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*

**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*

**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*

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

“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

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

Elliot Wehrle  
B.Sc. Geology  
Laurentian University  

Ethan’s interview  
Elliot’s interview
Team Schistosité

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

Christophe Wakamya
M.Sc Candidate
University of Arkansas

Manon Valette
PhD Candidate
U. du Quebec à Montreal

Issoufou’s interview
Christophe’s interview
Manon’s interview
Team J

Josh Hughes
Ph.D. Candidate
University of Durham

Jack Thornton
B.Sc Geology Student
University of Leeds

Joey Vrzovski
M.Sc. Candidate
Lakehead University

Josh’s interview
Jack’s interview
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

Georgi Milenkov  
M.Sc.  
University of Geneva

Malte’s interview  
Georgi’s interview
Team Reunite Gondwanaland

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

Nikita La Cruz
Ph.D. Candidate
University of Michigan

Stephan Dunn
M.Sc. Geology
University of Stellenbosch

Renan’s interview
Nikita’s interview
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

<table>
<thead>
<tr>
<th>Regional Deformation History Interpretation</th>
<th>Principal Strain Orientation ($\sigma_1$)</th>
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</thead>
<tbody>
<tr>
<td><strong>Eoeburnean</strong> 2187 - 2158 Ma</td>
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<tr>
<td>Sefwi Group volcanism and sedimentation</td>
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<tr>
<td><strong>D1, N-S shortening</strong></td>
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<tr>
<td>Regional scale folding in the Sefwi Group</td>
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<tr>
<td>Possible gold mineralisation</td>
<td></td>
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<tr>
<td><strong>D2 Extension Phase (2154 - 2125 Ma) Unknown orientation</strong></td>
<td></td>
</tr>
<tr>
<td>Kumasi Group sedimentation</td>
<td></td>
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<tr>
<td><strong>D3, NW-SE shortening</strong></td>
<td></td>
</tr>
<tr>
<td>Tarkwa Basin Formation (2107 - 2097 Ma)</td>
<td></td>
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<tr>
<td>km scale folds in Birimian and Tarkwaian</td>
<td></td>
</tr>
<tr>
<td>Emplacement of NE-SW thrust faults (Ashanti, Kenyase, Bibiani) and shear corridors (Akropong, Asankrangwa)</td>
<td></td>
</tr>
<tr>
<td><strong>D4, NNW-SSE shortening</strong></td>
<td></td>
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<tr>
<td>Sinistral shear reactivation of D3 thrusts</td>
<td></td>
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<tr>
<td>S4 crenulation cleavage ENE-WSW</td>
<td></td>
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<tr>
<td>Greenschist retrograde metamorphism</td>
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<tr>
<td>ENE-WSW brittle structure</td>
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<tr>
<td><strong>Peak gold event in the Kumasi Basin</strong></td>
<td></td>
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<tr>
<td><strong>D5</strong></td>
<td></td>
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<tr>
<td>Recumbant folds (&lt;m)</td>
<td></td>
</tr>
<tr>
<td>Subhorizontal crenulation cleavage</td>
<td></td>
</tr>
<tr>
<td>Last pyrite/gold mineralisation associated with quartz vein</td>
<td></td>
</tr>
<tr>
<td><strong>D6, NE-SW shortening</strong></td>
<td></td>
</tr>
<tr>
<td>Low amplitude folds + crenulation cleavage ~N320 / 70 (RH)</td>
<td></td>
</tr>
<tr>
<td>Reverse faults oriented NW-SE</td>
<td></td>
</tr>
</tbody>
</table>

Modified from Perrouty et al., (2012)
Ashanti Greenstone Belt – Cross-section

Perrouty et al. 2012

10 km
Ghana Gold Endowment

KUMASI BASIN

ASHANTI BELT

SEFWI BELT

AGM (11Moz)

Akyem (5Moz)

Obuasi (62Moz)

Edikan (9Moz)

Wassa (5Moz)

Prestea-Bogoso (22Moz)

Iduapriem + Damang (20Moz)

Mine visited
# Gold deposit characteristics – Part 1

<table>
<thead>
<tr>
<th></th>
<th>Iduapriem</th>
<th>Damang</th>
<th>Wassa</th>
<th>Obuasi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deposit Type</strong></td>
<td>Paleoplacer</td>
<td>Overprinted paleoplacer by orogenic</td>
<td>Orogenic (oldest deposit, D1 gold event?)</td>
<td>Orogenic</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Ashanti G.B.</td>
<td>Ashanti G.B.</td>
<td>Ashanti G.B.</td>
<td>Ashanti G.B.</td>
</tr>
<tr>
<td><strong>Host Rock</strong></td>
<td>Tarkwa Gp. (Blanket Conglomerate)</td>
<td>Tarkwa Gp. (Blanket Conglomerate)</td>
<td>Birimian Volcanics &amp; Sediments</td>
<td>Birimian Group (sediments) &amp; sills</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td>Along synform (no evidence of control by shear zone or fault)</td>
<td>Anticline &amp; SE dipping Damang Fault</td>
<td>Fold hinges zones with ore bodies affected by two deformation phases</td>
<td>Axim-Konongo Shear Zone</td>
</tr>
<tr>
<td><strong>Alteration</strong></td>
<td>Hem</td>
<td>Chl – (Fe)Cb – Tourm</td>
<td>Chl – Ser – (Fe)Cb</td>
<td>Chl – Ser – (Fe)Cb</td>
</tr>
<tr>
<td><strong>Sulphide</strong></td>
<td></td>
<td>Py ± Po</td>
<td>Py – Po</td>
<td>Apy – Py</td>
</tr>
<tr>
<td><strong>Mineral Resource (M + I)</strong></td>
<td>5.5 Moz @ 1.42 g/t</td>
<td>4.82 Moz @ 2.24 g/t</td>
<td>3.33 Moz @ 2.38 g/t</td>
<td>33.5 Moz @ 7.37 g/t</td>
</tr>
<tr>
<td><strong>Total Reserve (P+P)</strong></td>
<td>1.84 Moz @ 1.27 g/t</td>
<td>1.6 Moz @ 1.73 g/t</td>
<td>1.33 Moz @ 2.37 g/t</td>
<td>5.49 Moz @ 8.01 g/t</td>
</tr>
</tbody>
</table>
# Gold deposit characteristics – Part 2

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

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

Conglomeratic sample from the orebody B /Iduapriem Mine
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

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

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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
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 (e.g., 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 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

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

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

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

**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)
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)

<table>
<thead>
<tr>
<th>Producing Gold Mine Visited</th>
<th>Recovery (%)</th>
<th>Gravity Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iduapriem</td>
<td>95%</td>
<td>/</td>
</tr>
<tr>
<td>Damang</td>
<td>80-90%</td>
<td>40%</td>
</tr>
<tr>
<td>Wassa</td>
<td>95%</td>
<td>30%</td>
</tr>
<tr>
<td>Prestea</td>
<td>94%</td>
<td>60%</td>
</tr>
<tr>
<td>Chirano</td>
<td>94%</td>
<td>/</td>
</tr>
<tr>
<td>Asanko</td>
<td>93.5%</td>
<td>50%</td>
</tr>
</tbody>
</table>

*/ 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!
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