Past, Present, & Future:

What the current state of pyrite tells about historic conditions & means for decision-making

Kathryn Royce, D.Phil. Candidate, University of Oxford

SEAHA
EPSRC CENTRE FOR DOCTORAL TRAINING
SCIENCE AND ENGINEERING IN
ARTS HERITAGE AND ARCHAEOLOGY

National Museums Liverpool

SoGE School of Geography and the Environment

UNIVERSITY OF OXFORD

national museum cardiff
amgueddfa genedlaethol caerdydd

OR 3D
Digitise Dimension Design

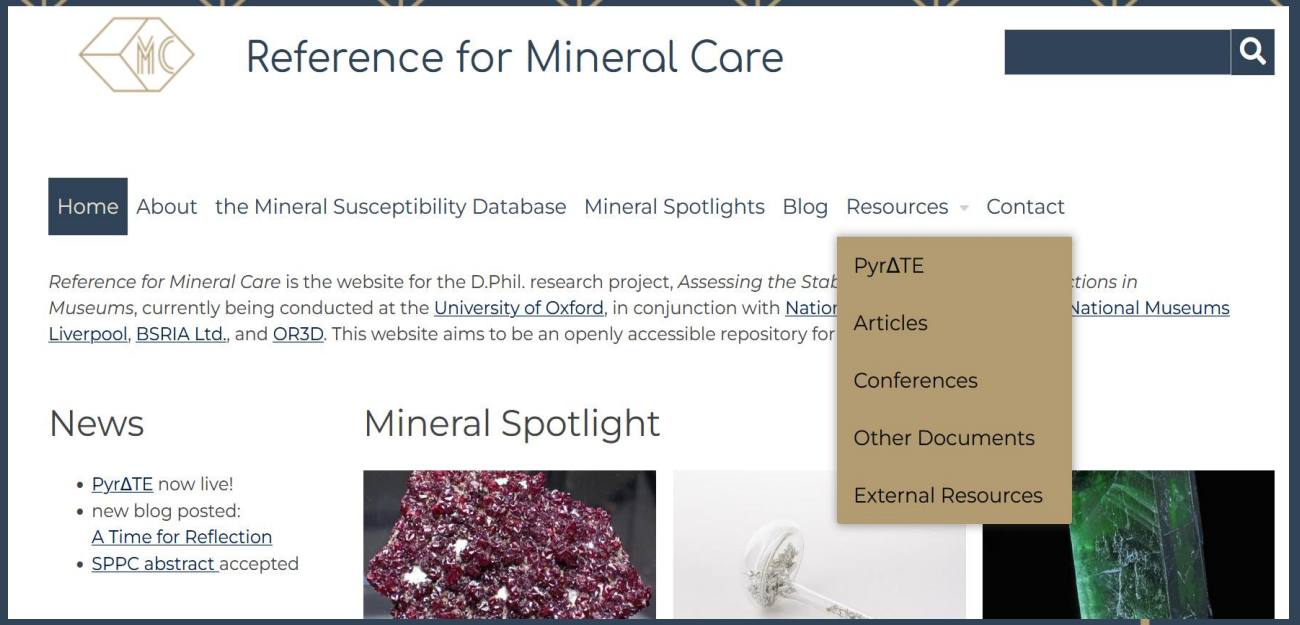
BSRIA

Preface

- Large data set => can't cover all here
- Still undergoing analysis

- Extra slides @ back
  - Go to **Reference for Mineral Care** to download http://mineralcare.web.ox.ac.uk
  - Under 'Resources' > 'Conferences' > SPPC

- Please bookmark website!
  - 2nd part to survey => colour!
  - Further project updates will be available here



the DP State Survey Method

- Developed new & unique approach
  - Tackle subjectivity, ambiguity, & variability
- Examine state objectively & quantitatively
  - View signs of change neutrally
- Quickly perform on whole or fraction of collection

- Objectives:
  - ✓ Identify changes that occur
  - ✓ Determine specimens more susceptible to change
  - ✓ Confirm alignment between literature & reality
  - ✓ Identify gaps in knowledge
  - ✓ Correlate patterns to agents of change
  - x Determine if fit for use, has value, or in 'good' condition

Deterioration Phenomena (DP)

Dimple	Rounded	Corrosion	Tarnish	fflorescence	Powder	Crumbling	Flaking	Breakages	Cracks	Dull/Matte	Darker	Lighter	Opacity	olour Change
0	0	1	1	0	0	0	0	0	1	1	0	0	0	1
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	0	1	0	0	0	0	0	0	1	1	0	0	0	1
0	0	0	1	0	0	1	0	1	1	0	0	0	0	0
0	0	0	1	0	0	0	0	0	1	1	1	0	0	1
0	0	0	1	0	0	1	0	1	1	1	0	0	0	1
0	0	1	1	0	0	0	0	0	0	0	1	0	0	1
0	0	0	1	0	0	0	0	0	1	1	0	0	0	0
0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	1	0	0	1
0	0	1	1	0	0	0	0	0	0	0	0	0	0	1
0	0	0	1	1	0	0	0	0	1	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	1	0	0	1	0	0	1	1	0	0	0	1
0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
0	0	0	1	0	0	1	0	0	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

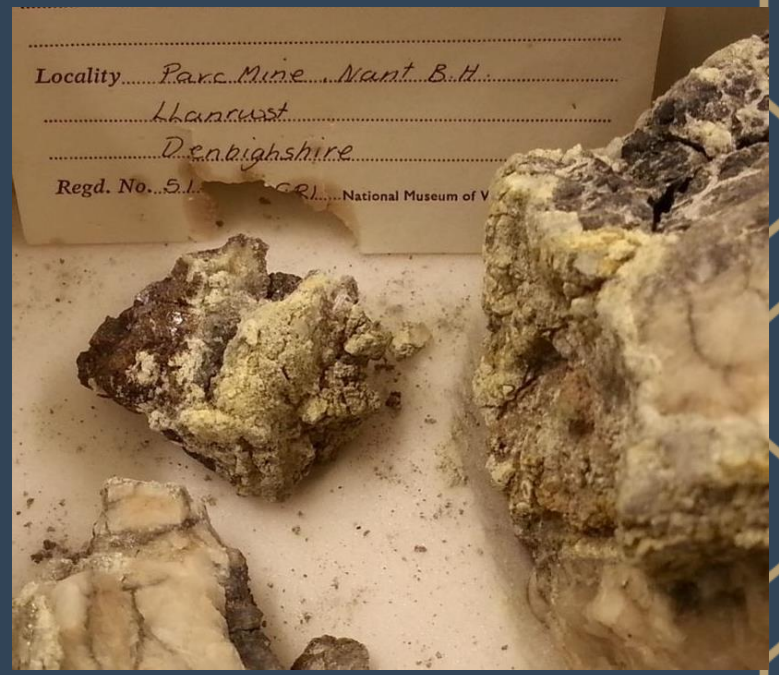
- Visually indicative of change to a mineral
  - Not all applicable to every species
  - Some more indicative of deterioration than others
- Limited & pre-defined
- Presence/absence only (1 / 0)
  - No determination of extent/severity
  - Increase speed, reduce variability, avoid assigning quantitative values to subjective perception
- Cause of change attributed during data analysis
  - Minimise distraction, interpretational bias, & attribution error

Identifying Deterioration

- Presence of multiple phenomena suggests deterioration has occurred
- Out of scope of survey to determine if active or not
  - Cannot be determined by visual observations alone

- Certain combinations suggest potential reaction types:
  - surficial oxidation
  - oxidation at depth
  - pollutant-induced oxidation
  - efflorescence
  - surface wetting
  - physical forces

  - First order = affects > 50%
  - Second order = affects < 50%



Museums Surveyed

Museum	Approx. Age	Pyrites	Hours	Days	Ave. Rate (min/hr)
OUNHM	c.1790 – present	358	6	2	61
NMC	c.1850 – present	482	11	5	54
NML	c.1950 – present	135	3	1	45
Sedgwick	c.1650 – c.1900	298	8	5	44
	Total	**1,273**	**28**	**13**	**51**

Allow me to tell then show

Intervariable analysis not yet performed

- Not 100% sure which variables most important for stability
- Don't have to stats to back it up (YET)

Take everything after this slide with a grain of…


Castorly Stock


Kindel Media


Nature's Expressions

Here's what I've seen - Climate

- All museums (save NML) have specimens pre-dating HVAC & climate control
  - If it's stable, it can handle typical T & RH fluctuations
  - Statement might no longer apply => climate change… :/
- All unsealed micro-environments 'fail' => reach ambient RH (≥ ~40%)
  - Don't know when => 10+ years old
- Sealed microclimates are VERY difficult to survey
  - Not worth creating for every specimen => not all pyrite created equally





Here's what I've seen – Habit

40 habits & forms

- 9 most common (represented by 25+ specimens):
  - Cubic
  - Massive
  - Nodule
  - Octahedral
  - Pyritohedral
  - Aggregate
  - Cubic aggregate
  - Pyritohedral aggregate
  - Microcrystalline

<u>Across all habits</u>

- 1st order reaction type = surficial oxidation
- Two deterioration groups, generally correlates to habit
  - 1.) Tarnish only
  - 2.) Typical pyrite decay
- Supported by survey, color data, & geosciences literature

Corrosion	11%
Tarnish	86%
Efflorescence	23%
Powder	7%
Crumbling	21%
Flaking	5%
Breakages	9%
Cracks	56%
Dull	78%
Dark	57%
Pale	4%
Colour Change	33%
# of Specimens	1,274

Here's what I've seen – Habit

Single crystals generally more stable

- cubic, octahedral, pyritohedral
  - 2 intergrown seems ok
- Doesn't mean no change
  - Tarnish = common

Tarnish

- Dull & dark => grey
- Colour change => orange/red toned
  - Iridescent, red, orange, brown, yellow/brassy
  - Colour data confirms

Pyrite Habit	cubic	octahedral	pyritohedral
Corrosion	7%	5%	7%
Tarnish	88%	85%	92%
Efflorescence	20%	10%	20%
Powder	4%	0%	8%
Crumbling	13%	21%	23%
Flaking	4%	5%	8%
Breakages	6%	13%	10%
Cracks	49%	54%	55%
Dull	78%	67%	76%
Dark	55%	33%	53%
Pale	4%	3%	2%
Colour Change	37%	31%	37%
# of Specimens	340	39	264

Here's what I've seen – Habit

2 habits more prone pyrite decay

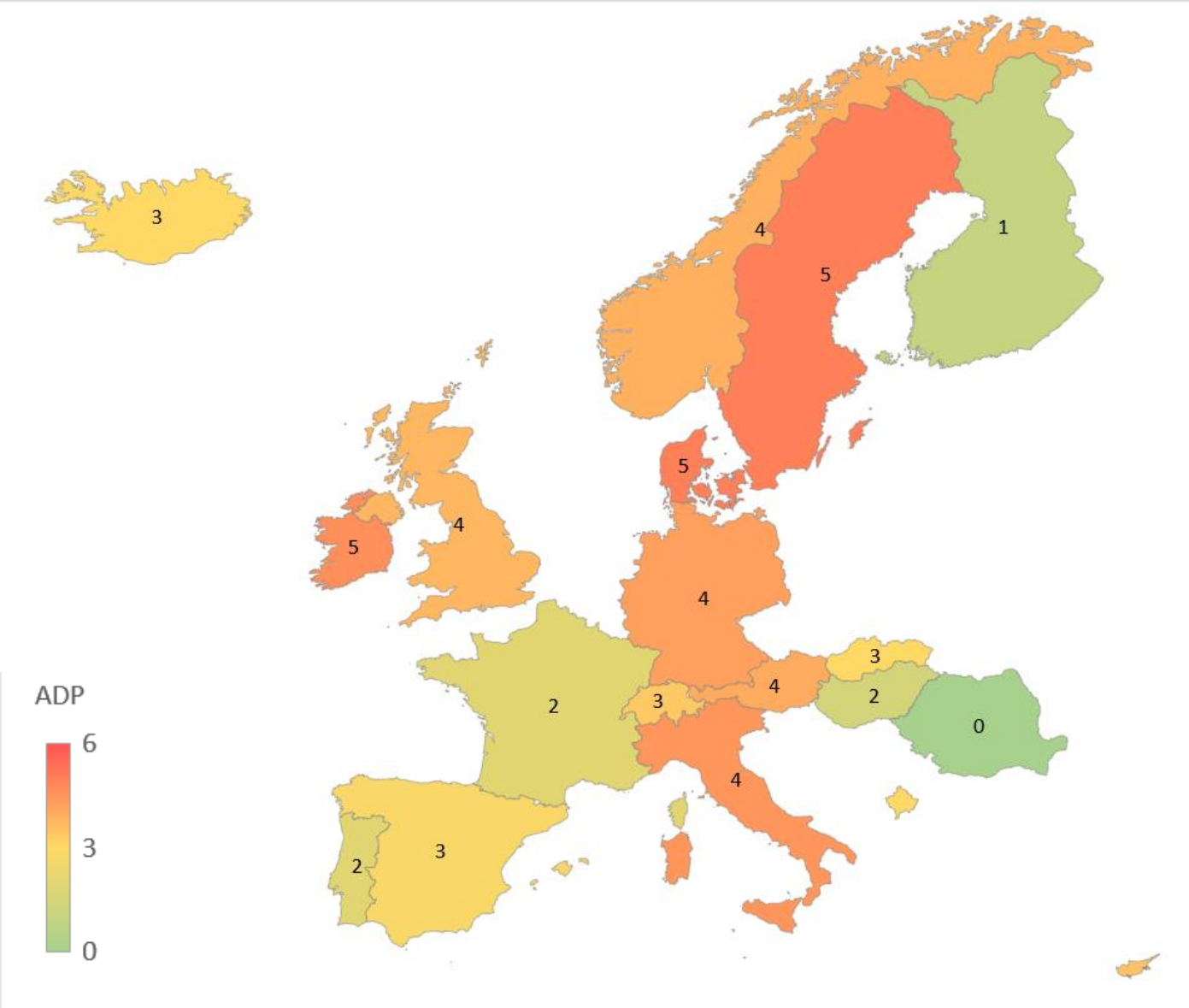
- Nodule = really unstable once open
  1. Tarnish
  2. Effloresce
  3. Structural Instability
  4. Repeat
- Aggregate = most prone to efflorescence & structural instability

Massive

- most prone to colour change
  - Iridescence, red, orange, brown, yellow/brassy, silvery/grey

Pyrite Habit	aggregate	massive	nodule
Corrosion	4%	4%	51%
Tarnish	84%	89%	87%
Efflorescence	36%	29%	33%
Powder	12%	9%	7%
Crumbling	40%	25%	17%
Flaking	0%	3%	6%
Breakages	8%	12%	9%
Cracks	60%	77%	51%
Dull	88%	83%	93%
Dark	60%	64%	86%
Pale	12%	4%	6%
Colour Change	20%	90%	48%
# of Specimens	25	112	87

Here's what I've seen – Locality



Better correlation w/ stability

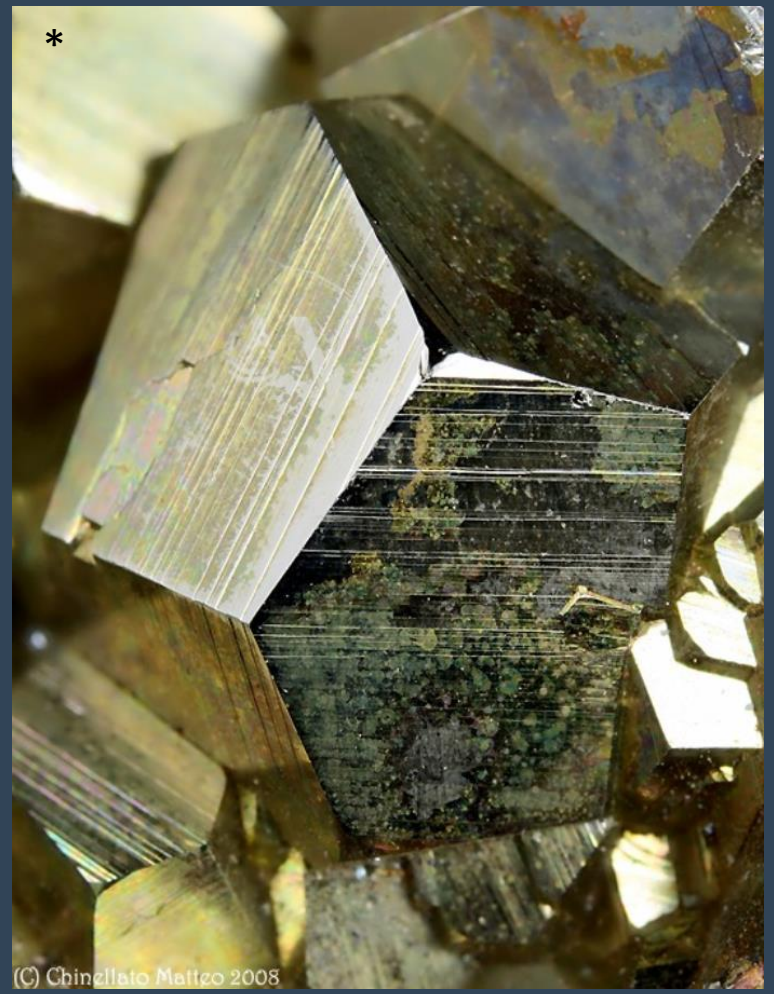
- Habits = common across localities & formation conditions
  - data averages out
- Clearer pattern emerges when examining locality-specific DP

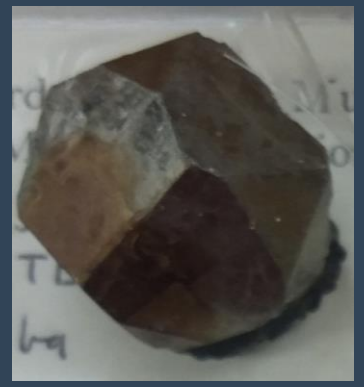
38 countries

- Top 6 (25+ spec.)
  - 15 regions (10+ spec.)
  - 12 mines (5+ spec.)

	Rio	Elba
# of Spec.	15	55
Corr.	0%	7%
Tarnish	100%	95%
Efflor.	33%	24%
Powder	7%	5%
Crumb.	33%	33%
Flaking	0%	16%
Break.	7%	16%
Cracks	60%	69%
Dull	40%	53%
Dark	7%	24%
Pale	0%	2%
Colour Change	47%	33%
ADP	3	4

*Photos from mindat.org
pyrite gallery





Museum	Age	Habit	Total DP	# of spec.
NMC	1983	pyritohedral	2	4
			6	3
			1	3
			3	1
			4	1
Sedgwick	1840-1900?	pyritohedral, aggregate	8	1
OUNHM	1890s?	octahedral	1	1
OUNHM	1905	pyritohedral, aggregate	5	1

Rio La Marina

Elba, Tuscany, Italy

# of Spec.	9
Corr.	0%
Tarnish	67%
Efflor.	11%
Powder	11%
Crumb.	22%
Flaking	0%
Break.	11%
Cracks	44%
Dull	67%
Dark	44%
Pale	0%
Colour Change	33%
ADP	3


*


*

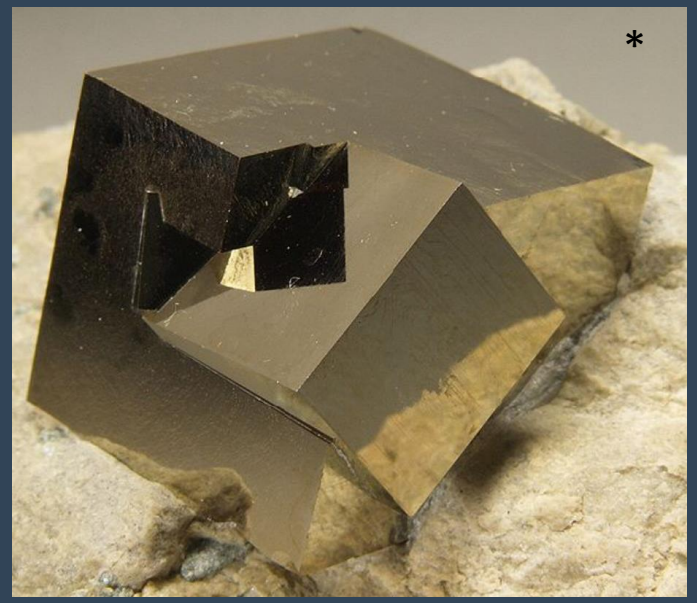
French Creek Mines

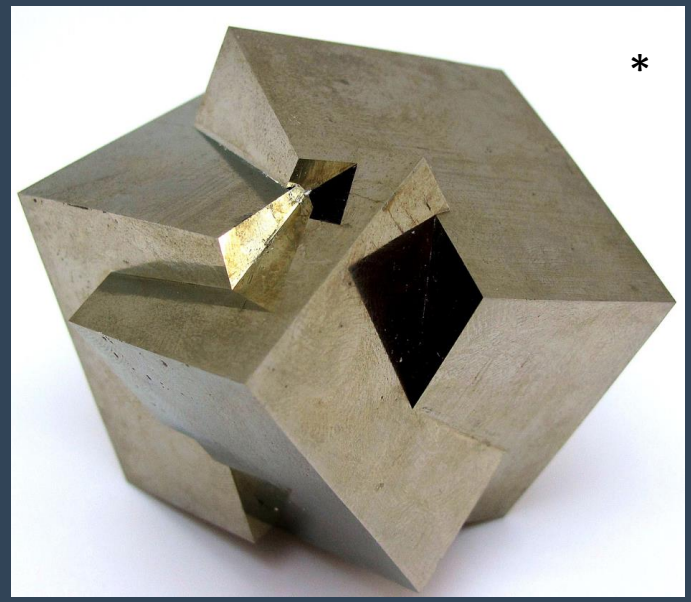
French Creek, PA, USA


*

Museum	Age	Habit	Total DP
Sedgwick	1899	cubic, aggregate	8
Sedgwick	1885?	pyritohedral	3
Sedgwick		cubic	6
OUNHM			3
OUNHM	1940s?	bladed	1
OUNHM	1899?	octahedral	2
OUNHM	1902		4
OUNHM	1903	octahedral	1
OUNHM	1906?	cubic	0

# of Spec.	10
Corr.	0%
Tarnish	0%
Efflor.	0%
Powder	0%
Crumb.	0%
Flaking	0%
Break.	0%
Cracks	20%
Dull	0%
Dark	0%
Pale	0%
Colour Change	0%
ADP	0





Navajún

La Rioja, Spain

Museum	Age	Habit	Total DP	# of spec.
OUNHM	1992	cubic	1	2
			0	8

**Photos from mindat.org – pyrite gallery*

Why this spread?

- Oxford only 1 w/out HVAC
  - % generally lower across all DP
  - Is no HVAC good?!
- A bit to do w/ collection history & storage conditions
- Mostly down to luck & time
  - Stable specimens survive
  - Long disposed of bad specimens

Museum	NMC	NML	OUNHM	Sedgwick	Total
Corrosion	2%	7%	14%	23%	11%
Tarnish	91%	92%	70%	94%	86%
Efflorescence	25%	38%	3%	37%	23%
Powder	3%	11%	0%	19%	7%
Crumbling	22%	16%	16%	29%	21%
Flaking	3%	4%	2%	11%	5%
Breakages	4%	4%	7%	22%	9%
Cracks	63%	59%	51%	50%	56%
Dull	80%	89%	53%	99%	78%
Dark	57%	75%	16%	98%	57%
Pale	7%	5%	0%	1%	4%
Colour Change	25%	44%	34%	40%	33%
# of specimens	482	135	359	298	1,274

What does this mean for collections care?

Display

- Navajún produces stable display-quality specimens

Conservation

- More focused efforts
  - Don't have to treat every specimen as prone to pyrite decay
  - Pre-emptively treat/store susceptible specimens

Accessioning/Acquisition

- Refusing to accession specimens from unstable localities
  - Use 'disposably': display, handling, teaching, etc.
- Focusing on collecting from under-represented countries/regions
  - S. America, Africa, Asia, S. Pacific
  - If willing to take risk of unknown stability

Main Take-Aways: Pyrite

- Data shows fractions, patterns, & likelihoods
- Still chance 'good' habits & localities could decay
  - May occur under different timescales or storage conditions

- Data does indicate stability linked to locality's formation conditions
  - Temperature, pressure, inclusions/impurities
  - Likely some instability inherent to habit => crystallography
  - Inclusions/impurities likely variable affecting stability
    - Explains why specimens of same habit react differently under same conditions

- Justifies scientific experiments to profile localities' formation conditions

Main Take-Aways: the DP Method

Produces wealth of information

- Customisable to collection being examined => not just minerals or pyrite
- Can be used in conjunction w/ analytical techniques
  - To confirm patterns seen & why they occur
  - e.g., colorimetry, spectroscopy, imaging
- Produces statistical estimates of likelihood for types of change
  - Used to infer reaction pathways => strengthened w/ contextual info

Most powerful when data from multiple collections

- Simply down to statistics
- Hopefully inspires collaboration & communication
- Potential use with other species/objects w/ unknown reaction pathways

Thank you for listening!

This survey is an output of a collaborative doctoral research project, supported by collaborators from the following institutions:

- University of Oxford, School of Geography & the Environment – Prof. Heather Viles
- National Museum Cardiff – Dr. Jana Horak, Tom Cotterell
- National Museums Liverpool – Dr. Christian Baars
- BSRIA Ltd. – Tom Gagarin
- OR3D – James Earl

The PhD project is part of the Science and Engineering in Arts, Heritage, and Archaeology Centre for Doctoral Training (SEAHA CDT).

Funding has been provided by:

- The Engineering and Physical Sciences Research Council (EPSRC)
- The Barbara Whatmore Trust
- The Pilgrim Trust
- The National Conservation Service

Questions?

kathryn.royce@ouce.ox.ac.uk

http://mineralcare.web.ox.ac.uk

Extra Slides

Dimpled

Rounded

Corrosion

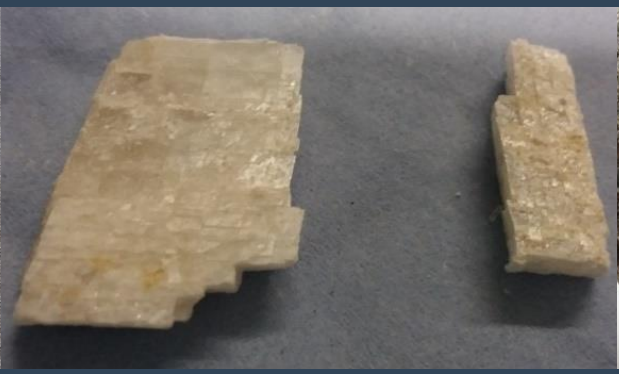
Tarnish

Efflorescence

Powder

Crumbling

Flaking



Breakages

Cracks

Dull

Dark

Pale

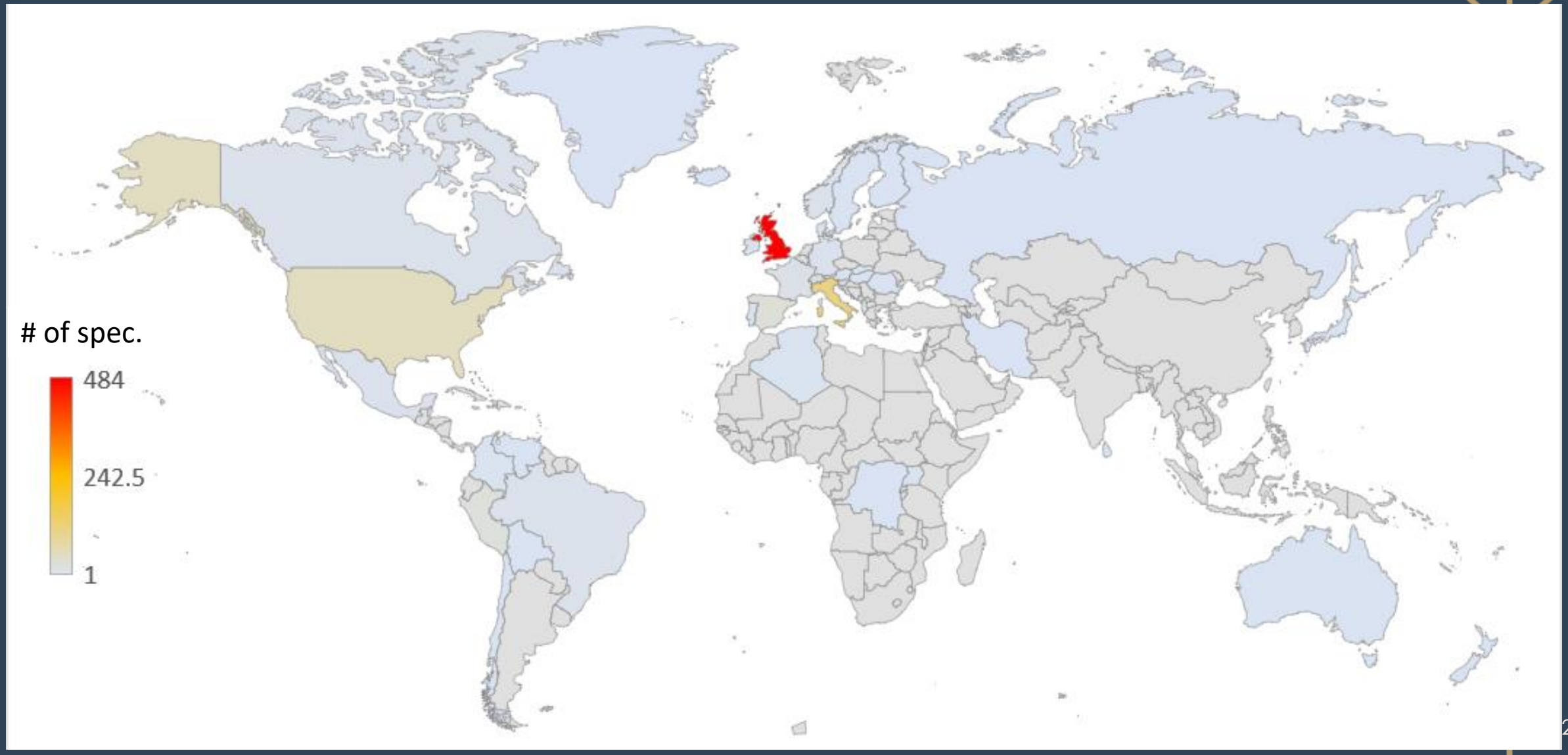
Opacity

Colour Change

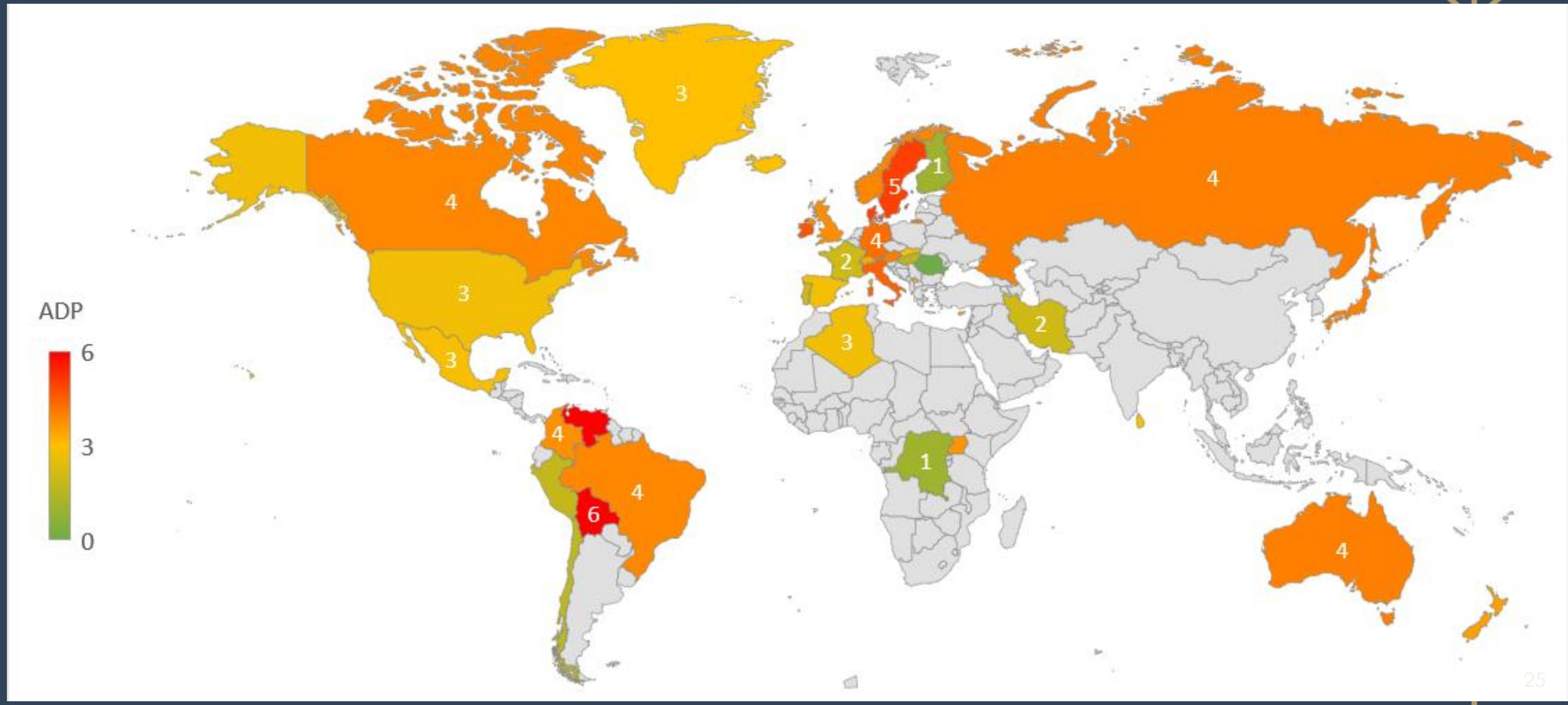
Pyrite Habit	aggregate	cubic	cubic, aggregate	massive	micro	nodule	octahedral	pyritohedral	pyritohedral, aggregate
Corrosion	4%	7%	11%	4%	4%	51%	5%	7%	2%
Tarnish	84%	88%	82%	89%	75%	87%	85%	92%	88%
Efflorescence	36%	20%	30%	29%	25%	33%	10%	20%	20%
Powder	12%	4%	10%	9%	6%	7%	0%	8%	12%
Crumbling	40%	13%	21%	25%	27%	17%	21%	23%	32%
Flaking	0%	4%	2%	3%	0%	6%	5%	8%	0%
Breakages	8%	6%	5%	12%	7%	9%	13%	10%	20%
Cracks	60%	49%	52%	77%	61%	51%	54%	55%	63%
Dull	88%	78%	79%	83%	72%	93%	67%	76%	61%
Dark	60%	55%	59%	64%	55%	86%	33%	53%	44%
Pale	12%	4%	3%	4%	4%	6%	3%	2%	0%
Colour Change	20%	37%	43%	90%	12%	48%	31%	37%	24%
# of Specimens	25	340	61	112	67	87	39	264	41

**most common = represented by 25+ specimens*

Locality: Global

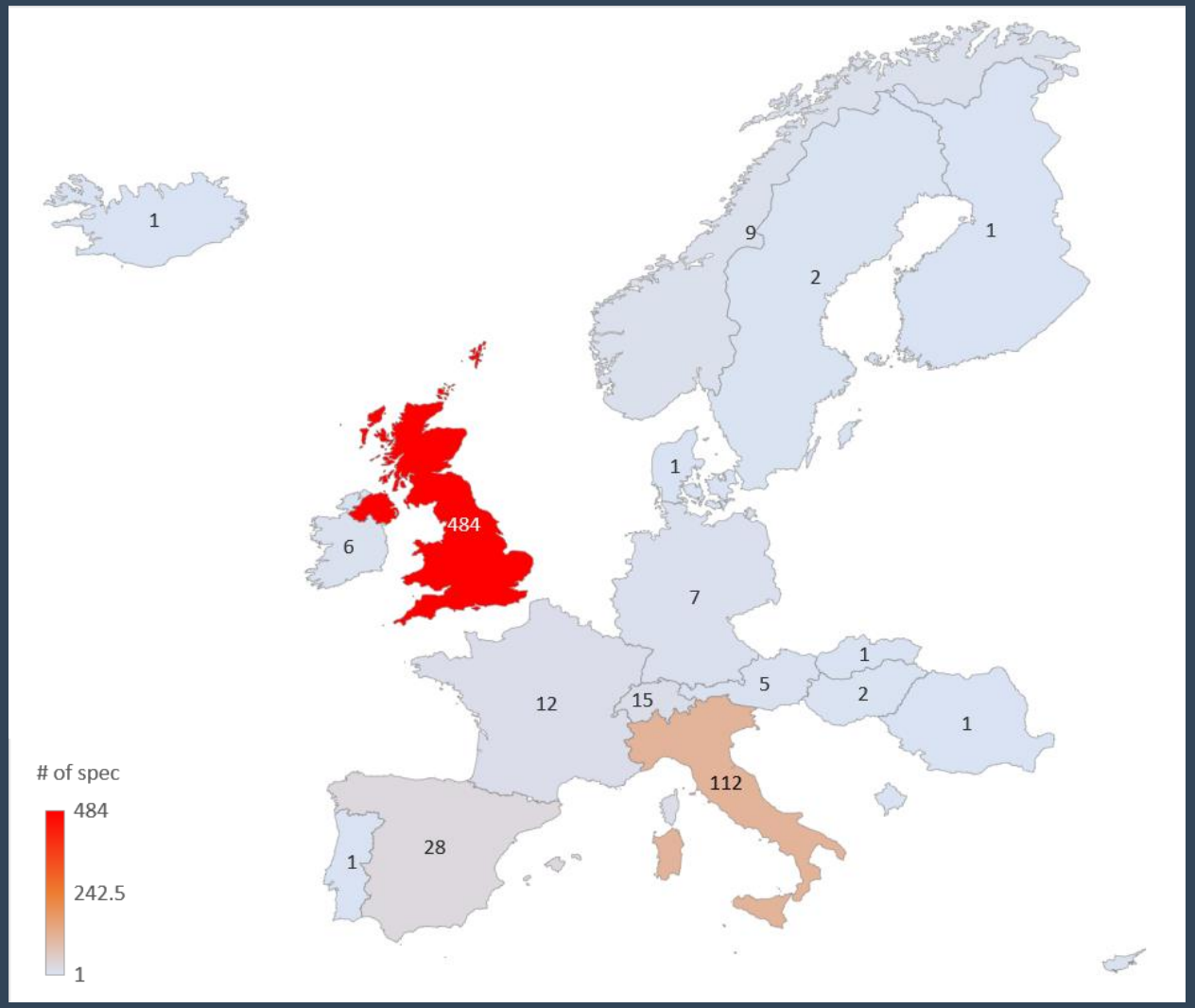


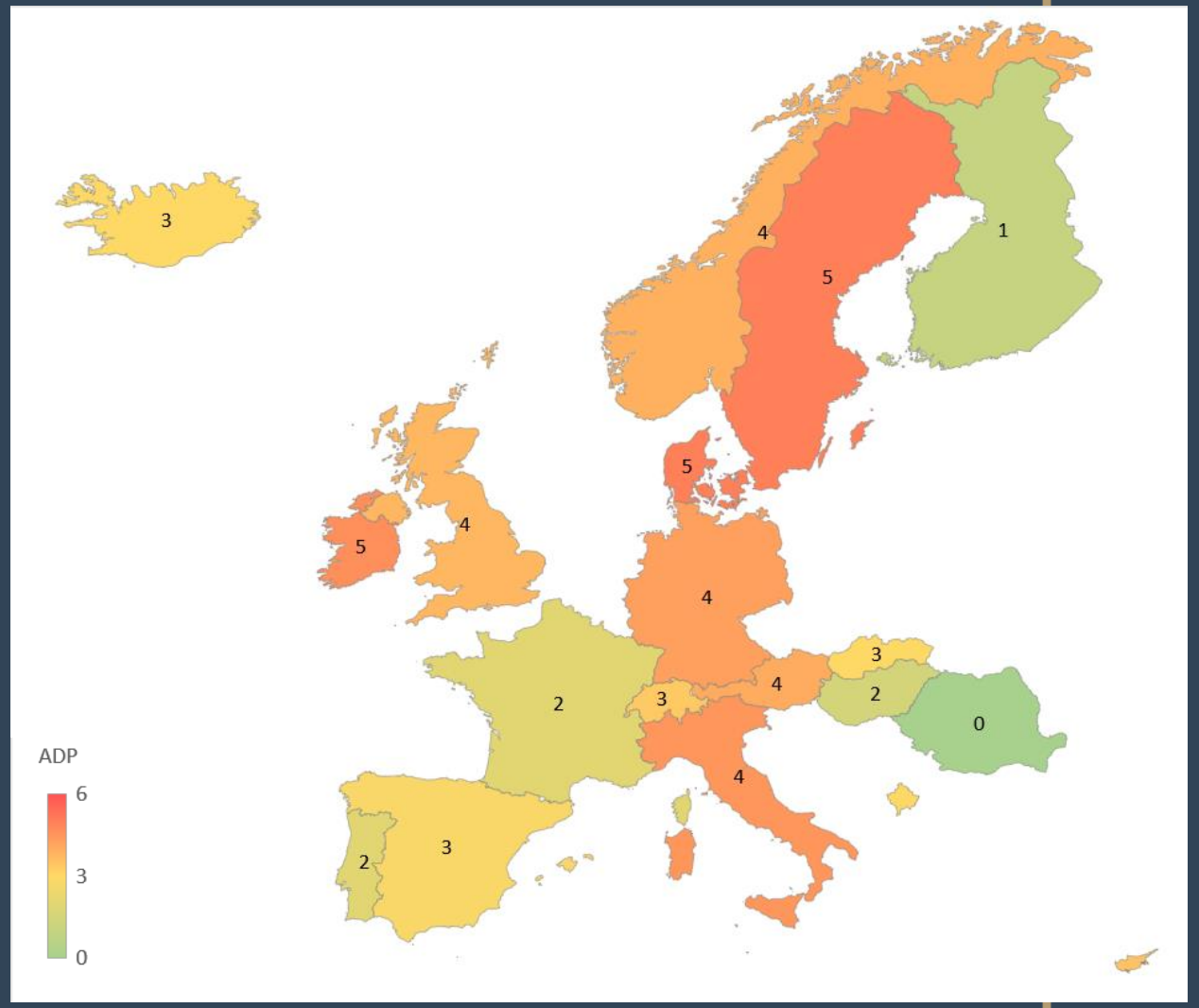
Locality: Global



Locality: Europe

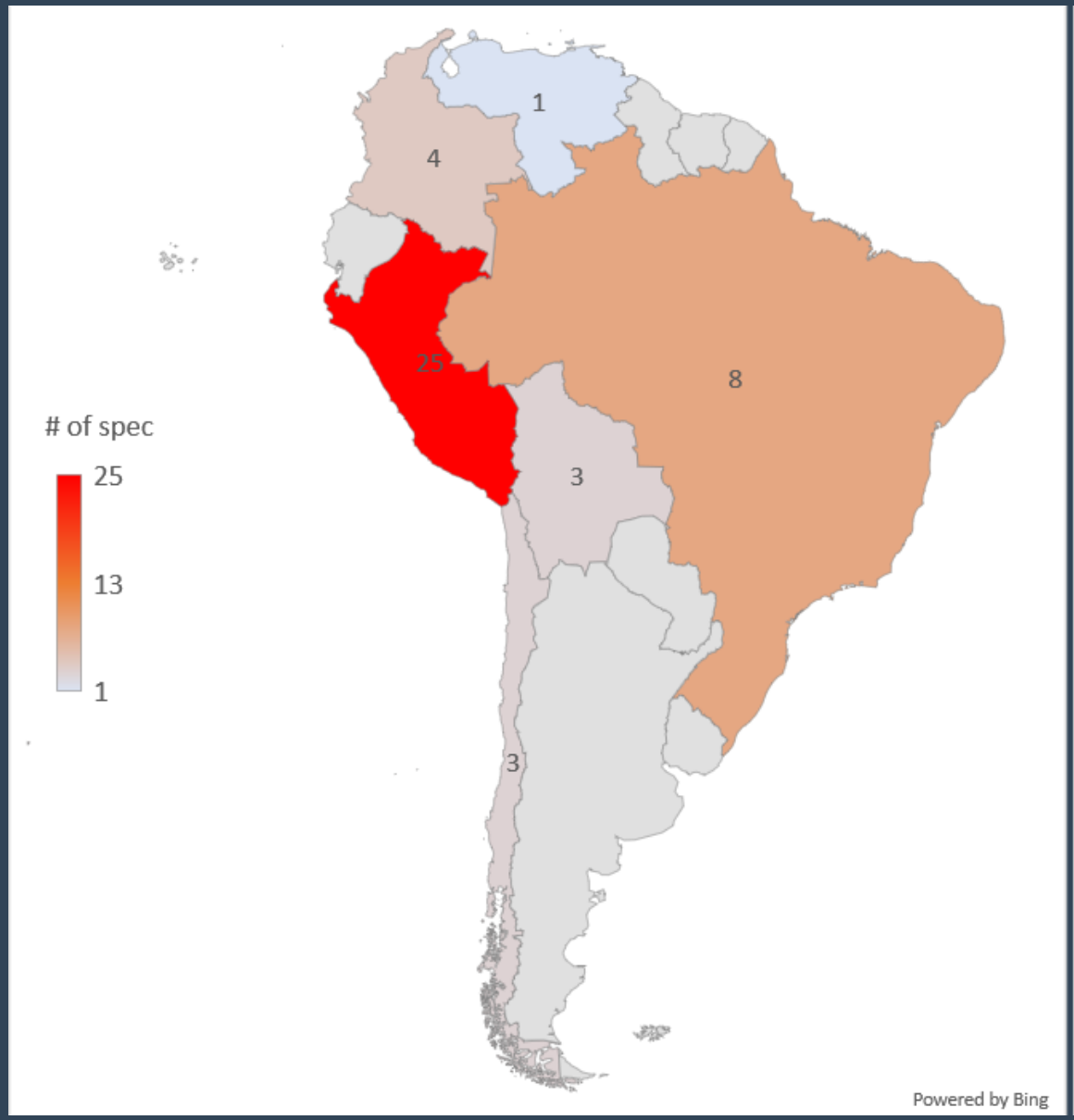
22 countries; 709 specimens

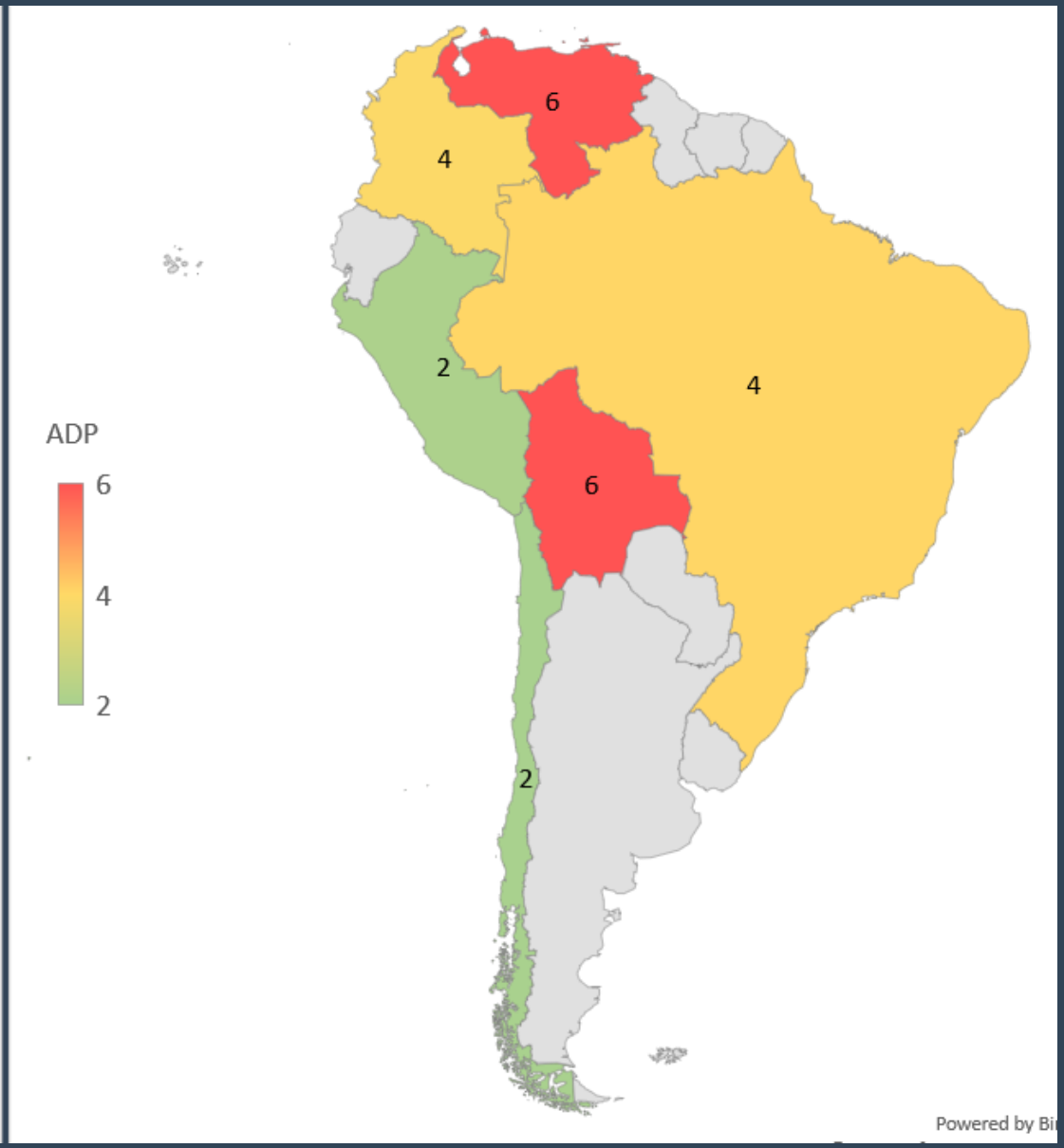




Locality: South America

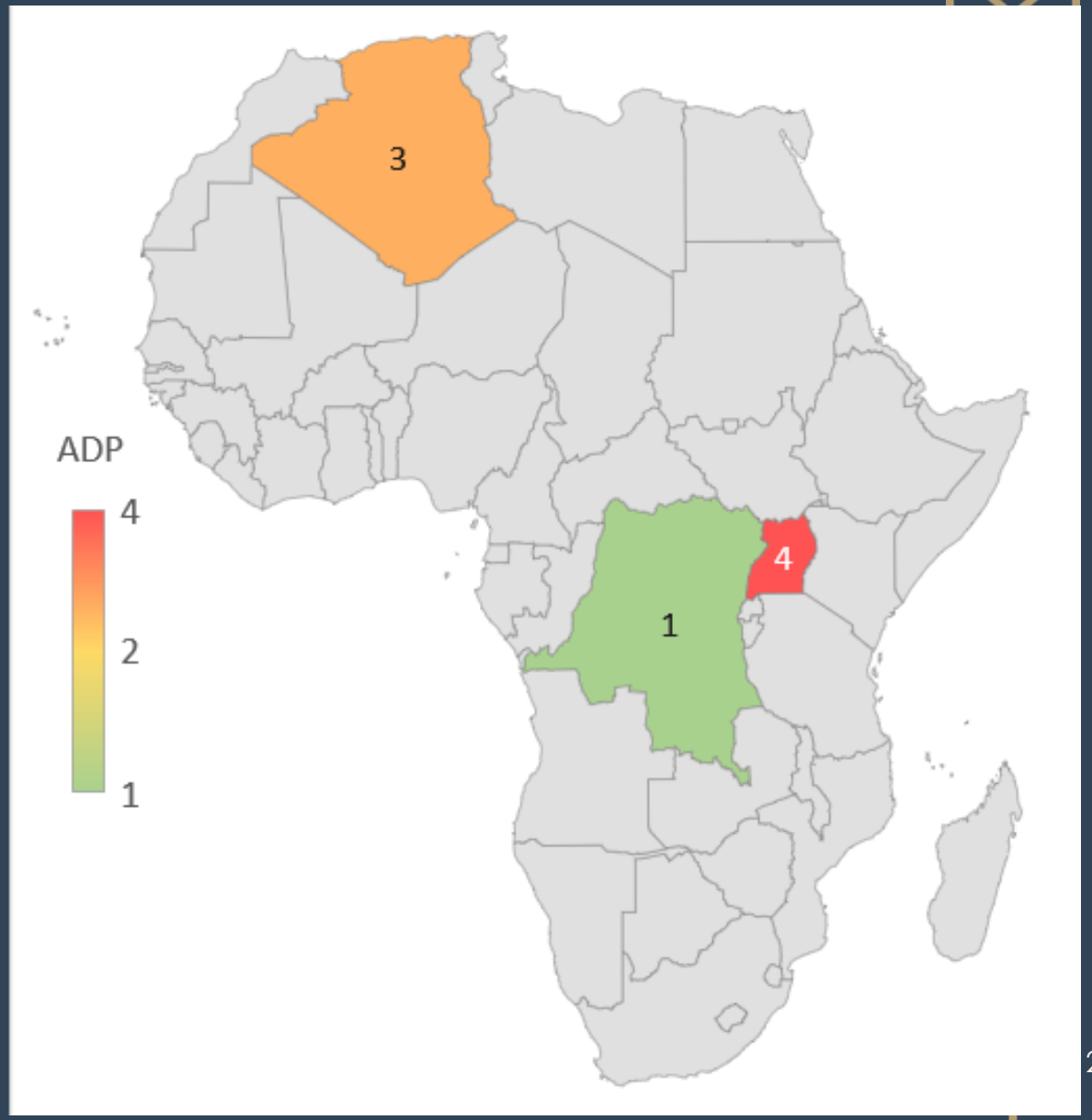
6 countries; 44 specimens





Locality: Africa

3 countries; 8 specimens



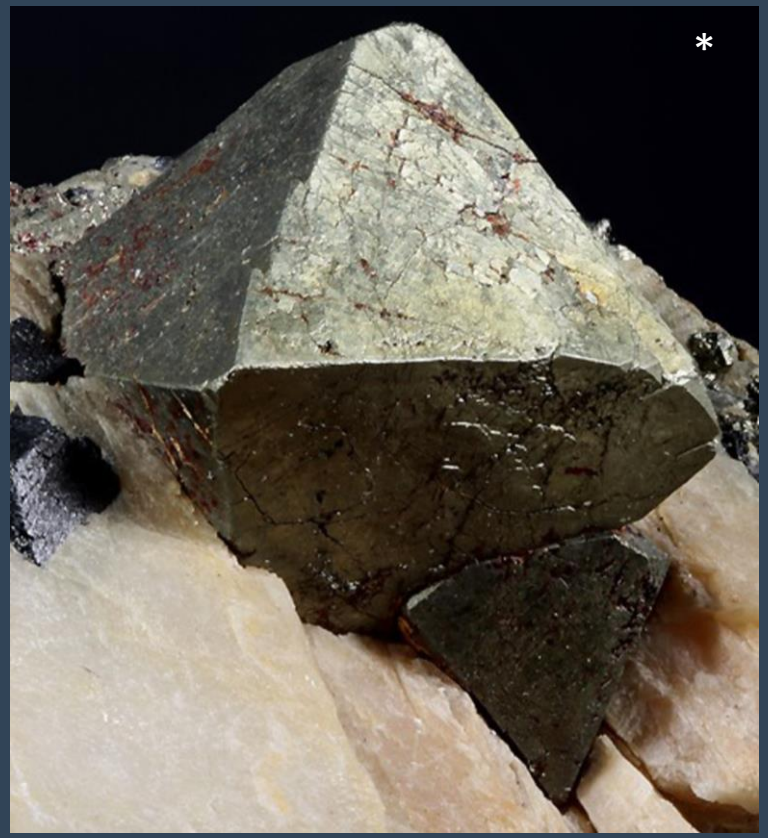
Top 6 Localities

Locality		# of spec.	1st Order	2nd Order
England	*Cornwall*	96	Surficial Oxidation	Physical Forces
	Cumbria	33	Surficial Oxidation	Physical Forces
	Devon	29	Surficial Oxidation	Oxidation At Depth
	Kent	13	Surficial Oxidation	Oxidation At Depth
Italy	*Piedmont*	49	Surficial Oxidation	Oxidation At Depth
	Tuscany	57	Surficial Oxidation	Physical Forces
Peru	*La Libertad Department*	8	Surficial Oxidation	
Spain	*Andalusia*	7	Physical Forces	
	La Rioja	11		Physical Forces
USA	*Colorado*	18	Surficial Oxidation	Physical Forces
	New York	7	Surficial Oxidation	
	Pennsylvania	12	Surficial Oxidation	Physical Forces
Wales	*Carmarthenshire*	26	Surficial Oxidation	Oxidation At Depth
	Ceredigion	15	Surficial Oxidation	Physical Forces
	Denbighshire	13	Surficial Oxidation	Oxidation At Depth
	Gwynedd	102	Surficial Oxidation	Physical Forces
	Powys	12	Physical Forces	Surficial Oxidation
	Vale of Glamorgan	18	Surficial Oxidation	Physical Forces

- Country: represented by 25+ specimens
- Region: represented by
  - 10+ (UK) specimens
  - 5+ (non-UK) specimens

	Locality	# of spec.	Corrosion	Tarnish	Efflor.	Powder	Crumb.	Flaking	Break	Cracks	Dull	Dark	Pale	Colour Change
England	*Cornwall*	96	13%	85%	19%	2%	25%	3%	15%	59%	81%	57%	3%	22%
	Cumbria	33	9%	88%	24%	6%	12%	6%	6%	52%	85%	70%	0%	27%
	Devon	29	3%	100%	28%	3%	34%	7%	14%	76%	97%	79%	0%	34%
	Kent	13	77%	100%	38%	15%	31%	8%	23%	69%	100%	92%	0%	69%
Italy	*Piedmont*	49	6%	94%	39%	29%	45%	10%	29%	76%	82%	76%	0%	57%
	Tuscany	57	7%	95%	23%	5%	32%	16%	16%	68%	54%	26%	2%	32%
Peru	*La Libertad Department*	8	0%	75%	0%	0%	0%	0%	0%	50%	50%	25%	13%	38%
Spain	*Andalusia*	7	29%	57%	29%	0%	57%	0%	0%	86%	71%	29%	0%	43%
	La Rioja	11	0%	9%	0%	0%	0%	0%	0%	27%	0%	0%	0%	9%
USA	*Colorado*	18	0%	89%	6%	0%	11%	0%	6%	28%	33%	17%	6%	22%
	New York	7	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
	Pennsylvania	12	0%	75%	17%	8%	17%	0%	8%	42%	75%	58%	0%	42%
Wales	*Carmarthenshire*	26	4%	81%	27%	0%	19%	4%	4%	42%	81%	73%	4%	46%
	Ceredigion	15	0%	100%	20%	0%	27%	0%	7%	73%	87%	73%	7%	7%
	Denbighshire	13	0%	85%	46%	0%	0%	15%	0%	38%	85%	46%	23%	23%
	Gwynedd	102	1%	83%	25%	1%	29%	2%	3%	69%	67%	48%	5%	21%
	Powys	12	0%	75%	25%	42%	25%	0%	0%	92%	67%	50%	8%	17%
	Vale of Glamorgan	18	6%	100%	33%	6%	33%	6%	11%	94%	100%	89%	22%	17%

	Mine	Trav.
# of Spec.	10	26
Corr.	0%	8%
Tarnish	100%	92%
Efflor.	30%	23%
Powder	20%	12%
Crumb.	50%	38%
Flaking	10%	4%
Break.	10%	15%
Cracks	70%	69%
Dull	100%	65%
Dark	100%	54%
Pale	0%	0%
Colour Change	90%	77%
ADP	6	5


*

Points of note re. photos
- Cracks
- Orange tarnish

Sedgwick	Age: 1920-21	
Habit	**Total DP**	**# of spec.**
pyritohedral	6	3
	5	2
	4	2
	9	1
cubic, pyritohedral	5	1
octahedral, pyritohedral	8	1

*


*


*

Traversella Magnetite Mine

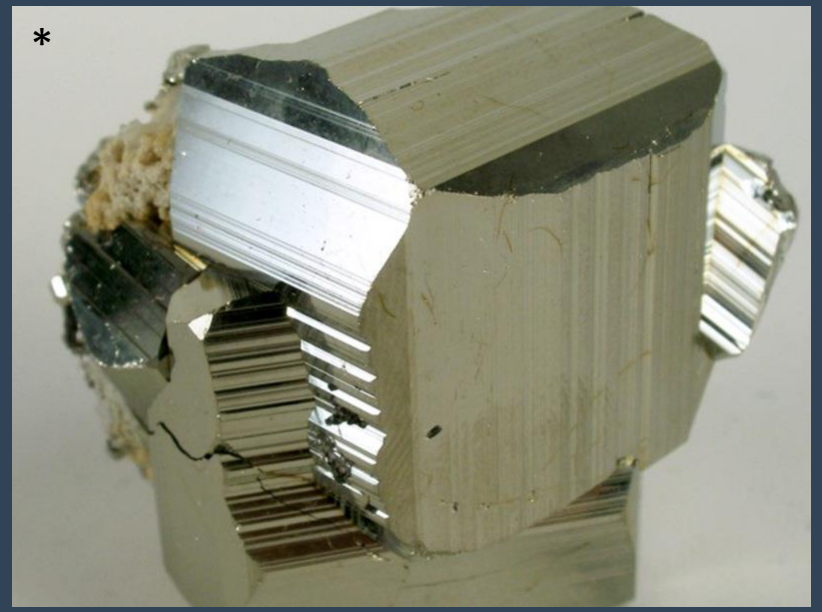
Traversella, Piedmont, Italy

*Photos from mindat.org – pyrite gallery

# of Spec.	8
Corr.	0%
Tarnish	75%
Efflor.	0%
Powder	0%
Crumb.	0%
Flaking	0%
Break.	0%
Cracks	50%
Dull	50%
Dark	25%
Pale	13%
Colour Change	38%
ADP	3

*Photos from mindat.org pyrite gallery


*


*

Museum	Age	Habit	Total DP
OUNHM	1985?	pyritohedral, aggregate	2
NMC	1986	cubic	1
NMC	1983	pyritohedral	3
NMC	1983	pyritohedral	4
OUNHM	1977?	pyritohedral, aggregate	0
NMC	1978	pyritohedral	5
NMC	1978	pyritohedral	3
OUNHM	1988?	pyritohedral, aggregate	2


*

Points of note re. photos
- Appears generally fine
- Tarnish develops along cracks & with fingerprints

Quiruvilca Mine
Quiruvilca, La *Libertad, Peru*