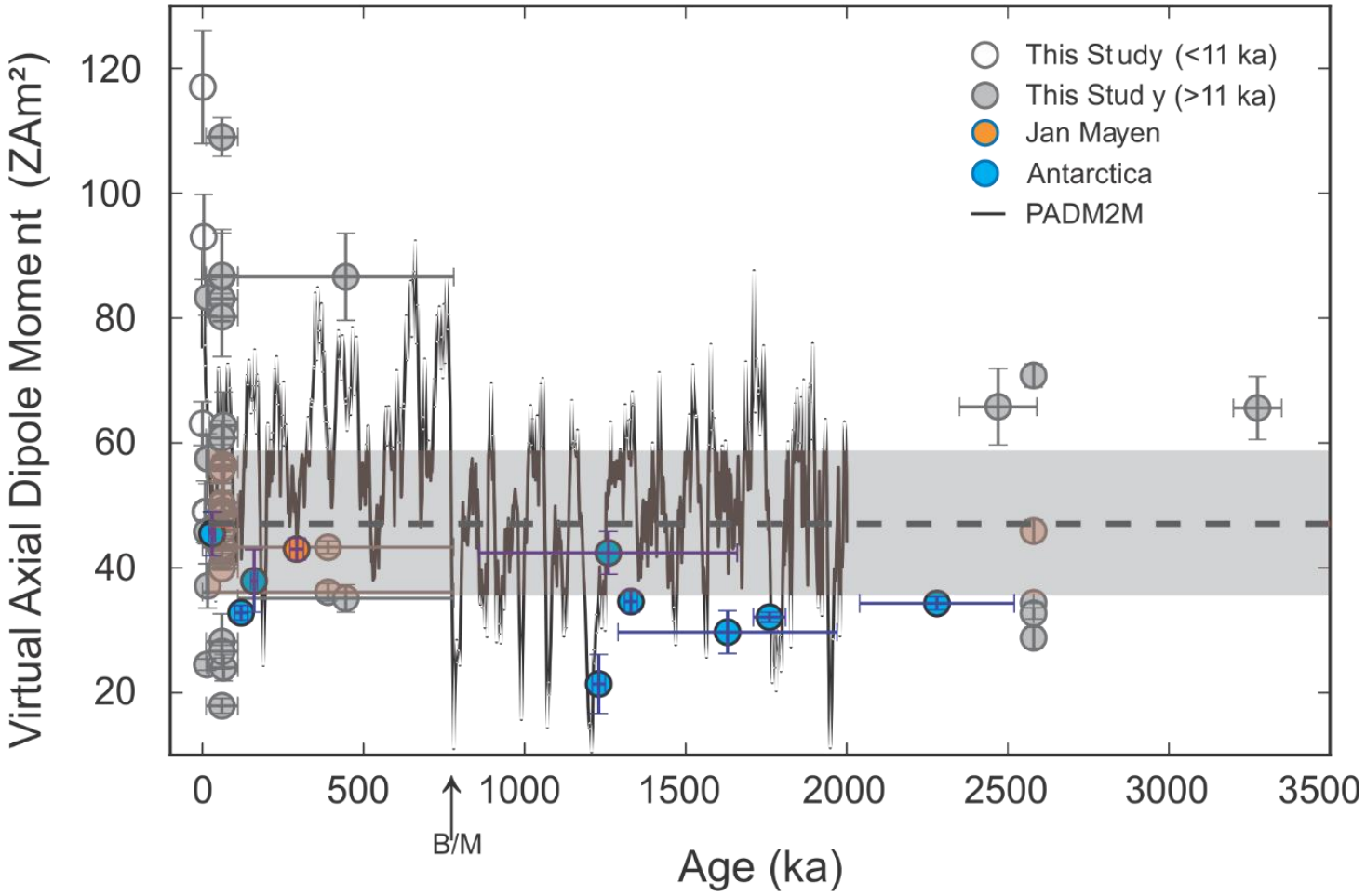
Arctic vs. Antarctic

Published Results w/ Strict Criteria

Antarctica, N=9 (Lawrence et al., 2009)
34.3 ± 3.6 ZAm^2

Jan Mayen, N=1 (Cromwell et al., 2013)
40.9 ± 4.9 ZAm^2

Iceland, N=44 (This study)
47.0 ± 11.6 ZAm^2



Cromwell et al., submitted

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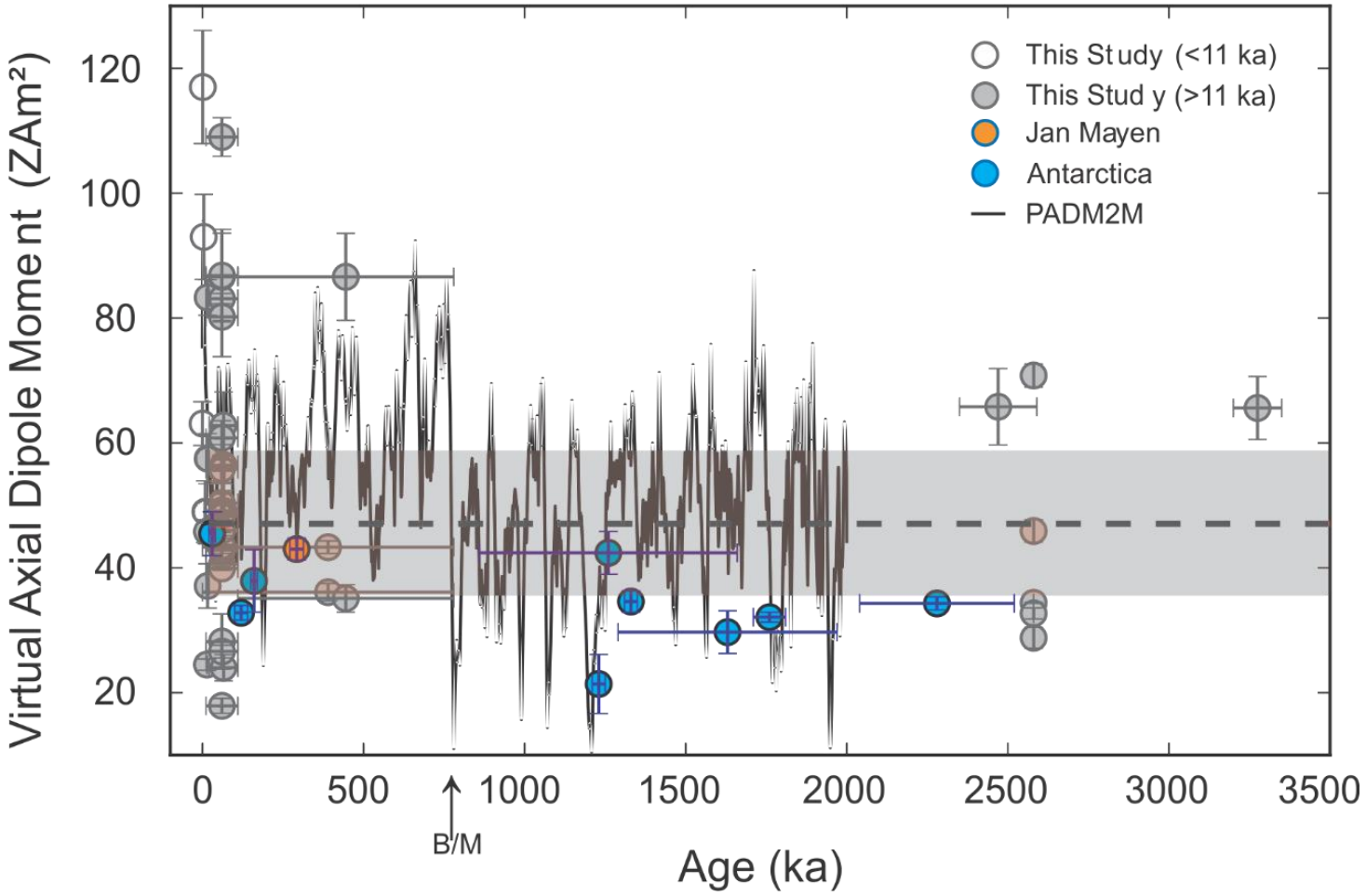
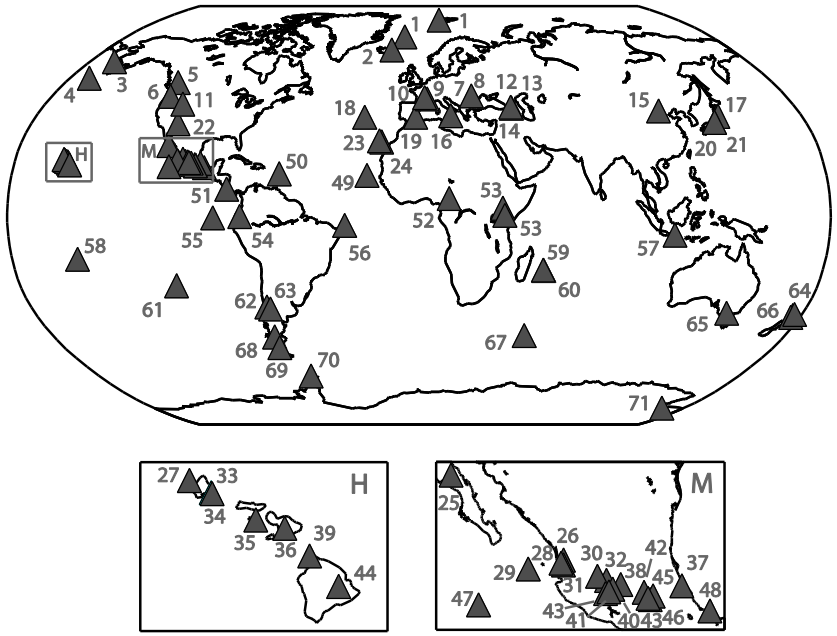
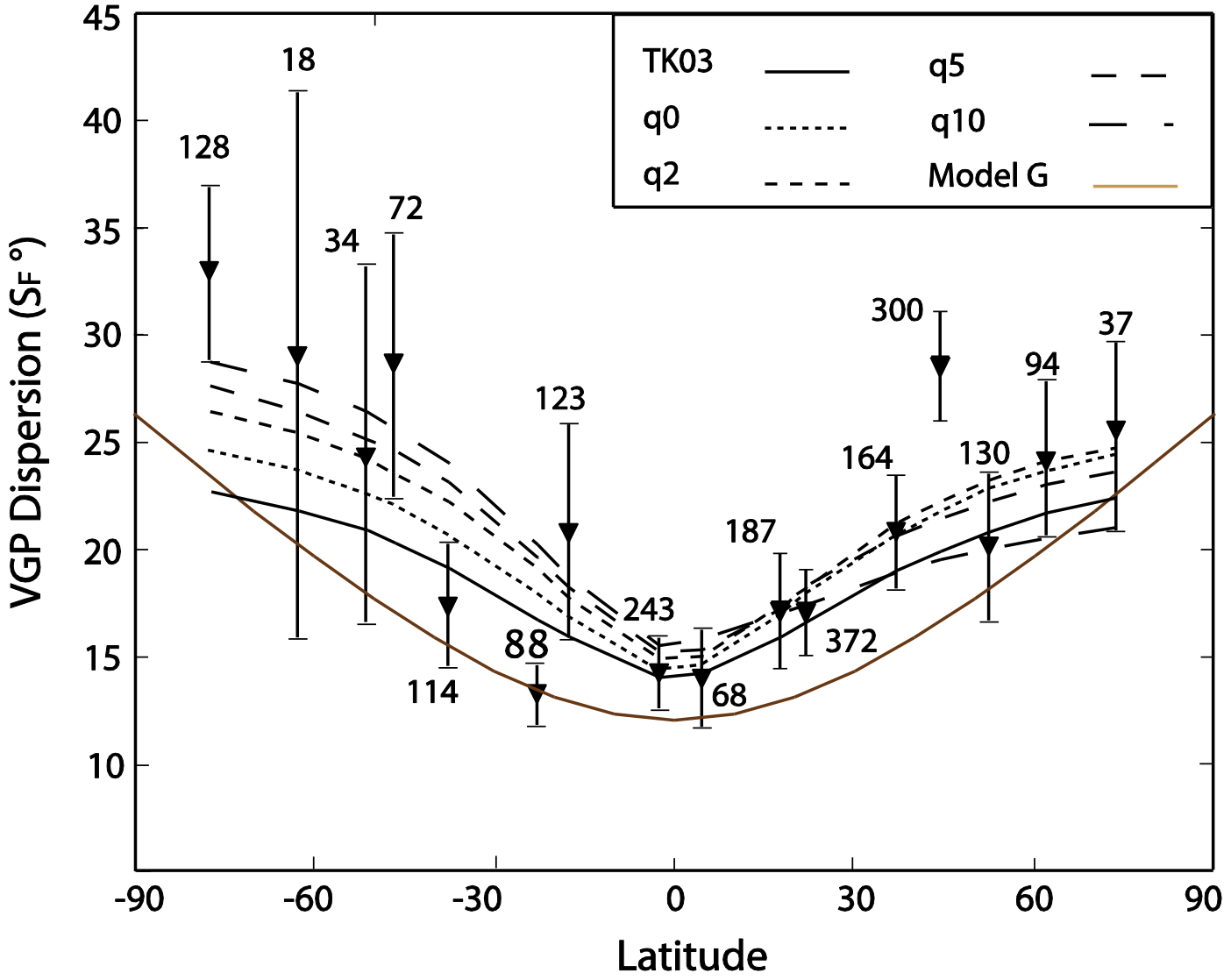
Too few comparably aged sites for any reasonable evaluation!!



Cromwell et al., submitted

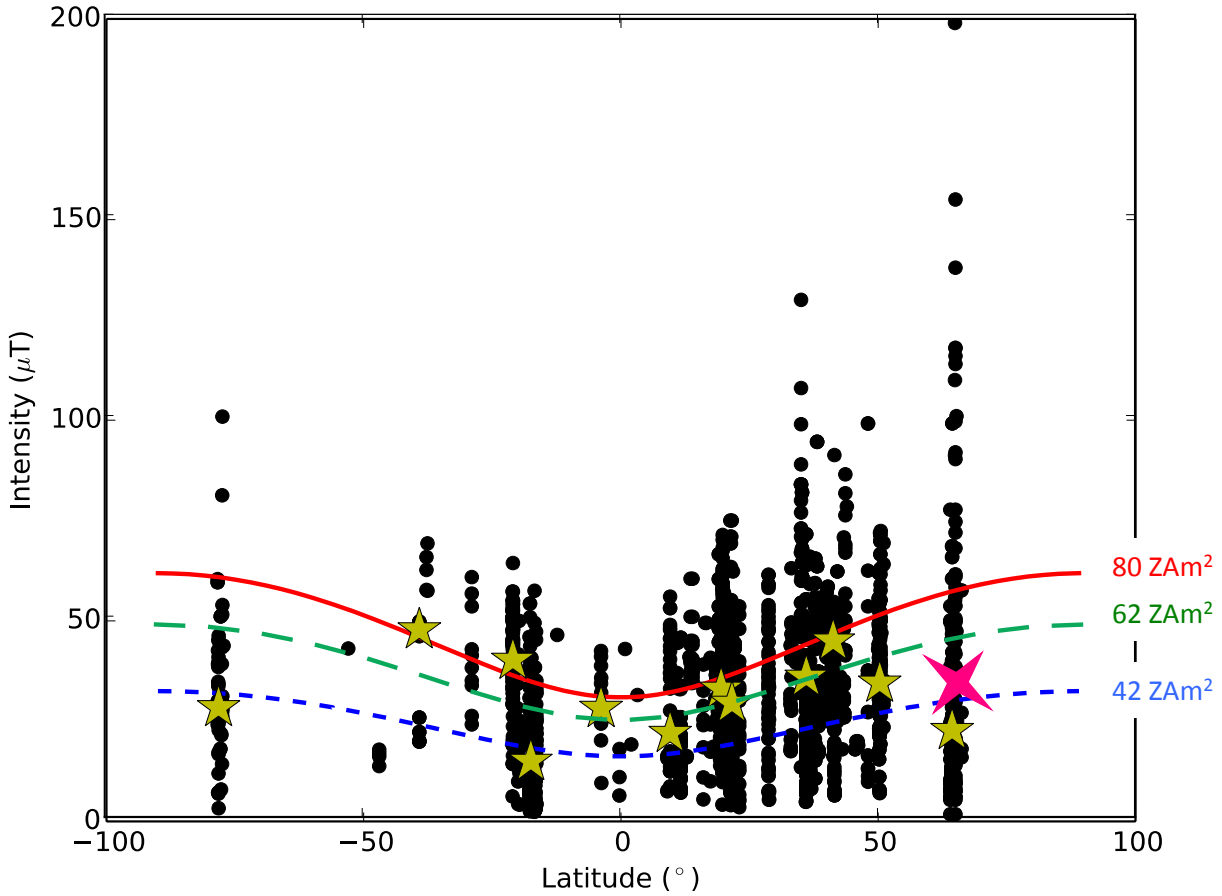
PSV10 Directional Dataset





Cromwell et al., in prep

Global Paleointensity Estimates



Long-term estimates depend on data selection

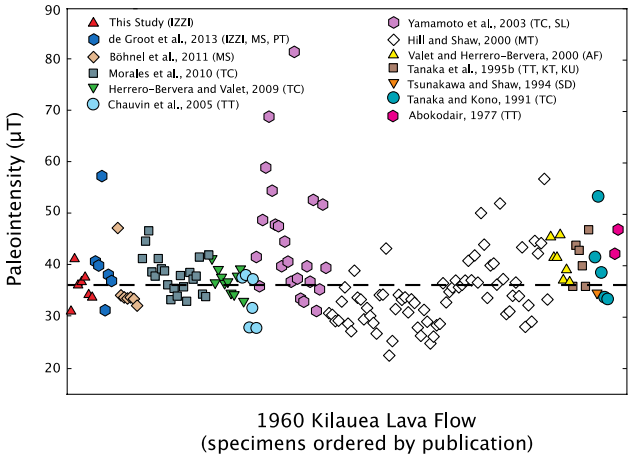
PADM2M and
Tauxe and Yamazaki (2007)

- Minimum site criteria, accept all experiment types

Tauxe et al (2013) and
Juarez et al (1998)

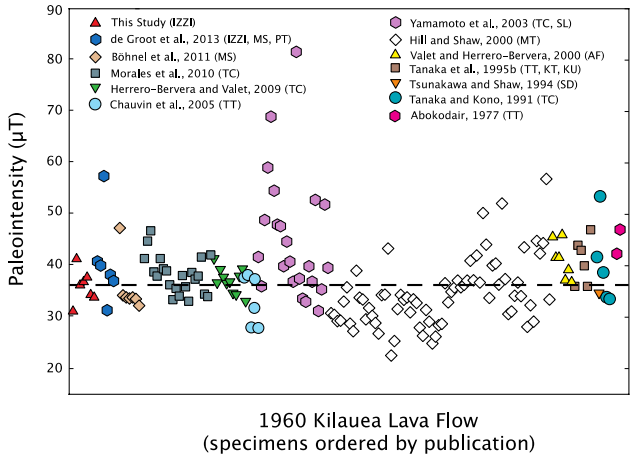
- Minimum site criteria, experiments with alteration checks

Cromwell et al., submitted



Simulations with Published Intensity Data

Cromwell et al., 2015



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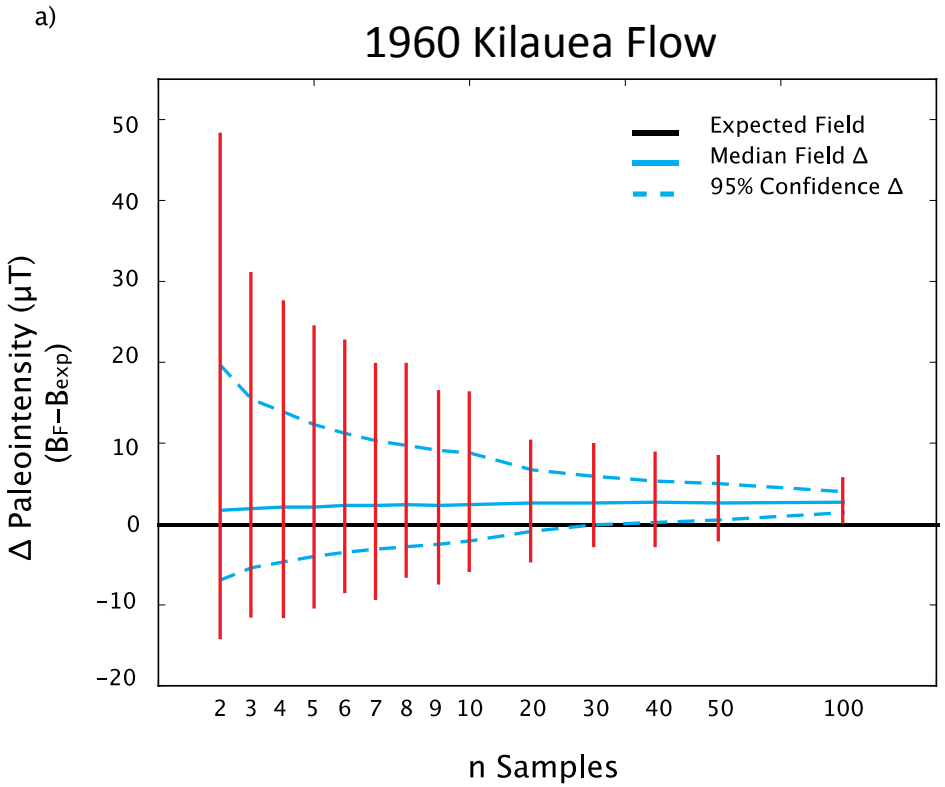
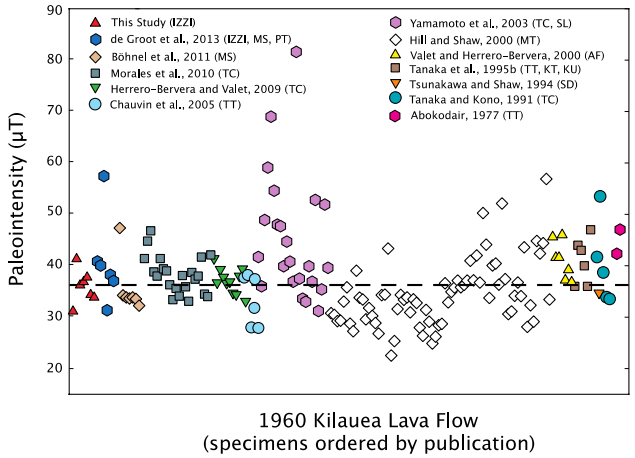


Cromwell et al., 2015



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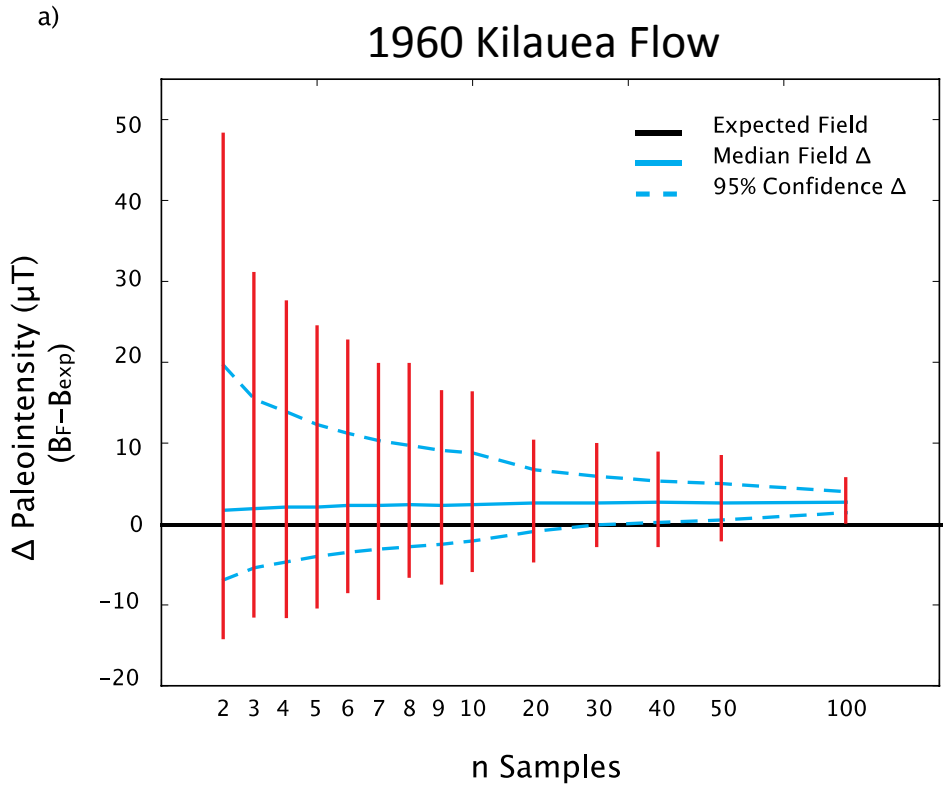
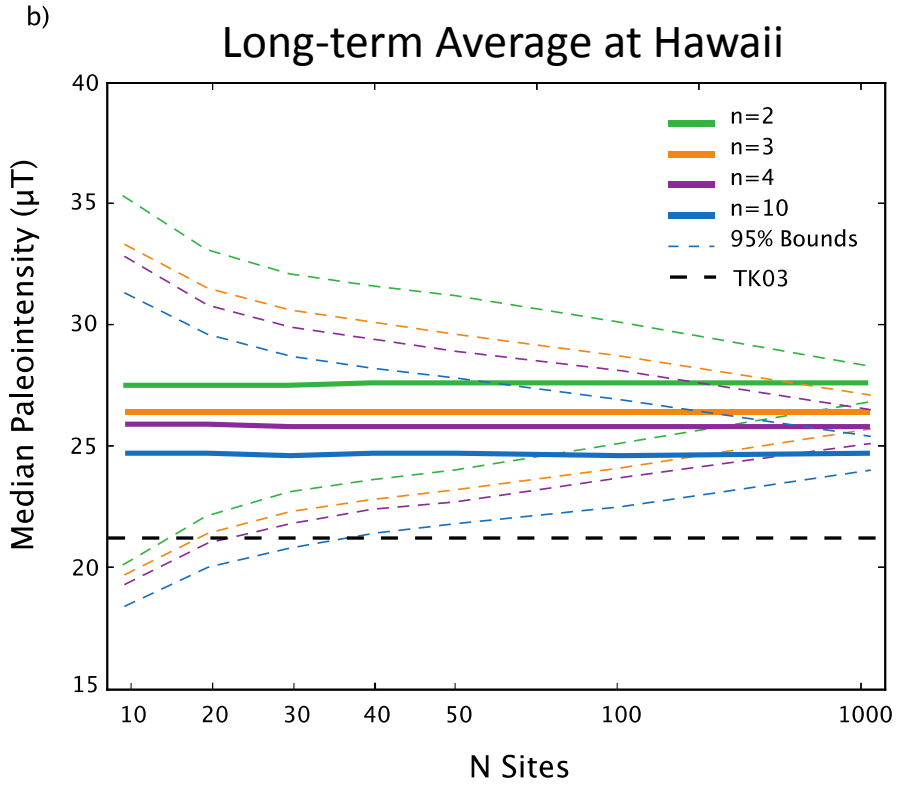
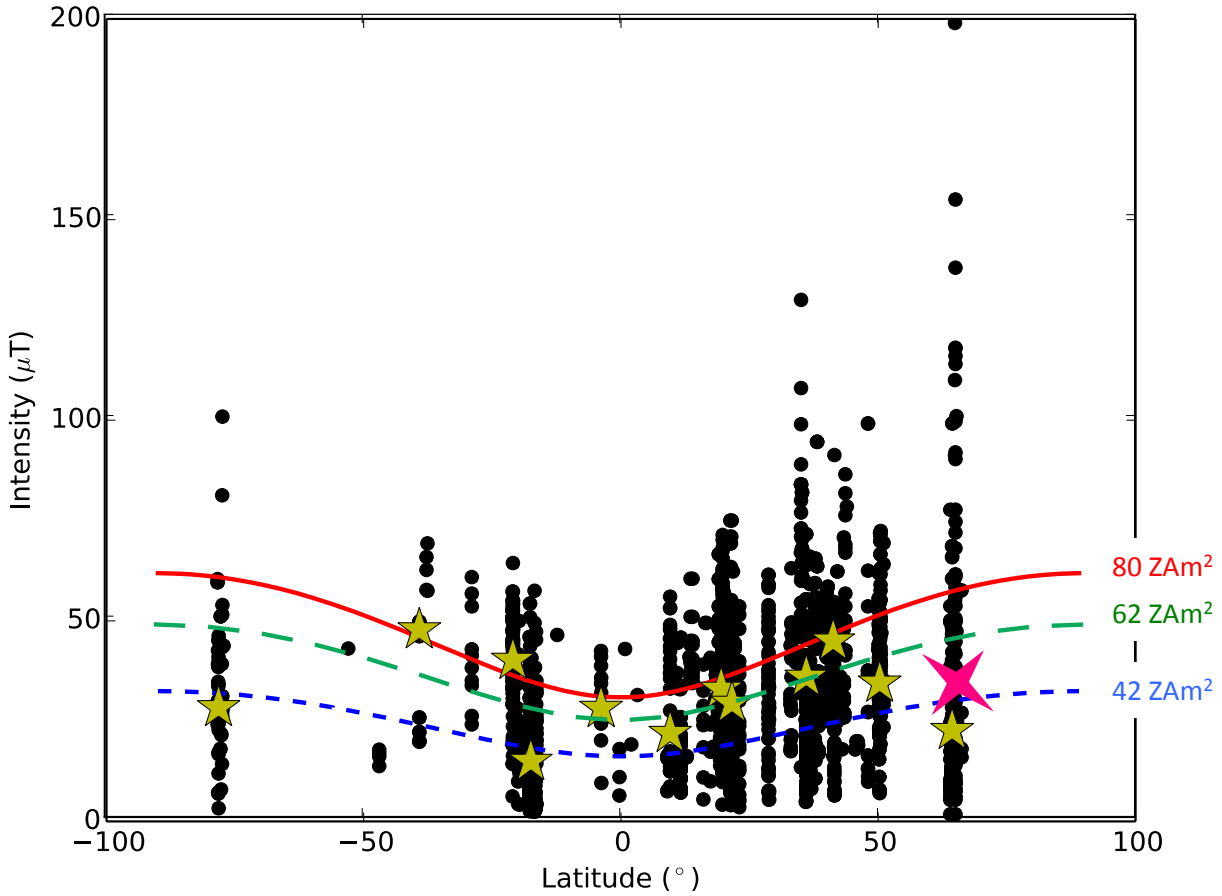




Cromwell et al., 2015

Global Paleointensity Estimates



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Summary

- Methodology for paleointensity experiments
  - Volcanic glass and strict selection criteria
  - Accurate results for historic Hawaiian lavas

- New Icelandic results (0-3.3 Ma)
  - 44 sites from subglacial, subaerial lavas
  - Low median field strength
    - Half present day field and some long-term averages
    - Confirms “low” Arctic intensity (e.g. Tauxe et al., 2013)
    - Intensity database needs re-evaluation
    - More Arctic/Antarctic studies

- Simulations of long-term averages
  - Skewed distribution of published data
  - Possible overestimate of geomagnetic strength by 25%