Regional deformation and mineral systems (gold focus)

[1]John Miller*, [2]Yan Bourassa, [3]Kim Hein, [1]Denis Fougerouse, [1]James Davis, [1]Vanessa Markwitz, [4]Elodie Le Mignot, [5]Luc Siebenaller, [5]Didier Béziat, [5]Stefano Salvi, [4]Anne-Sylvie André-Mayer, [5]Lenka Baratoux, [1]Vasek Metelka, [5]Sylvain Block, [1]Mark Jessell, [6]Stephane Perrouty [1]Nicolas Thébaud, [1]Campbell McCuaig, [7]Stanislav Ulrich

[1]Centre for Exploration Targeting, University of Western Australia
[2]Golden Star Resources Ltd, Toronto
[3]School of Geosciences, University of the Witwatersrand, South Africa
[4]GeoRessources, Université de Lorraine-CNRS-CREGU, France
[5]IRD, Université Toulouse III, Toulouse, France
[6]Earth Sciences, Western University, Canada
[7]Anglogold Ashanti, Australia

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WAXI- West African Exploration Initiative

IXOA- L'Initiative d'Exploration Ouest Africaine

At close of Stage 2

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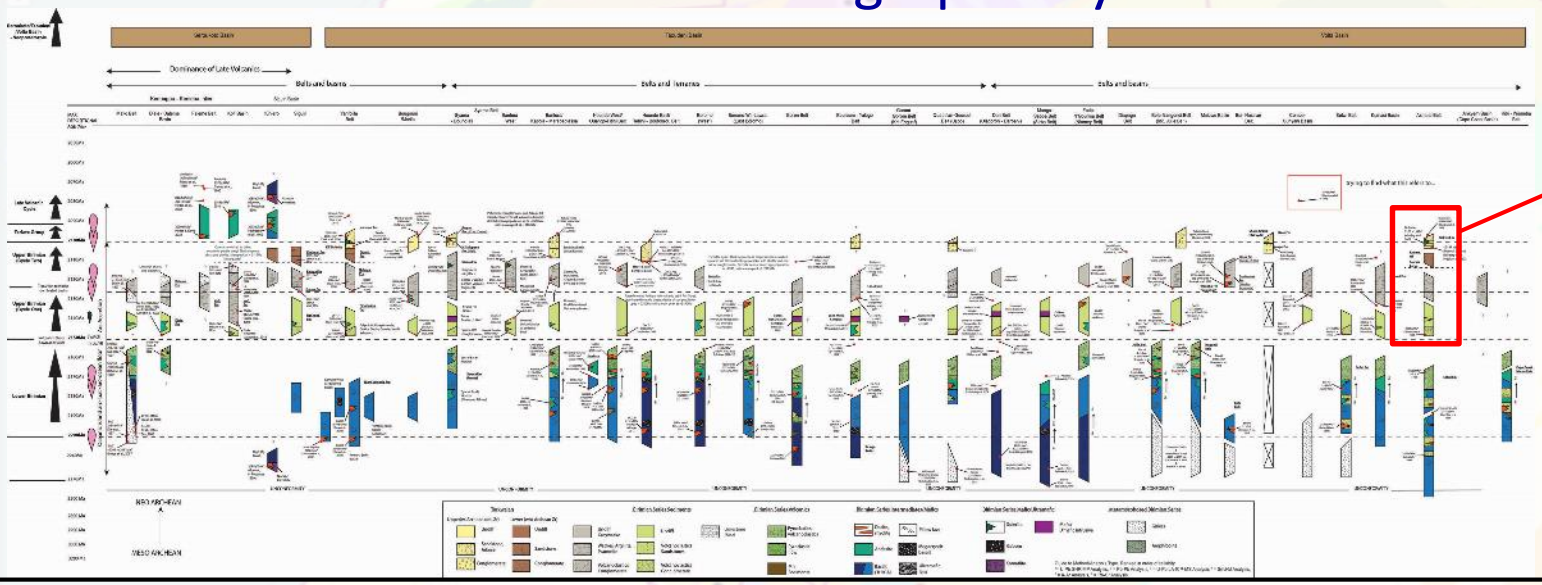
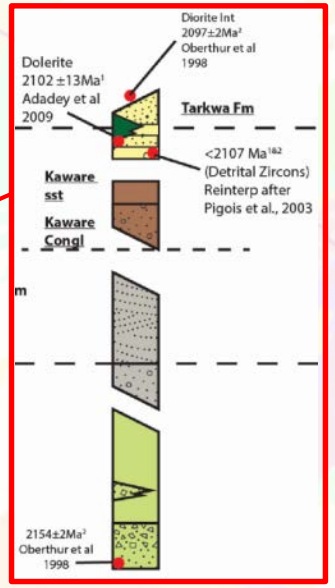
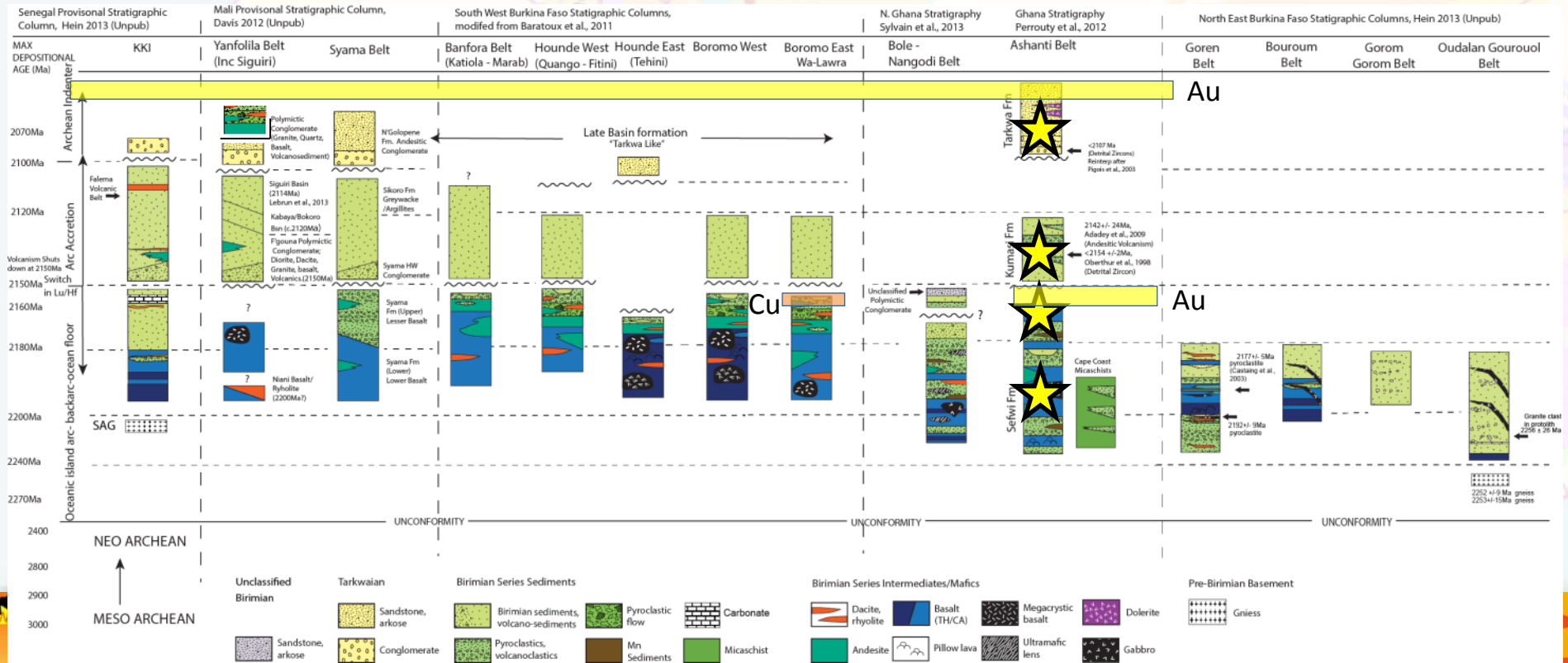
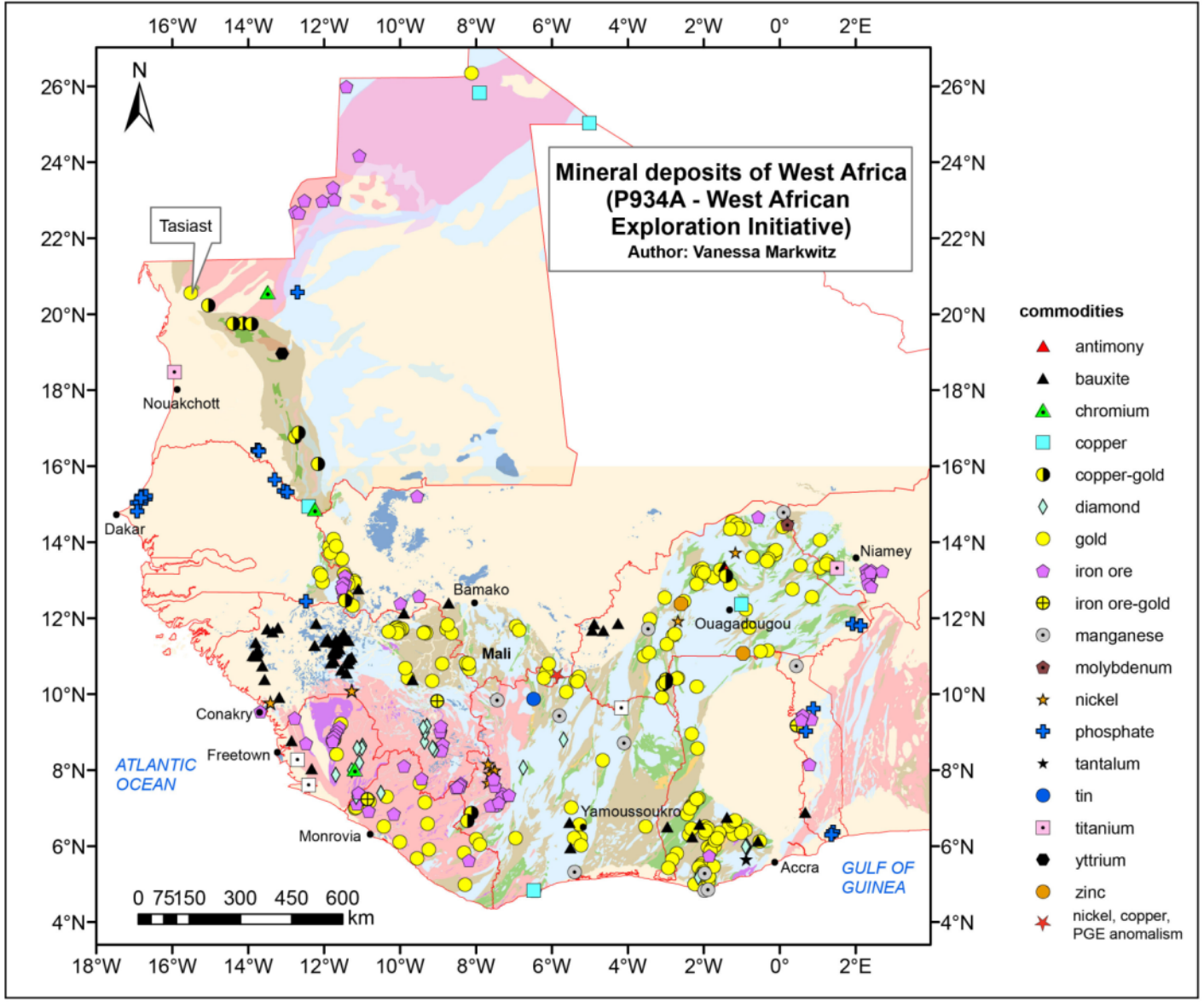
WAXI2 Stratigraphic Synthesis



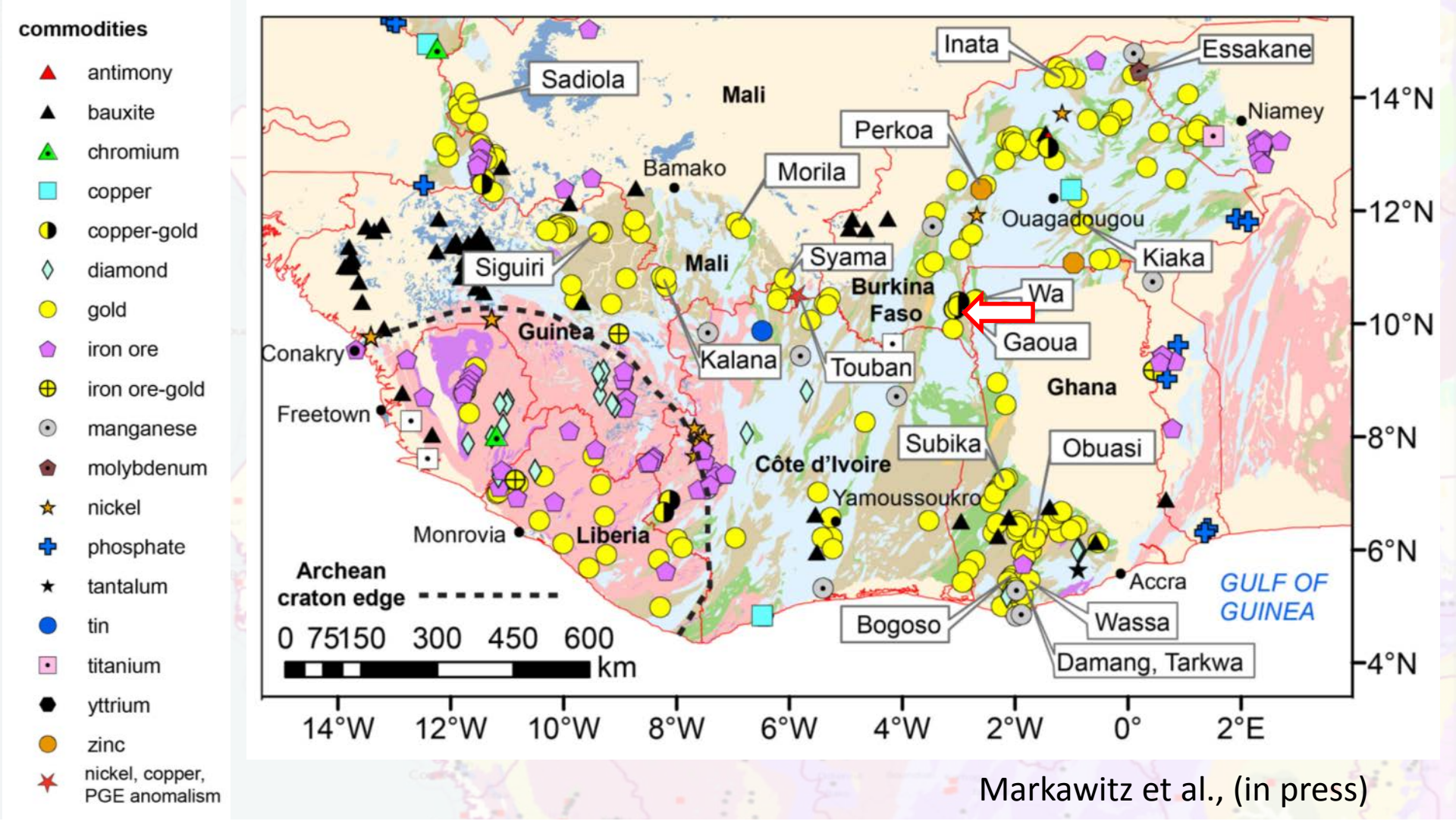






- WAXI2 deposit data base
- Produced by Vanessa Markwitz
- In press with PreCambrian Research

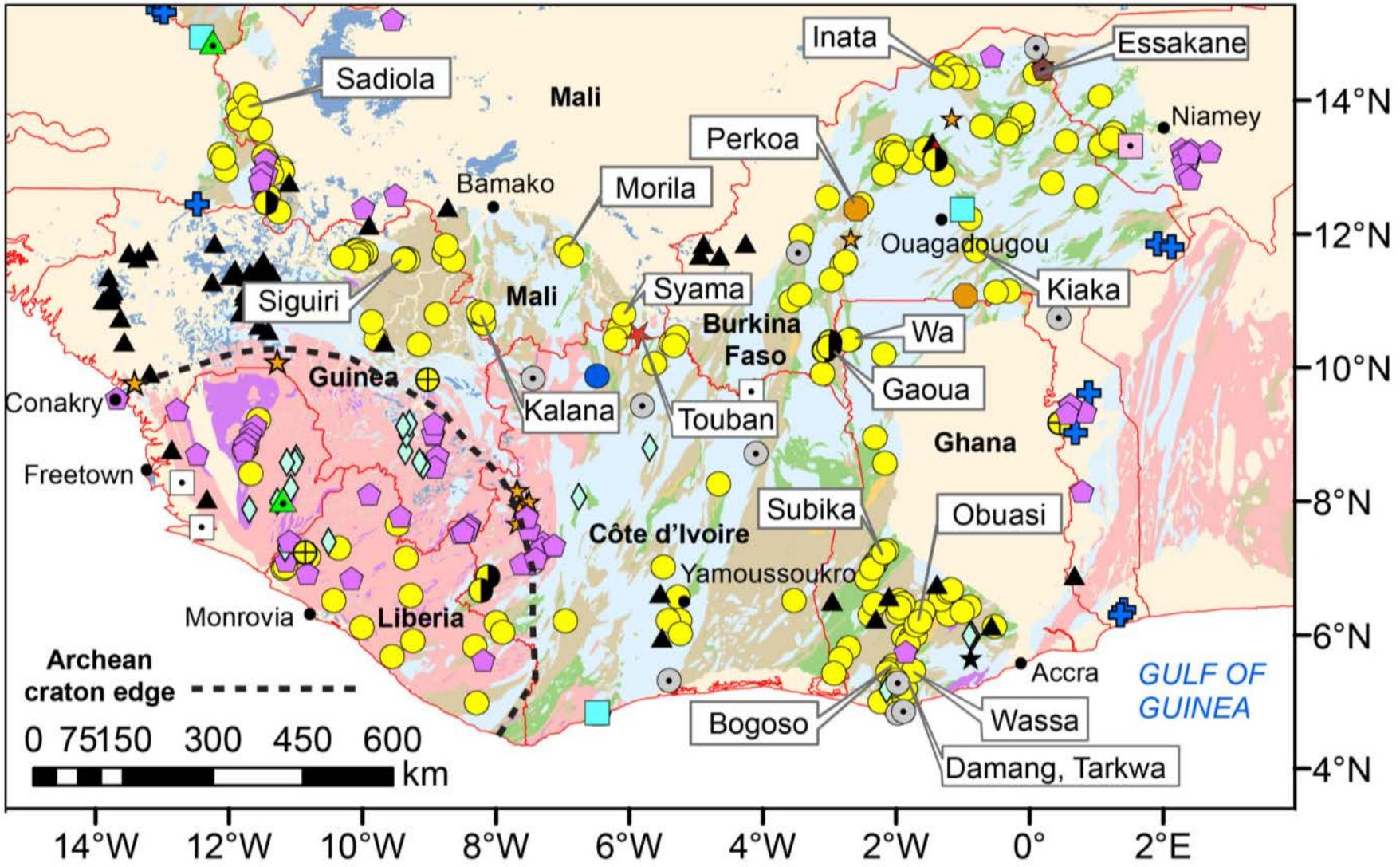
Birimian volcano-sedimentary belts with associated granitoids (2.25 to 1.96 Ga)
Late sedimentary sequence (2010-2000Ma)



Markawitz et al., (in press)

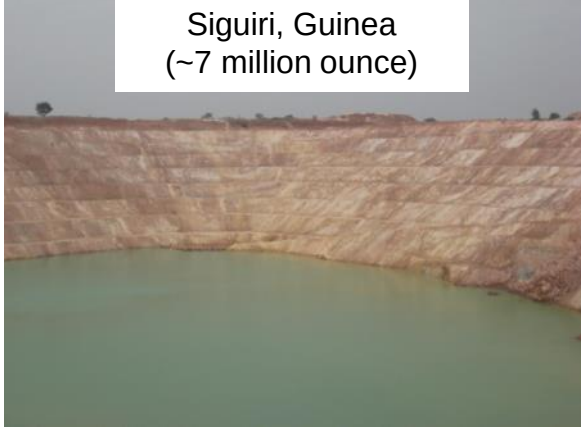
1) *Ni deposits and Platinoid occurrences* are along Archean Craton Margin and ultramafic intrusions
2) *Base metal and copper-gold systems.* The Boromo Belt in Burkina Faso has VMS deposits (Zn-rich Perkoa deposit) and Cu-Au porphyry systems with calc-alkaline volcanic rocks (Gaoua).

The restricted nature of the distribution of these systems compared to the gold-only systems, is inferred to reflect the distinct tectonic settings that these deposits form in.



Major focus on gold-only systems on WAXI2 – very diverse distribution

Siguiri, Guinea
(~7 million ounce)



Komana, Mali

Mana ~ 2 million ounces
Burkina Faso

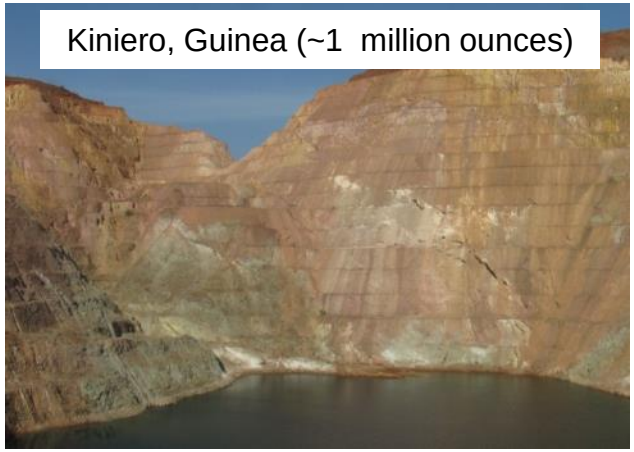
Morila, Mali
(~7 million ounce)

Sadiola, Mali
(~5 million ounce)

Obuasi, Ghana
(~50 million ounces)

Syama, Mali
(~5 million ounce)

Kiniero, Guinea (~1 million ounces)



Bogoso, Ghana (~5 million ounces)

Gold deposit host rocks (2.2-2.1 Ga)

Host rock types range from;

- carbonate-hosted (Sadiola)
- sediment-hosted (Siguiri, Obuasi)
- sediment and granitoid hosted (Kalana)
- mafic intrusive hosted (e.g., Syama)
- mafic volcanic hosted (e.g. Kiniero)
- granitoid hosted (e.g. Banfora, Subika)
- placer deposits in quartz-pebble conglomerates (Tarkwa).

Tarkwa Lode (late stage basin)

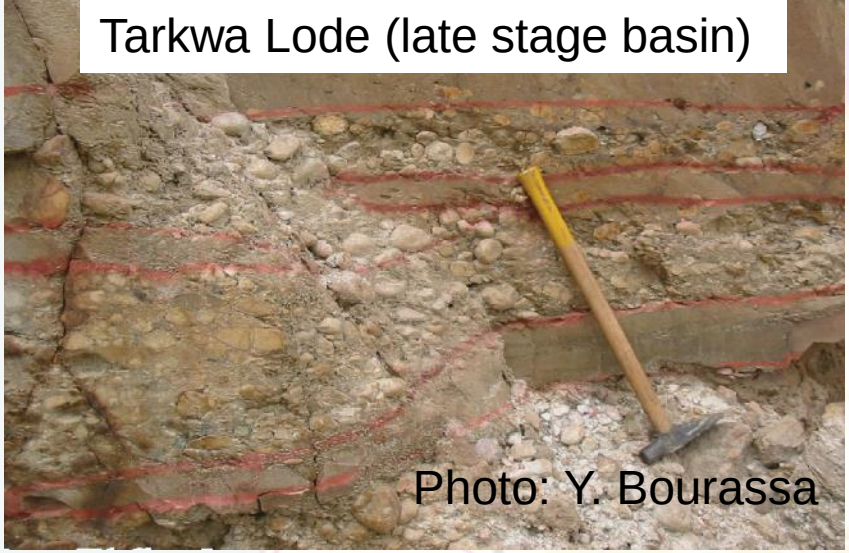
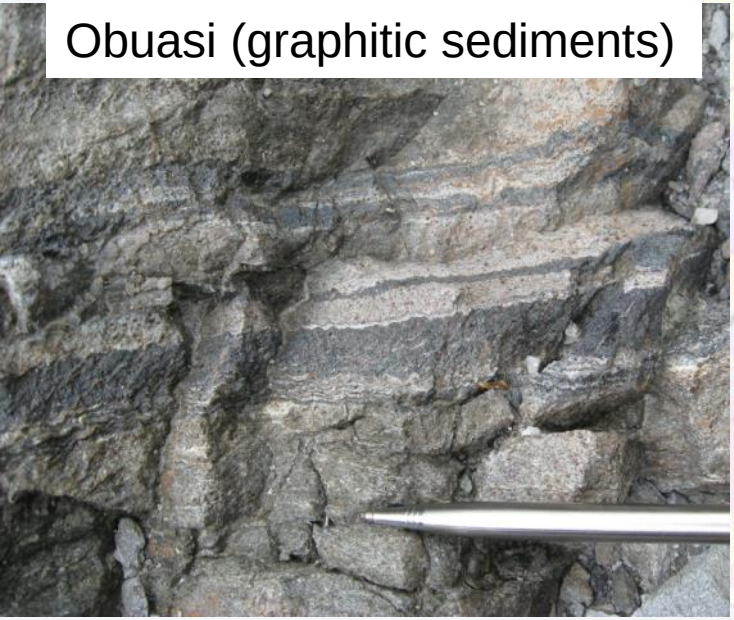


Photo: Y. Bourassa

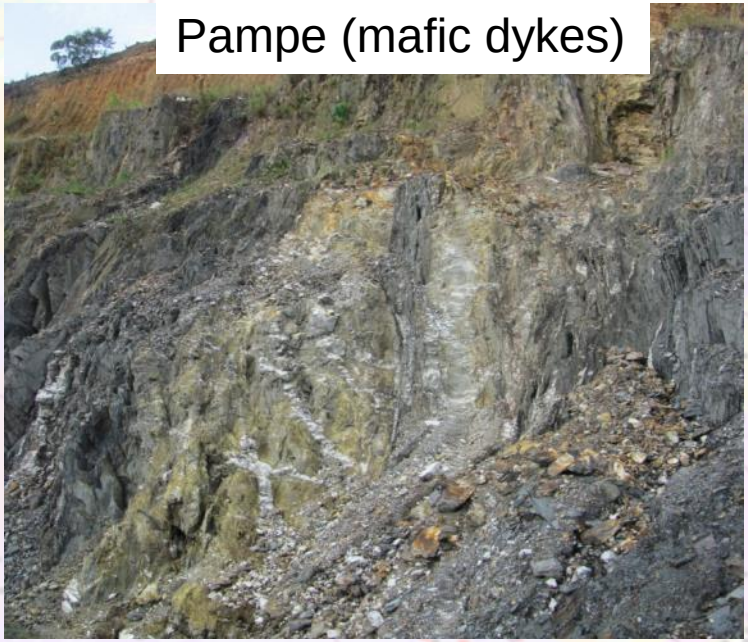
Sadiola (carbonate)

Obuasi (graphitic sediments)



West Banfora (granitoid)

Pampe (mafic dykes)



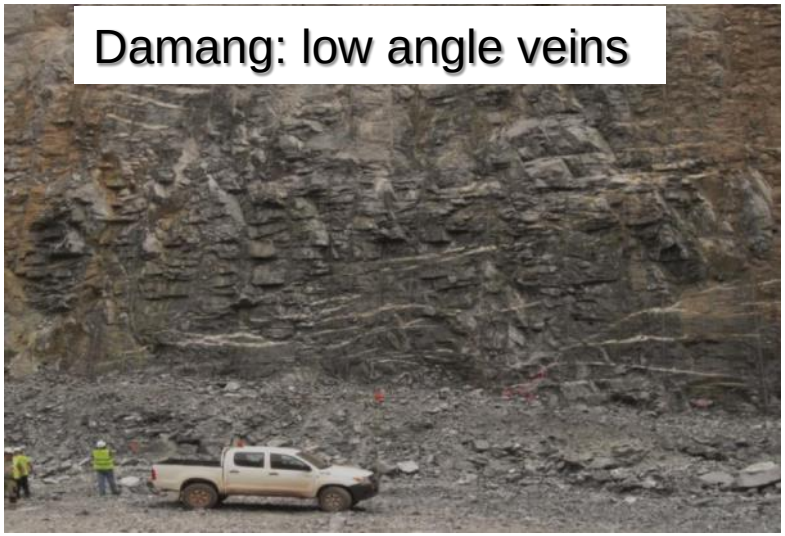
Deposit styles/ models

- Intrusion-related (e.g. ~8 Moz Morila deposit; McFarlane et al., 2011)
- Classic fault-valve orogenic gold models (e.g. > 5 Moz Damang deposit; Tunks et al., 2004)
- Paleoplacer systems (e.g. >28 Moz Tarkwa deposit; Pigois et al. 2003)
- Cryptic early poly-deformed deposits (e.g., ~5 Moz Wassa deposit; Bourassa, 2003).
- Ductile shear zones (Wassa), fault-vein arrays (Kalana, Damang), and Low-T brittle high level breccias (Syama).

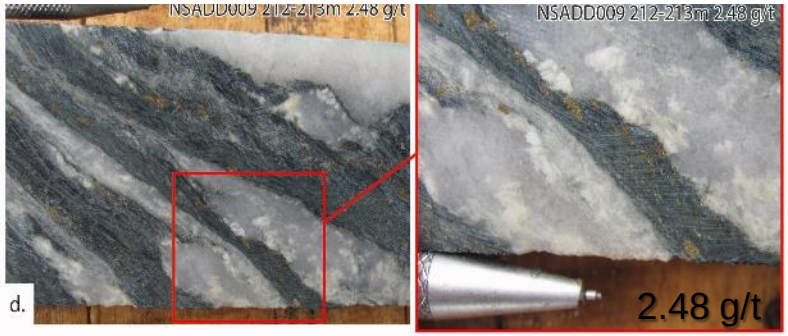
Morila: high T
with partial melts

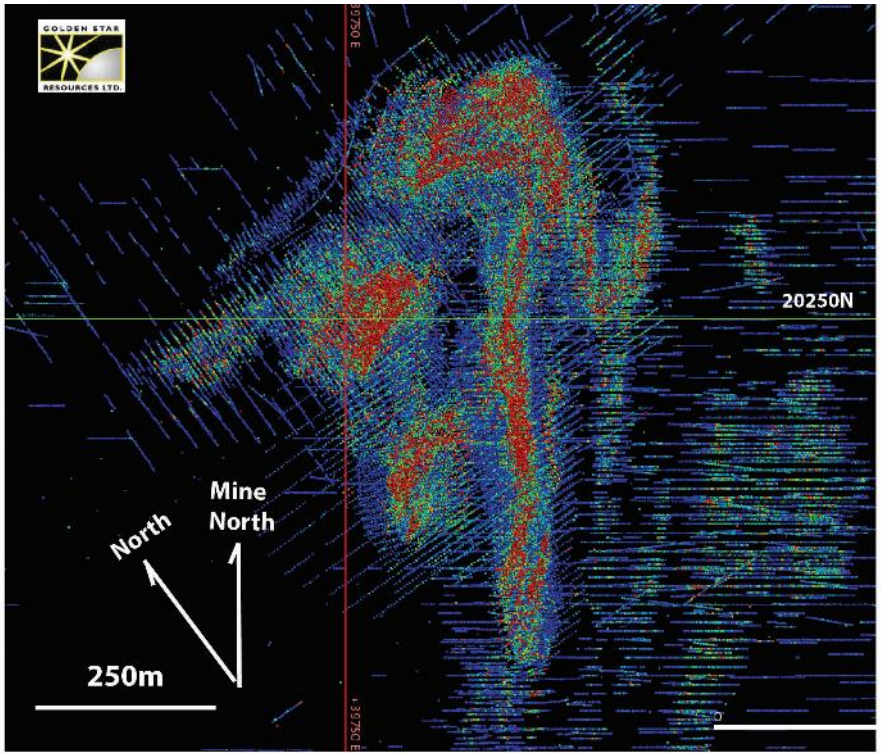
Syama: low –T breccia (mafic intrusive)

Damang: low angle veins



Wassa: folded ductile shear zone (mafic volc.)



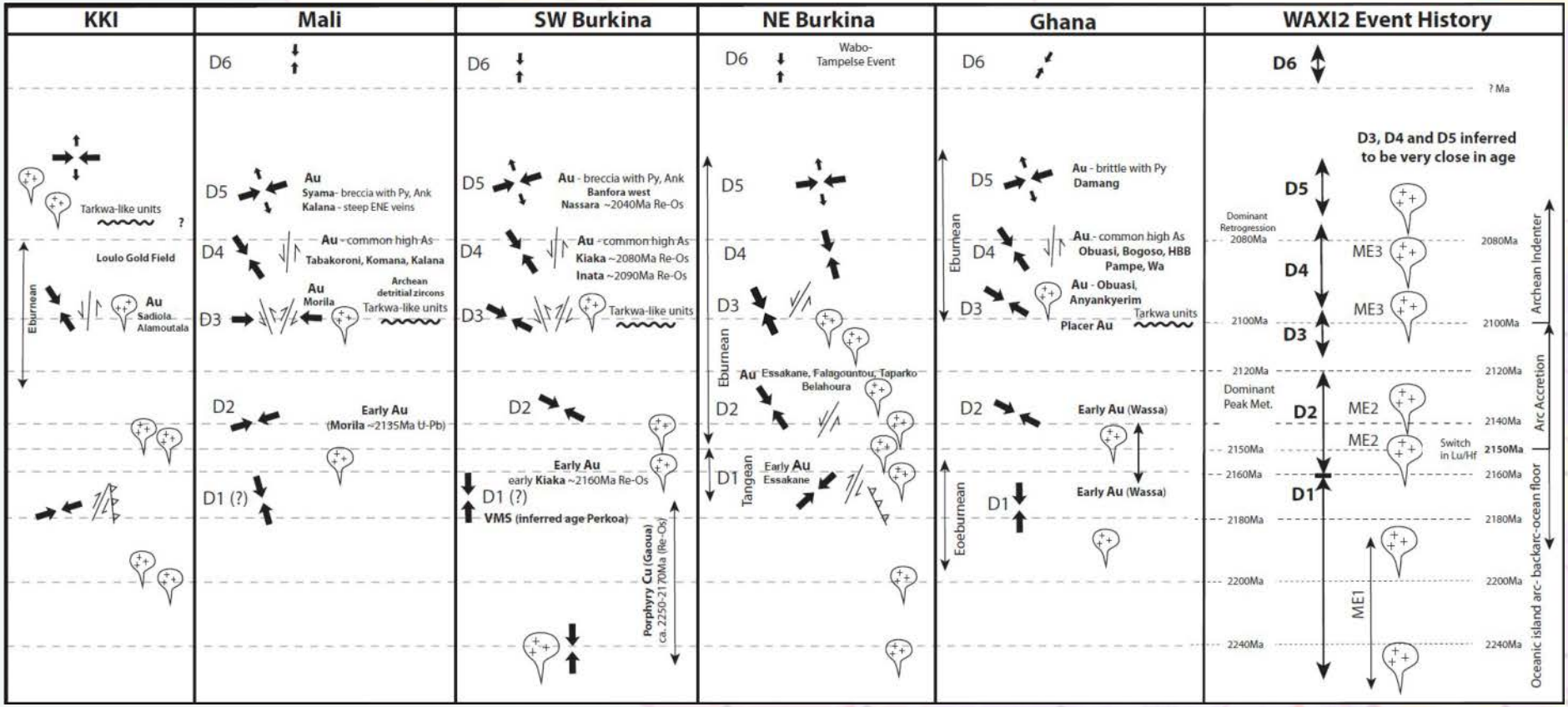


Kinematics

- Multiple phases of gold mineralization with different kinematics and alteration occurred, in some cases within the same belt
- Regionally a dominant late-stage gold D4 event at ca. 2100 - 2070 Ma (Feybesse et al., 2006), which is commonly associated with NW-SE shortening and high arsenic e.g., Obuasi (Allibone et al., 2002).
- Also later stage D5 brittle stage (Syama and Damang)
- World class Tarkwa Formation Paleoplacers in the Ashanti belt predate the D4 gold event – this requires an older gold event to have acted as a source
- Evidence for early D1/D2 gold systems that pre-date Tarkwa deposition groups deposits is strong (in comparison for example to early gold models in the Yilgarn Australian Archean orogenic gold deposits = MAJOR DIFFERENCE in the systems)

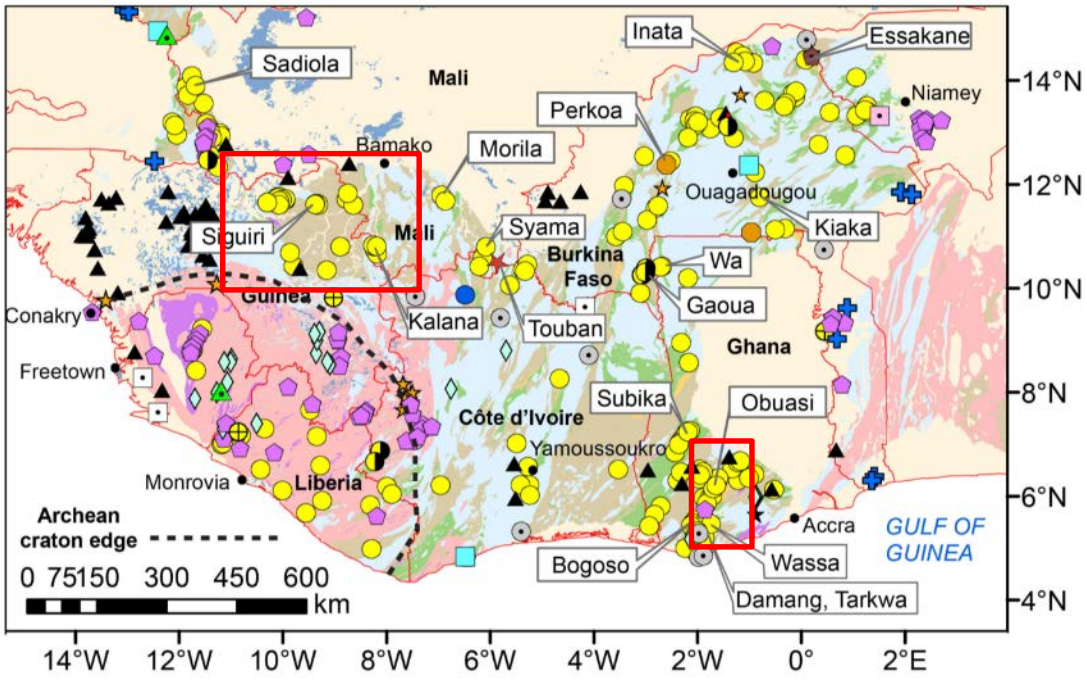
WAXI2 Space-Time Correlation Chart

SENEGAL MALI SW BURKINA FASO NE BURKINA FASO GHANA

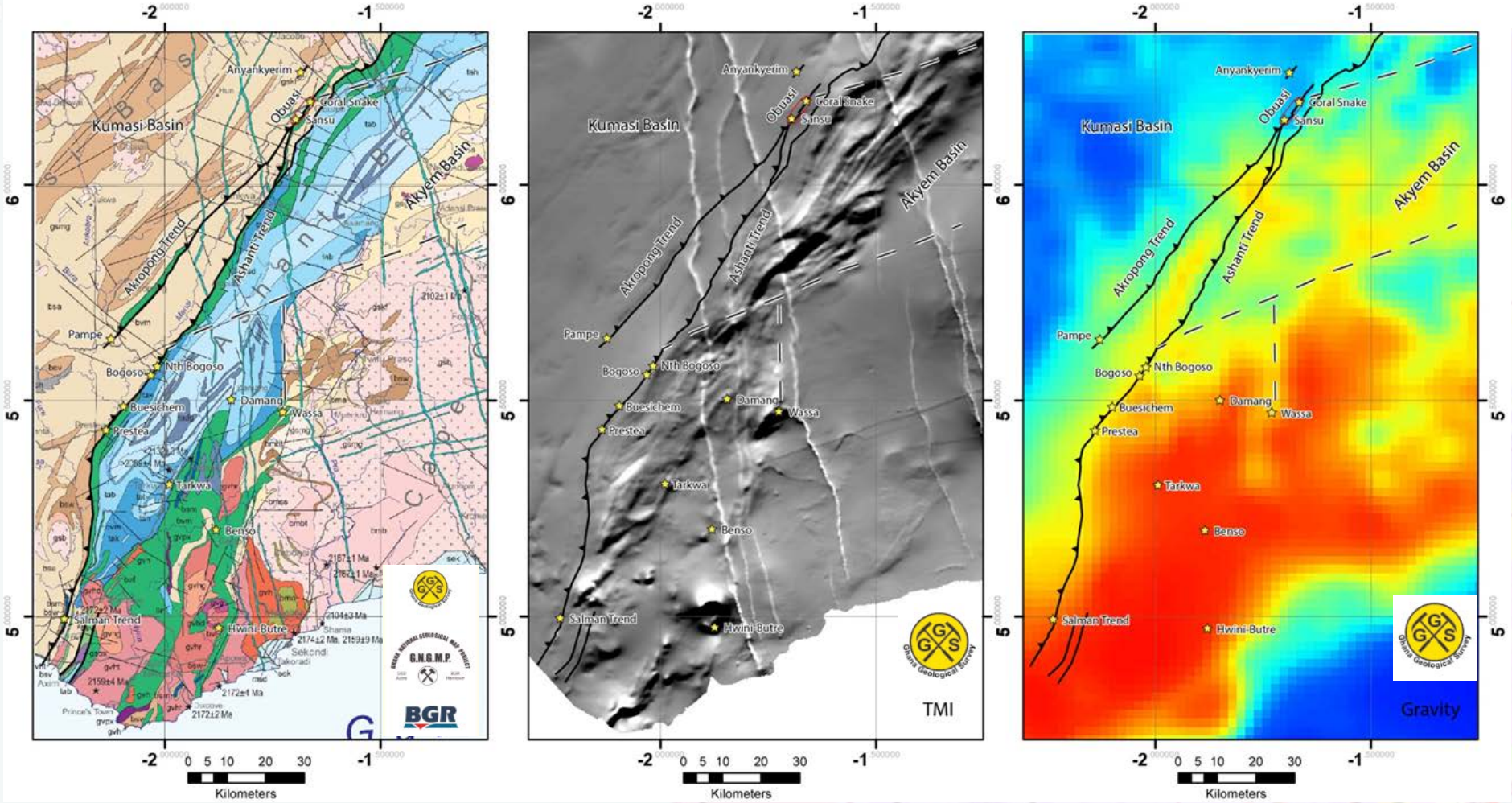


Architectural Controls

- Deposits formed at different geological times and have markedly host rocks and different deposit styles defined by observable structural, metamorphic and alteration.
- *At the belt and regional scale architectural controls appear to be a key control on the gold deposit locations*
- *This could be an effective targeting tool within a prospective greenstone belt*
- *Similar observations made for the Western Australian Goldfields*

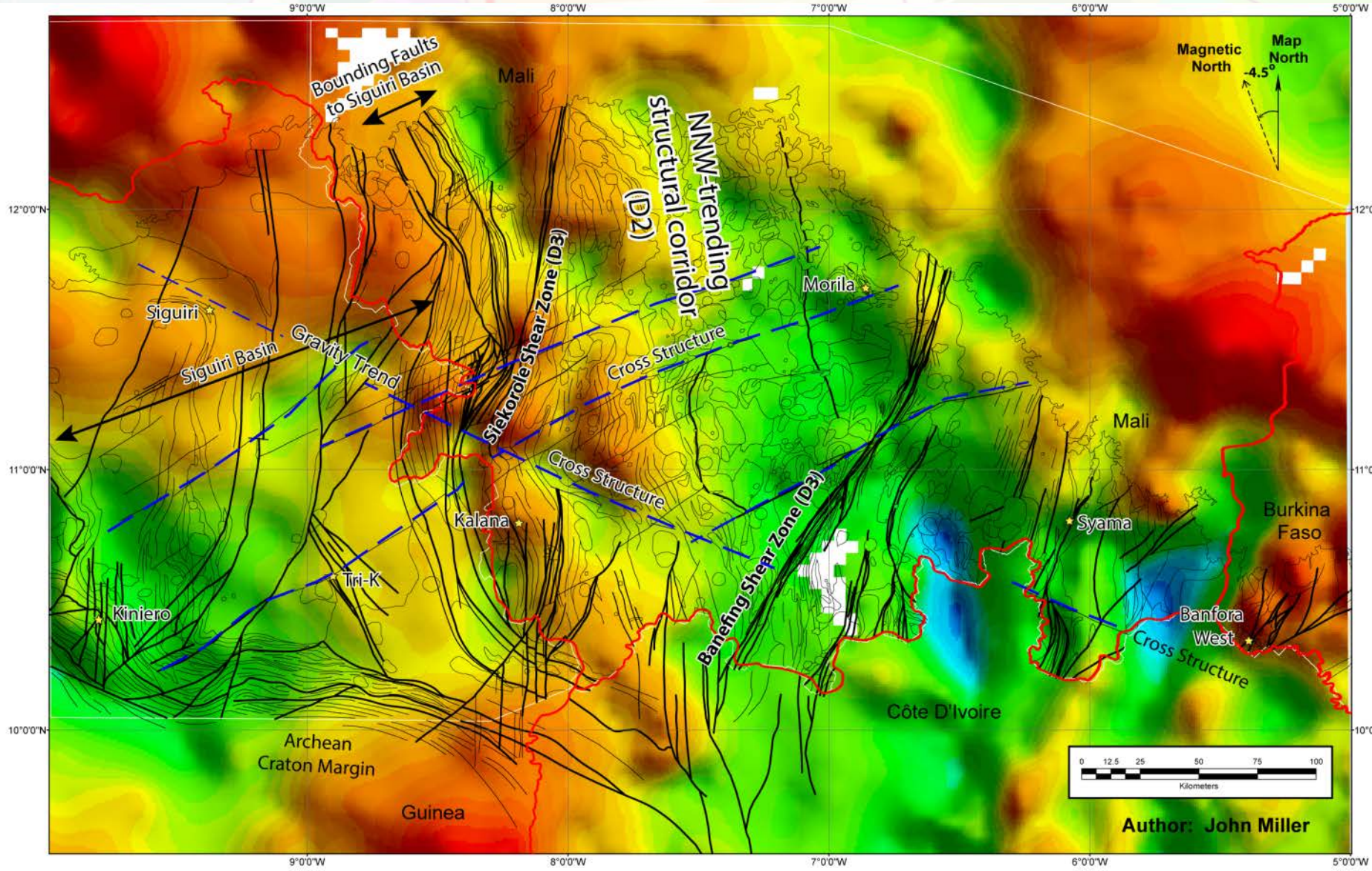


Major variations between individual deposits. Belt scale architectural controls appear to be a control on deposit location.



Intersections, ENE- & N-trending architecture (dykes map these)

Guinea and Mali (interpretation with gravity data)



Cryptic cross structures, linked to along strike facies changes and mineralisation

MINERALISATION - STRUCTURAL TIMING

(SOUTHERN MALI AND GUINEA)

Four economically significant stages of mineralisation have been identified;

1) Possible early D2 mineralisation at the Morila deposit with a strong late-stage gold over print linked to ME3 magmatism
2) Regionally extensive D4 associated gold lodes related to NW-SE shortening (commonly with quartz and arsenic; e.g. Kalana and Tabakoroni),
3) Steep-dipping gold-bearing quartz veins linked to post-D4 extensional collapse e.g. Kalana and Siguiri (=major artinisal sites)
4) Late-stage D5 high-crustal level low-T breccias associated with ankerite and pyrite e.g. Syama, Banfora.

	Klnléro Deposit	Siguiri Deposit	Siekorole Shear Zone (SSZ)	Kalana Splay Fault (KSF)	Kalana Deposit	Banefing Shear Zone (BSZ)	Granitoids adjacent to Banefing Shear Zone (BFZ)	Morila Deposit	Syama Belt (Tab., Tellem, Qtz Ridge Deposits)	Syama Deposit	Banfora Deposit	Event History	Baratoux et al., 2012
							Conjugate pegmatite dykes	Conjugate pegmatite dykes				Wabo Tampabe Event ?	
					Folding of steep veins			Veins with visible Au in Granodiorite		Breccias with Ank-Py-Qtz[6]	Breccias with Py	D5 ME3/4 Au (Ank Py Qtz)	
		Steep ENE-trending veins[1]			Steep ENE-trending veins			Steep ENE-trending Mo-bearing veins			E-trending veins	Post D4 collapse?	
2085			Sinistral overprint of SSZ	Sinistral overprint of KSF	NW-directed thrusts and En Echelon veins[3]	Oblique foliation & sinistral faults	ENE- trending fabrics (flattened enclaves)[5]	Doming and Au remobilisation linked to magmatism[7]	Sinistral-slip, Qtz, Au, Asp, Py Dilational & contractional jogs[8]	Quartz veins (with Py?)[7]	Stringer?, Fourkoura?	ME3 D4 Au (Qtz-Asp)	D3?
	Dextral system (N- and NE-fault's)		Formation of Dextral SSZ	Formation of Dextral KSF		Formation of Dextral BSZ	N- to NNW-trending fabrics (flattened enclaves, magmatic foliation[9]) BUT NE-trending fabrics in BSZ.	Folding of D1 foliation (N-trending F2 axes) Gold within NNW-trending S2 fabrics[7]	Formation of linear faults		Shearing main trends form	ME3 D3 "Tarkwa-like"	D2
~2100	Inversion of Basin		Formation of NNW trending fabrics?	Formation of NNW-trending fabrics?		Formation of NNW trending fabrics?	Basic to intermediate intrusions with well foliated margins[5A]	Formation of NNW-trending D1 fabrics. Early Au[11]	Formation of Arcuate Greenstone belt	Folding of stratigraphy. Early Au?[12]		ME2 D2	D1
~2140													
2160					Early East-trending folds[4]		Folding of dykes by early East-trending folds[1]					D1 ME1	

Poster presentation on Mali and Guinea outside

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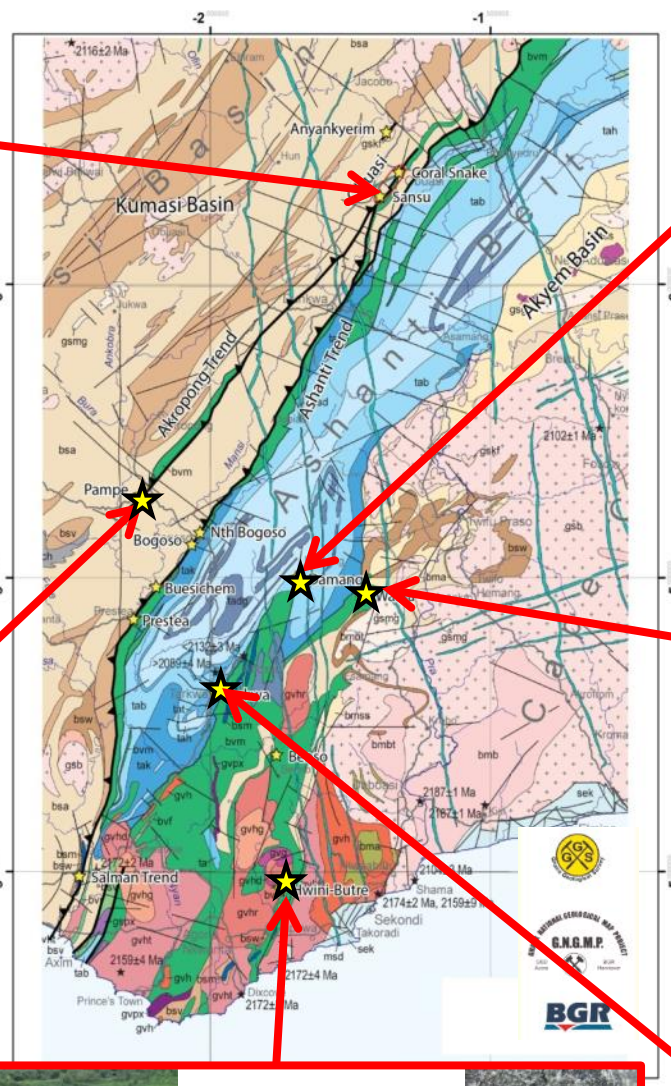
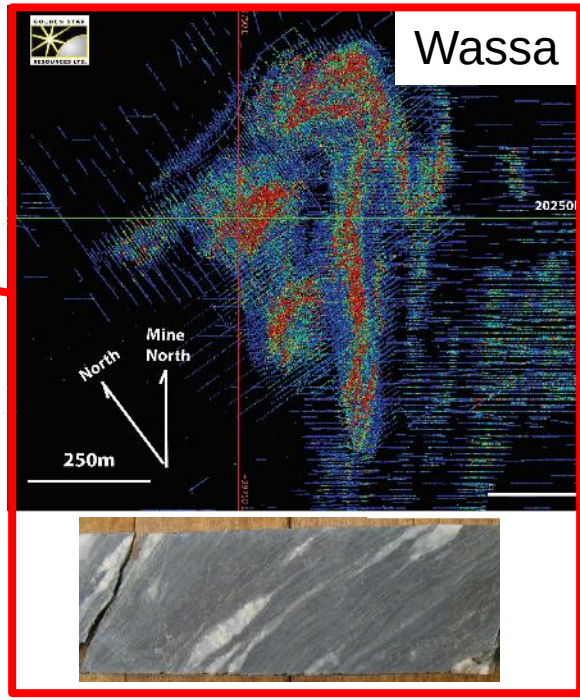
Ashanti Belt (Ghana). Major deformation events and phases of gold

- Poorly defined early events
- Early D1 gold at Wassa – this is pre-deposition of Tarkwa unit
- Deposition of Tarkwa units and paleoplacers
- D2 = Early bedding parallel fabrics (Obuasi, Bogoso)
- Major D3 NW-SE shortening linked to regional folding of all sedimentary sequences and shear development
- Gold related to horizontal stretching and NW-SE shortening (defined as late D3, could mark switch to D4)
- Regional D4 event linked to a ***major phase of gold mineralisation*** with a regional cross cutting D4 crenulation cleavages, sinistral slip linked to NNW-SSE shortening (*=D3,D4 and D5 of Allibone et al., 2002*)
- D5 NE-SW to ENE-WSW shortening linked to low angle veins and associated gold mineralisation within the Tarkwa units at Damang
- Early N-trending and ENE-trending architecture is a probable control on deposits (combined with fault intersections)





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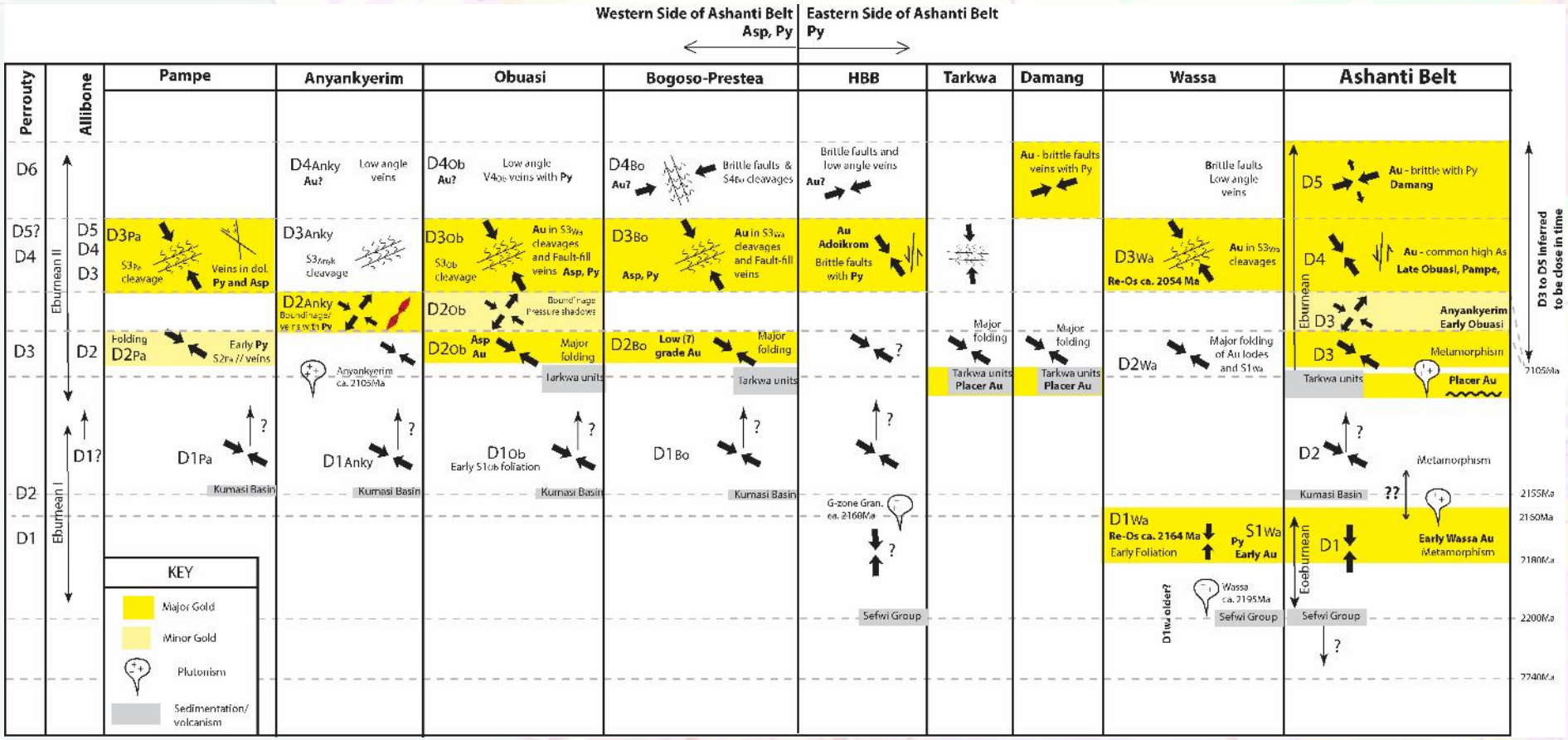
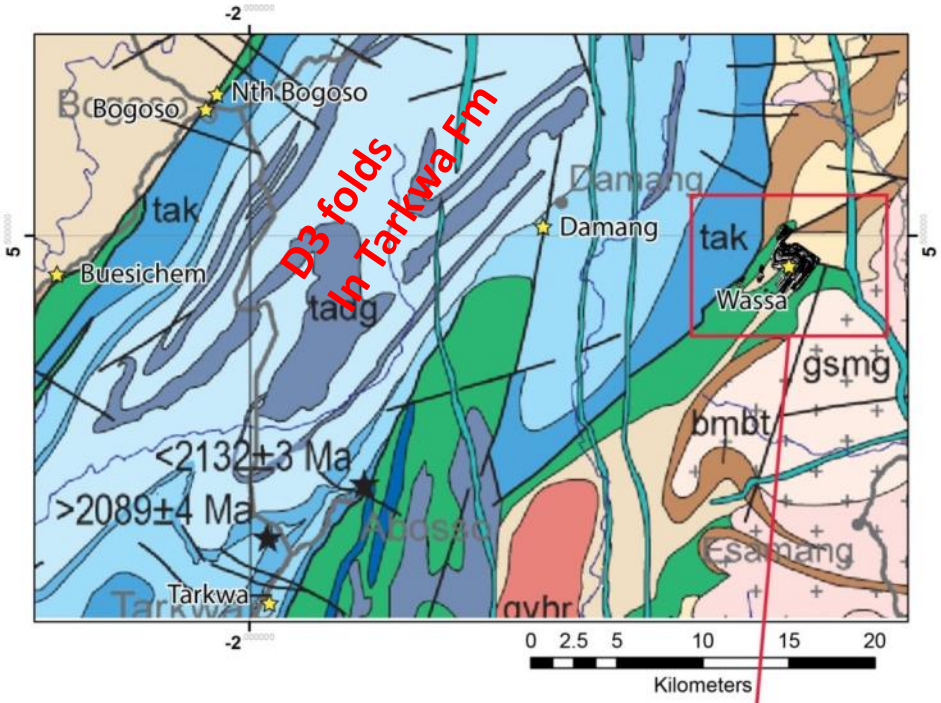
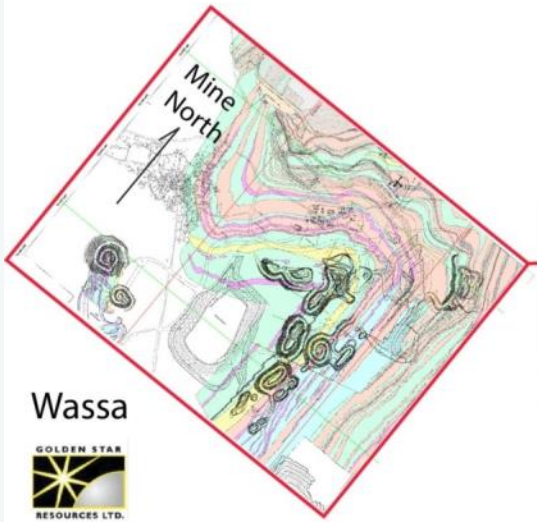
Ashanti Belt – linked to WAXI2 event history

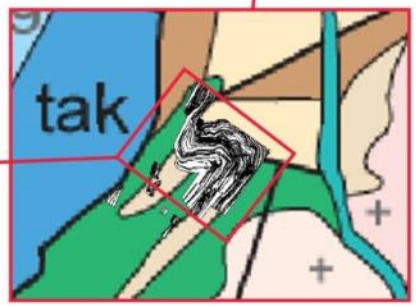


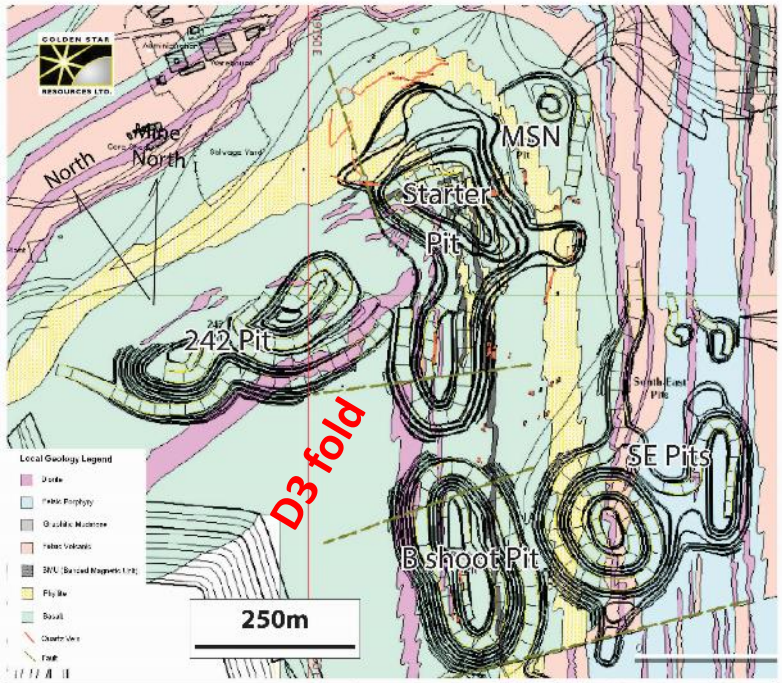
Local events versus WAXI2 event history
D1 and D2 poorly constrained

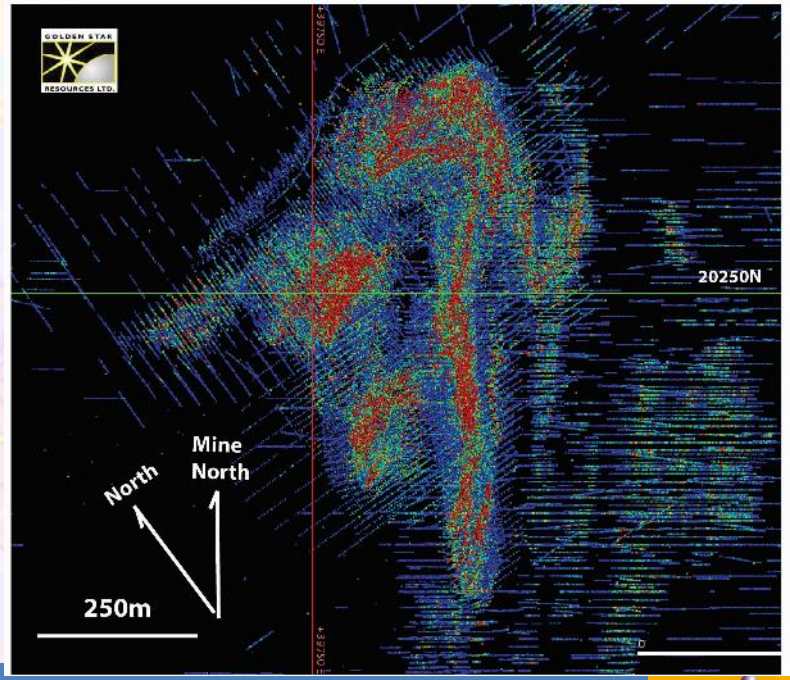
Wassa (Early Gold, interpreted D1 with overprints)



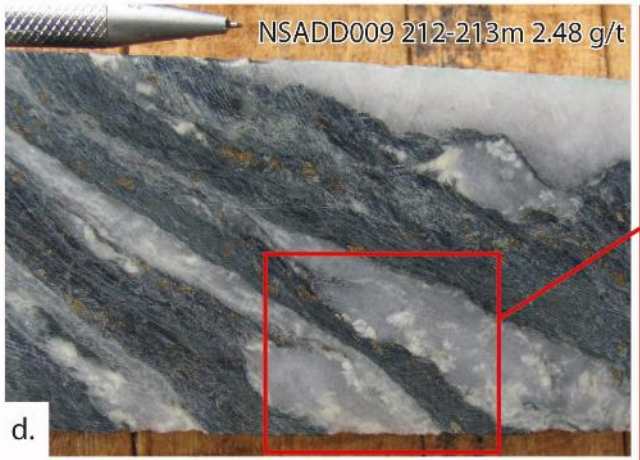


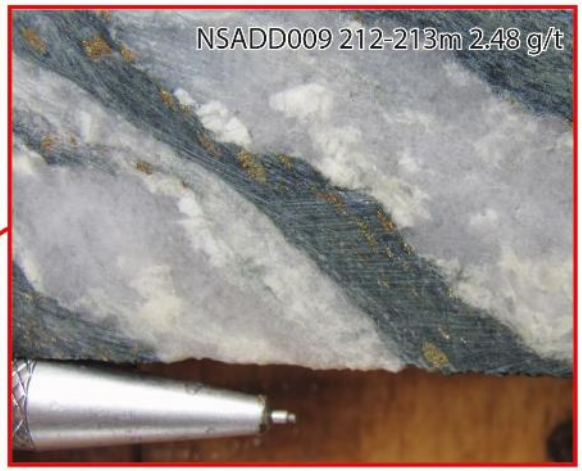


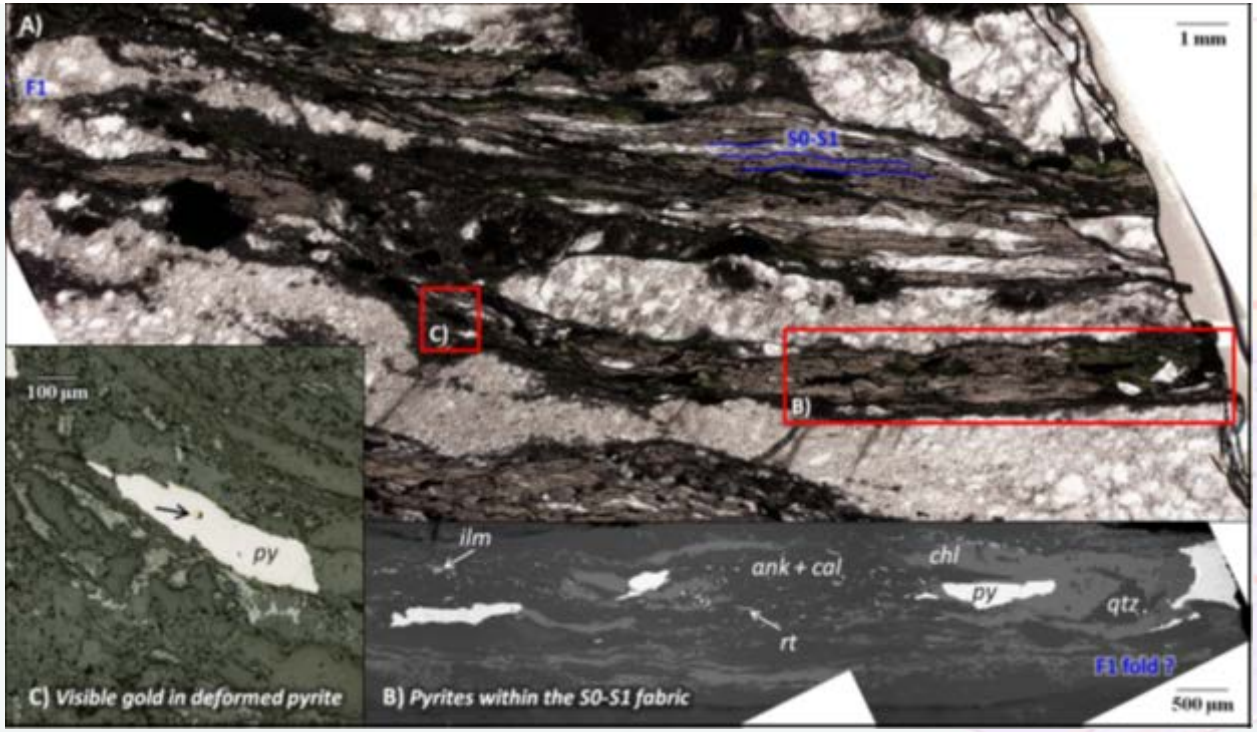




Wassa (Early Gold, interpreted D1, strongly over printed deposit)



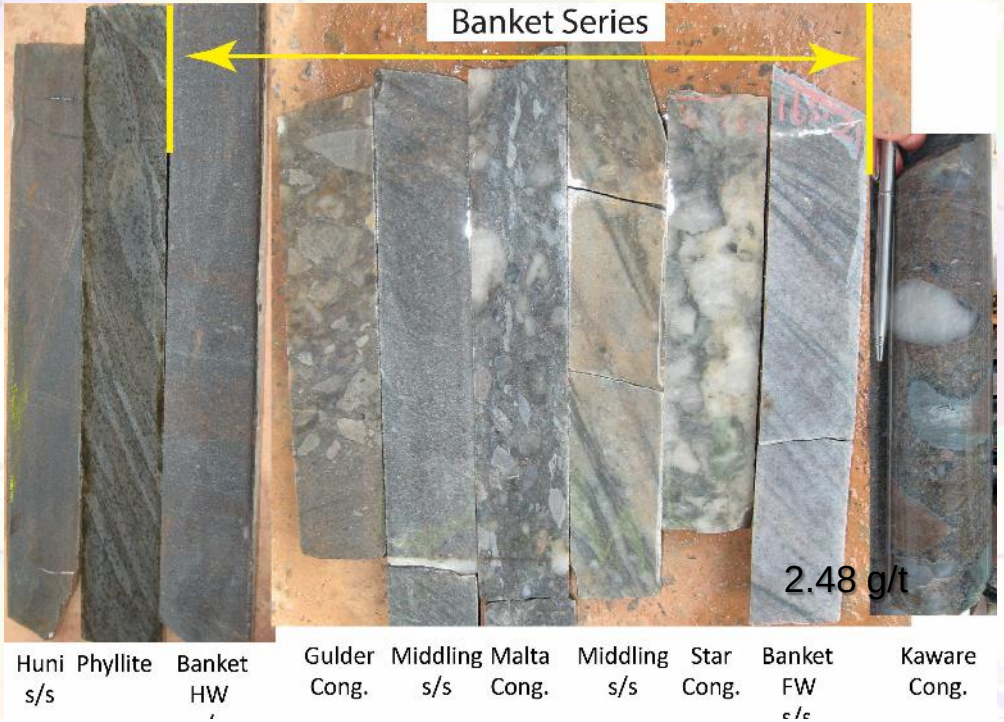


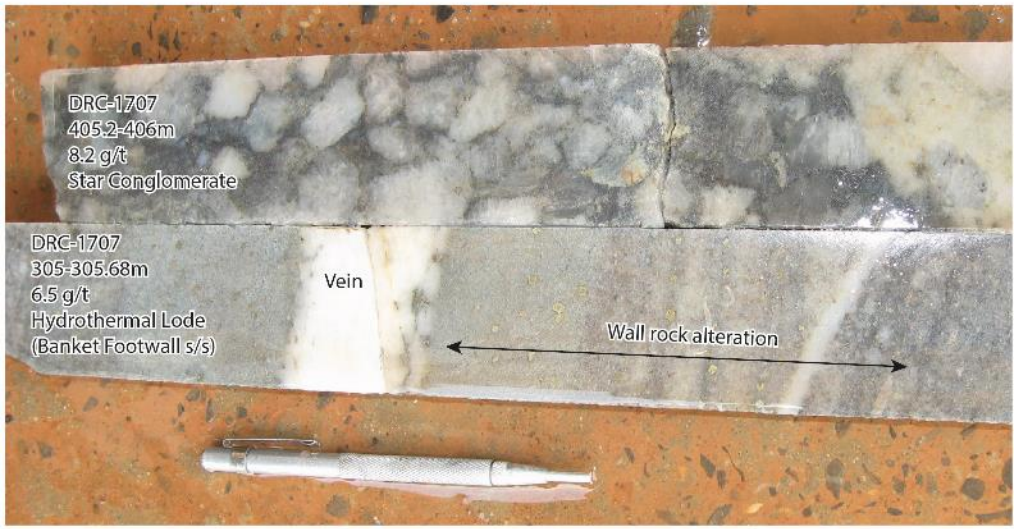


- Texturally early gold
- Grade control data suggests lodes are folded
- Re-Os ages of sulphides from the Wassa deposit produced two ages 2164±22 Ma and 2054±11 Ma (Le Mignot et al., in review).

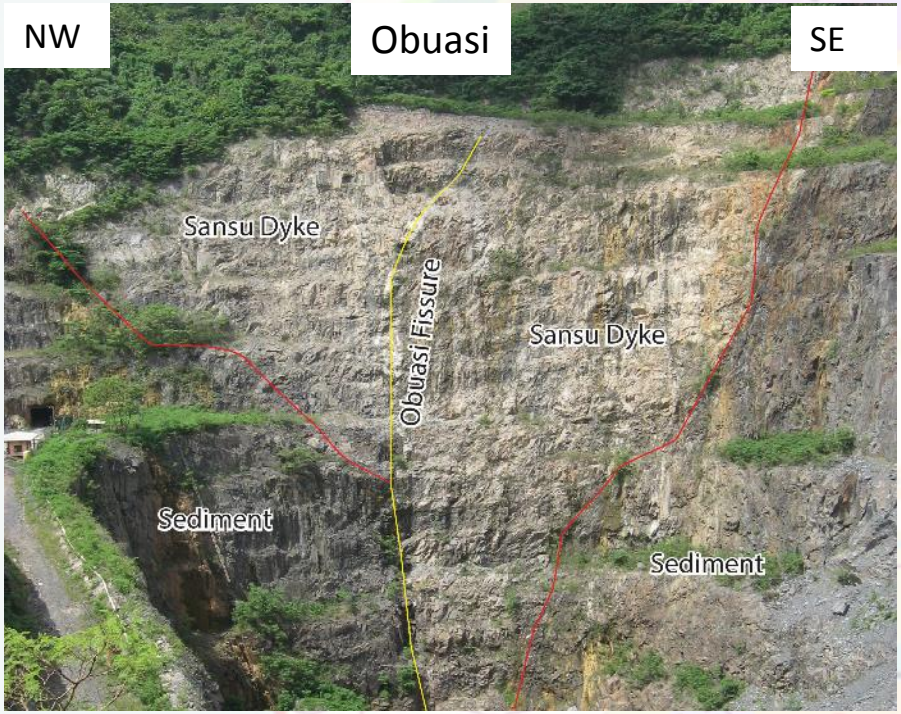
Tarkwa Unit Paleoplacer (Tarkwa)

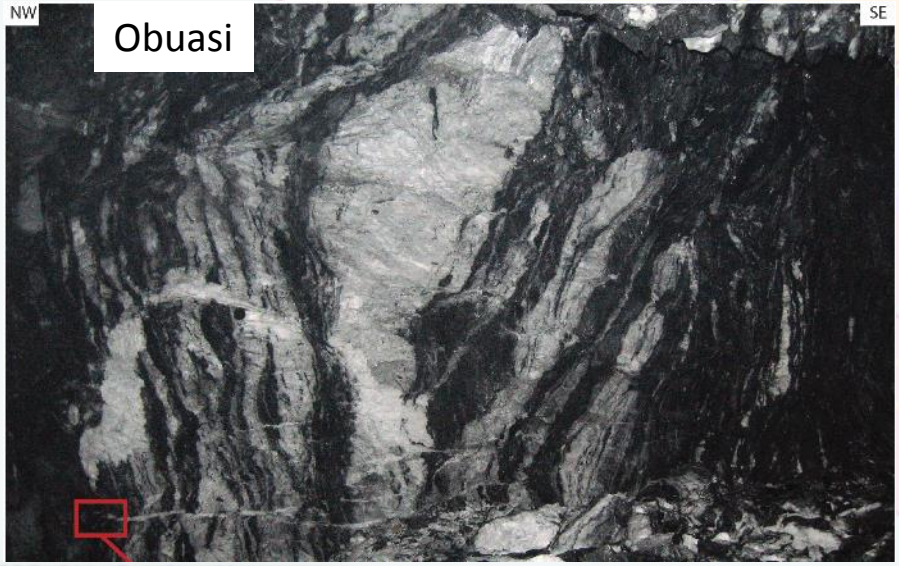
Paleoplacer with hydrothermal overprint (Damang)

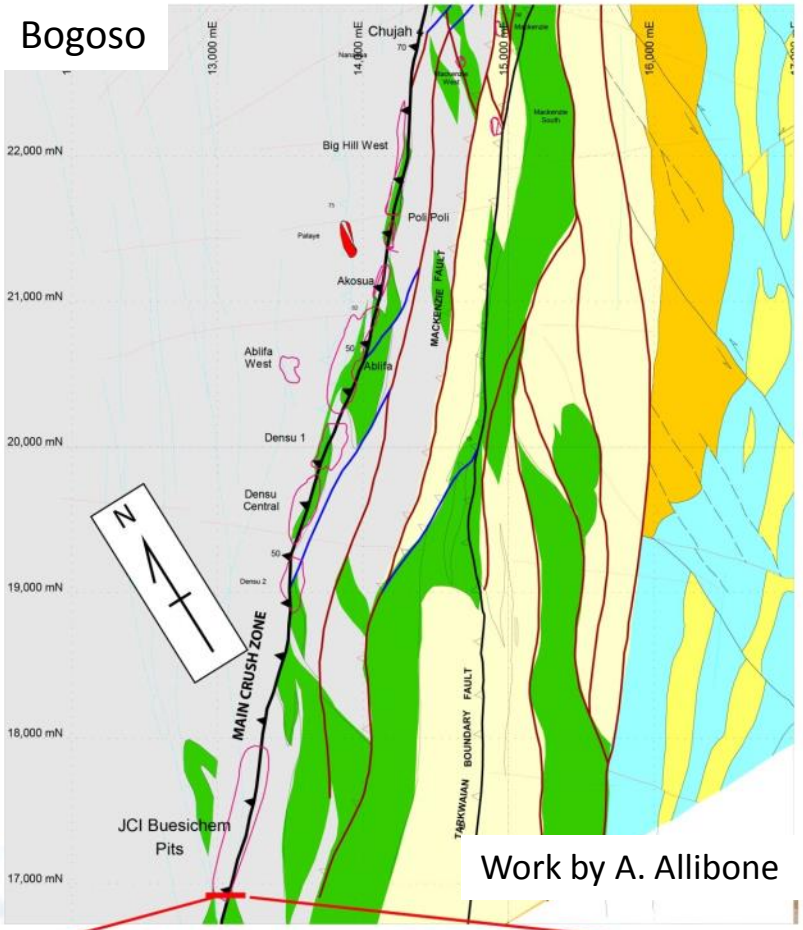




D3 graphitic shears (Obuasi and Bogoso)

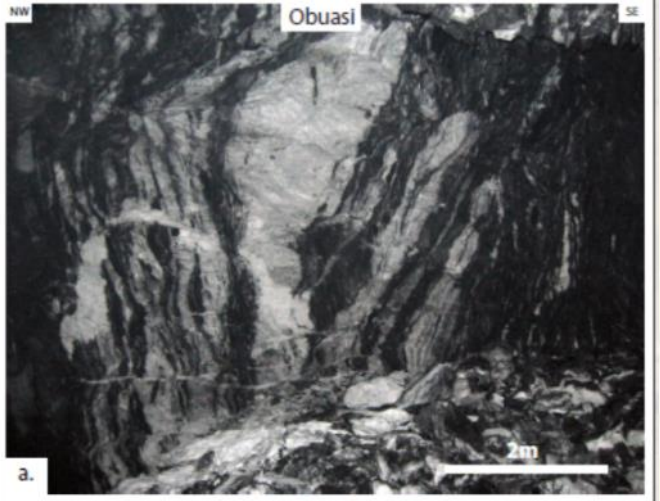


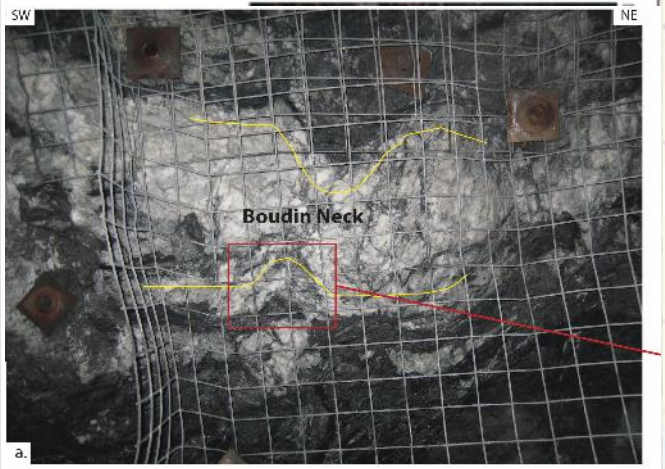


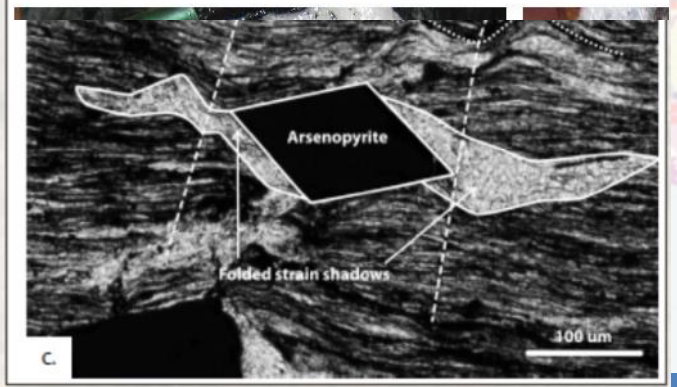


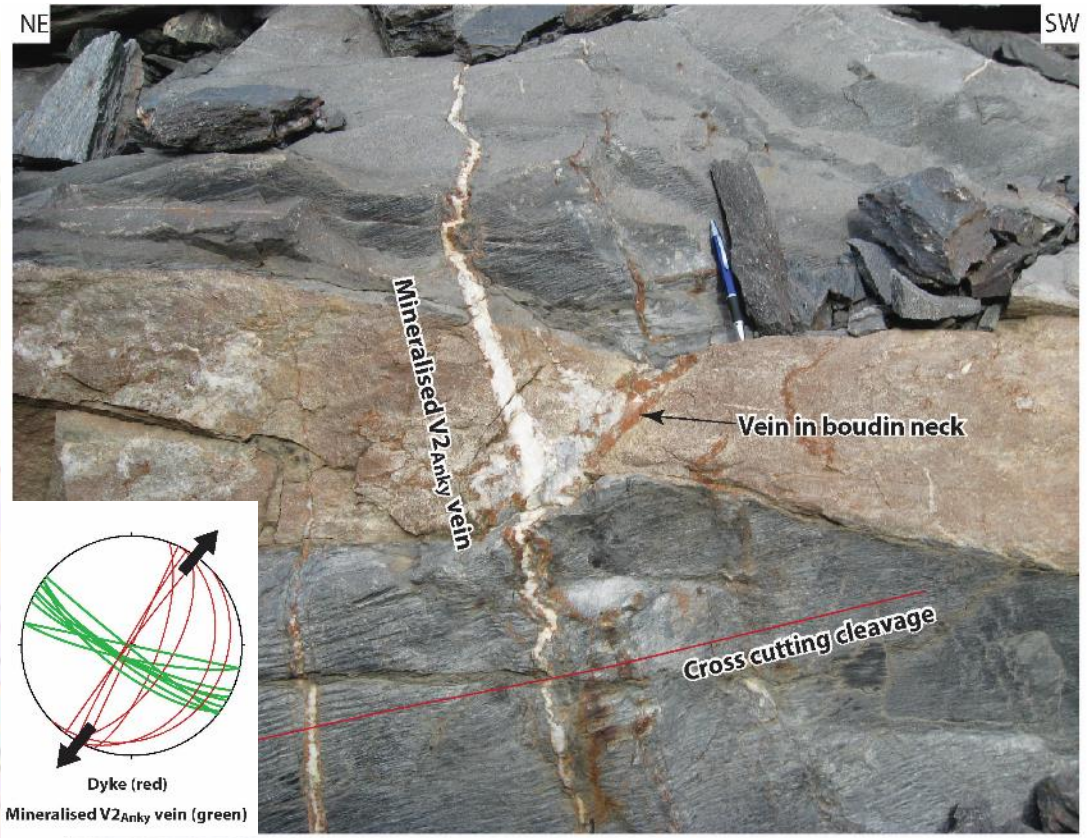
Work by A. Allibone

Late D3 = NE-SW directed stretching and NW-SE shortening
Linked to gold (overprinted by D4 cleavages)



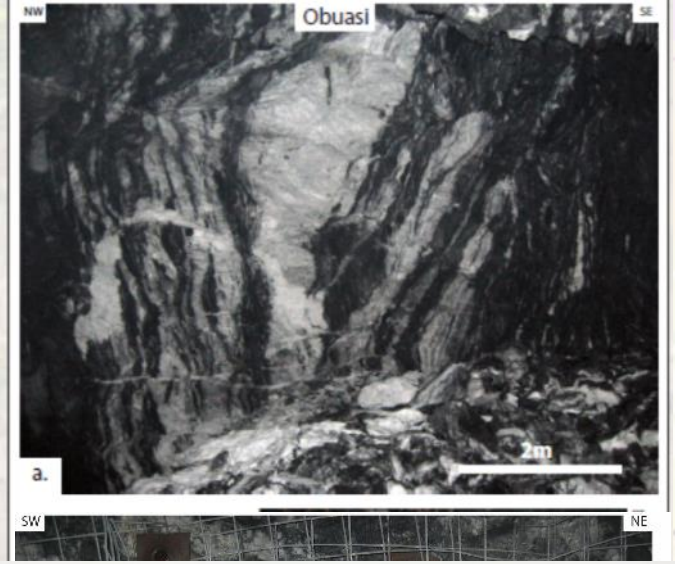


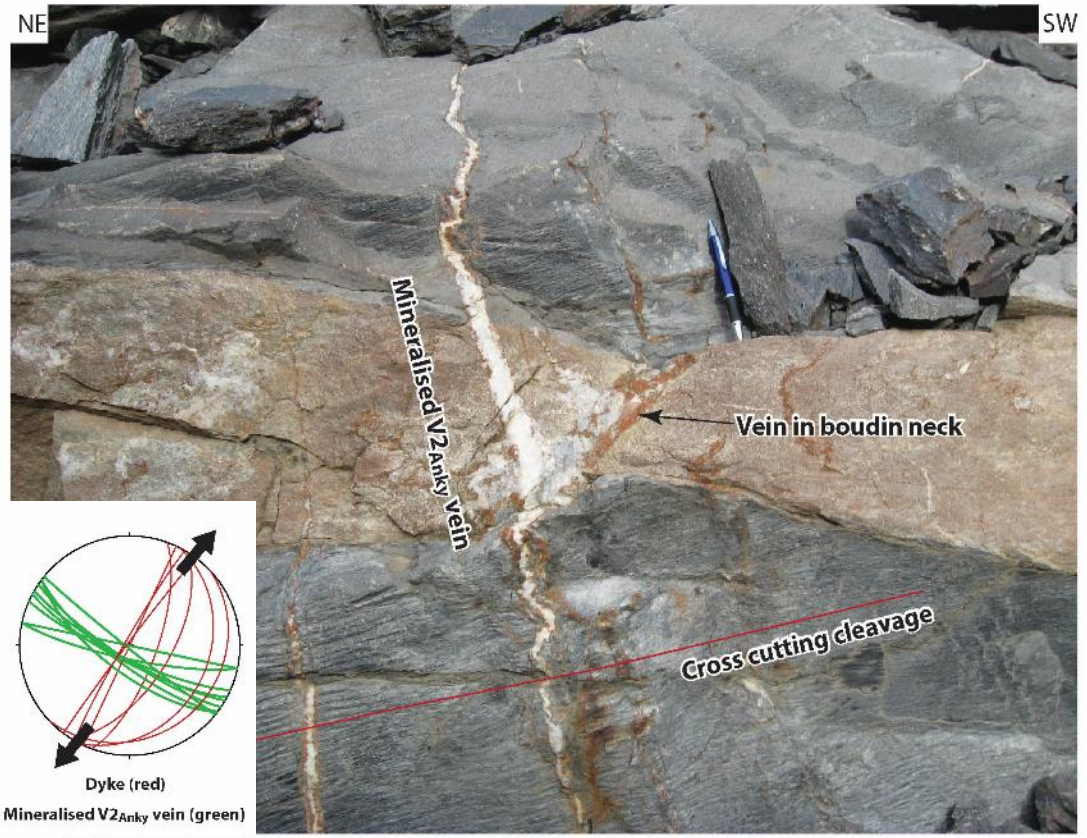




The Anyankyerim Deposit has metaturbidites and mineralised granitic sills (2105±2Ma; Oberthur et al., 1998)
Low angle lineation / principal stretch direction
Gold-bearing disseminated arsenopyrite at Obuasi is late D3 to early in the D4 event (pressure shadows folded by D4 cleavages). Junner 1932 noted same relationships.

Late D3 = NE-SW directed stretching and NW-SE shortening
Linked to gold (overprinted by D4 cleavages)





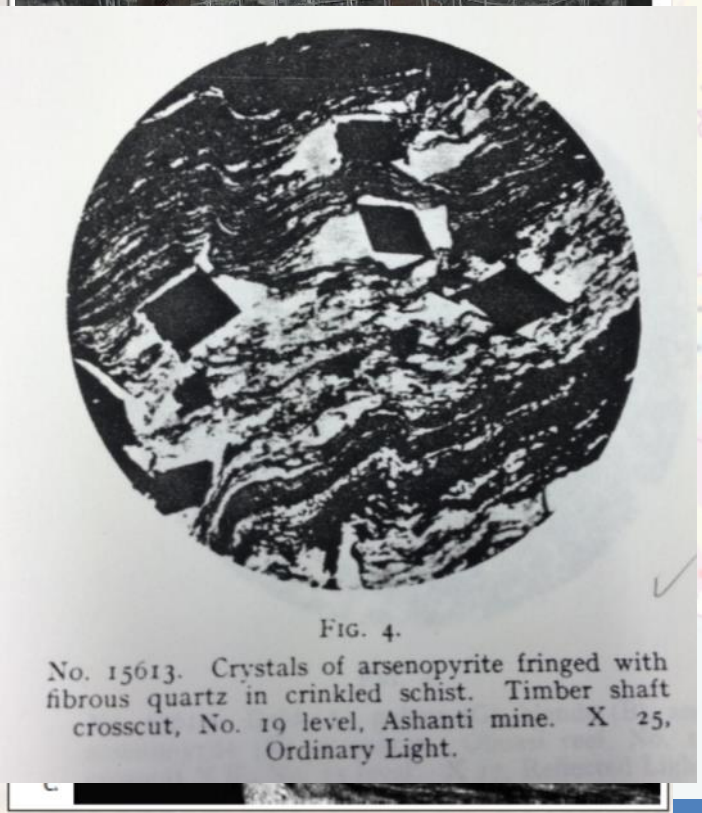


FIG. 4.

No. 15613. Crystals of arsenopyrite fringed with fibrous quartz in crinkled schist. Timber shaft crosscut, No. 19 level, Ashanti mine. X 25, Ordinary Light.

The Anyankyerim Deposit has metaturbidites and mineralised granitic sills (2105±2Ma; Oberthur et al., 1998)
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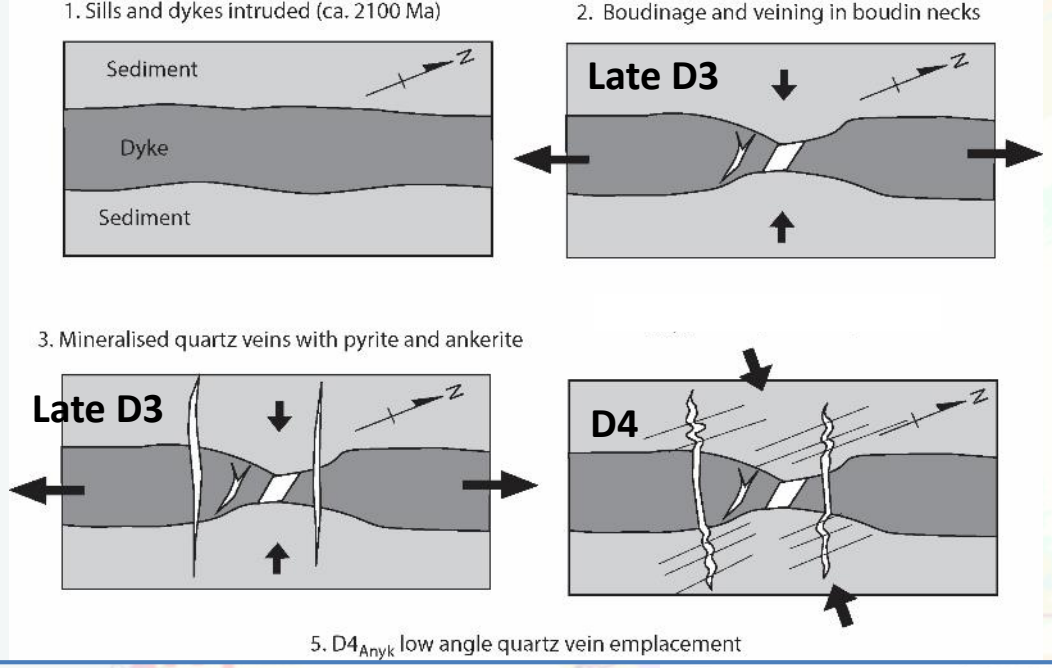
Anyankyerim

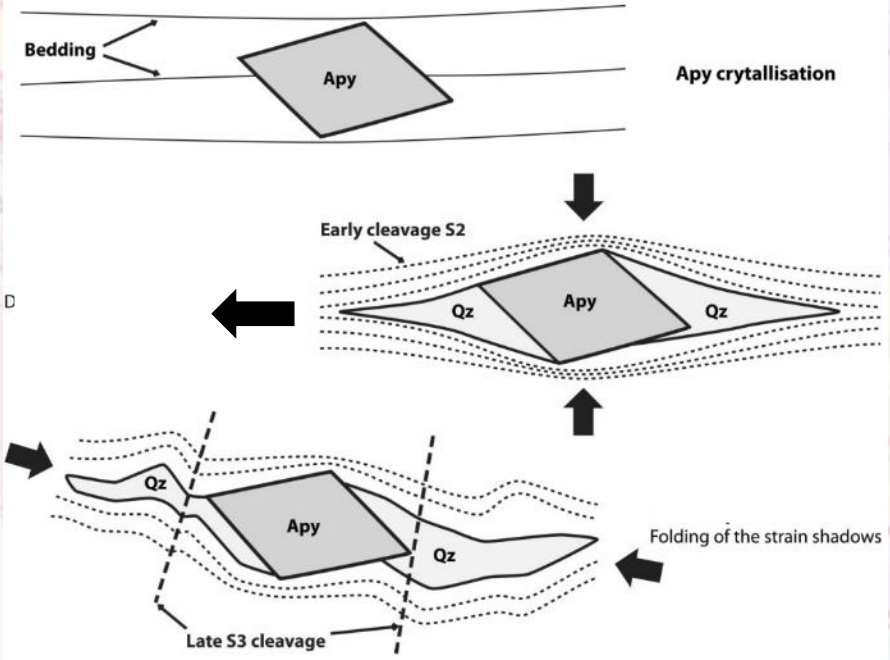


Obuasi

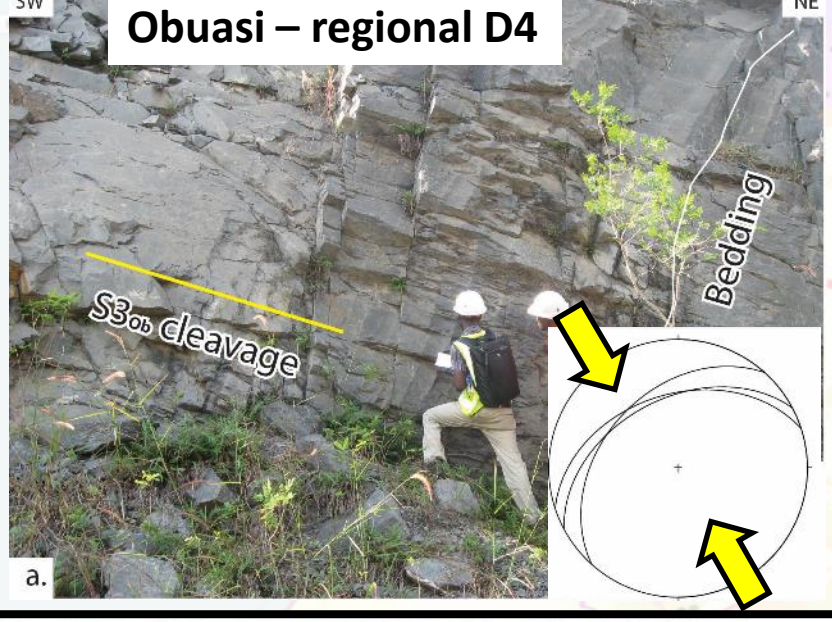
Late Regional D3

Regional D4

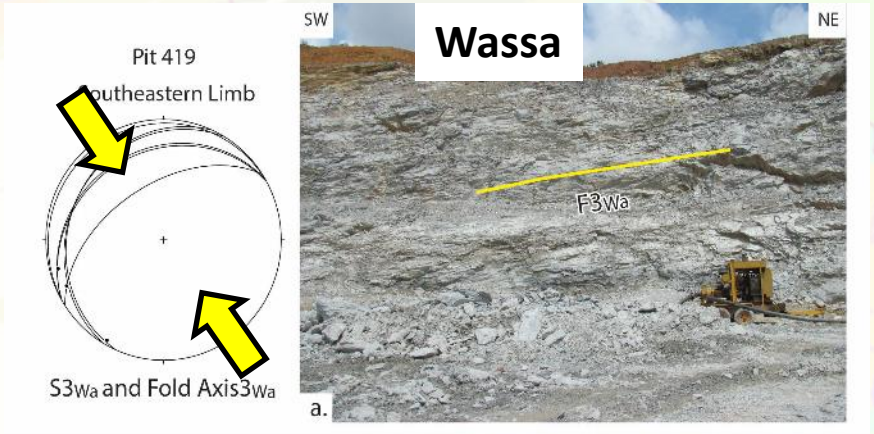
NW-SE to NNW-SSE compression

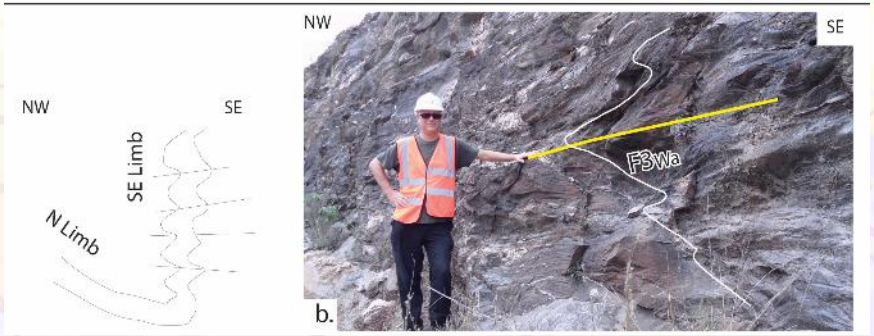


Obuasi – regional D4

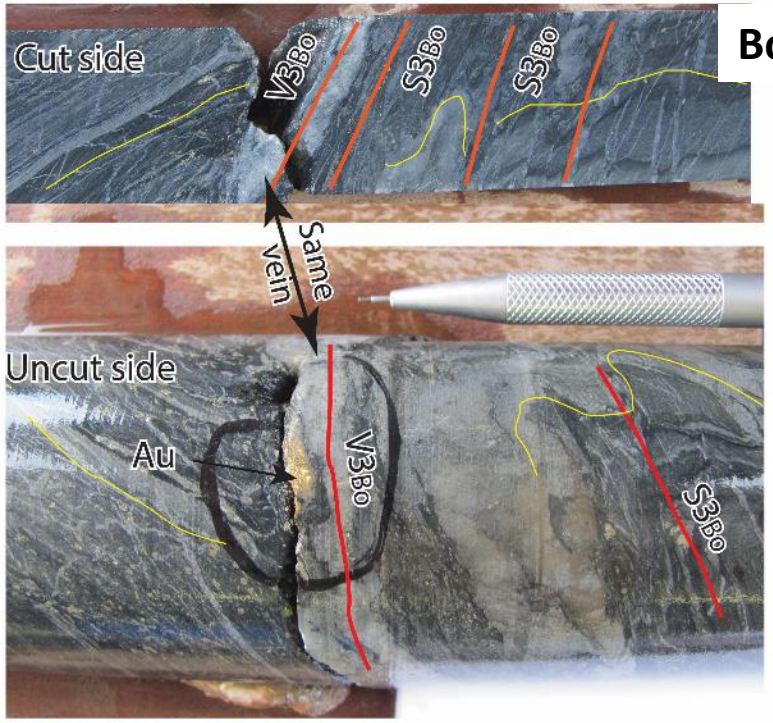


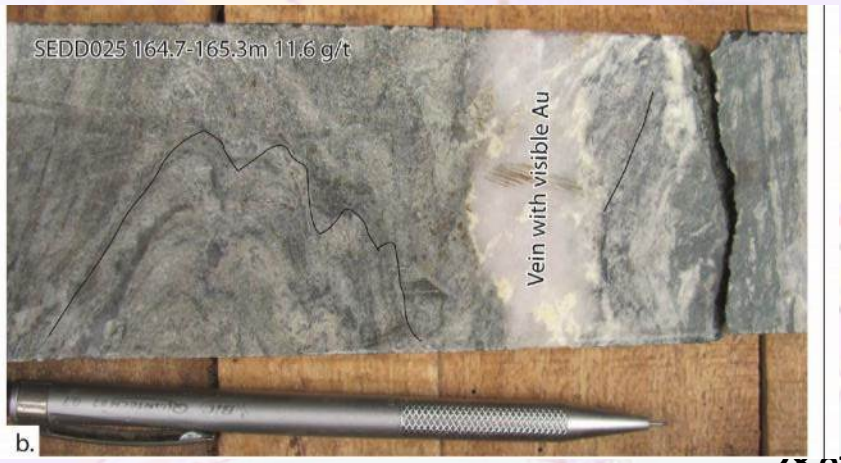
Regional gold-associated D4 cleavage



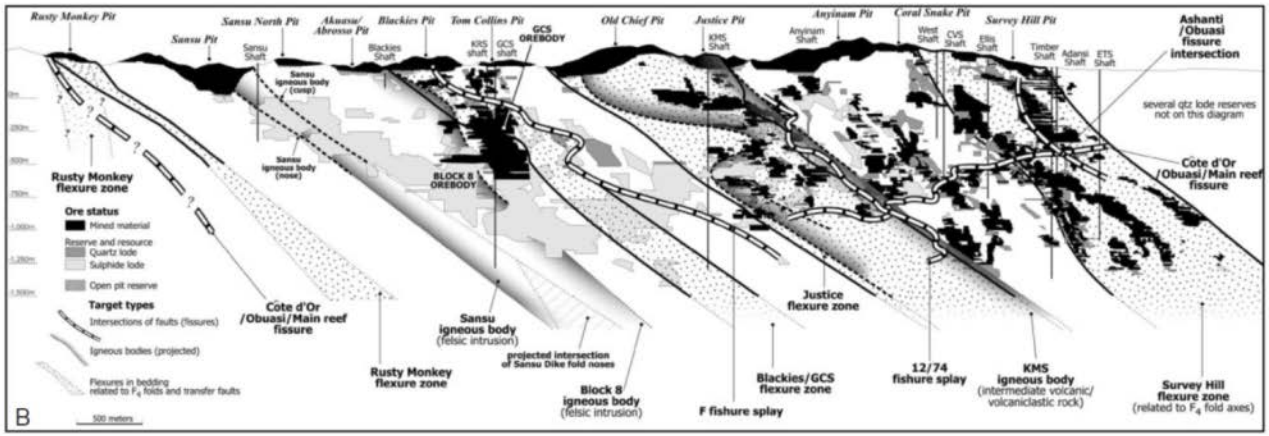


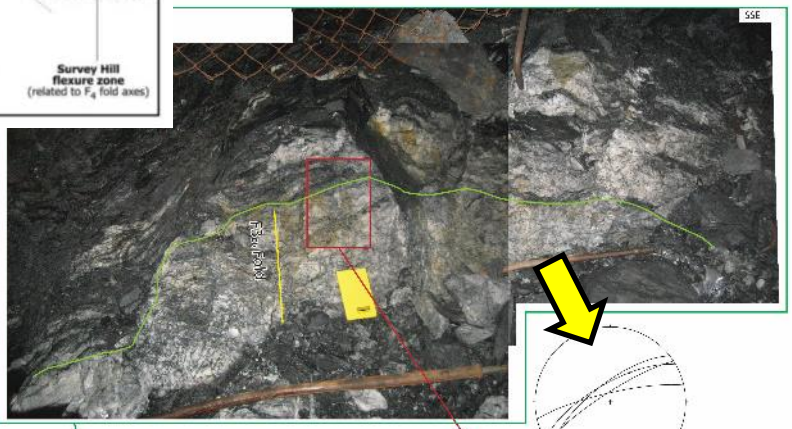
Bogoso

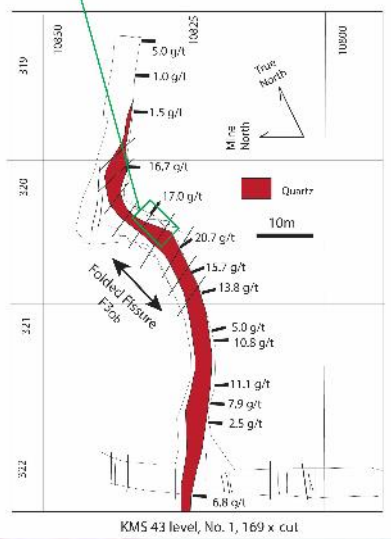




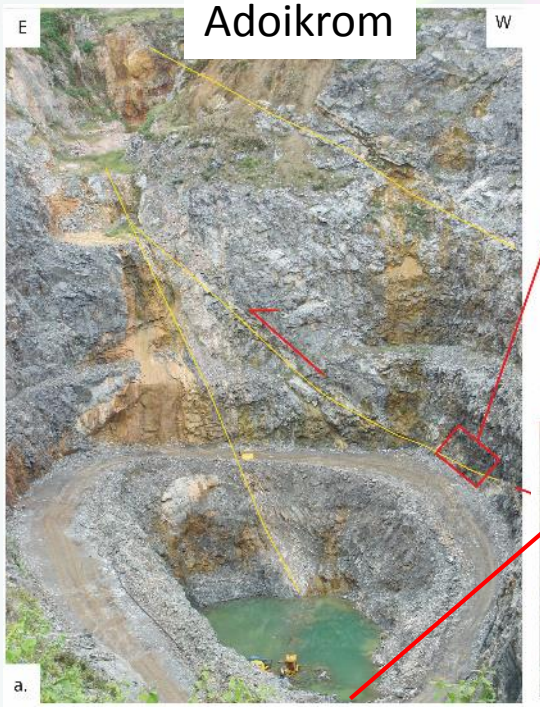
Obuasi - Major gold control from D4 cleavages (Allibone et al., 2002)

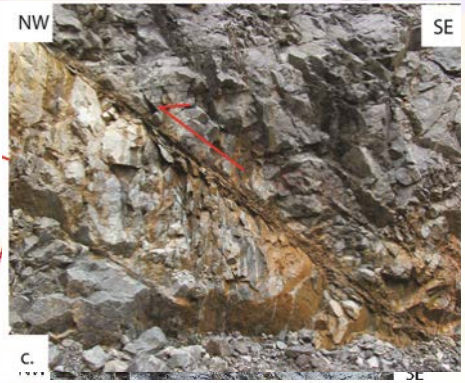


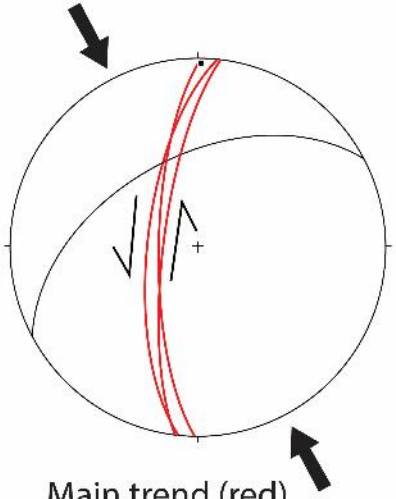


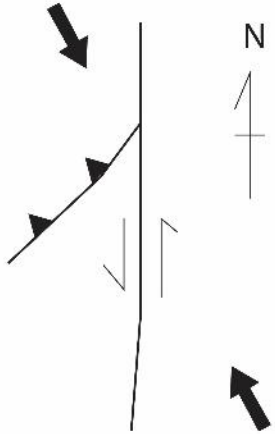


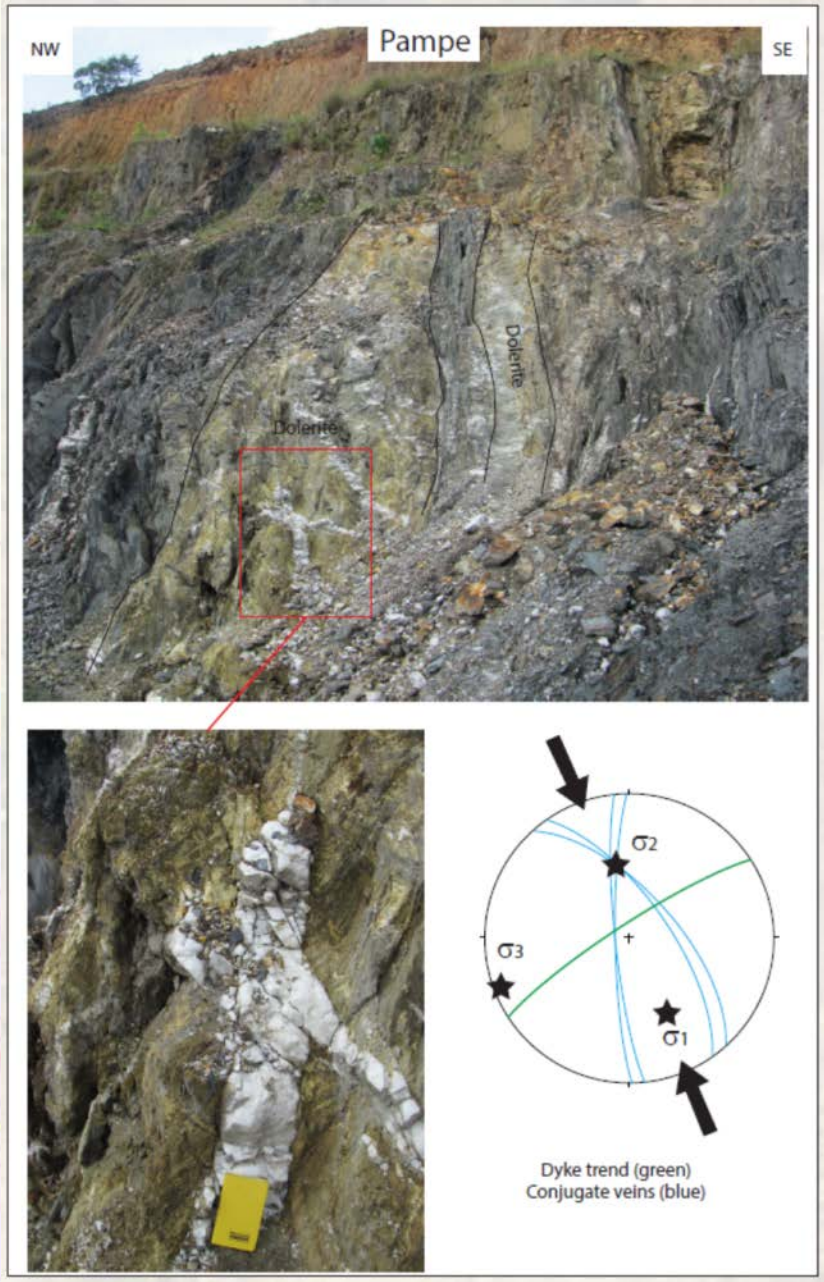
D4 gold mineralisation (gabbro and dyke hosted) NW-SE shortening



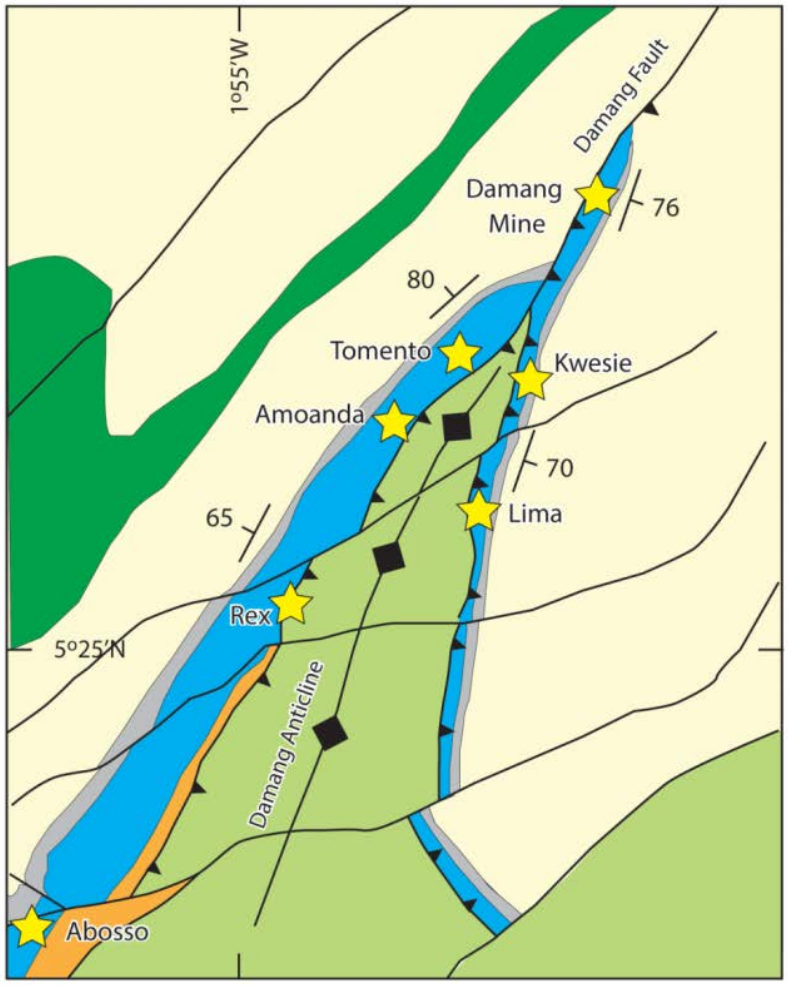


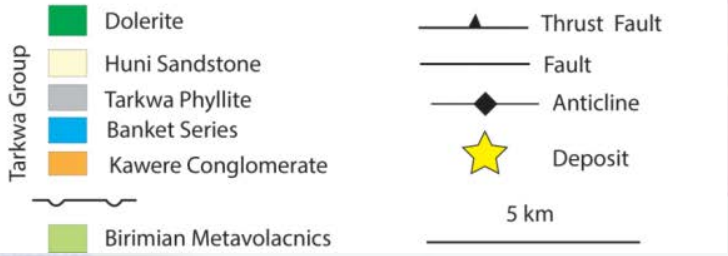




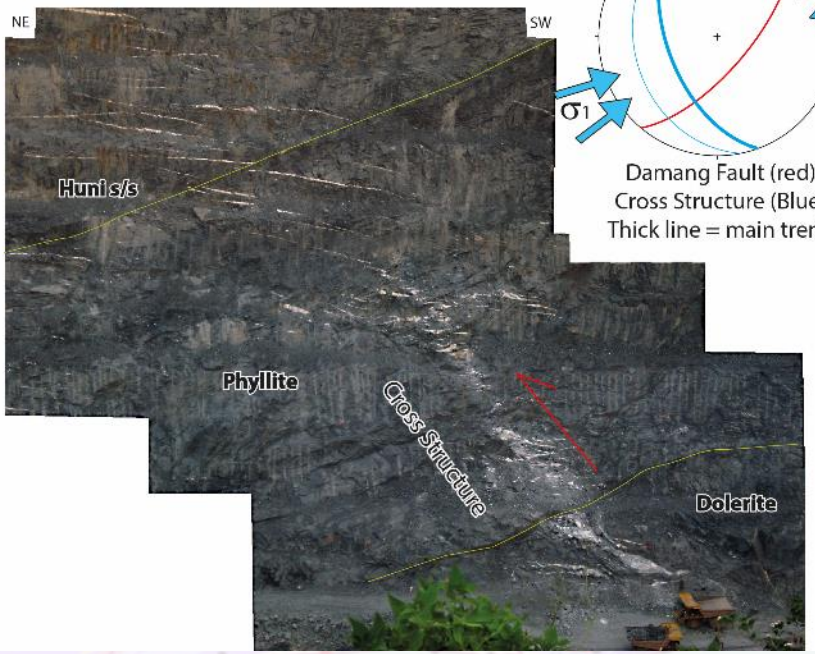


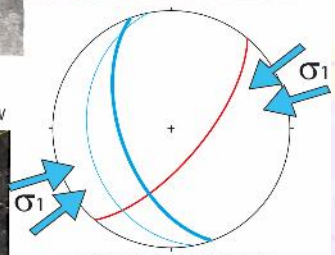
D5 gold mineralisation NE-SW shortening





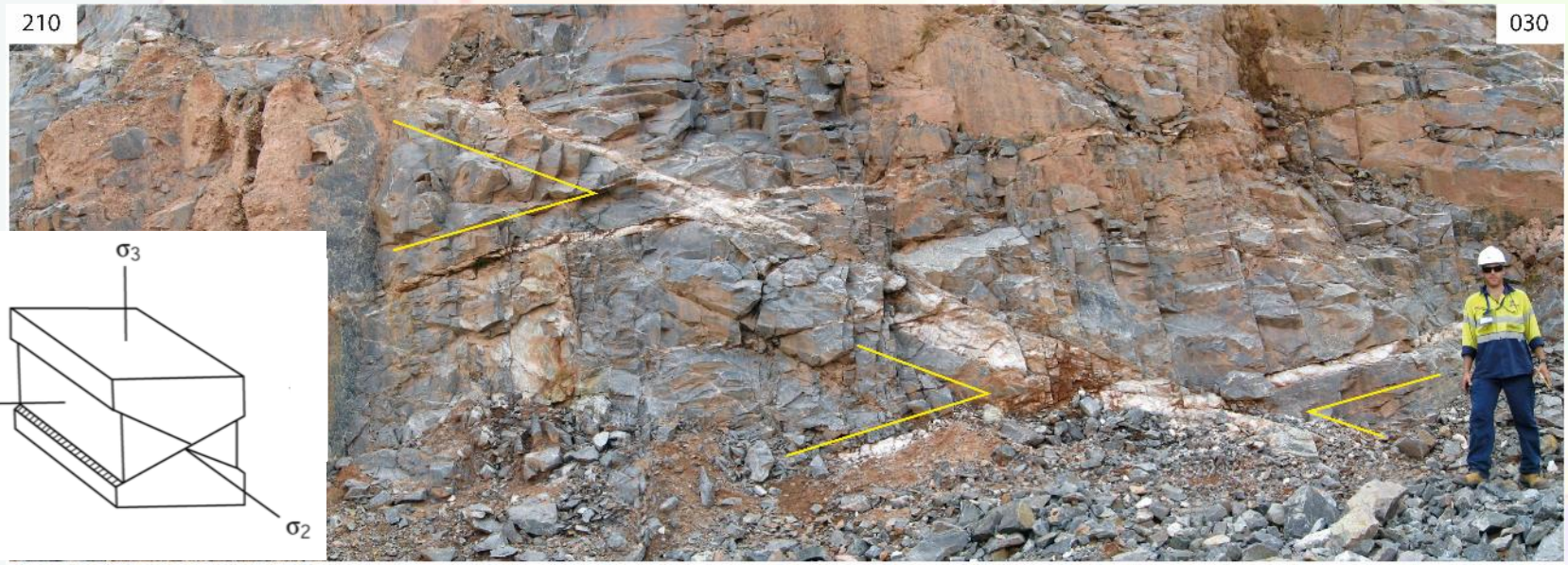
Main Damang Pit

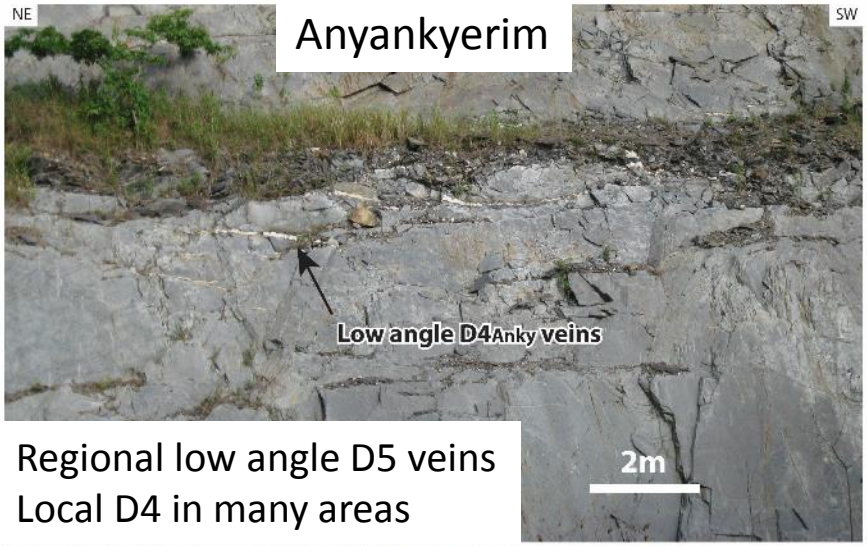




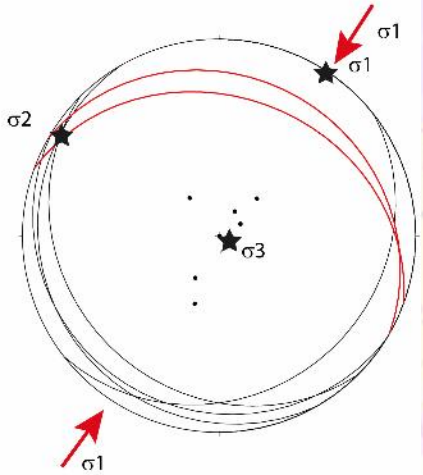
Damang Fault (red)
Cross Structure (Blue)
Thick line = main trend

D5 Damang deposit (& late D5 veins at Anyankyerim)





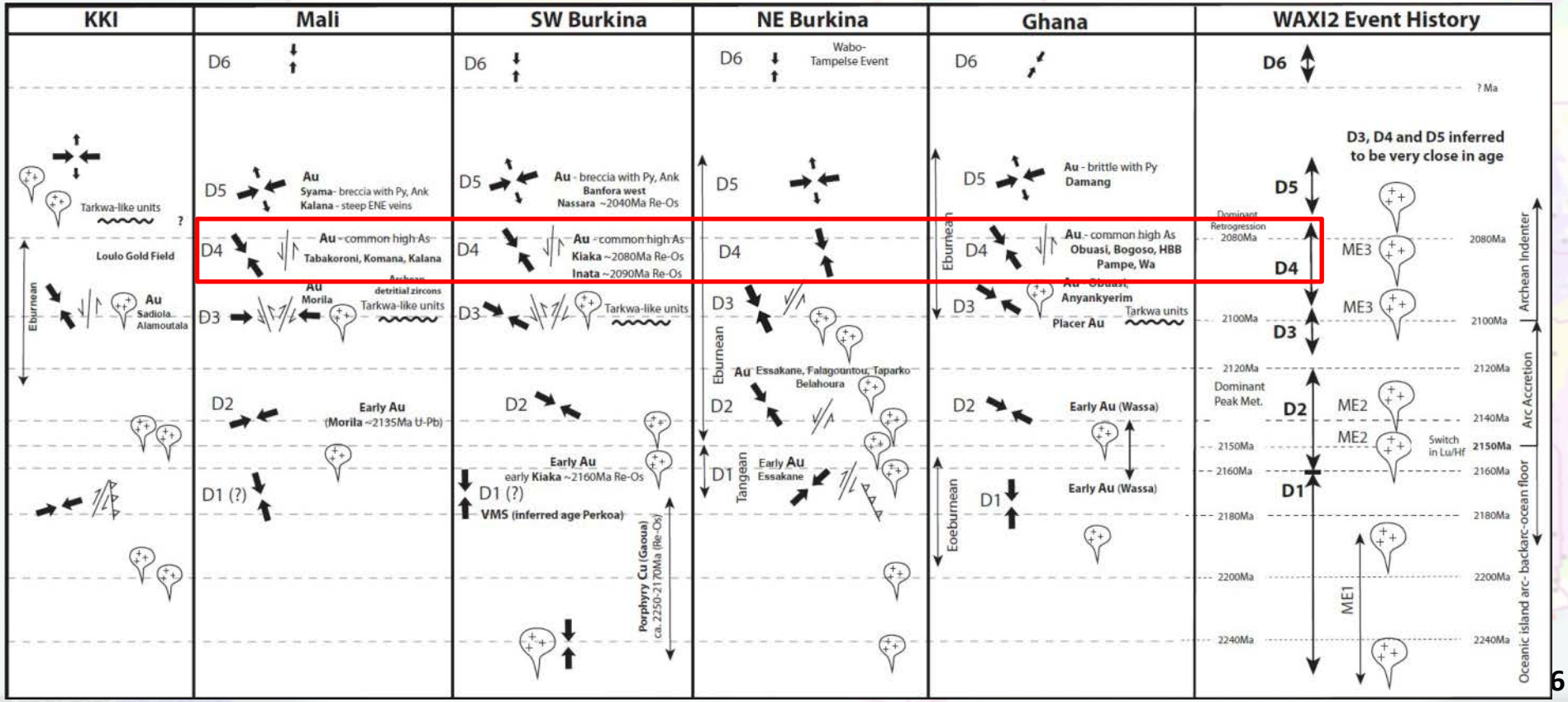
Regional low angle D5 veins
Local D4 in many areas



WAXI2 Space-Time Correlation Chart

In the Ashanti Belt there is a strong late D4 NW-SE shortening event linked to Au. In this belt, and across the Birimian, it is more complex in terms of the timing of the gold, and not all world class gold deposits fit into this event

SENEGAL MALI SW BURKINA FASO NE BURKINA FASO GHANA



SUMMARY

- Gold deposits have a broad geographic extent and structural styles ranging from ductile shear zones at High-T (Morila), fault-vein arrays (Kalana, Damang), to brittle high level low-T breccias (Syama).
- Host rock types for the gold deposits range from sediment-hosted (Siguiri), sediment and granitoid hosted (Kalana), volcanic and mafic intrusive hosted (Syama)
- Multiple phases of gold mineralization with different kinematics and alteration occurred
- Some phases of gold predate the deposition of the Tarkwa units (Wassa and interpretation for Morila). These deposits could be potential analogues of the source for the world-class palaeo-placer deposits occurring within the Tarkwa Formation in Ghana.
- There is a dominant D4 gold event, commonly associated with high arsenic mineralization, with consistent kinematics linked to NW-SE shortening.
- Architectural controls on all systems, and the controls on the localisation of early gold deposits (e.g. Wassa), should be a focus area of research.