Gold Deposits of the Birimian and Tarkwaian in Ghana

SEG Foundation Student Field Trip 17
April 22 – May 1, 2018

Outline

- Introduction – what is the SFT?
- Meet the participants
- Geology and metallogeny of Ghana
  - Regional geology and deposit summary
  - Paleoplacer-style deposits and processes
  - Exploration criteria for orogenic deposits
- Processing and metallurgy
- Culture
- How to get involved in the future

What is the SFT program?

- Annual trip to a major ore district, organized and funded by the SEGF
- 16 geology students from around the world are selected to participate, along with 2 leaders and 4 mentors with expertise in the related field
- Trips are generally 10 days and consist of mine and prospect visits, workshops, and lectures from industry professionals and mentors
- **SFT 17: Gold Deposits of the Birimian and Tarkwaian in Ghana**

192 years of experience on 6 continents

Dave, Simon, Raymond, Doug, Eugene, Rael

Meet the leaders

Rael Lipson

Consulting Geologist
Adjunct Faculty at Colorado School of Mines

46 years' global experience

Specialises in paleoplacer & orogenic Au

Former Chief Exploration Geologist Gold Fields

Watch Rael talk about his motivation for being a leader on the trip

Raymond Kudzawu-D'Pherdd

Consulting Geologist at Geogamut Ghana Ltd
General Secretary for Ghana Institution of Geoscientists

14 years' experience

Policy, planning, monitoring & evaluation in exploration projects across West Africa

Specialises in gold, diamonds, bauxite, uranium

Watch Raymond talk about his motivation for being a leader on the trip

Meet the mentors

Douglas Kirwin

Independent Consulting Geologist

46 years' in mining industry

Involved in 18 orebody discoveries & expansions including Oyu Tolgoi (Mongolia)

Why Doug wanted to get involved

Simon Meadows Smith

Managing Director at SEMS Exploration Services

25 years' in mining industry

Provides technical services to exploration projects and mining companies across West Africa

Why Simon wanted to get involved

David Rhys

Consulting Geologist at Panterra Geoservices

28 years' in mining industry

"Structural geology guru"
-Students on SFT-17

Why David wanted to get involved

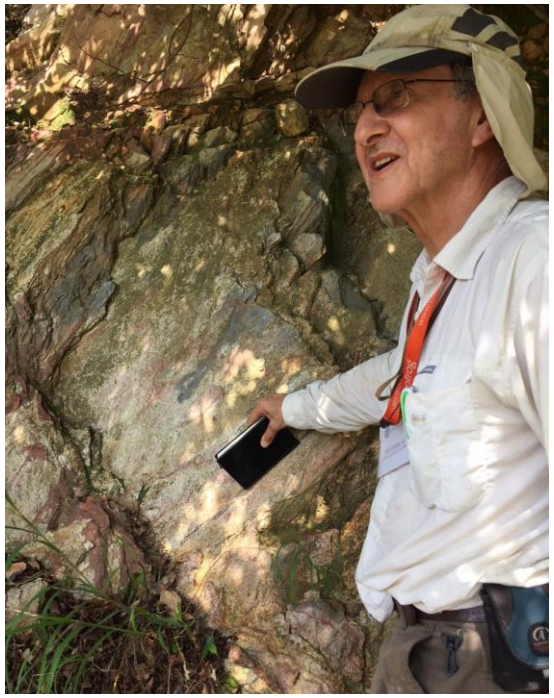
Eugene Flood

Geologic Consultant at Flood Consulting

33 years' in mining industry

Specialist in geospatial mineral prospectivity analysis

Why Eugene wanted to get involved



Learning from those at the forefront of exploration

Josh, Nikita, Jo and Christophe with mentor Eugene, atop Essase 6 Moz Au deposit soon to be mined.

"A valuable insight into the industry and chatting with the mentors has inspired and focused my own career ambitions. To be a tenth as successful would be just incredible."
Jo Miles, UK

"Absolute privilege to have the opportunity to see such a large number of producing gold mines and exploration projects – a unique experience."
Josh Hughes, UK

"Interacting with the mentors has been a colourful opportunity for young geologists to expand their knowledge."
Christophe Wakamya, DRC

"This was a fantastic opportunity to see interesting rocks, while networking and making new friends. Thanks SEG! Thanks mentors!"
Nikita La Cruz, Guyana

Meet the students

- From 50 applications of student economic geologists, 16 students from 11 countries were chosen from around the globe
- Students range in academic levels from undergraduate to Ph.D candidates

- Click the video links to hear students talk about why they wanted to apply!

It’s always sinistral, unless it’s dextral!

Team E

Ethan Amyotte
B.Sc. Geology Student
University of Manitoba

Ethan's interview

Elliot Wehrle
B.Sc. Geology
Laurentian University

Elliot's interview

Team Schistosité

Issoufou Maiguizo
M.Sc Candidate
China U. of Geosciences, Wuhan

[Issoufou's interview]

Christophe Wakamya
M.Sc Candidate
University of Arkansas

[Christophe's interview]

Manon Valette
PhD Candidate
U. du Quebec à Montreal

[Manon's interview]

Team J

Josh Hughes
Ph.D. Candidate
University of Durham

Josh's interview

Jack Thornton
B.Sc Geology Student
University of Leeds

Jack's interview

Joey Vrzovski
M.Sc. Candidate
Lakehead University

Joey's interview

Team J – con’t

Jo Miles
Ph.D. Candidate
University of Bristol

Jo’s interview

Jamie Price
Ph.D. Candidate
Cardiff University

Jamie’s interview

Team Continental Europe

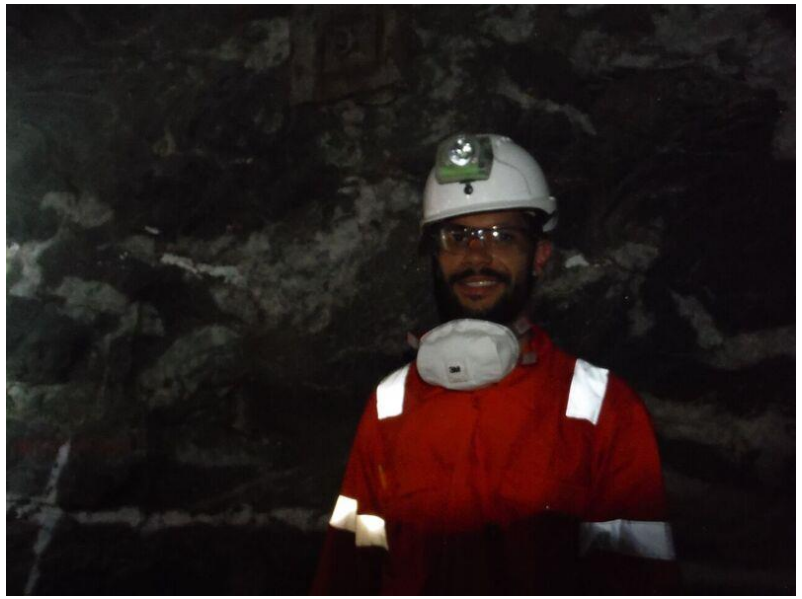
Malte Stoltnow
MSc Geology
TU Bergakademie Freiberg

[Malte's interview]

Georgi Milenkov
M.Sc.
University of Geneva

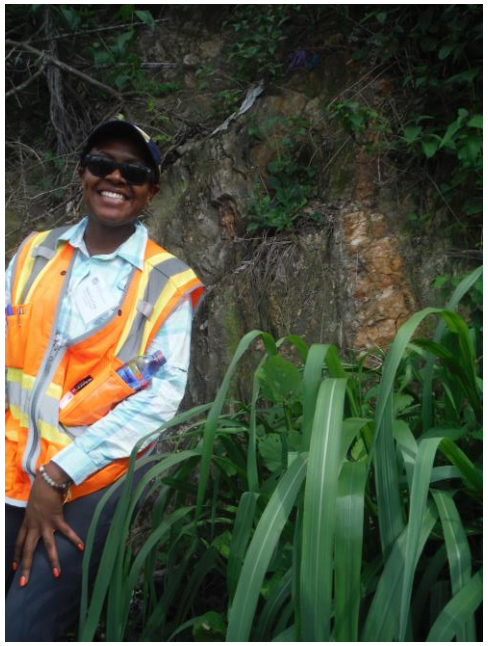
[Georgi's interview]

Team Reunite Gondwanaland



Renan de Souza
B.Sc. Geology Student
Federal U. of Rio Grande do Sul

Renan's interview



Nikita La Cruz
Ph.D. Candidate
University of Michigan

Nikita's interview

Stephan Dunn
M.Sc. Geology
University of Stellenbosch

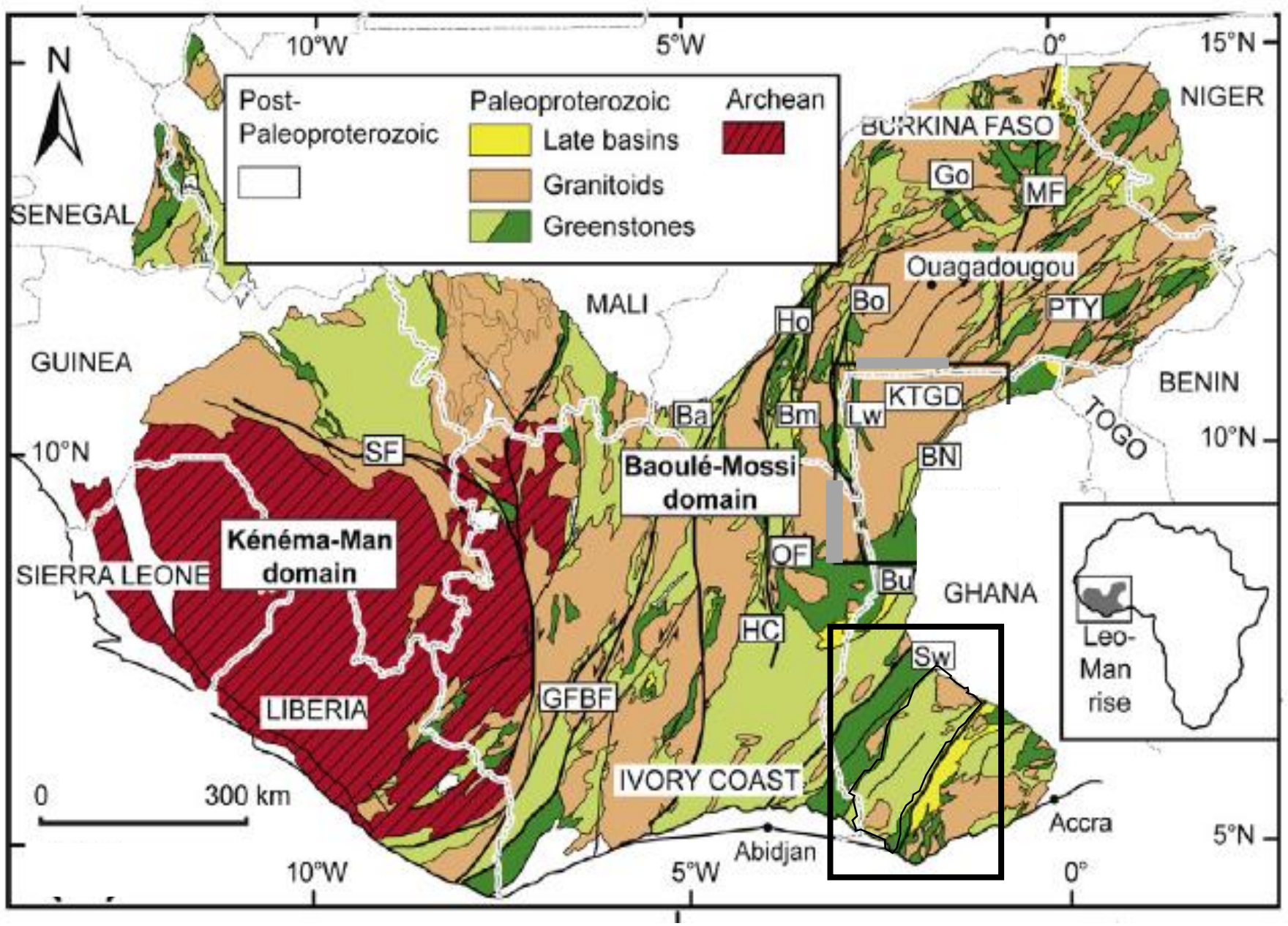
Stephan's interview

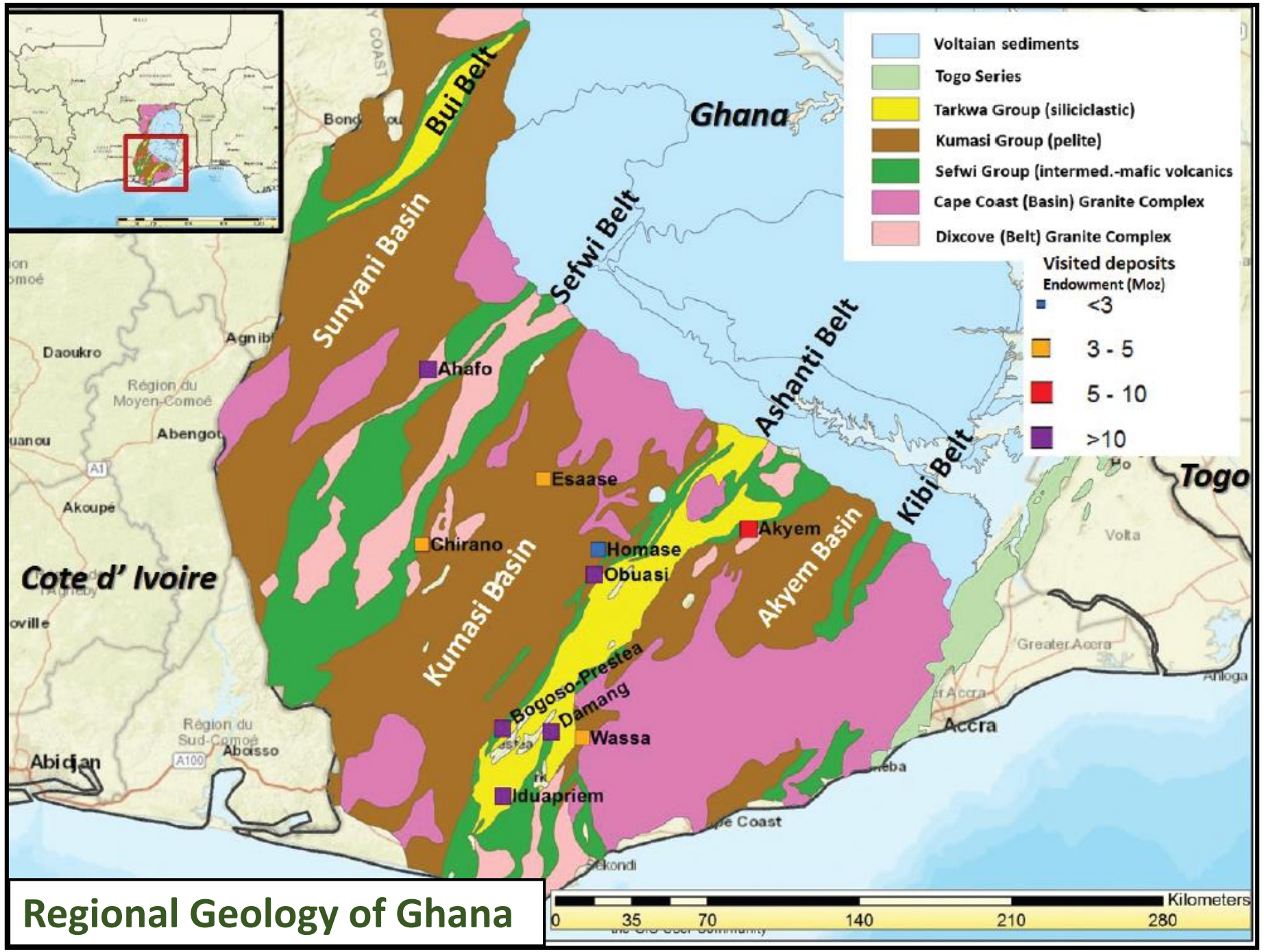
Team Fly-High

Brayden “The Drone Mane” St. Pierre
MSc
INRS-ETE

[Brayden’s interview]

The West African Craton & The Leo-Man Shield

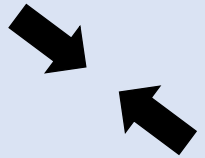




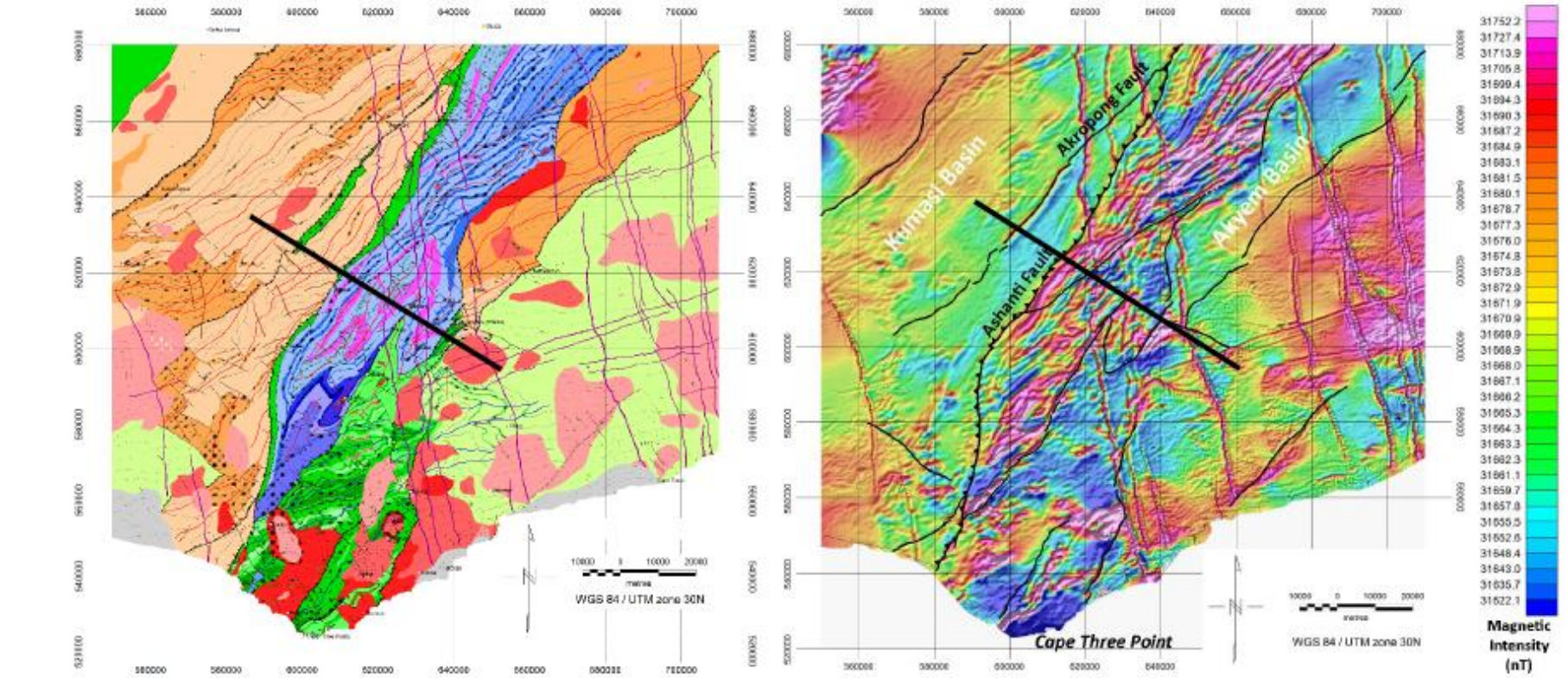
Regional Geology of Ghana

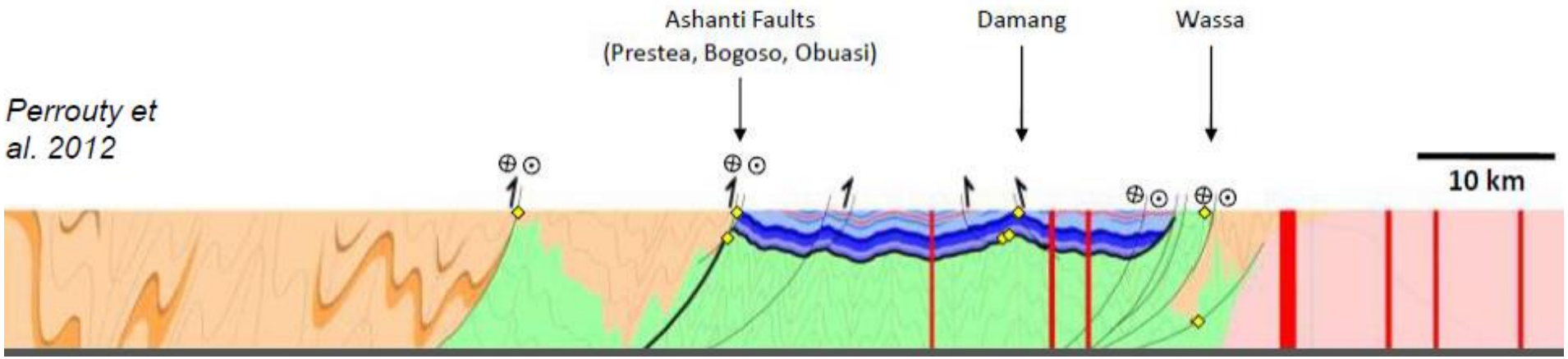
Tectono-stratigraphic History

Modified from Perrouty et al., (2012)

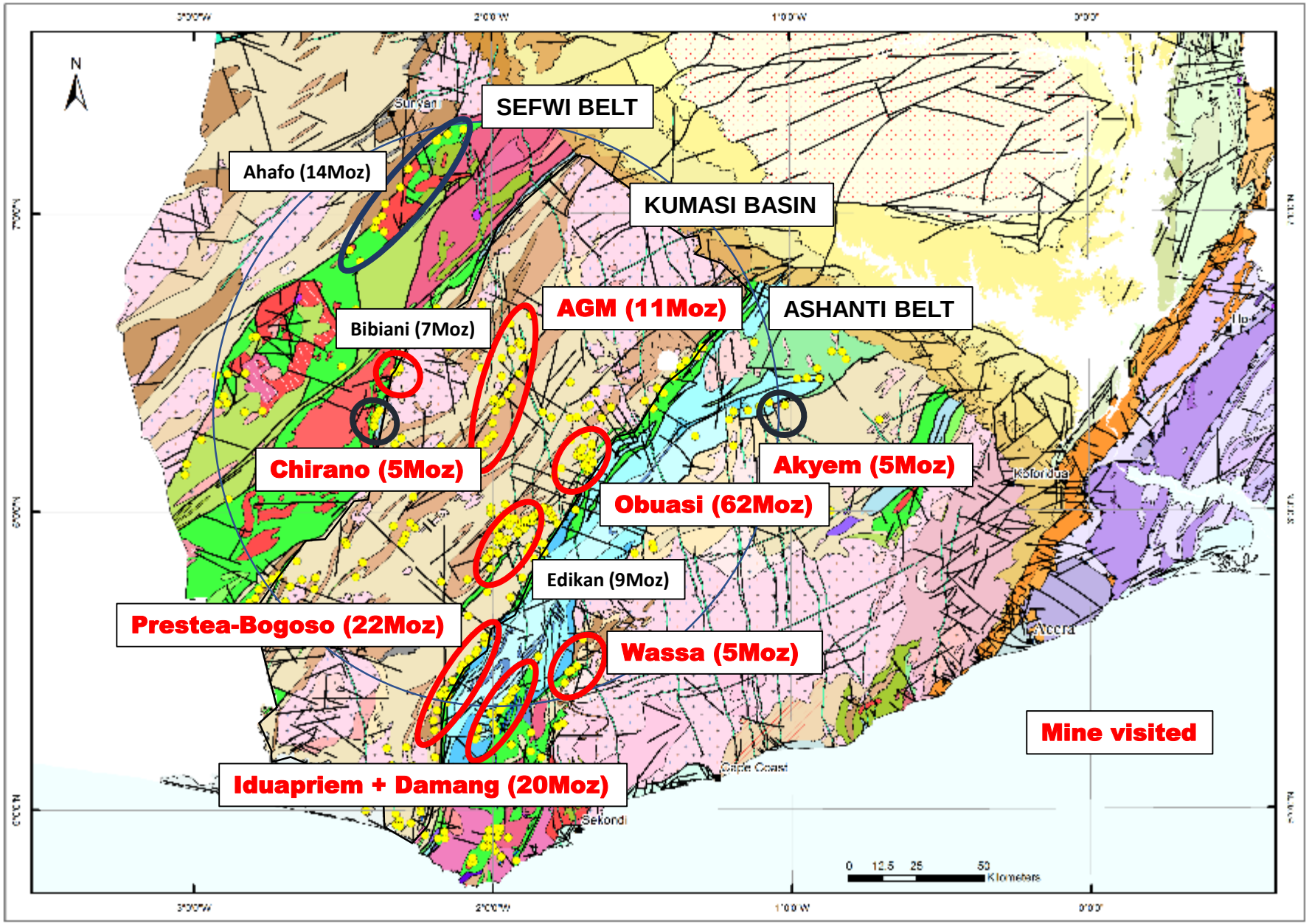
Regional Deformation History Interpretation		Principal Strain Orientation (σ1)
Eoeburnean 2187 - 2158 Ma	Sefwi Group volcanism and sedimentation	
	D1, N-S shortening Regional scale folding in the Sefwi Group Possible gold mineralisation	
D2 Extension Phase (2154 - 2125 Ma) Unknown orientation **Kumasi Group sedimentation**		
Eburnean 2125 - 1980 Ma	**Tarkwa Basin Formation (2107 - 2097 Ma)** **D3, NW-SE shortening** km scale folds in Birimian and Tarkwaian Emplacement of NE-SW thrust faults (Ashanti, Kenyase, Bibiani) and shear corridors (Akropong, Asankrangwa)	
	D4, NNW-SSE shortening Sinistral shear reactivation of D3 thrusts S4 crenulation cleavage ENE-WSW Greenschist retrograde metamorphism ENE-WSW brittle structure **Peak gold event in the Kumasi Basin**	
	D5 Recumbant folds (<m) Subhorizontal crenulation cleavage Last pyrite/gold mineralisation associated with quartz vein	
	D6, NE-SW shortening Low amplitude folds + crenulation cleavage ~N320 / 70 (RH) Reverse faults oriented NW-SE	

Ashanti Greenstone Belt – Cross-section





Ghana Gold Endowment



Gold deposit characteristics – Part 1

	Iduapriem	Damang	Wassa	Obuasi
Deposit Type	Paleoplacer	Overprinted paleoplacer by orogenic	Orogenic (oldest deposit, D1 gold event?)	Orogenic
Location	Ashanti G.B.	Ashanti G.B.	Ashanti G.B.	Ashanti G.B.
Host Rock	Tarkwa Gp. (Blanket Conglomerate)	Tarkwa Gp. (Blanket Conglomerate)	Birimian Volcanics & Sediments	Birimian Group (sediments) & sills
Structure	Along synform (no evidence of control by shear zone or fault)	Anticline & SE dipping Damang Fault	Fold hinges zones with ore bodies affected by two deformation phases	Axim-Konongo Shear Zone
Alteration	Hem	Chl – (Fe)Cb – Tourm	Chl – Ser – (Fe)Cb	Chl – Ser – (Fe)Cb
Sulphide		Py ± Po	Py – Po	Apy – Py
Mineral Resource (M + I)	5.5 Moz @ 1.42 g/t	4.82 Moz @ 2.24 g/t	3.33 Moz @ 2.38 g/t	33.5 Moz @ 7.37 g/t
Total Reserve (P+P)	1.84 Moz @ 1.27 g/t	1.6 Moz @1.73 g/t	1.33 Moz @ 2.37 g/t	5.49 Moz @ 8.01 g/t

Gold deposit characteristics – Part 2

	Bogoso & Prestea	Nkran, Akwasiso & Esaase	Chirano	Akyem
Deposit Type	Orogenic	Orogenic	Orogenic	Orogenic
Location	Ashanti G.B.	Kumasi Gp. (Sedimentary rocks)	Sefwi G.B.	Ashanti G.B.
Host Rock	Intercalated lenses of Tarkwa sandstone in Birimian rocks	Birimian Sediments & Granitic intrusions	Birimian Intrusives	Birimian Gp. (Sedimentary rocks)
Structure	Ashanti "Fault" Carbonaceous (graphitic) ductile shear zone	Asankrangwa Shear Zone	Chirano Shear Zone	Akyem Carbon Shear Zone
Alteration	Ser – (Fe)Cb	Chl – (Fe)Cb – Ser – Alb	Fuch – Alb – (Fe)Cb – Ser	Alb – (Fe)Cb – Ser – Chl
Sulphide	Apy – Py	Apy – Py	Py	Py
Mineral Resource (M + I)	2.45 Moz @ 3.85 g/t	7.94 Moz @ 1.71 g/t	3.8 Moz @ 2.75 g/t	0.23 Moz @ 1.79 g/t
Total Reserve (P + P)	0.582 Moz @ 8.96g/t	5.25 Moz @ 2.68	0.567 Moz @ 2.10g/t	2.82 Moz @ 1.53 g/t

Tarkwaian Paleoplacer Au

Principal characteristics

- Free Au hosted in the matrix of quartz pebble-rich conglomerate layers of the Tarwa Group
- Higher grade occurs in zones of coarser-grained, more closely-packed conglomerate units
- Matrix is rich in hem (±mag, ±py)

Conglomeratic sample from the orebody B /Iduapriem Mine

Examples: Iduapriem, Tarkwa, & Damang (Paleoplacer + Orogenic)

Tarkwaian Paleoplacer Au

Principal characteristics

- Fine gold distributed evenly throughout conglomerate matrix – not in basal channels as seen in modern placers (some modification possible?)
- Possible sourced from eroded older deposit to SE or E, with Wassa speculated as a potential source. Fine particulate gold and lack of nugget gold or gold in quartz suggests source from a disseminated gold deposit, such as a sulphide-rich shear zone hosted deposit

Conglomeratic sample from the orebody B /Iduapriem Mine

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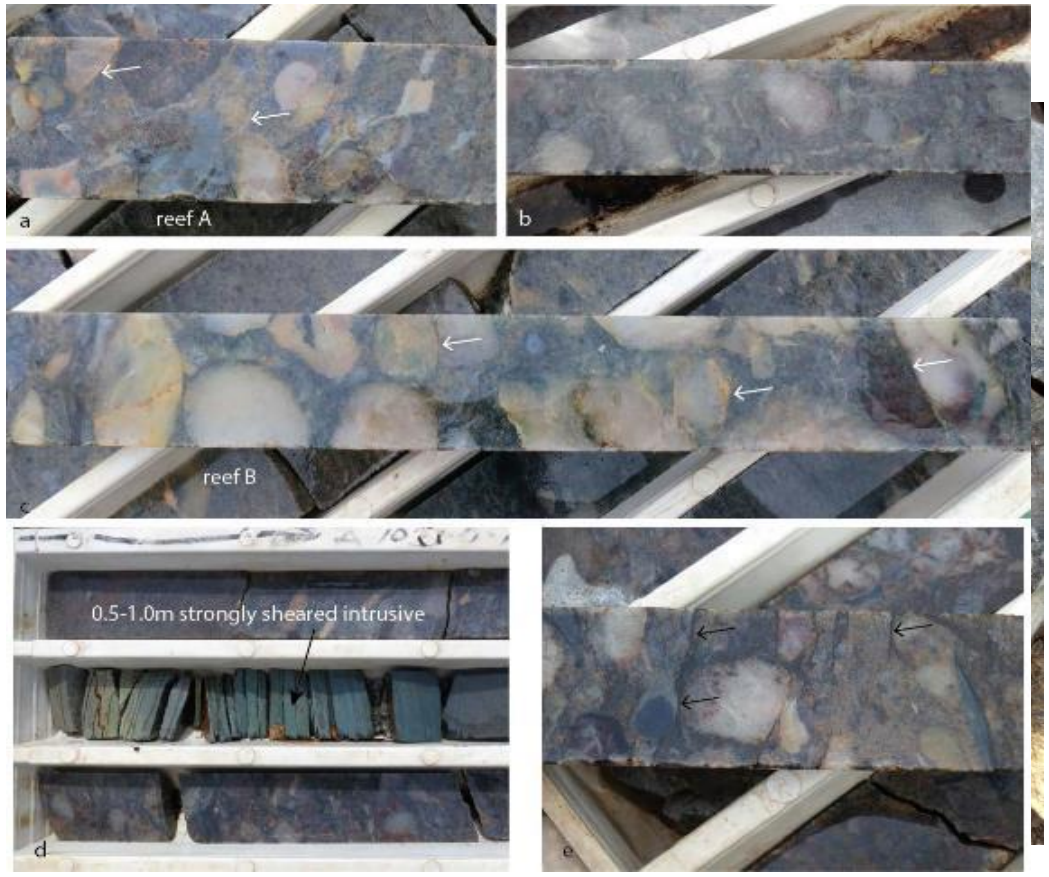


Conglomeratic sample from the orebody B /Iduapriem Mine

Examples: Iduapriem, Tarkwa, & Damang (Paleoplacer + Orogenic)

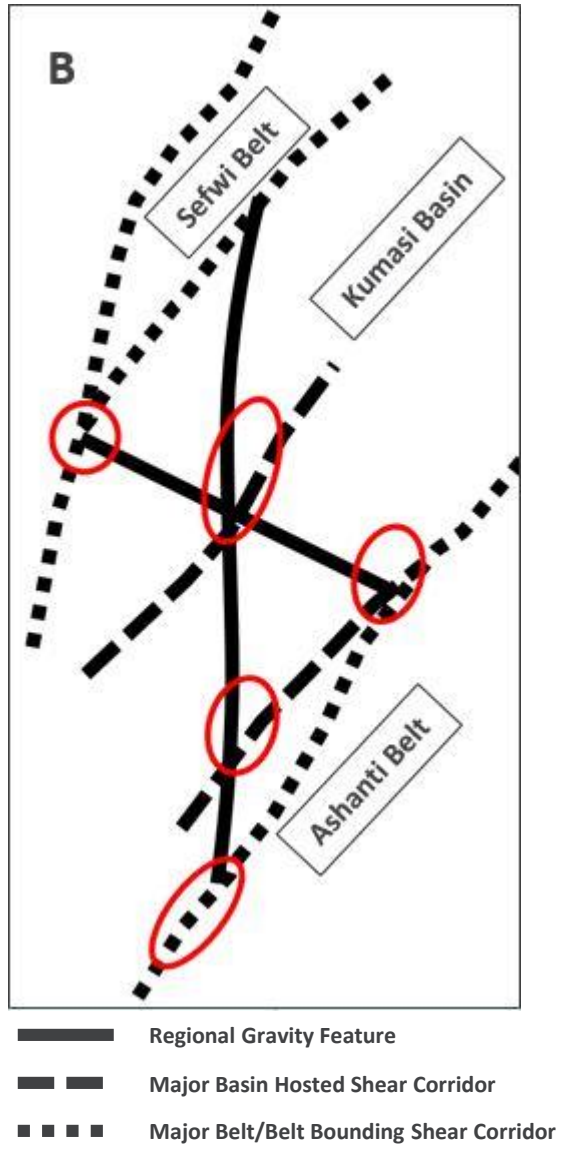
Orogenic gold exploration – Key points

Structural features are crucial!!!

1. **Dilation zones**

Regional – look for dilational jogs and 2nd to 3rd order fault splays. Act as conduit for hydrothermal fluid flow and localized dilatancy.

Intersecting lineaments along shear zones – (Asanko, Prestea-Bogoso, Obuasi, Bibiani).

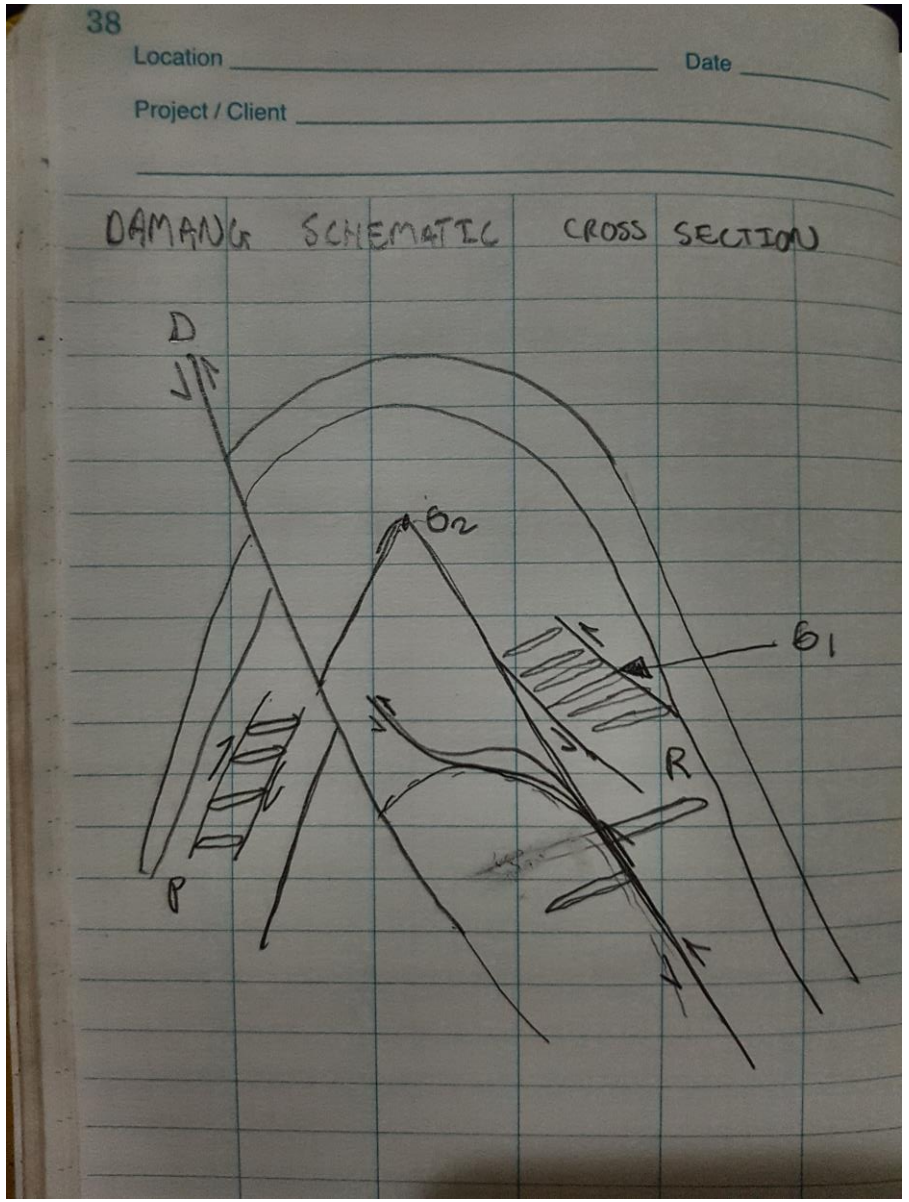


Orogenic gold exploration – Key points

1. **Deposit scale-** Fold hinges (Flexural slip, saddle Reef veins), shear zones, jogs along shear zones.

Brittle/Ductile vein arrays

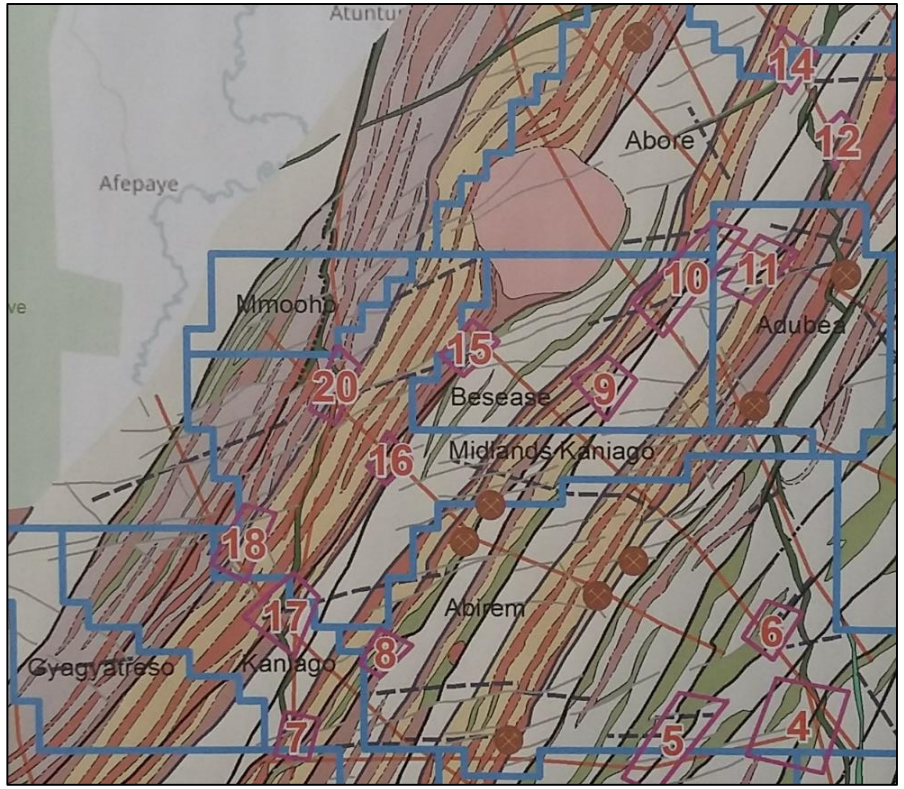
Central shear vein with extensional vein array near Damang



Orogenic gold exploration – Key points

2. Rheological competency contrast – heterogeneous stress variations between contrasting rock types (granite vs sandstone at Asanko Gold Mine and graphitic phyllite vs quartzite at Prestea-Bogoso Gold Mine). Strain is focused along these often promoting fluid pressure decrease and/or dilation during fault reactivation/fluid pumping.

Plan View Asanko



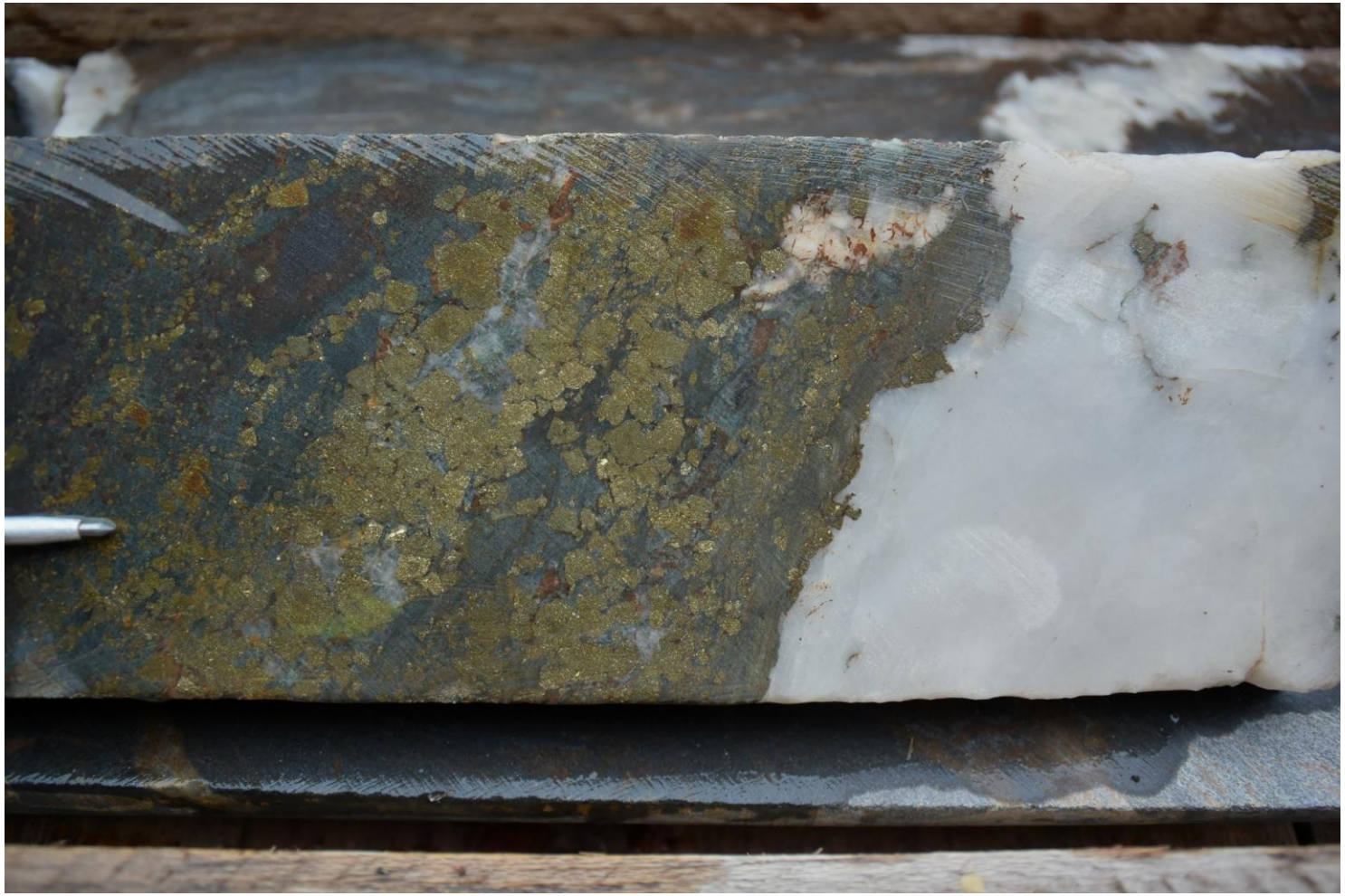
Quartzite boudins within graphitic phyllite

Orogenic gold exploration – Key points

3. Chemical Trap Sites– Gold precipitates in iron rich host rocks(eg, dolerites, BIFs, Magnetic mudstone units, e.g. Wassa).

High grade Banded Magnetic Unit (BMU)

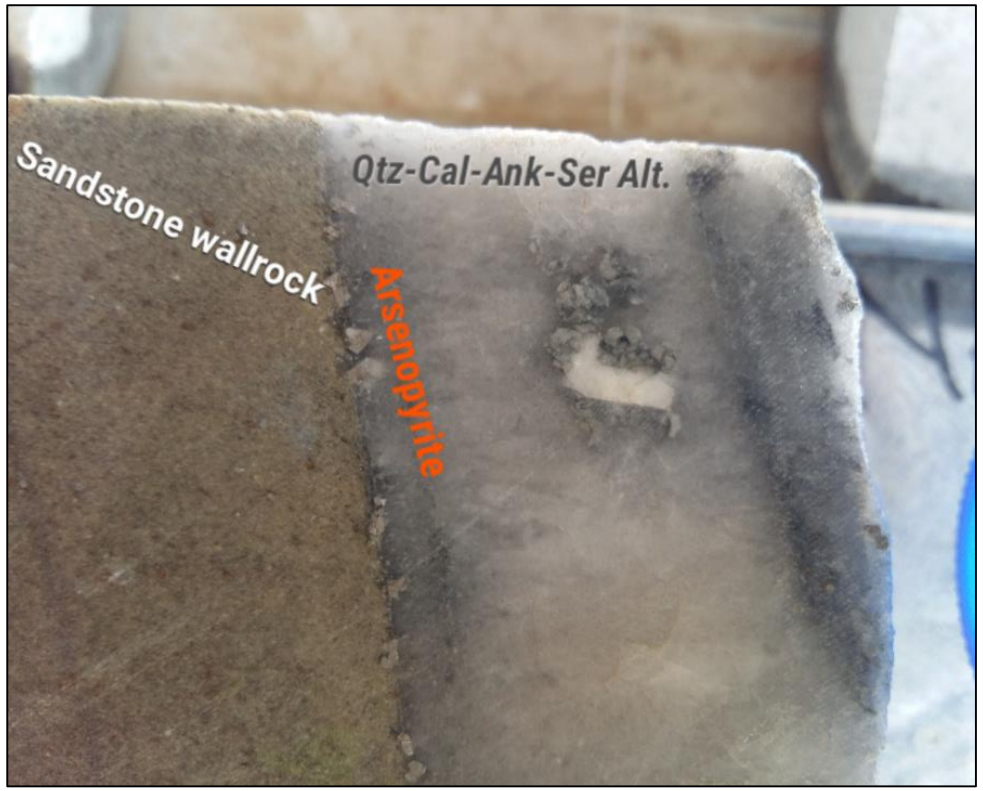
-Magnetite within banded Mudstone unit replaced by Pyrite, by the infiltration of gold bearing fluids reacting with magnetite and precipitating gold (shown on right, from Damang).



Orogenic gold exploration – Key points

Structural features are crucial!!!

4. Alteration assemblages- occurs on a much broader zonal scale than mineralization and easier to identify in the field.



Words of Wisdom

- Drill for structure, drift for grade
- Old mines never die, they just rest a while
- Many gold discoveries in West Africa result from following up on areas of artisanal mining
- Importance of testing ALL lithologies when exploring in new areas
- Kilometres of displacement can be accommodated by narrow shear zones; these may appear insignificant in drillcore, but can control multi-million oz gold deposits (e.g. Damang)

Artisanal miners in Ghana – a great vector for gold

Orogenic gold exploration – Key points

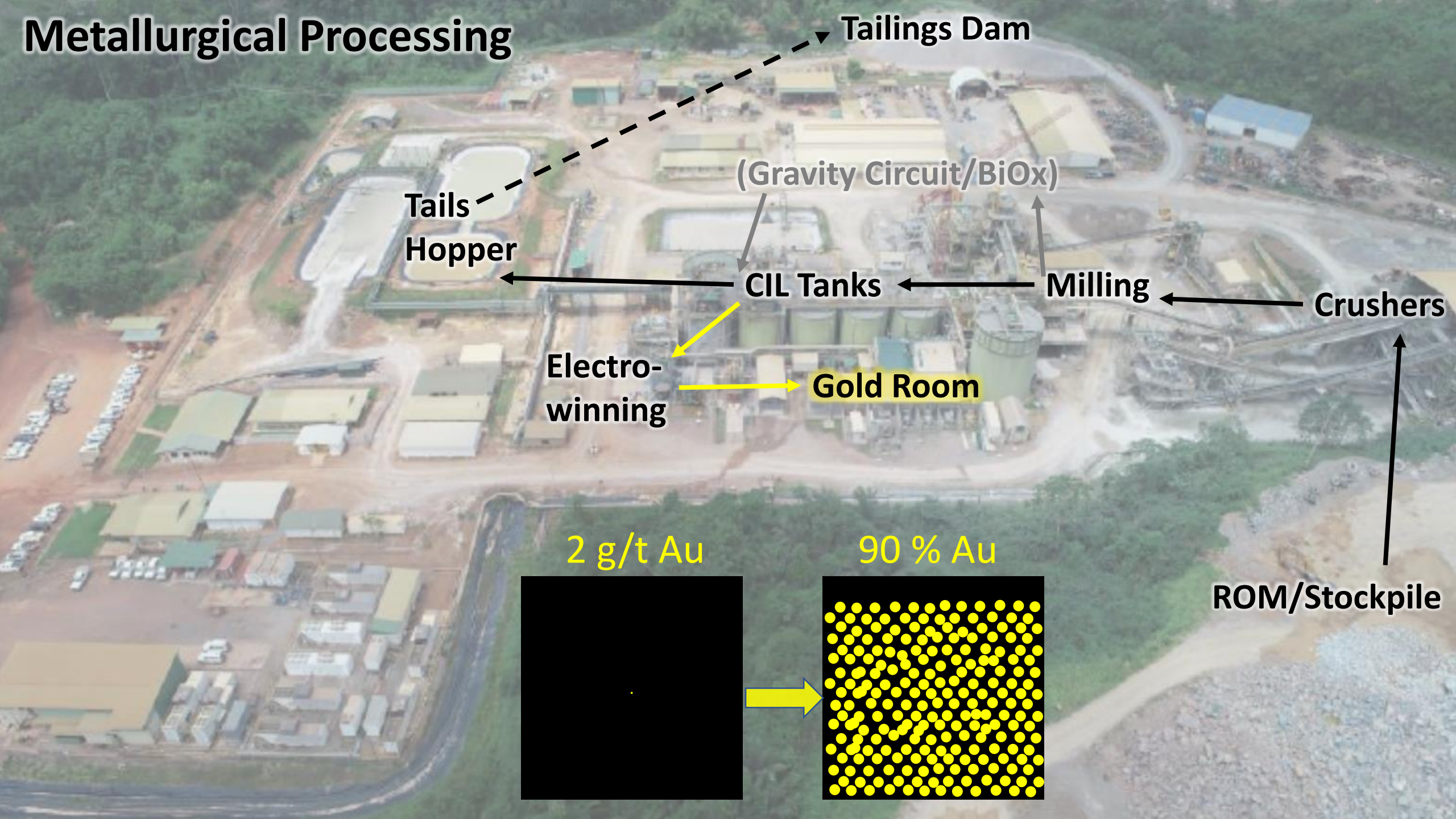
Don’t marry your model…..

….your EXPLORATION model

Metallurgical Processing

Processing Plant at Iduapriem

Metallurgical Processing



Metallurgical Processing 1

The following processes are used in processing Au at the Au mines visited.

ROM/Stockpile

- Transport ore to the processing plant/ROM
- Ore is separated in fresh, oxidized rock, low grade, and high grade
- Blend it for consistent grade and same hardness

Akyem Open Pit

Crushers

- Series of crushes: Jaw Crusher, Secondary Crusher, Tertiary Crusher and Screens
- Reduces the size of the ore to ~15 mm

Crusher at Asanko

Milling

- To reduce the size of the ore to final size for gold recovery
- From ~15mm to ~0.10mm
- Series of multiple mills: Semi-Autogenous (SAG) and Balls. Cyclones utilized (usually highest part of plant).

Metallurgical Processing 2

Gravity Settling

- Higher recoveries from gravity when gold is coarser grained
- Works on high relative density of gold
- Gravity recoveries vary from 30-60% when used

Gravity circuit in Asanko

CIL (Carbon-in-Leach)

- Leaching gold from ore into solution and adsorbing it to Carbon
- Oxygen added as oxidizing agent, lime as pH modified and thickener, cyanide to facilitate the reaction
- After multi-stage of leaching, gold is stripped from Carbon into solution, using caustic acid under T and P

BiOx

- BiOx is used for refractory ore (Au is locked up inside sulfides)
- Bacteria is used to eat away the sulfide crystals to liberate the gold
- High processing cost
- Used at Bogoso and Obuasi

Metallurgical Processing 3

Electro-winning

- Gold is now held in a loaded solution – needs to be removed
- Negatively charged anodes used to attract positively charged Au
- Steel rod/steel mesh to remove concentrated Au from the anodes

The finished product!

Smelting

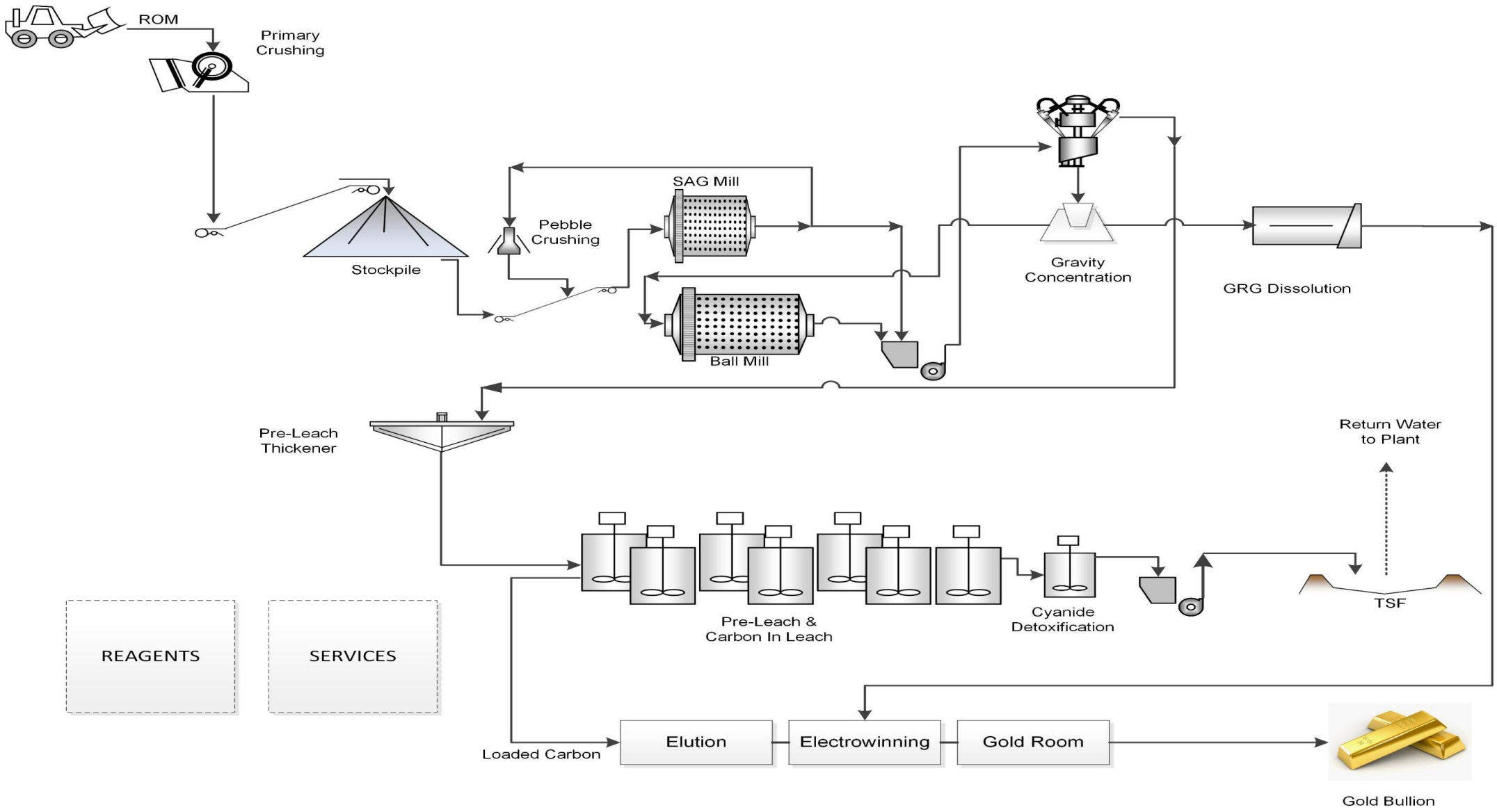
- Smelting is undertaken at temperatures between 1150-1450 degrees Celsius.
- When poured, gold settles in the first of multiple molds due to high density
- Shipped for refinement

Tailings

- Gangue material from the processing plant is pumped to a number of tails hoppers, and onwards to the tailings dam
- Grades in the talings as low as 0.01 g/t (Iduapriem)

Tailing at Chirano

Example: Plant flow-chart from Asanko



Metallurgical Processing

Recoveries for mines visited

- Au recovery varied in the mines visited
- Gravity recovery up to 60%
- Recovery depends on the nature of the gold mineralization (free vs. refractory ore)
- Residence times in the leach vats vary from 18 hours (Iduapriem) to 26 hours (Asanko)

Producing Gold Mine Visited	Recovery (%)	Gravity Recovery (%)
Iduapriem	95%	/
Damang	80-90%	40%
Wassa	95%	30%
Prestea	94%	60%
Chirano	94%	/
Asanko	93.5%	50%

**/ indicates no data*

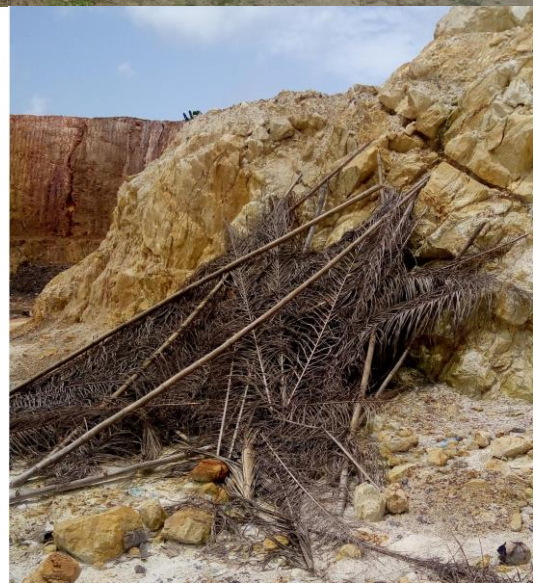
More than just rocks…

- For many of us, first time in Africa
- Amazing opportunity to experience a different culture
- It‘s a big world... Geology (and the SEG!) can help us see it

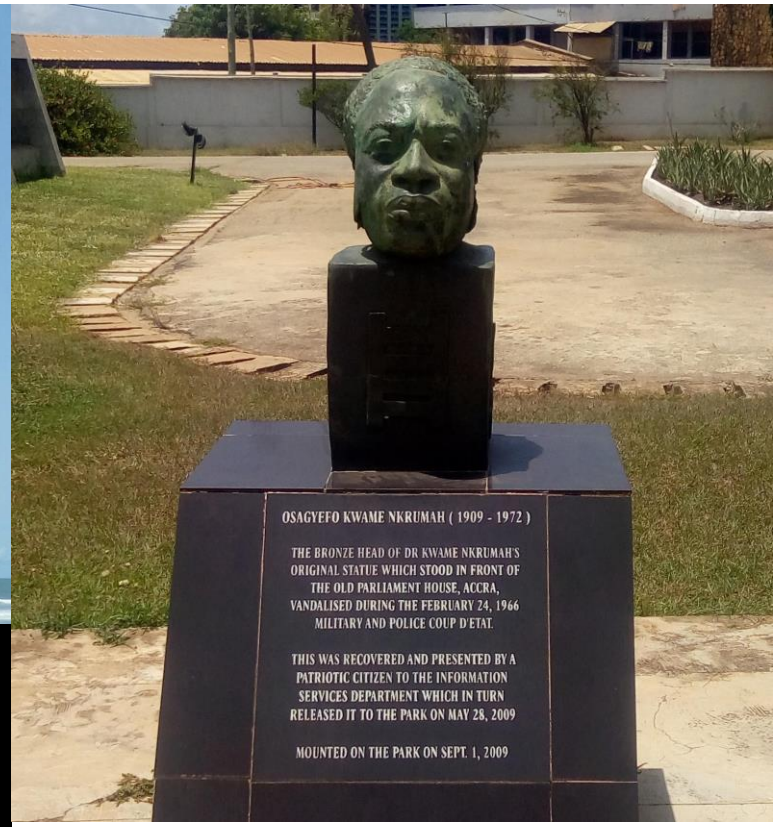
Lush Ghanaian rainforest (top); exploring the capital city Accra (bottom)

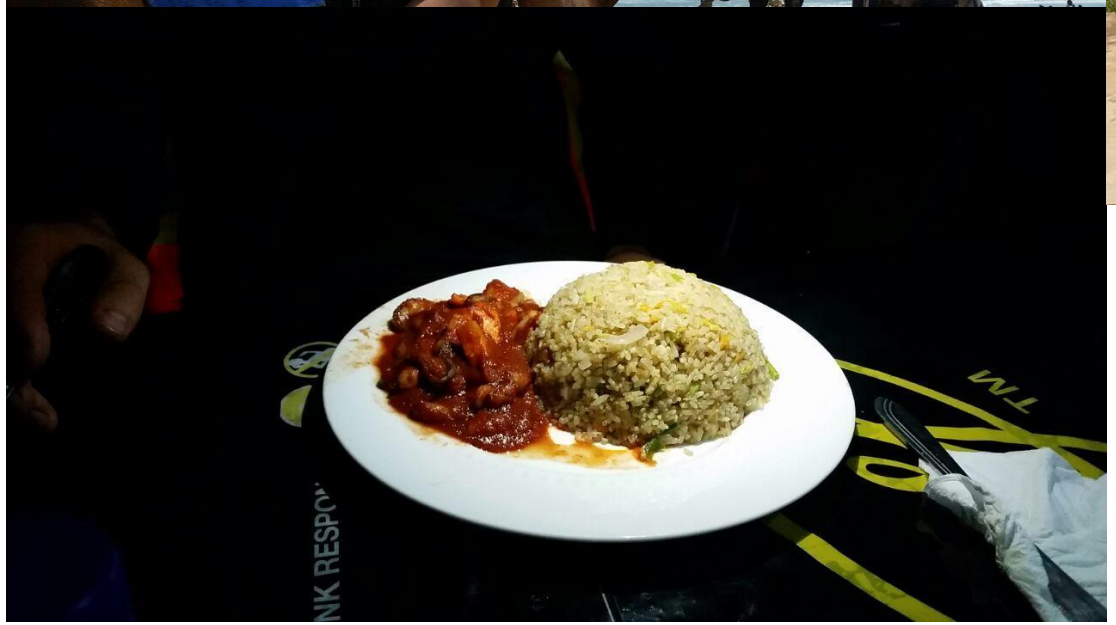
More than just rocks…

- Akwaaba! Ghanaians are warm, welcoming, happy
- Learned about European colonialism, Ghanaian independence, history of gold mining (in particular, artisanal mining)
- Had the honour of meeting the Kumasi chief!

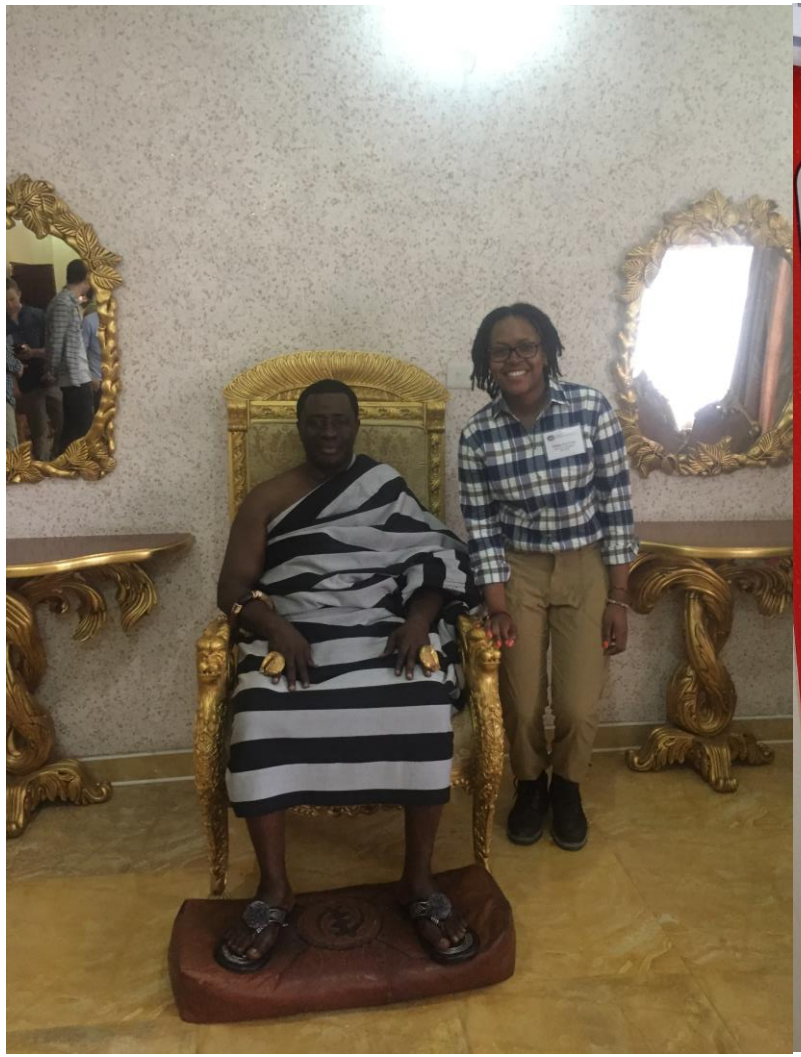


Learning the history of Bosumtwi Crater Lake (top); remnants of artisinal mining near Prestea (right)





Horse riding on the beach in Accra (top left); typical local cuisine (bottom left); statue of Dr. Kwame Nkrumah, Ghana's first president (top right)



Meeting chief Nana Kwadwo Atuahene of Asafo Kumasi (left); safety is our first priority (centre); words of wisdom from our bus driver (right)

Looking forward

- SEG aiming to establish presence (e.g. student chapters) in Ghana and West Africa

- SFT-18: Epithermal precious metal and Cu-Ag systems of Northern Chile; Jan. 12-19, 2019 (approximate dates)

- Information about previous trips, future activities, and applications can be found here:

  www.segweb.org/StudentFieldTripProgram