

SILVER BULLETS, FAKE NEWS AND MYTH: NEW TECHNOLOGY IN MINING – SAVIOUR OR DISTRACTION?

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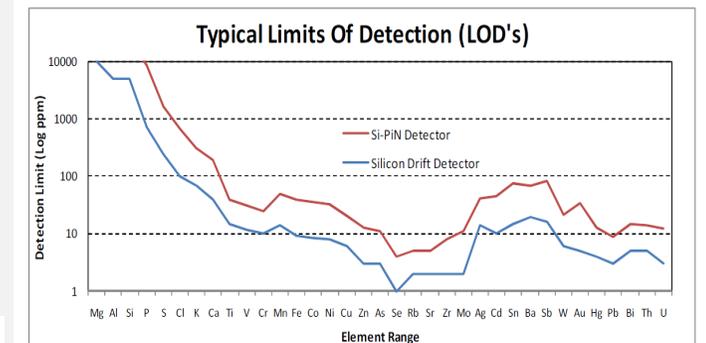
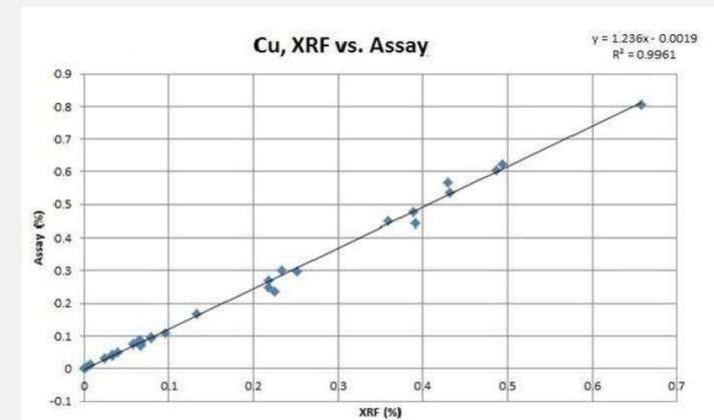
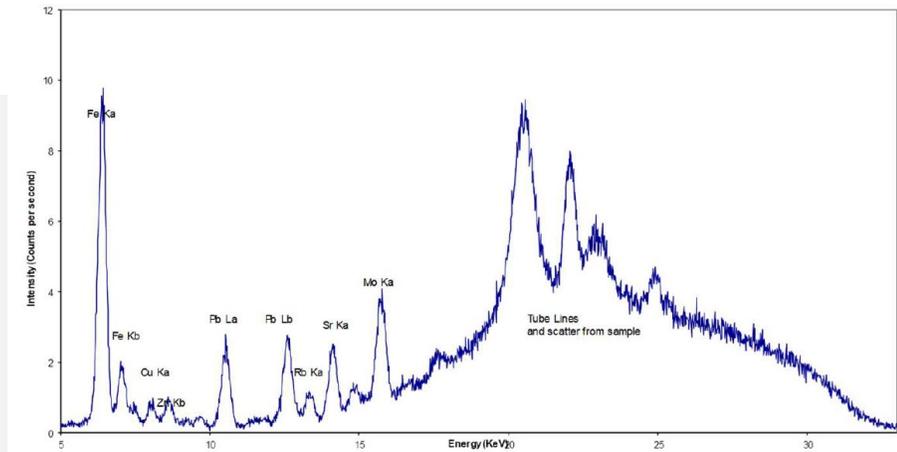




SILVER BULLETS

- XRF – A powerful tool for measuring elemental abundances
- Success depends on:
 - Understanding limitations (e.g. Au, REEs etc.)
 - Systematic use across users and units
 - Lab based? pXRF? Modes, times, etc.
 - Development of site-specific calibrations
 - Know your sample matrix
 - Development of consistent sample-prep workflows
 - Ideal samples are dried, ground, homogeneous and compacted

We're not picking on XRF, but rather highlighting that a single technique, system or software can't do everything; all tools have limitations



SILVER BULLETS

- Qemscan

Hendrickson et al., 2015

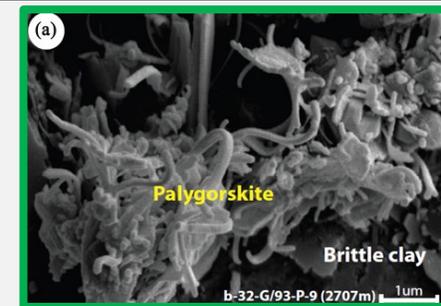
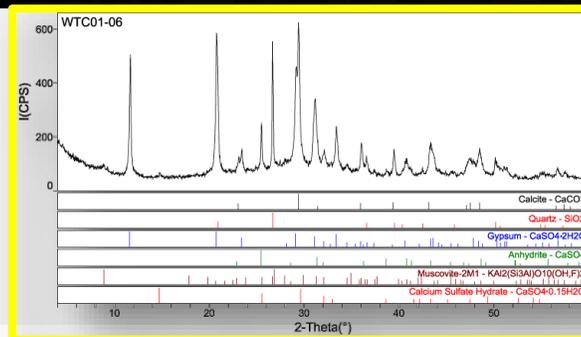
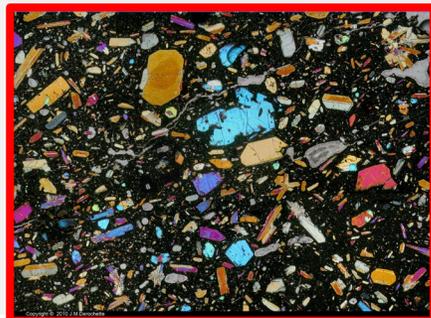
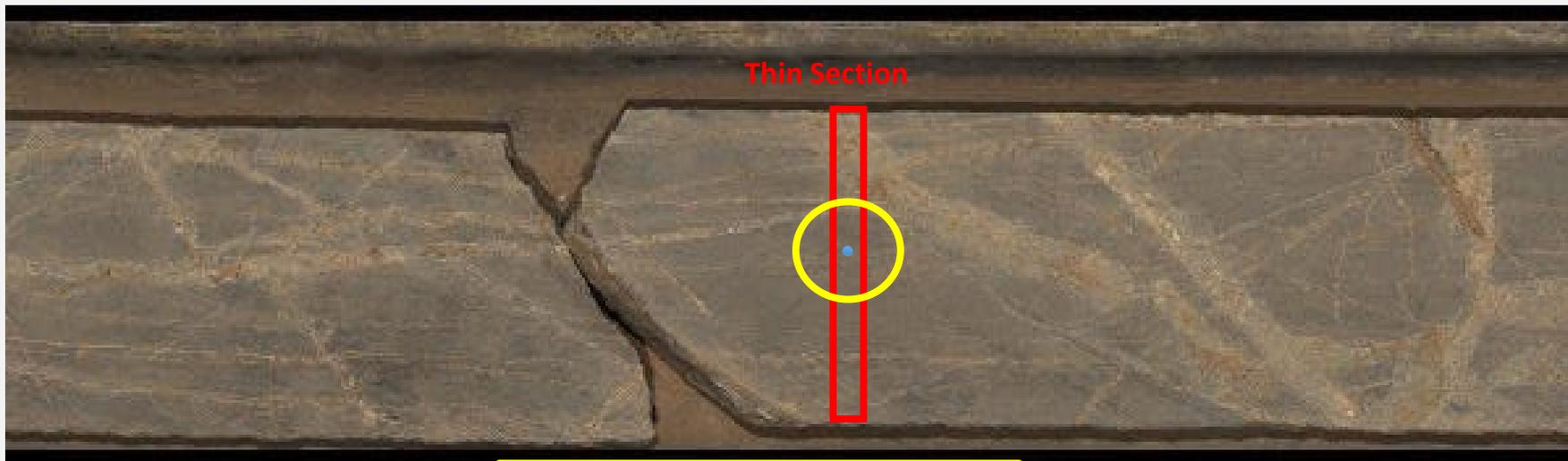


 Quartz	 Albite	 Ankerite	 Other Minerals
 Muscovite	 Potassium Feldspar	 Dolomite	 Void
 Chlorite	 Apatite	 Calcite	
 Biotite	 Rutile	 Chalcopyrite	

- Precise but limited interval, fine-scale mineralogy derived for geometallurgical modeling and process optimization
- While considered to be ultimate ‘truth’ by many workers, it is still a mineralogy model (not direct detection and ID), dependent on SIP libraries and expert analysis; all models depend on software and experts (which are fallible)

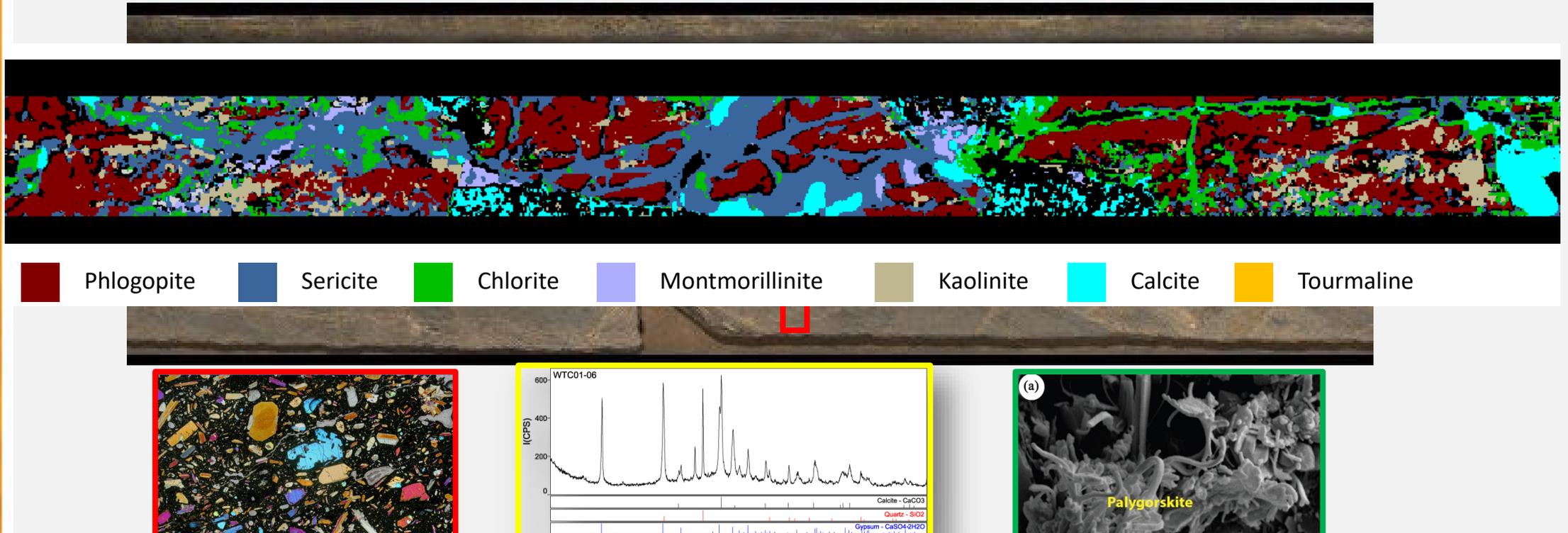
SILVER BULLETS

- Many mineralogical identification methods are performed on small (~1-2 cm) spatial intervals which may or may not be consistently retrieved throughout one (or many) boreholes



SILVER BULLETS

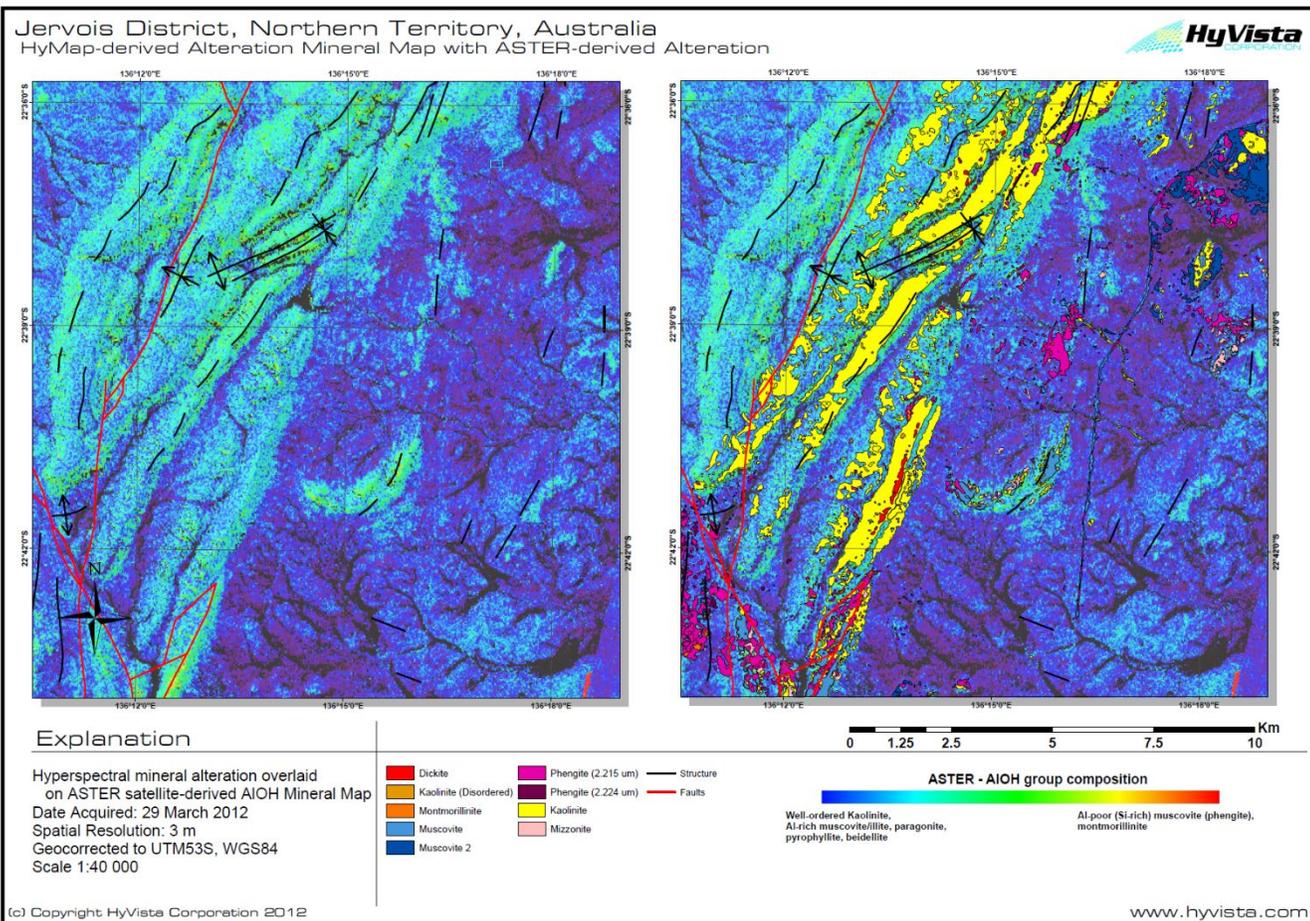
- Continuous mineralogy, from hyperspectral core imaging, provides a highly sampled accounting of rock mineralogy – BUT, it's not Whole Rock
- Furthermore, while ~200,000 datapoints per meter, HCl is still at ~500 micron spatial resolution; coarser than some fine-scale micro-analytical techniques (e.g. Qemscan)



Combining micro-techniques (with limited sample intervals) with continuous mineralogy is a better workflow (as hyperspectral core imaging is not a silverbullet either)

#FAKENEWS

- Satellite-based, thematic mapping that detects and identifies #AllTheMinerals...without ground-truth or absolute spectral sources



Training ASTER analysis with airborne spectroscopy

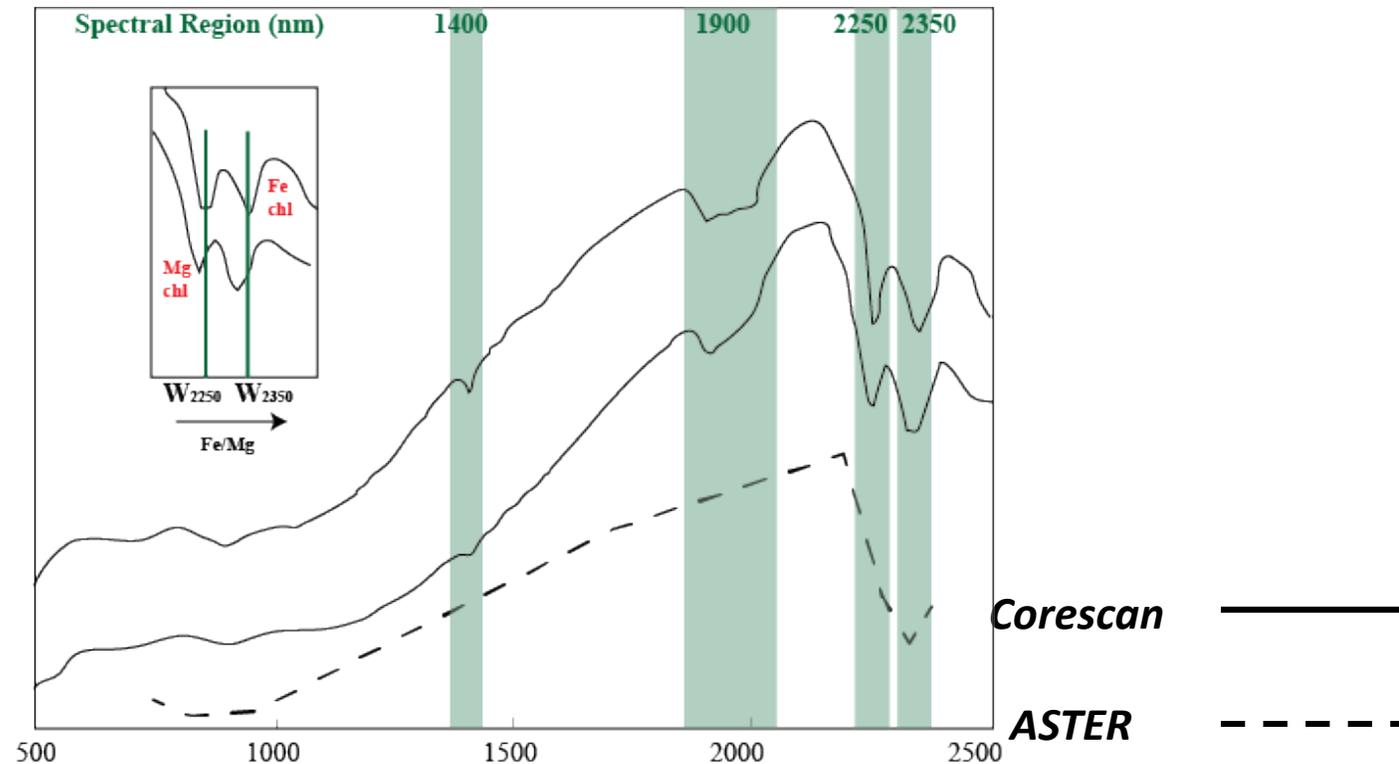
While ASTER can detect Al-OH content a priori – it cannot discriminate sub-species (e.g. kaolinite) without field or airborne data such as the HyMap analysis shown at right

#FAKENEWS

- Satellite and airborne systems; there is no free lunch and price is only one factor to consider
- If you want very high resolution pixels, you are giving up spectral resolution and area of coverage; if you want wider area coverage, you are gaining spectral resolution and signal-to-noise, but losing the spatial resolution

- What are you trying to do? Wide-area exploration? Fine-scale analysis of leach pads?

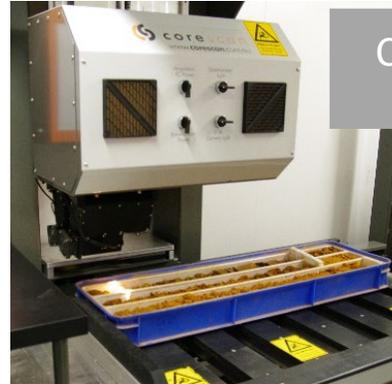
- What to ask?
 - Spectral Resolution
 - Spatial Resolution
 - Swath Width
 - SNR
 - Calibration



THE SPECTRAL ECOSYSTEM



Line Profiler:
HyLogger



Core Imaging:
Corescan



Outcrop/Face
Imagers: HySpex



Point System:
HALO

All of these systems aim to do one thing: measure spectral signatures from Earth materials



Satellite Imaging:
ASTER



Drone-based
Imaging



Airborne Imaging:
HyMap

Spectral techniques should be used in conjunction with one another – rather than used in isolation (not unlike the use of multiple geochemical techniques)



MYTH

- A tale of two extremes
- Humans can see and do everything you might want to see and do
- Artificial Intelligence (AI) will save the world

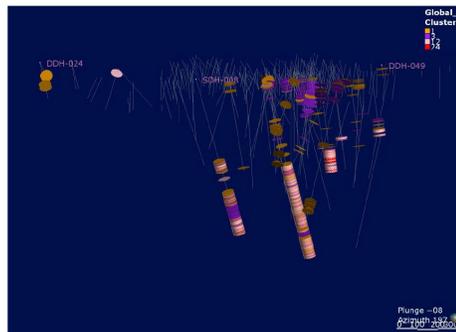


- In reality, a machine is only as smart as what you put into it, and those who program it

MYTH

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Gypsum

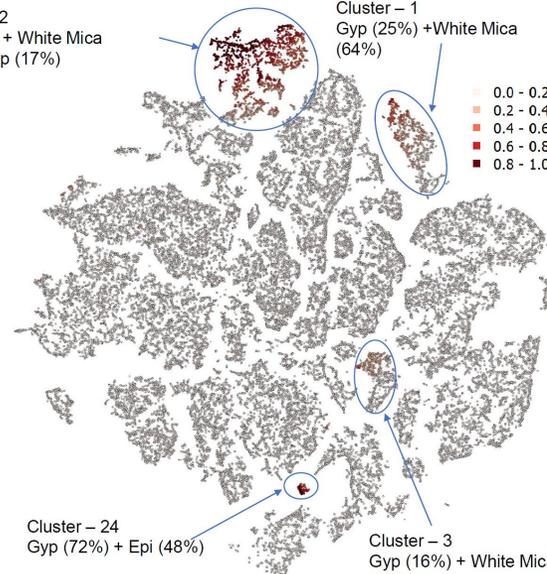


Cluster Number	aspectral_pxa	epidote_pxa	gypsum_pxa	white_mica_pxa
1	0.23	0.00	0.26	0.64
3	0.04	0.00	0.16	0.91
12	0.17	0.01	0.60	0.26
24	0.03	0.48	0.72	0.03

Cluster Legend showing average abundance (between 0-1)

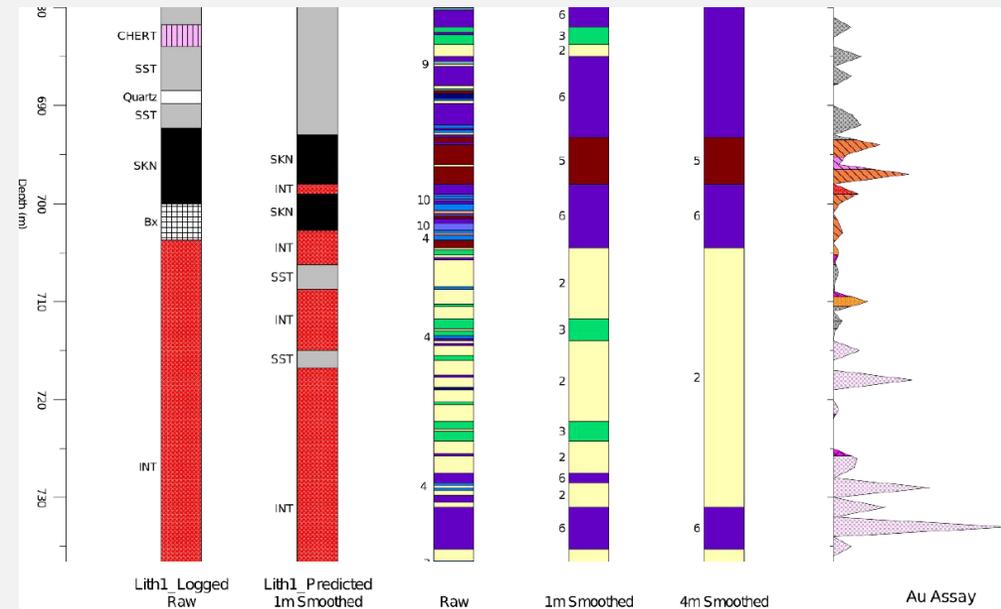
Cluster - 12
Gyp (60%) + White Mica
(26%) + Asp (17%)

Cluster - 1
Gyp (25%) + White Mica
(64%)



Cluster - 24
Gyp (72%) + Epi (48%)

Cluster - 3
Gyp (16%) + White Mica
(90%)

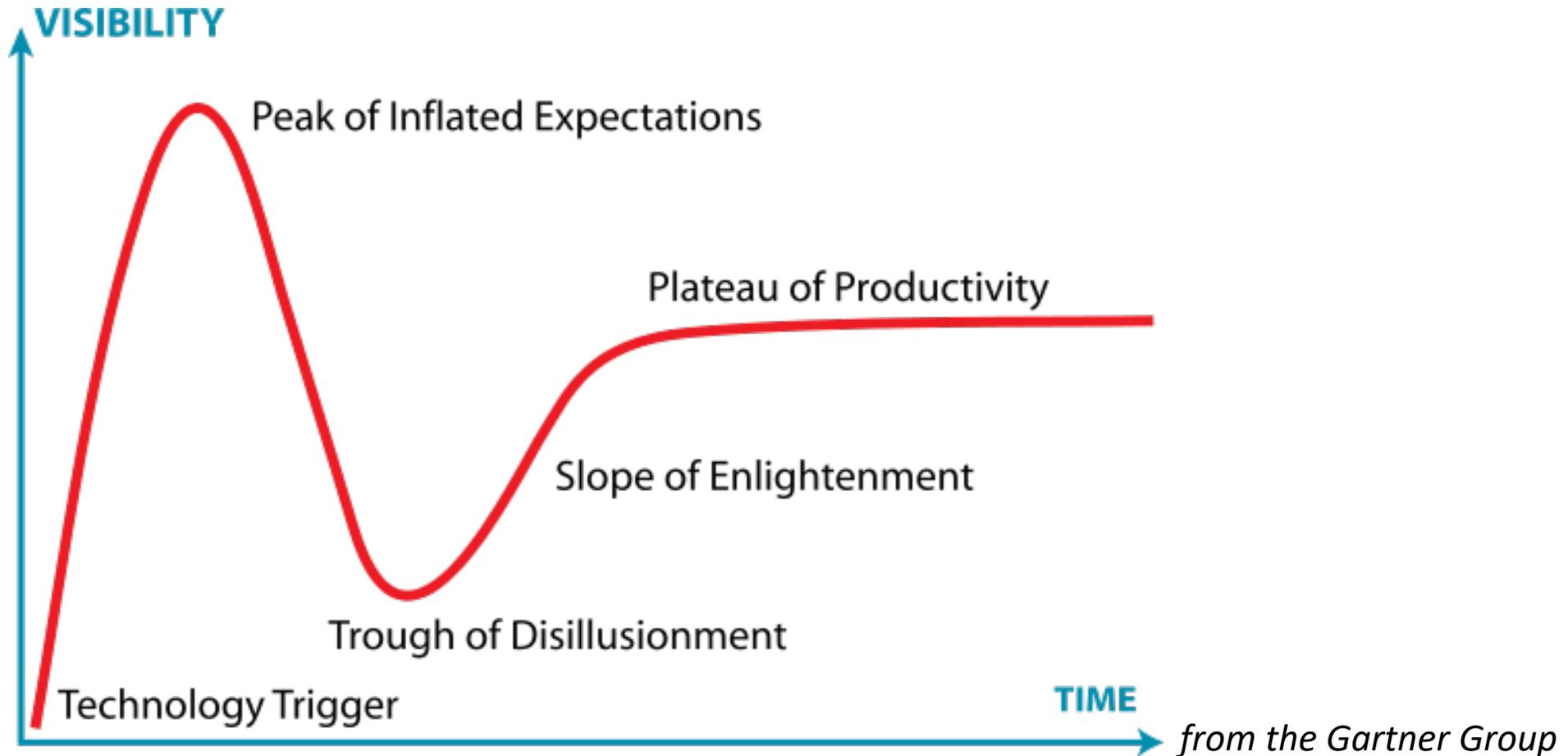


- In reality, a machine is only as smart as what you put into it, and those who program it...and **what** you do with it

NEW TECHNOLOGY – SAVIOUR OR DISTRACTION?

- Of course the answer is ***both***
- The increasing cost of mining (real capex, societal) coupled with shrinking supply and increasing exploration and development difficulties (i.e. deeper deposits, trickier recovery, etc.) means economics can be razor-thin
- New technology can mean the difference between an economic deposit and not; but how to walk the line between cost (including hardware, software and people) and time (both for inception and in-total) for implementation?
- **We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run (“Amara’s Law”)**

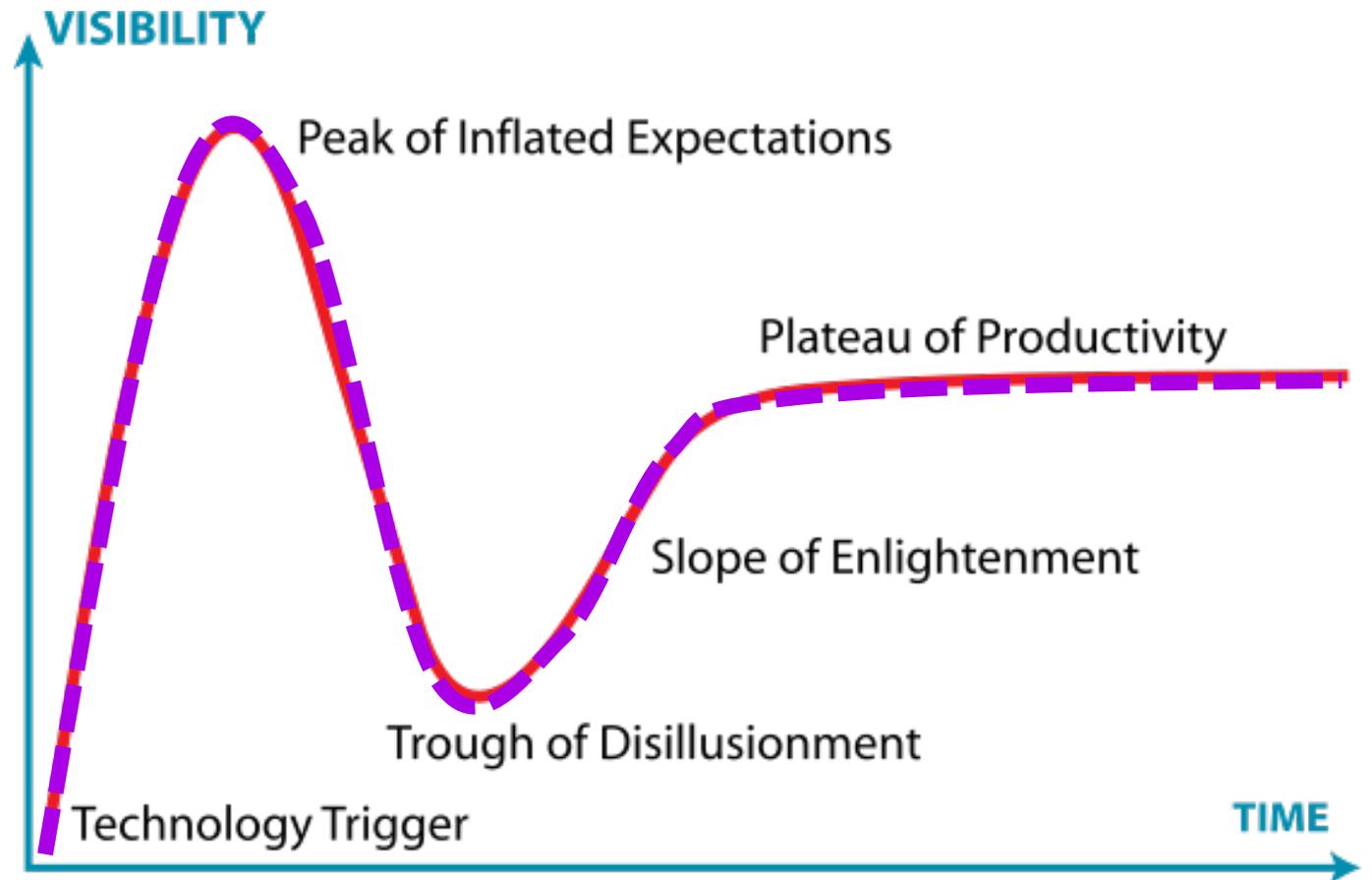
NEW TECHNOLOGY – THE ‘HYPE’ CYCLE



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NEW TECHNOLOGY- SPEED OF TRIAL AND ADOPTION

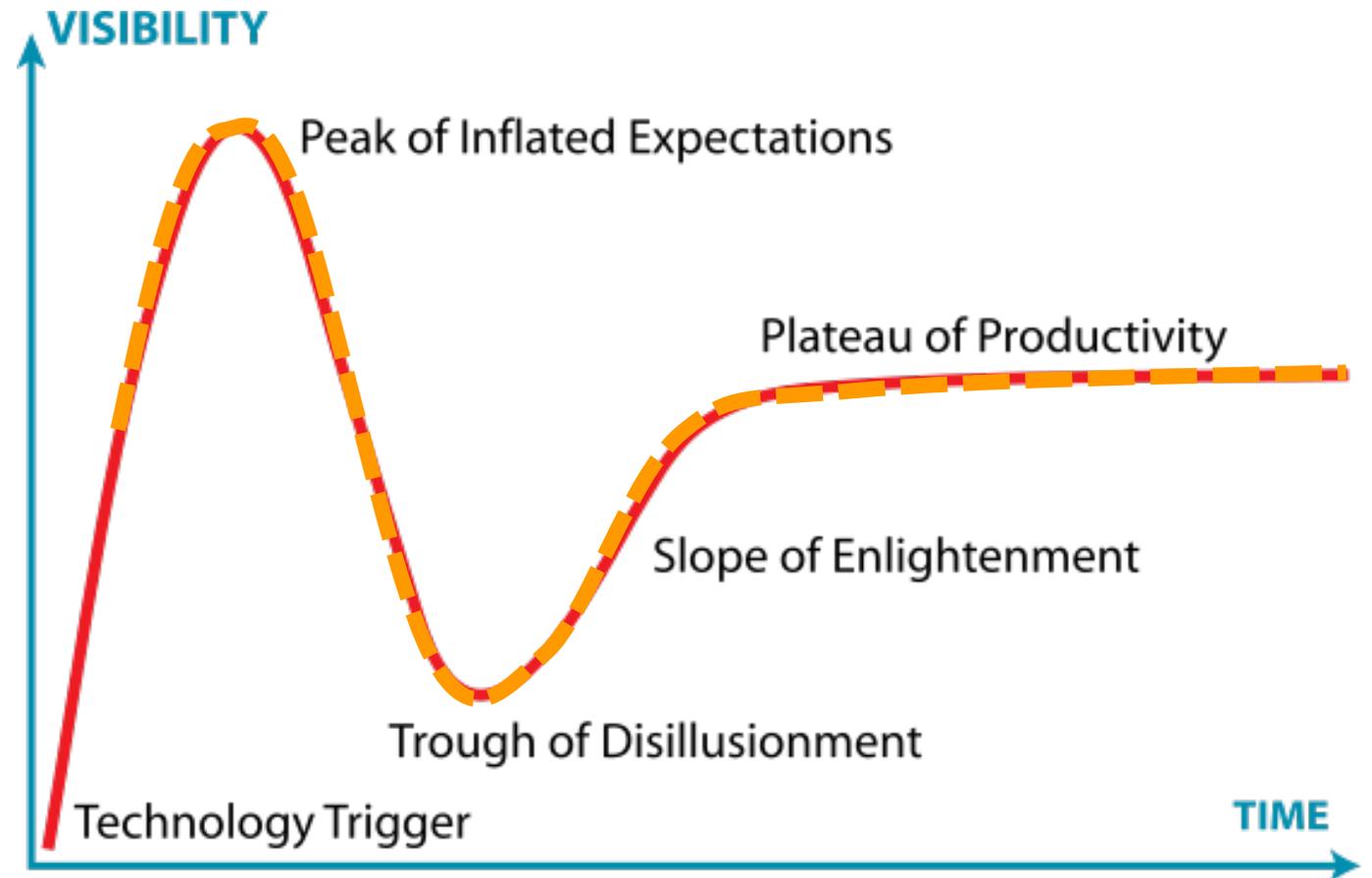
- Early adopters
- Fast followers
- Followers
- Slow followers (!)
- “Last Call” crew



Early adopters may spend more money and time in the short-term, but they gain a market advantage over competitors and save money/time in the long term

NEW TECHNOLOGY- SPEED OF TRIAL AND ADOPTION

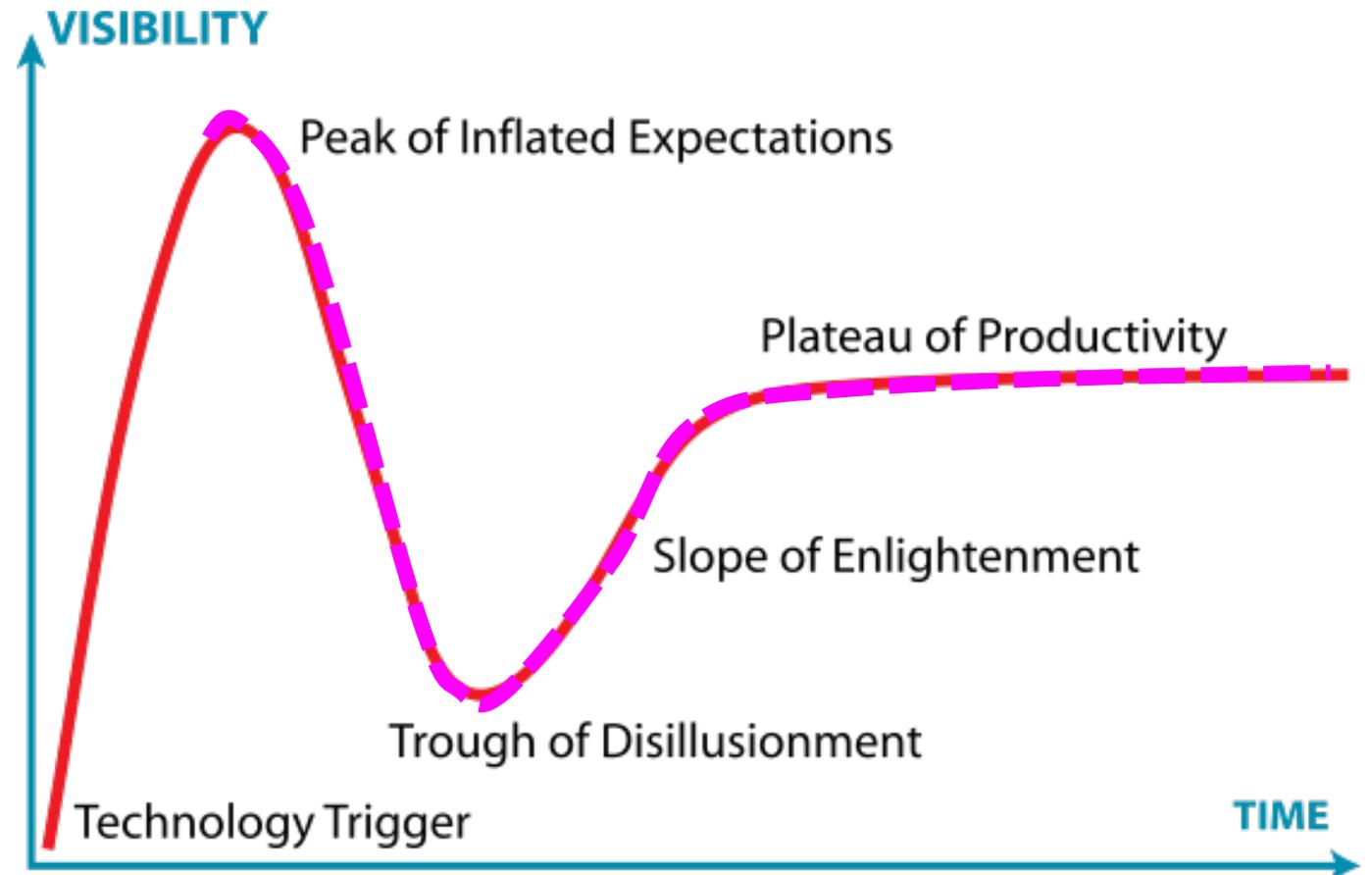
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Fast-followers gain much of the advantages of the early adopter, but lose some ability to dictate technology characteristics and implementation; still – a good place to come into the market

NEW TECHNOLOGY- SPEED OF TRIAL AND ADOPTION

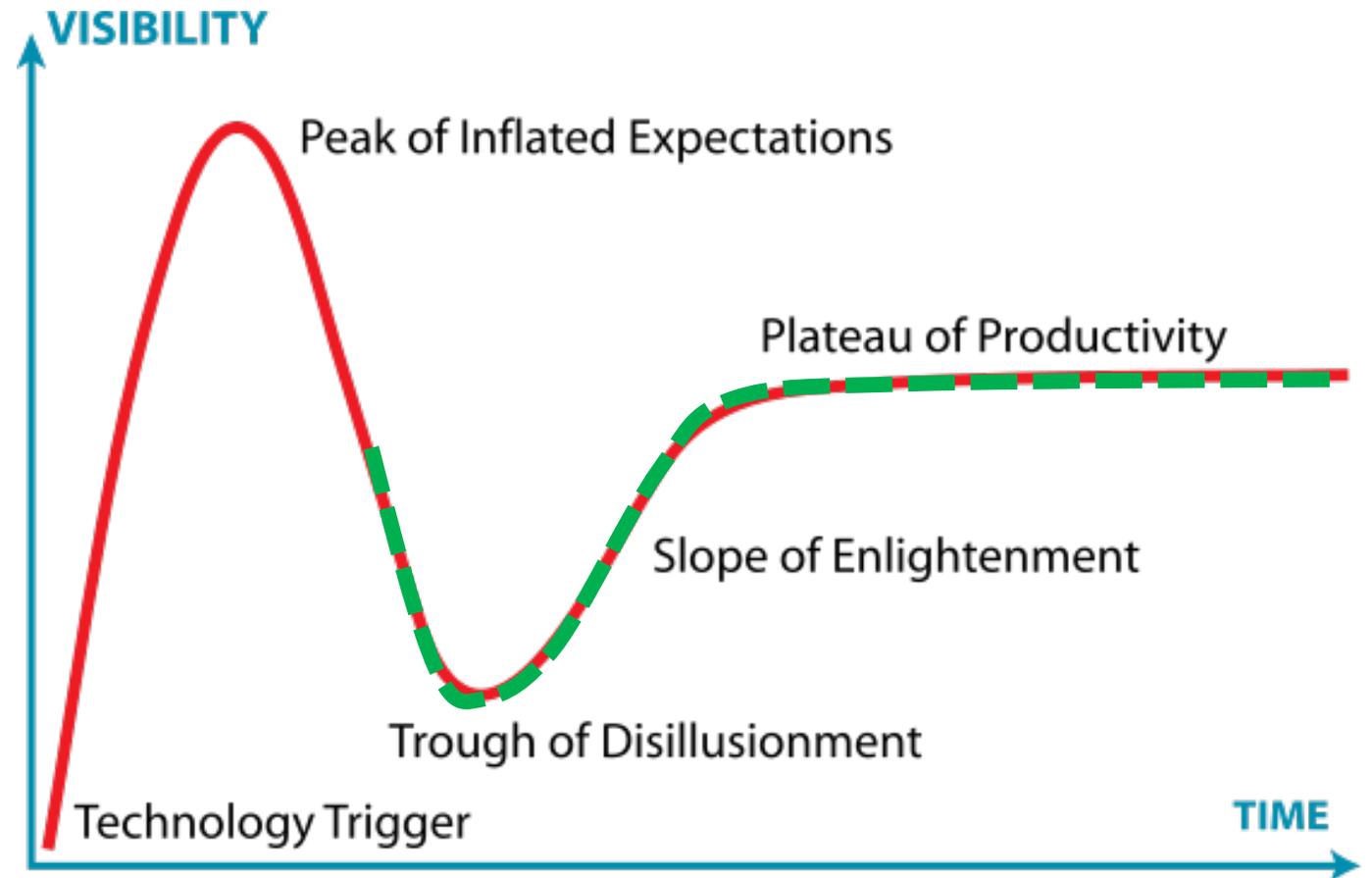
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Followers come in at the height of expectation and excitement; fairly good in terms of time/money spent – BUT can be more susceptible to the pain of ‘disillusionment’ that follows TOO close after adoption/trials

NEW TECHNOLOGY- SPEED OF TRIAL AND ADOPTION

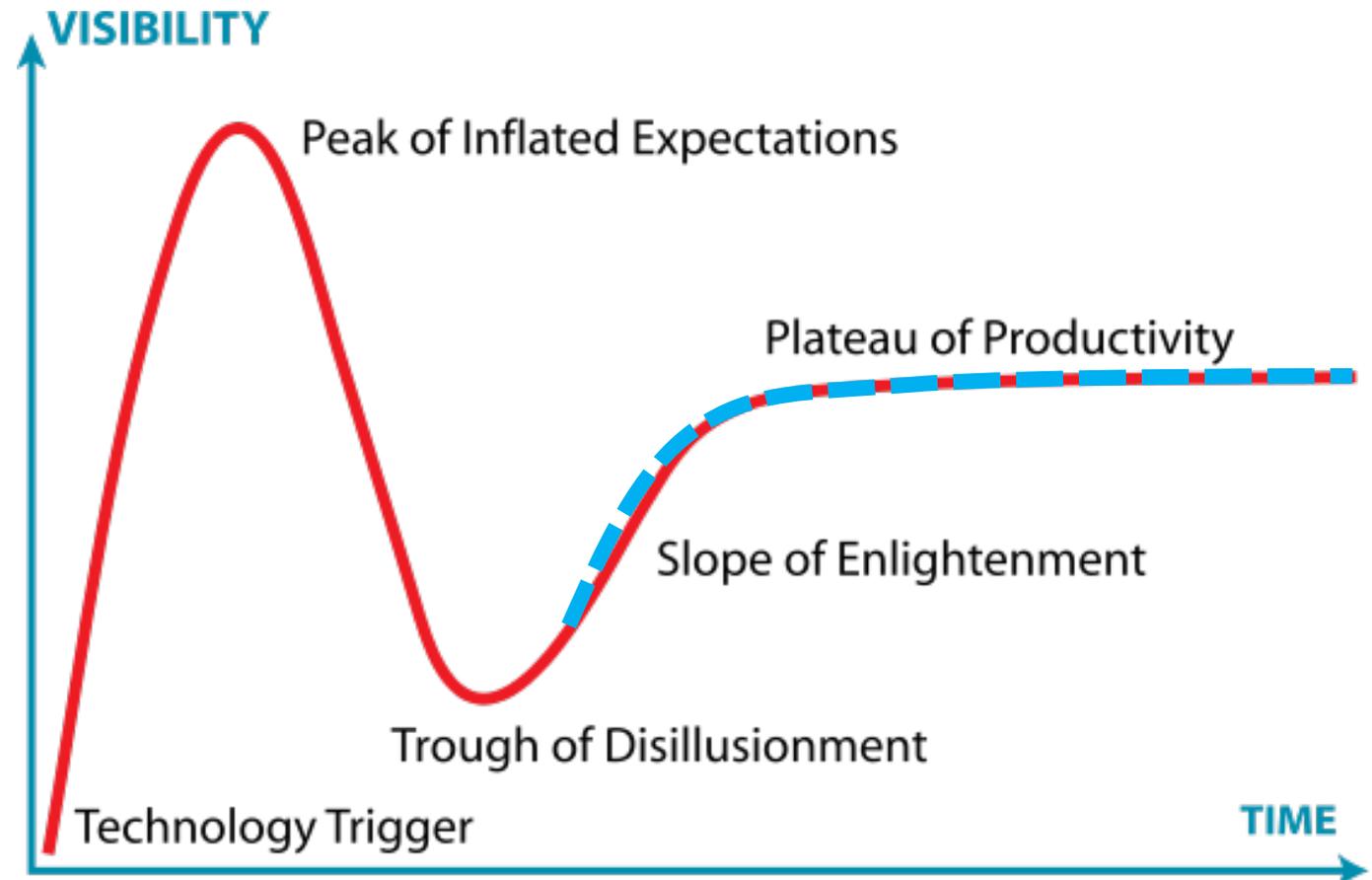
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Probably the worst time to come into a new technology as you've missed the chance to significantly contribute to product design and workflows as well as experiencing disillusionment soonest and for longer

NEW TECHNOLOGY- SPEED OF TRIAL AND ADOPTION

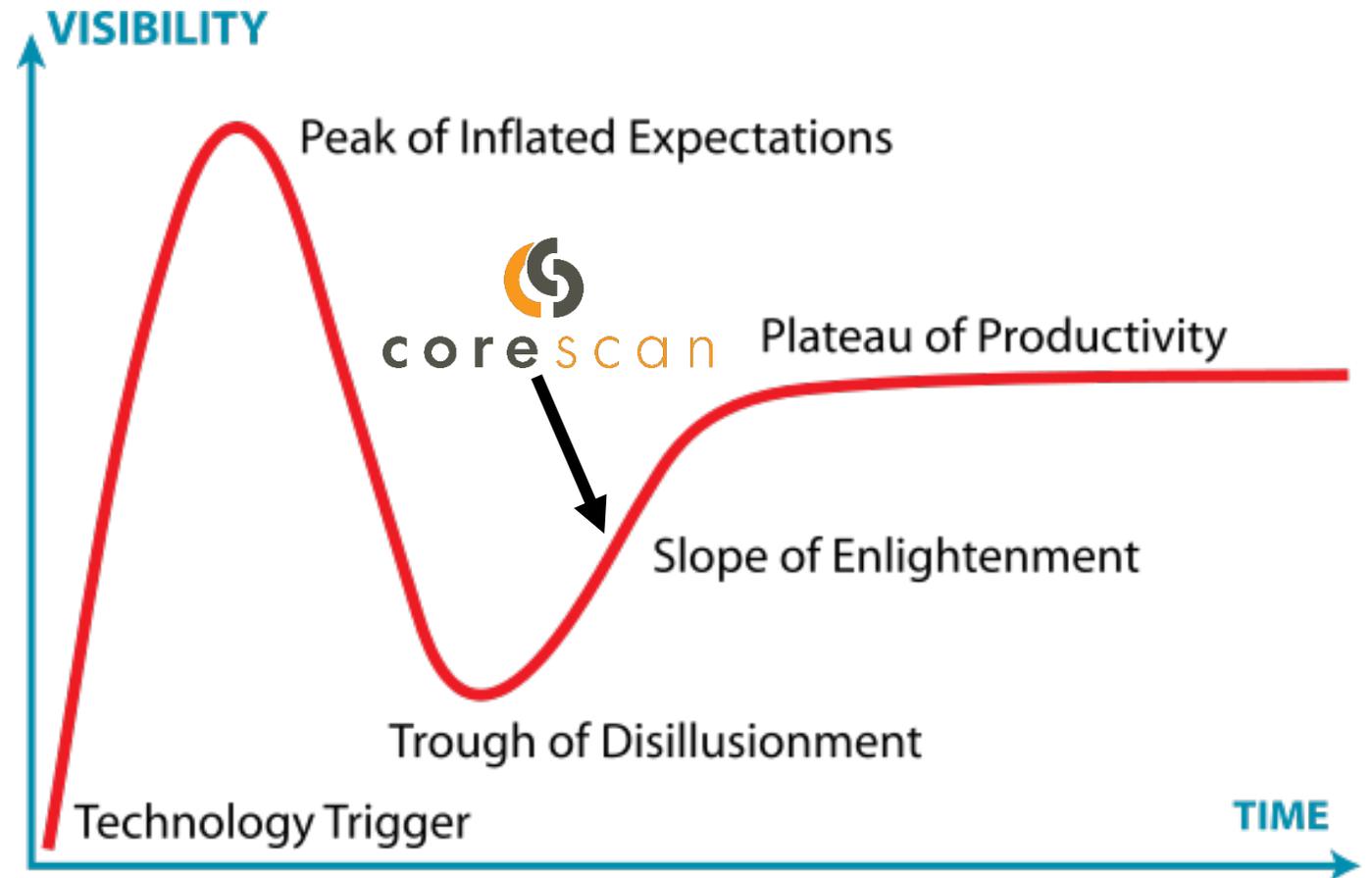
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The last-call crew comes in when all other operators have mostly figured things out; typical of some large majors. Very little human or physical capital expended for development – but now will need to spend more, more quickly, to integrate the new technology

NEW TECHNOLOGY- SPEED OF TRIAL AND ADOPTION

- Early adopters
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We believe Corescan has passed through the Trough of Disillusionment, and is on the slope of enlightenment as operators accept the technology, seek to define its role and phase its use into production and set workflows

NEW TECHNOLOGY: BACK UP...WHY DO IT??

- “Just because” ...NO
- “We had some year-end money” ...NO
- “I heard Teck was doing it” ...NO
- *So, what’s the reason then, to use new technology?*

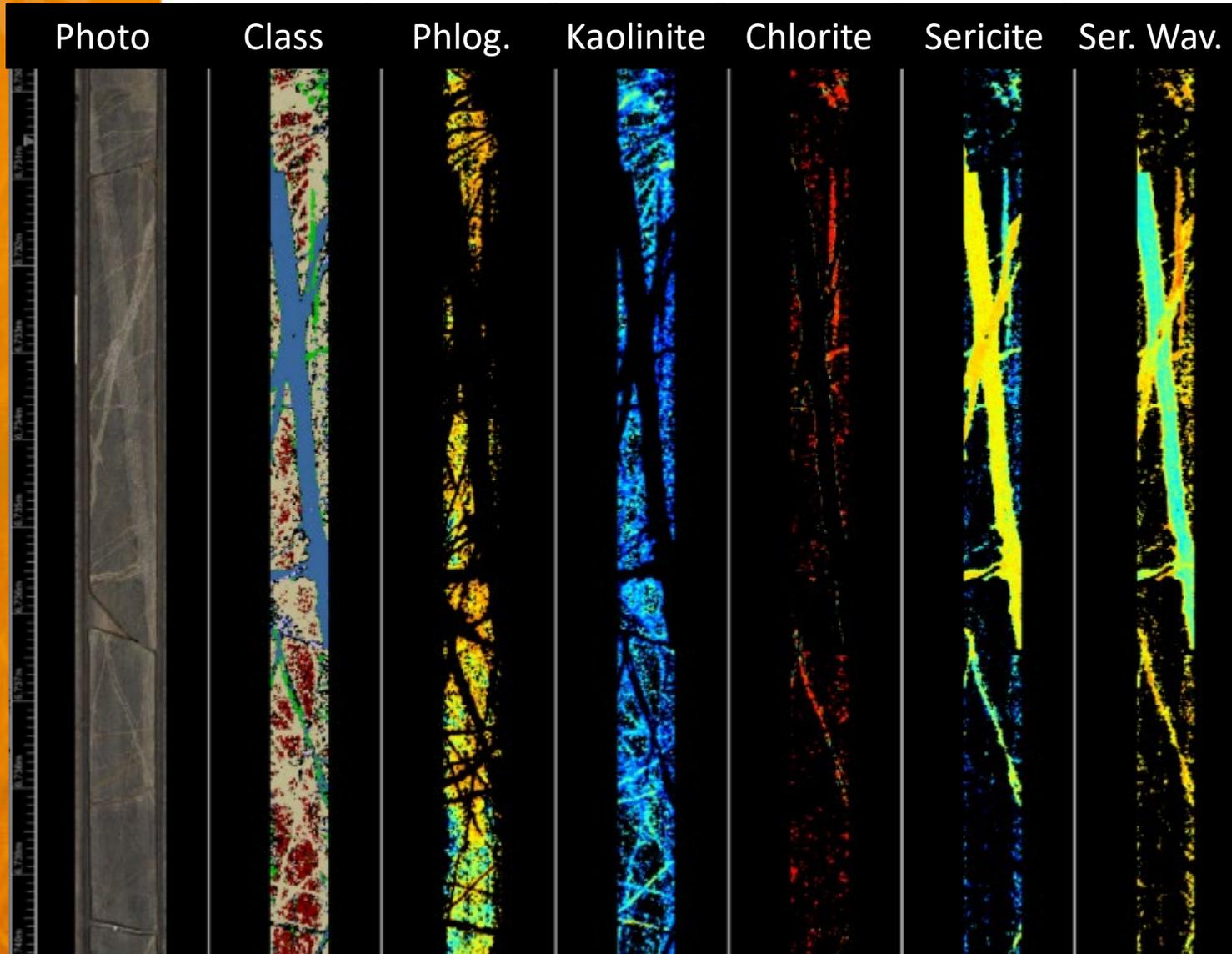
To answer a specific question...to solve a problem

HAVE A QUESTION (OR PROBLEM TO SOLVE)

- “Can hyperspectral imaging see biotite?”
 - Ok...but what they really wanted to know was, “Can I use Corescan to define my potassic?”
- “What can LIBS/Qemscan/XRF tell me?”
 - This is *ok*, especially if the technology is very new, but...
 - Most people are asking that because they have a ‘real’ question; i.e. “I really need to figure out if my micas have Li in them”
- “I suspect I have talc; can Technique A see it? If so, where is it? How is it distributed”
 - **A specific question that allows you to produce a specific result (and then to assess the success of the technique)**

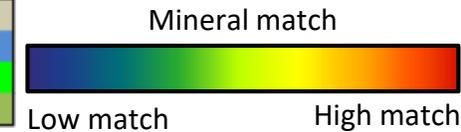
Real questions our team has been asked from less successful (top) to most successful (bottom)

CASE STUDY 1: "CAN YOU MAP TEXTURE?"



Mineral	Colour
Atacamite	Magenta
Chrysocolla	Purple
Carbonate	Cyan
Gypsum	Pink
Alunite	Light pink
Tourmaline	Orange
Kaolinite	Light green
Montmorillonite	Light blue
Phlogopite	Dark red
Chlorite	Green
Sericite	Blue
Aspectral	Grey

Textured Class Map Colours	Colour
Kaolinite+Aspectral	Light green
Sericite+Aspectral	Blue
Chlorite+Sericite	Green
Chlorite+Aspectral	Light green



White mica composition index (~2200 nm position)

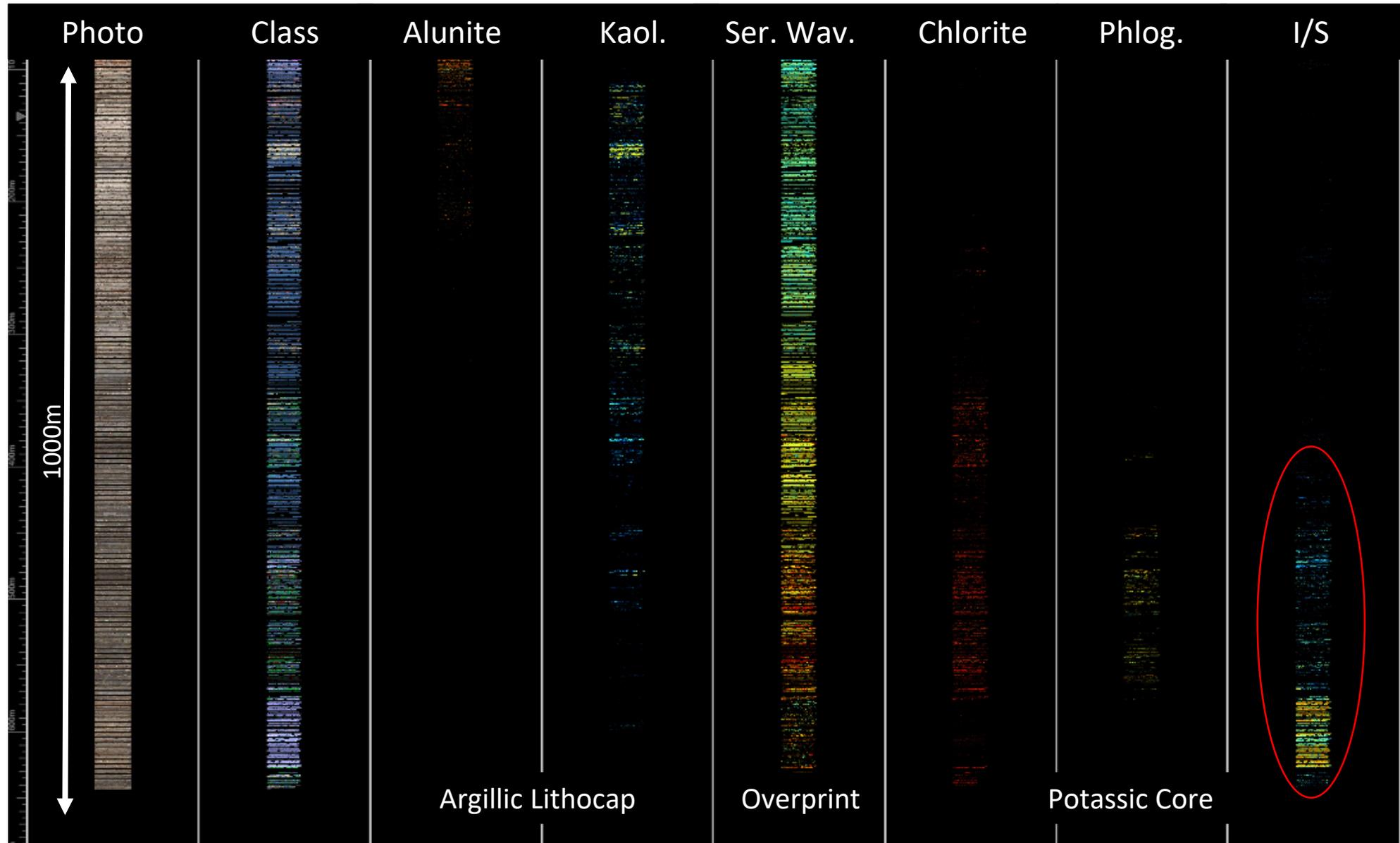
Increase in Na (Paragonite) Increase in K/Al (Muscovite) Fe substitution (Phengite)

2185 nm 2196 nm 2212 nm 2225 nm

←-----●-----●-----→
Porphphy

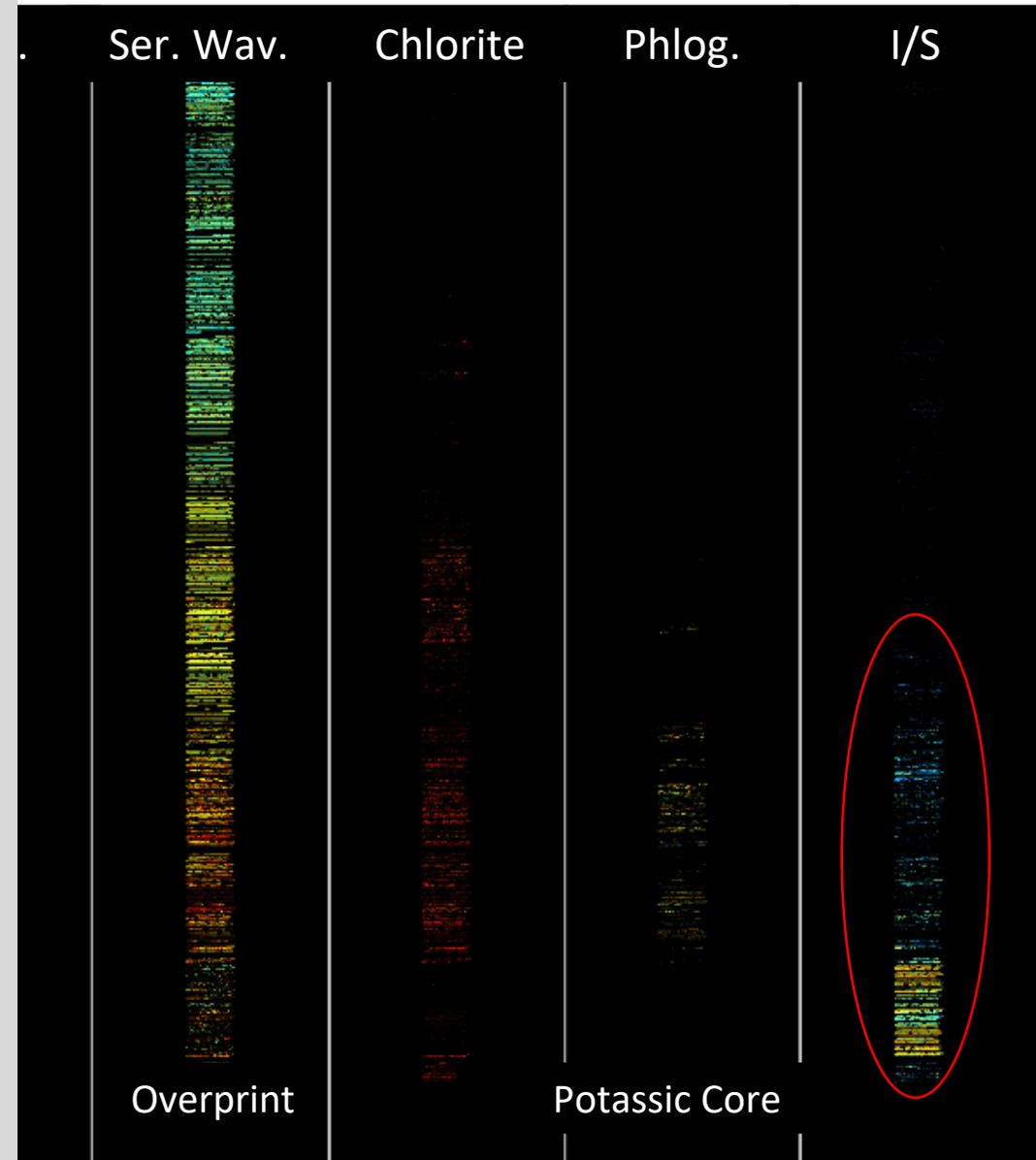
←-----●-----●-----→
2196 nm Muscovite 2212 nm

CASE STUDY 1: DEEP I/S ALTERATION – A MONKEYWRENCH



CASE STUDY 1: DEEP I/S ALTERATION – A MONKEYWRENCH

- While texture was successfully mapped (and paragenesis), the *real* question was more about why recovery was sub-optimal
- Texture was previously deemed an important variable towards this recovery question
- Ironically, unexpected alteration at depth threw the overall hyperspectral project into question
- Deep I/S (dominantly montmorillinite) was found to be altering the potassic feldspar populations – and correlated with Cu grade



CASE STUDY 1: DEEP I/S ALTERATION – A MONKEYWRENCH

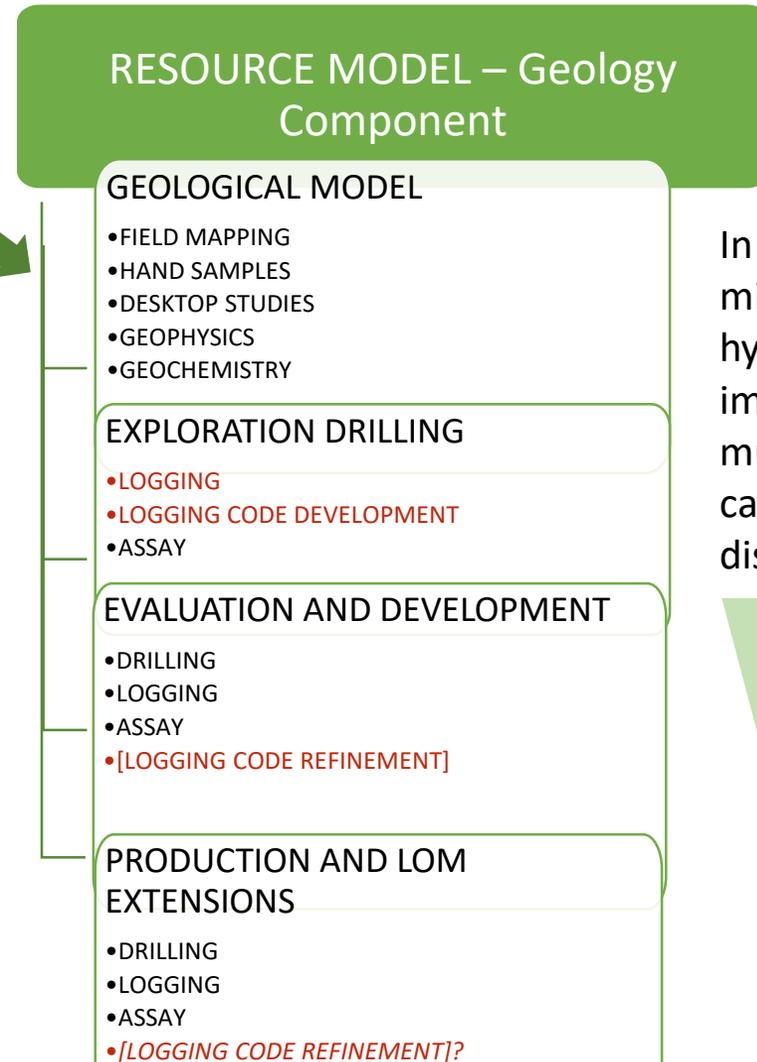
- Montmorillinite (or even 'smectite') was not in the historical logging codes
- Modeling did not include this species
- Furthermore, the deep montmorillinite was highly suspect to the local geology team
- The Corescan spectral geologists backed off; we don't spend day in and day out in these projects and respect those who do
- Also, we hadn't actually seen this behavior before either (this was only the ~5th porphyry we'd ever scanned)

CASE STUDY 1: TRUE DISRUPTION

- Ultimately – we should have advocated for a program of co-validation (integration) with some simple but robust thin section and XRD work (something we regularly prescribe now)
- We are also far more helpful with our clients in the arena of assisted logging and logging code augmentation/refinement
- We also more fully appreciate exactly what we are asking an operating mine to do when the logging codes/mineralogy change this much – *true* disruption

Optimally, robust mineralogical knowledge enters the geological model **early** and helps to define the resource model

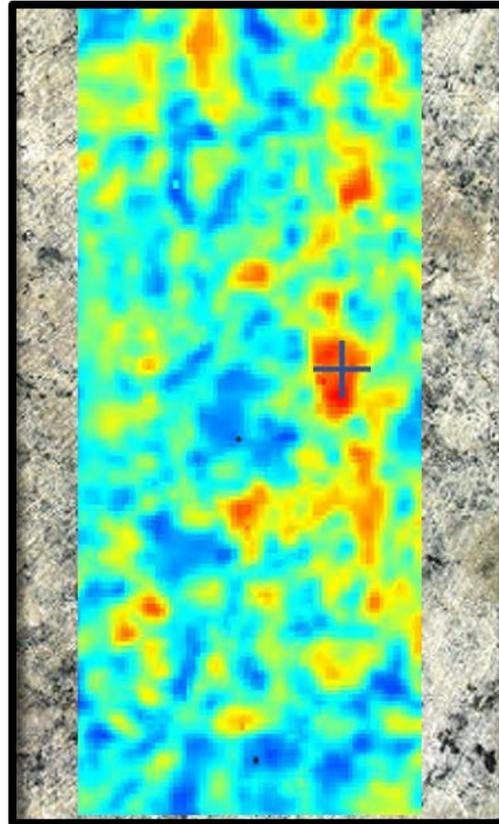
Logging Code Refinement



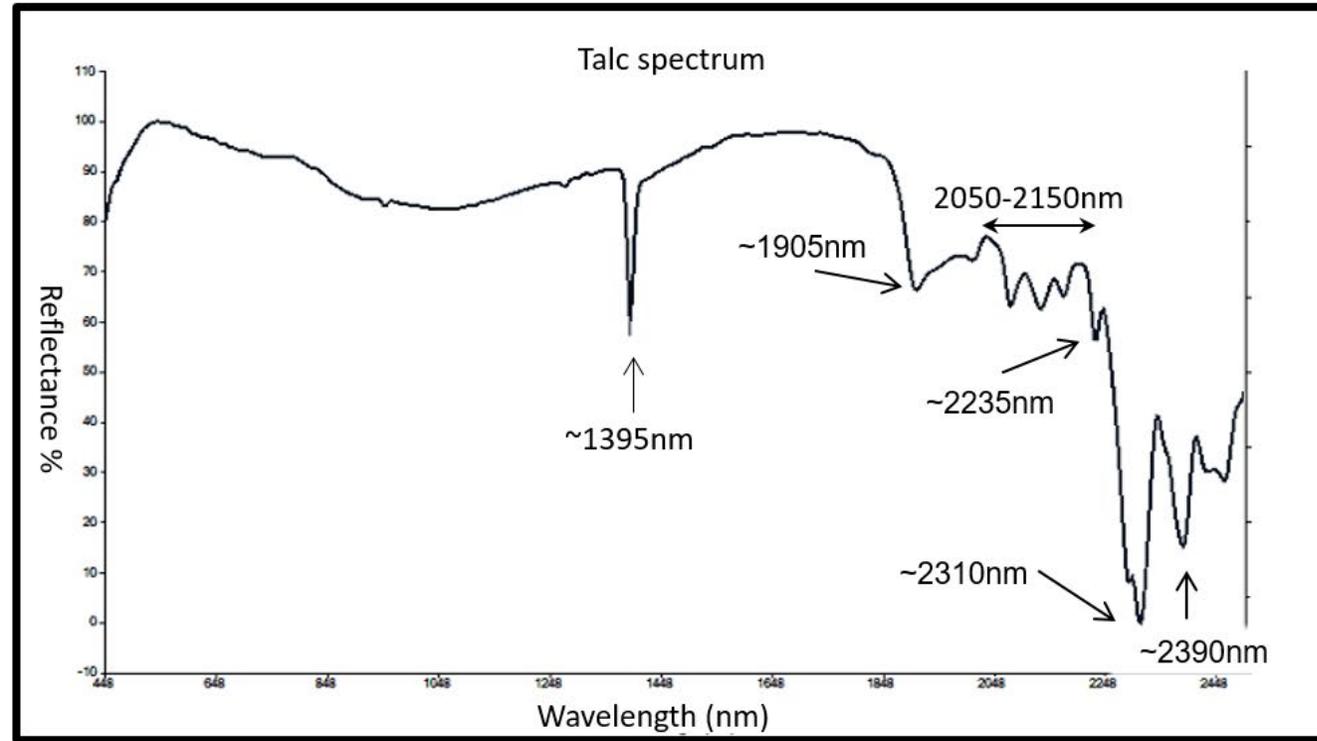
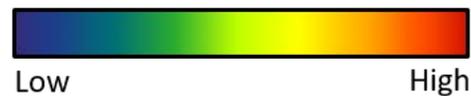
In an operating mine, hyperspectral core imaging enters much later and can cause significant disruption

...having said all this, the Cu-rich potassic intervals (dominated by montmorillinite) surely had/have an effect on recovery...

CASE STUDY 2: “I THINK I HAVE TALC; HOW MUCH DO I HAVE, WHERE IS IT, HOW IS IT DISTRIBUTED AND WHAT KIND?”

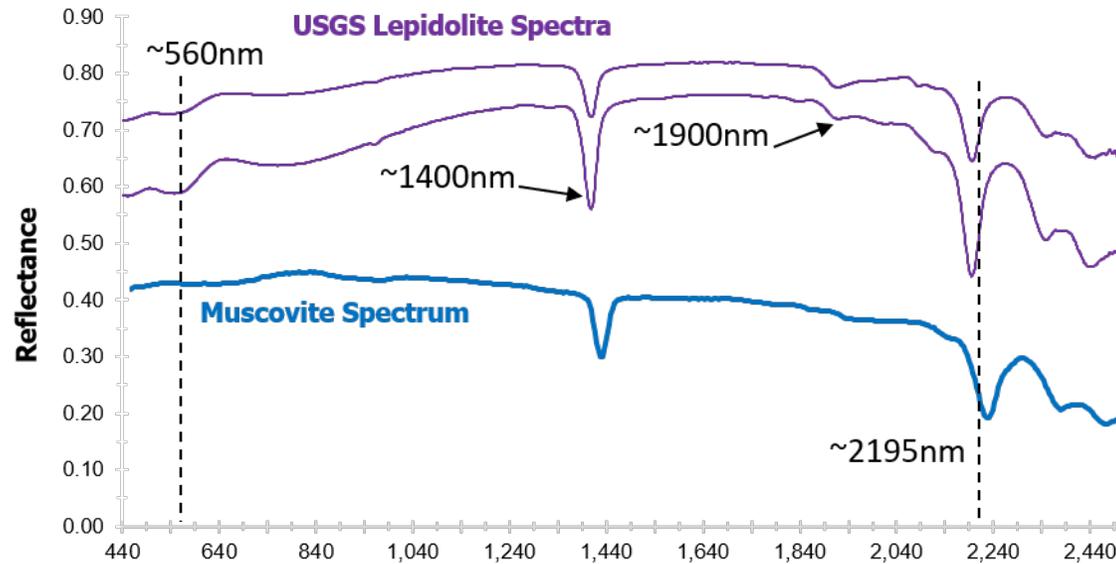


Talc Match

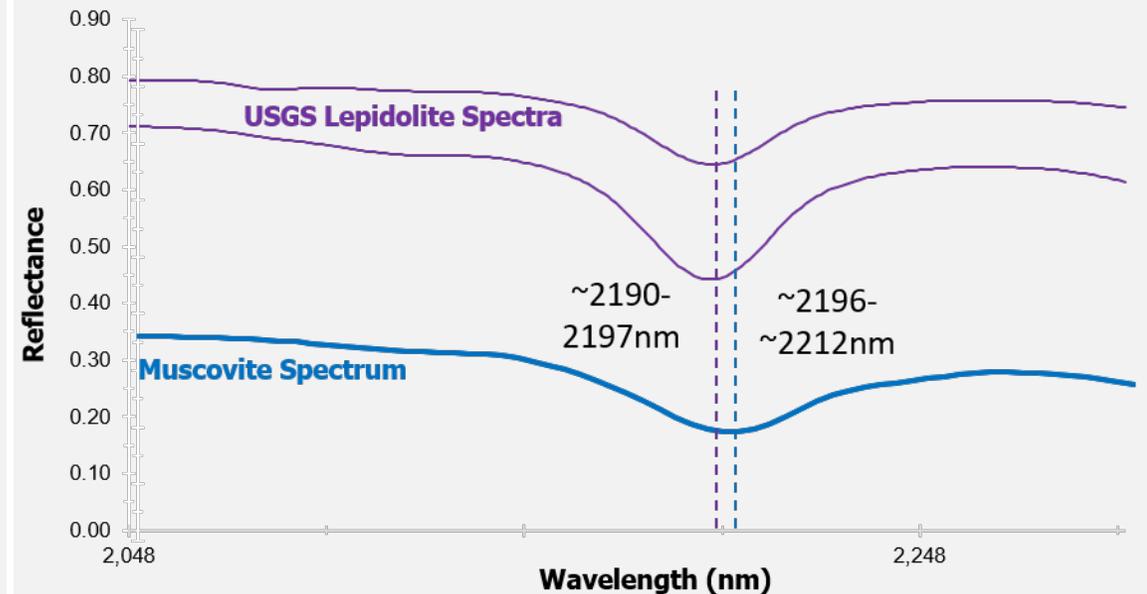
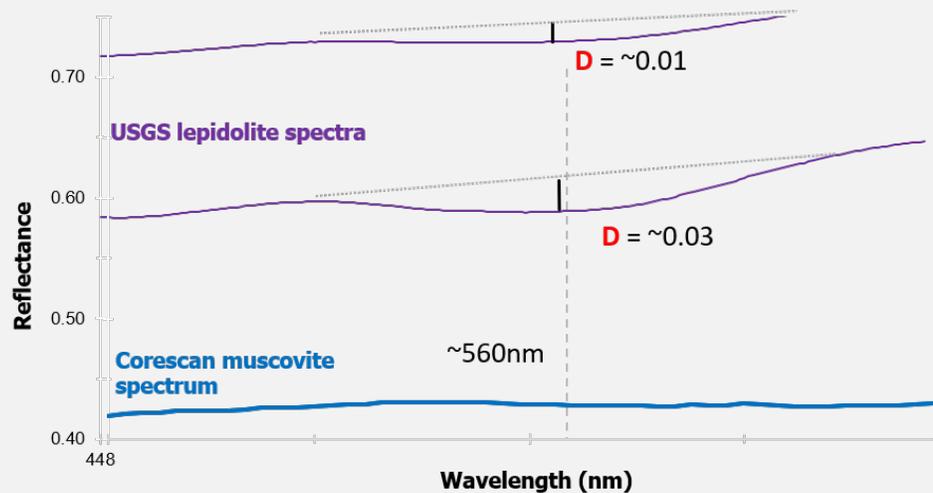


A company may know they have talc...but knowing how the talc is distributed (veined? pervasive?), how much they have, its characteristics (eg. highly crystalline?) and what it's in assemblage with is key; flotation of Mo and Cu is different when in assemblage with talc...

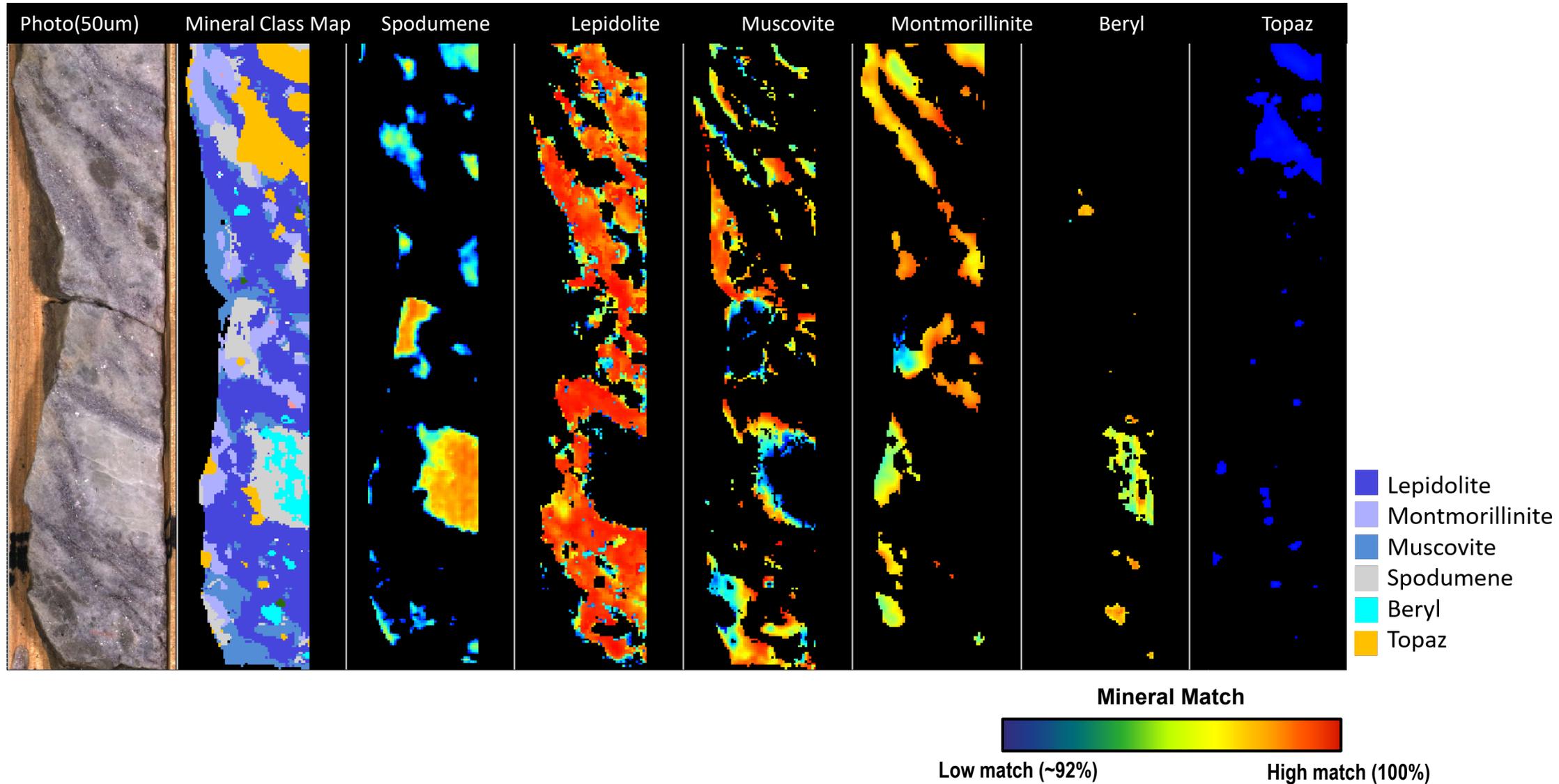
CASE STUDY 2: "I HAVE LITHIUM; WHERE IS IT HOSTED AND HOW MUCH DO I HAVE?"



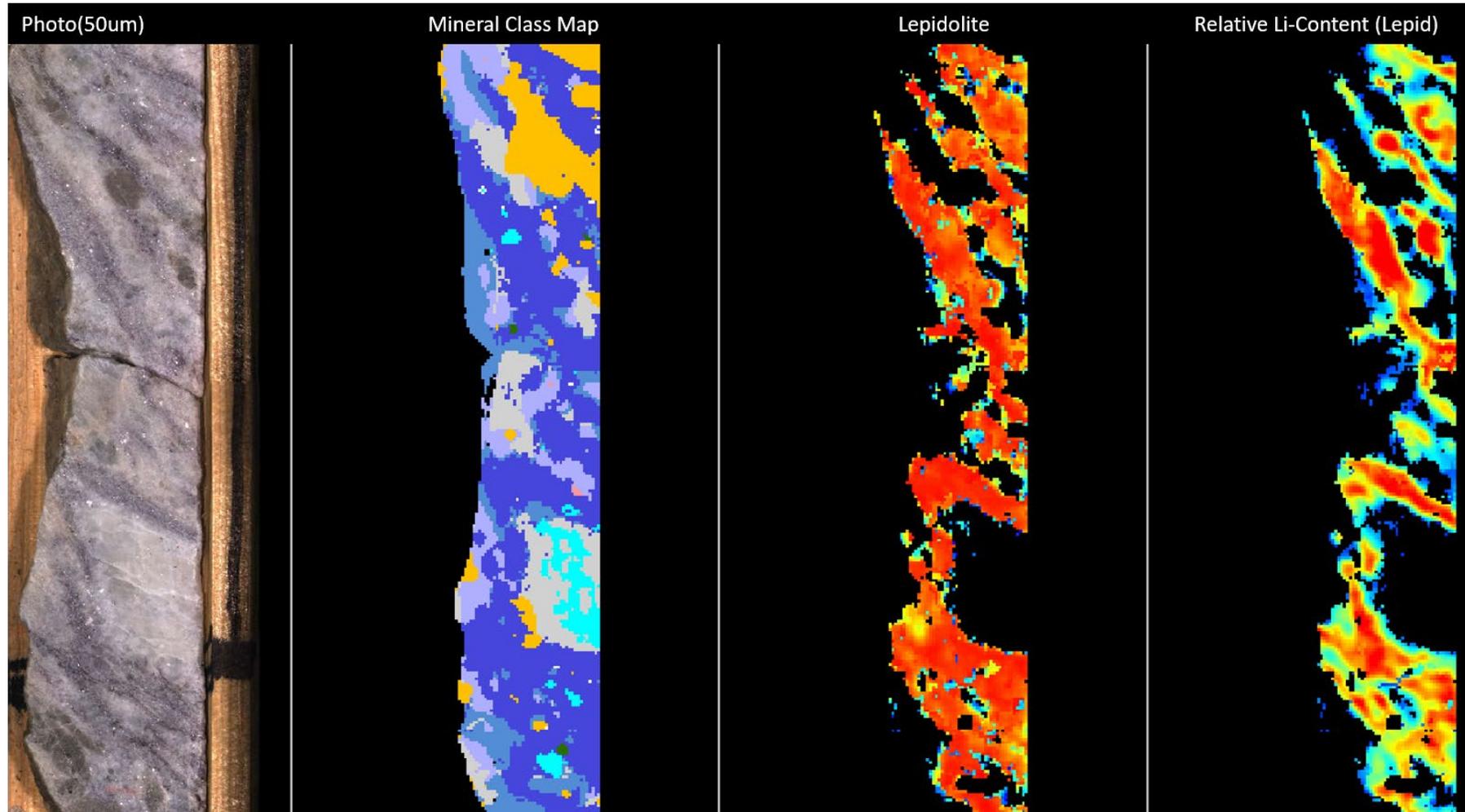
Li can be hosted in multiple minerals within pegmatic deposits including multiple mica species; including both Li-bearing muscovites and true Lepidolite



CASE STUDY 2: "I HAVE LITHIUM; WHERE IS IT HOSTED AND HOW MUCH DO I HAVE?"

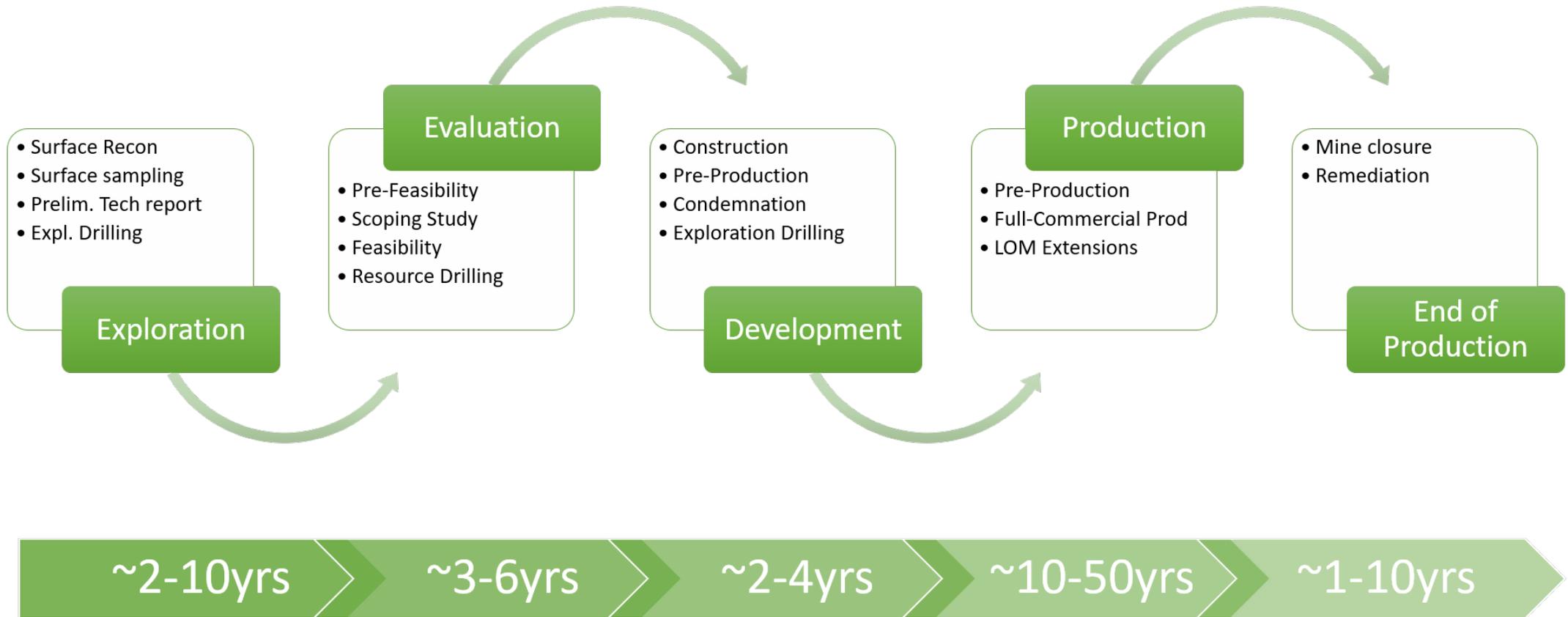


CASE STUDY 2: “I HAVE LITHIUM; WHERE IS IT HOSTED AND HOW MUCH DO I HAVE?”



- Lepidolite
- Montmor.
- Muscovite
- Spodumene
- Beryl
- Topaz

NEW TECHNOLOGY: BARRIERS



Time is not on our side...

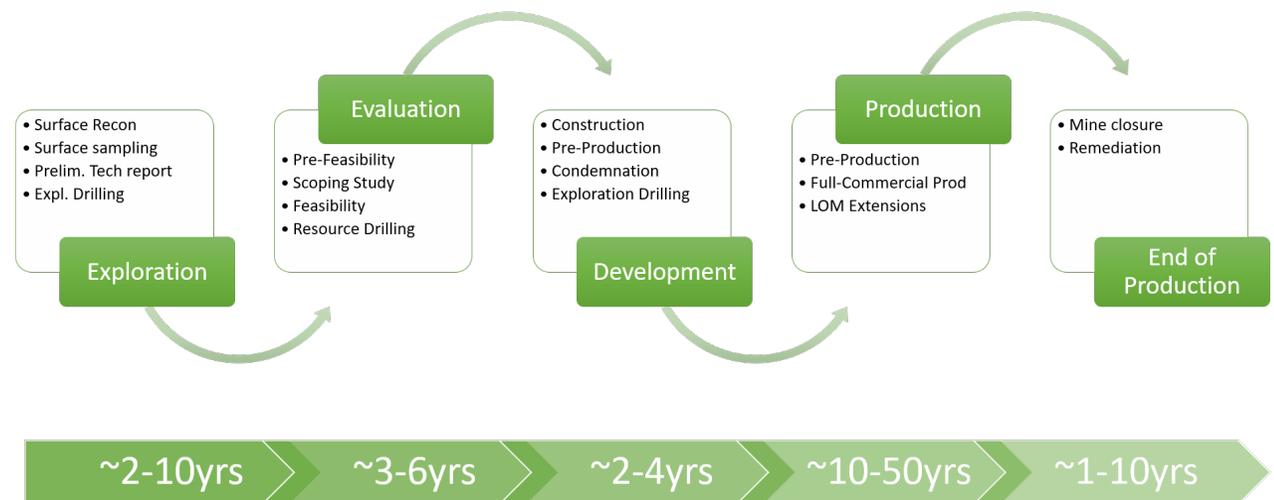
NEW TECHNOLOGY: BARRIERS AND SOLUTIONS

• Cost

- Funding for the surveys, instruments
- Which cost center? Exploration? The mine(s)?
- Implementation for a new technology may take ~5-8 years; how to secure funding over such a long period?
- Personnel (time=money)

Solutions

- Longer budget cycles (HA!)
- Consider isolated 'Director' or Executive level budgets to bridge funding gaps between 'hype', the 'pit of despair' and mine implementation



NEW TECHNOLOGY: BARRIERS AND SOLUTIONS

• **Procurement**

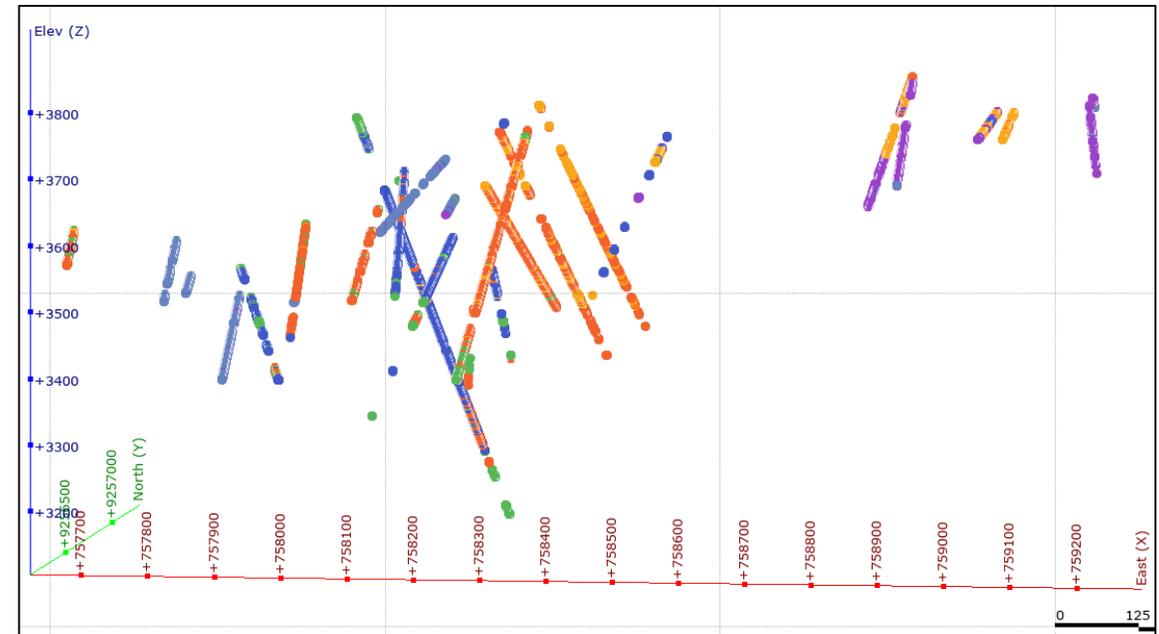
- New technology is generally not a 'widget' you can hand off for purchase
- Purchase of equipment can be easier – but not when there are only ~1-2 providers; technology is generally quite different between competitors in the early years
- If the technology is service-based, can be very difficult for procurement to assess long-term service contracts and content

Solutions

- A technical champion should be involved in purchase (HA!)
- Have very specific questions/problems to address; create well-defined, detailed RFP's for procurement to follow
- Trials (at free to reduced rates) are frequently at sums below the trigger for full procurement; test new tech first before splashing out (and feeling the pain later)

NEW TECHNOLOGY: BARRIERS AND SOLUTIONS

- Buying new technology and services is the easy part; using it successfully is the hard part; **expertise** is key
 - **In-house:** Generally not on staff to begin with (that's why it's 'new' tech); usually giving someone one more thing to do that has nothing to do with their job description or group KPI



NEW TECHNOLOGY: BARRIERS AND SOLUTIONS

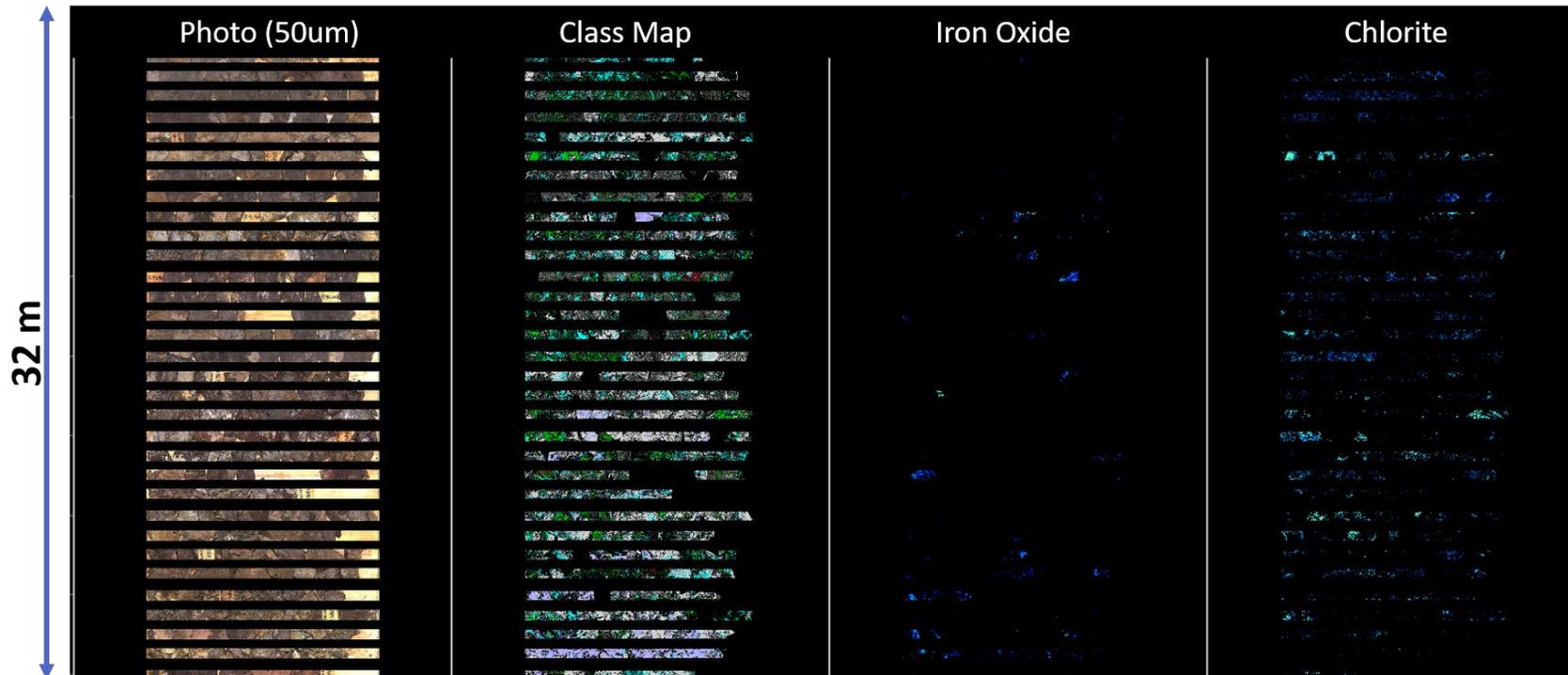
- Buying new technology and services is the easy part; using it successfully is the hard part; **expertise** is key
 - **Consultants:** While generally practical, can also be difficult to source for new technology streams; also tends to be quite expensive in the mid to long term
 - **Academia/Government:** A high quality option – but can have longer lead times and delivery schedules
 - A great investment in the long term health and understanding of new technology

NEW TECHNOLOGY: BARRIERS AND SOLUTIONS

- Buying new technology and services is the easy part; using it successfully is the hard part; **expertise** is key
 - **Vendors:** Highly technical, key personnel who are often contractually required to make you happy and make things work
 - Make vendors work together; we can create even more innovative products together
 - **Use us!** We are your highly trained, collaborators, co-conspirators and helpers...
 - ...until we aren't; everybody is selling something
 - Don't be afraid to ask detailed, specific questions; if we can't tell you the answer (whether pricing justification or technical requirements) you shouldn't buy from us

BARRIERS AND SOLUTIONS: CONFIRMATION BIAS

- The tendency to search for, interpret, favor and recall information in a way that confirms one's preexisting beliefs or hypotheses
- The effect is stronger for deeply entrenched beliefs
- Belief perseverance (when beliefs persist after the evidence for them is shown to be false)

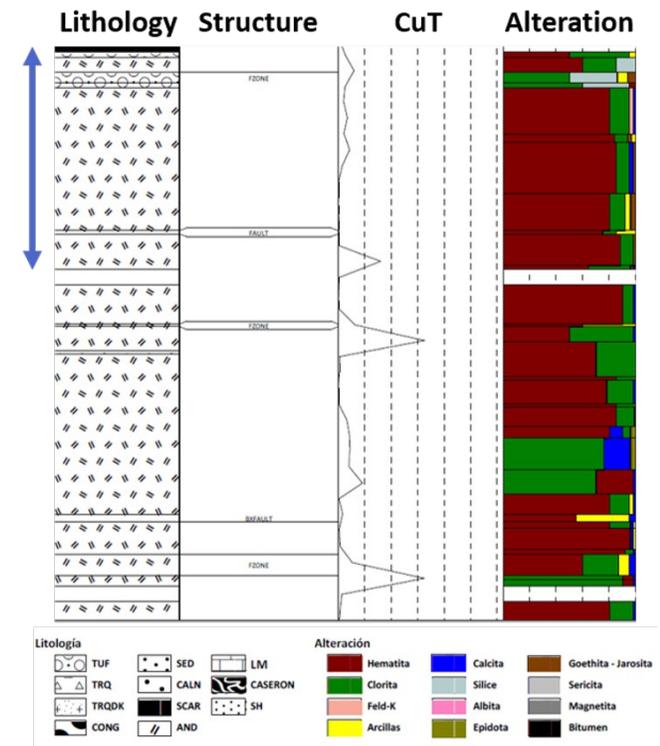
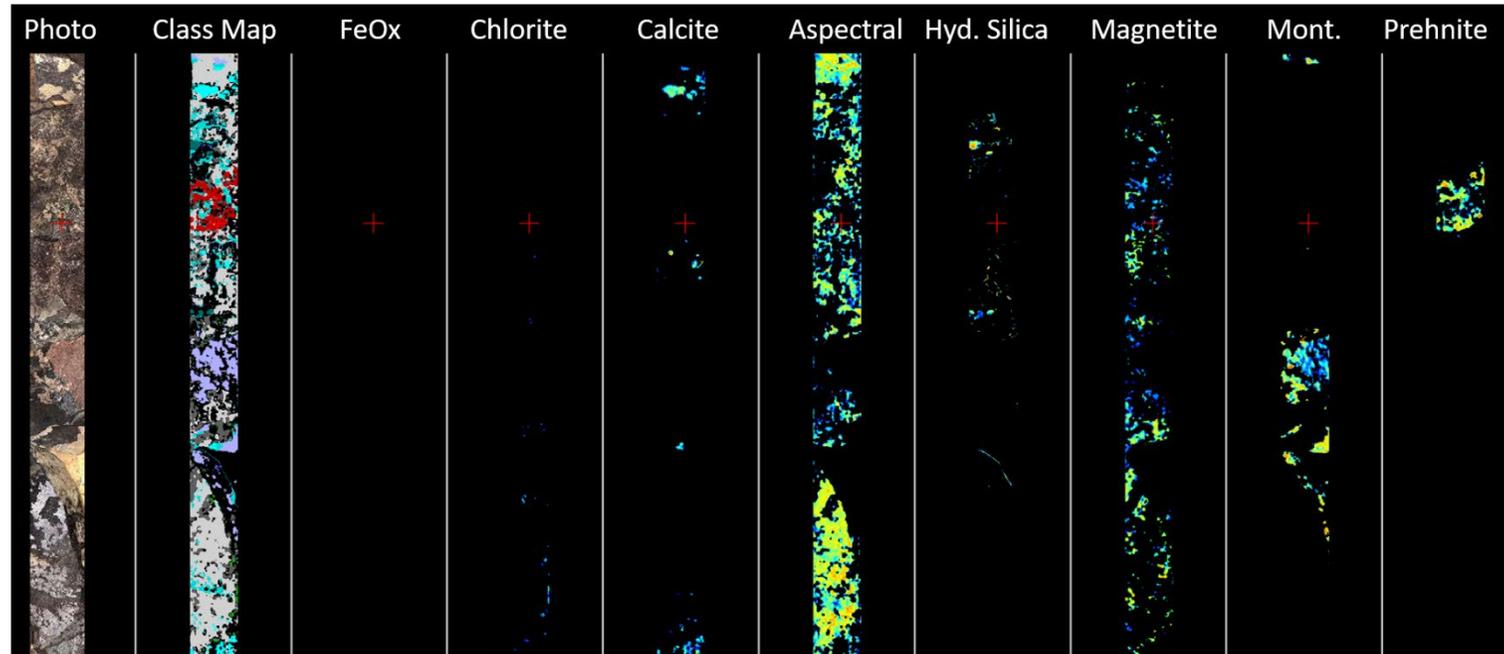


An example of an old mine with set logging codes and models; a new model of IOCG was emphasized...but Corescan results indicated very little iron oxide and it was difficult to get site geos to consider this piece of information

BARRIERS AND SOLUTIONS: CONFIRMATION BIAS

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- Irrational primacy effect (a greater reliance on information encountered early in a series)

While early logging codes had ~16 minerals, an additional 10 minerals from Corescan elucidated the deposit – but were never adopted



BARRIERS AND SOLUTIONS: CONFIRMATION BIAS

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- The effect is stronger for deeply entrenched beliefs
- Belief perseverance (when beliefs persist after the evidence for them is shown to be false),
- Irrational primacy effect (a greater reliance on information encountered early in a series)
- Explanation for observed bias can include **wishful thinking, limited human capacity to process information, people weighing up the costs of being wrong**, rather than investigating in a neutral, scientific way

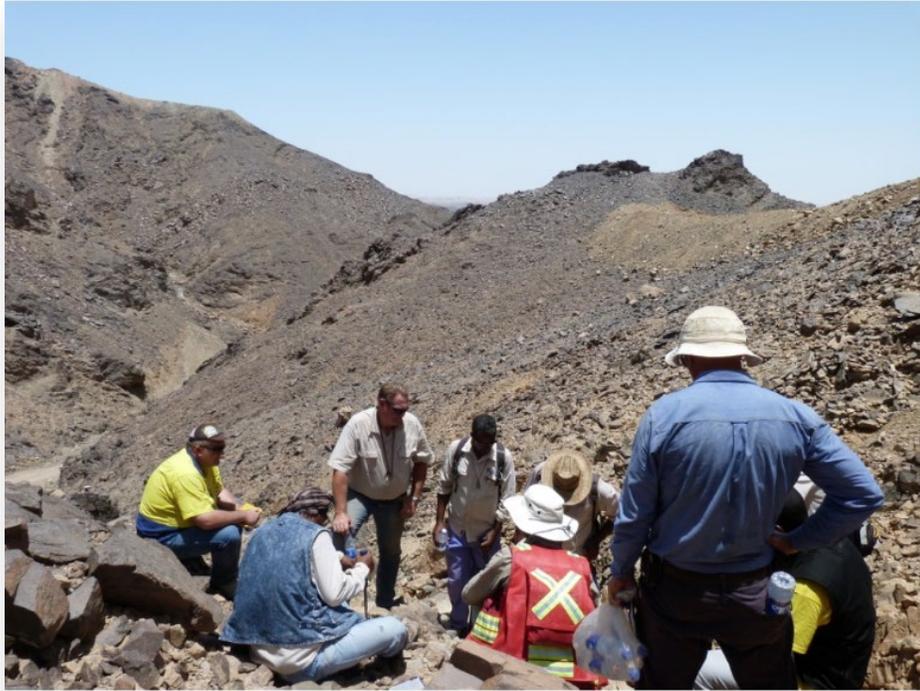
Solutions

- Imagine the opposite scenarios, "For argument's sake" or "Devil's Advocate" – it can take a team to a more reasoned place

THE FUTURE

- Multi-variate analysis in increasingly sophisticated software environments
- Machine-learning driven analysis
 - For hyperspectral...our 8 spectral geologists, have seen more spectra today, than the entire spectral community has seen in the past ~30 years
 - The other analytical techniques discussed in this talk are also producing unprecedented spatial resolutions, volumes and insight
- Systems with multiple analysis techniques – ‘The Tricorder paradigm’
- Pushing the real-time production of data and interp; driven by not only the machines, but our global connectivity and processing power

YOU'RE NOT GETTING RID OF US ANYTIME SOON...



- Geologists bring knowledge, context and hard-earned wisdom
- 'Domain experts' are indispensable
- The synthesis of humans and consistent, precise analytical data is best-practice