West African mineral systems (gold & structural focus)

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Centre for EXPLORATION TARGETING

WAXI- West African Exploration Initiative

IXOA- L'Initiative d'Exploration Ouest Africaine

At close of Stage 2

Project Broker& Coordinator

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Research Partners

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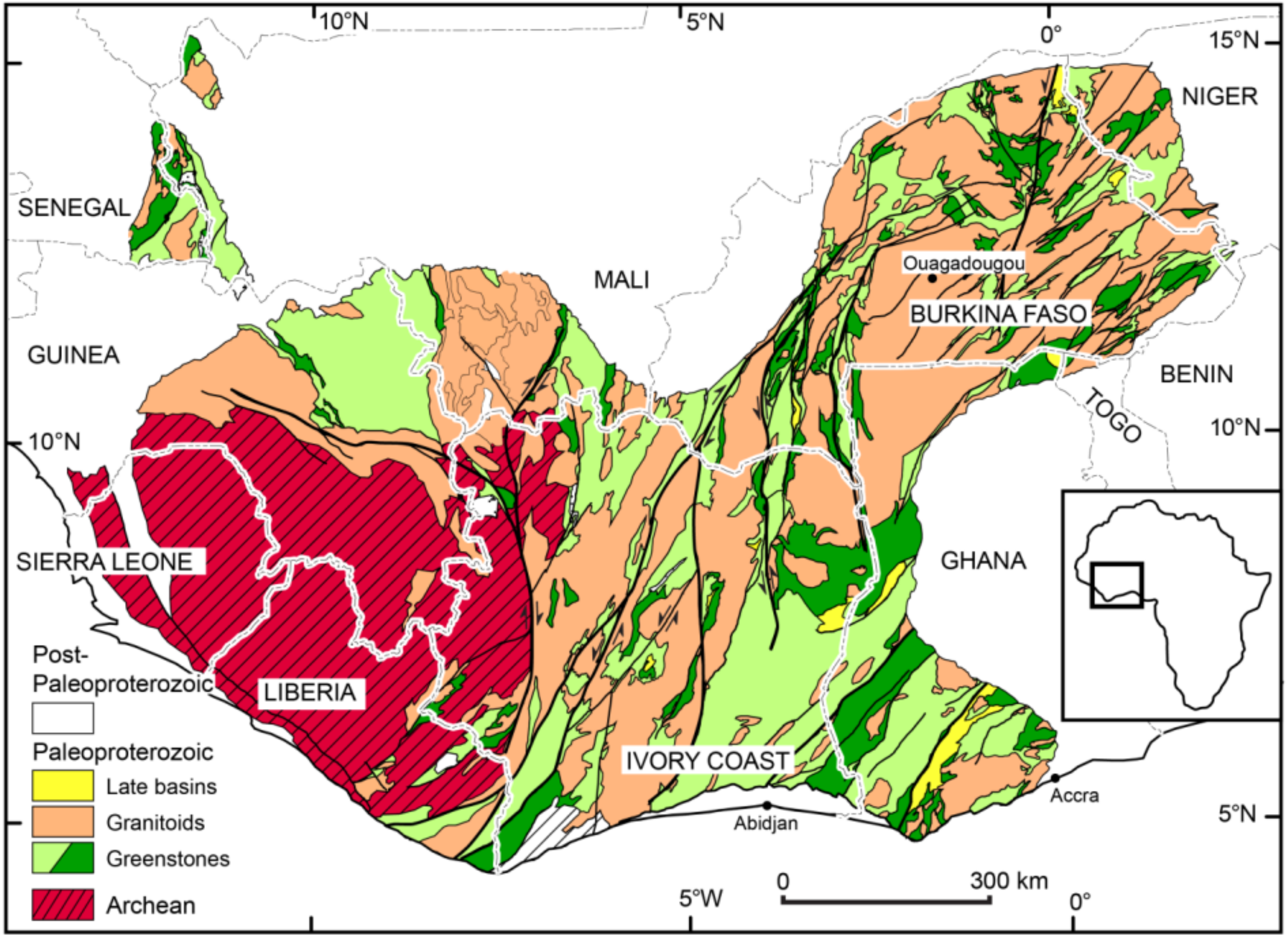
Geology of West Africa

Modified from Milési et al. 2004



Birimian volcano-sedimentary belts with associated granitoids (2250 to 1960 Ma)
Late sedimentary sequence (2010-2000Ma)

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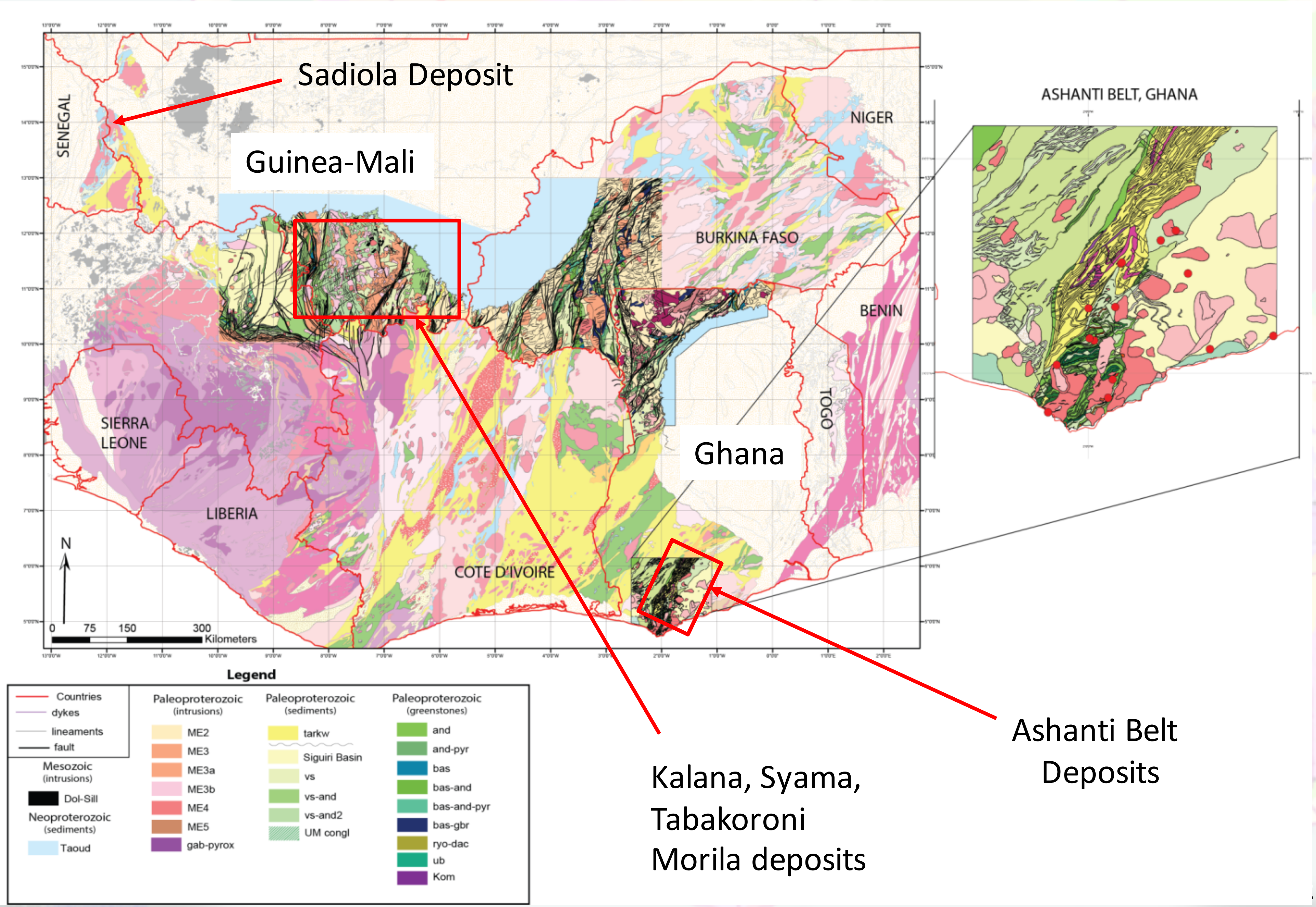
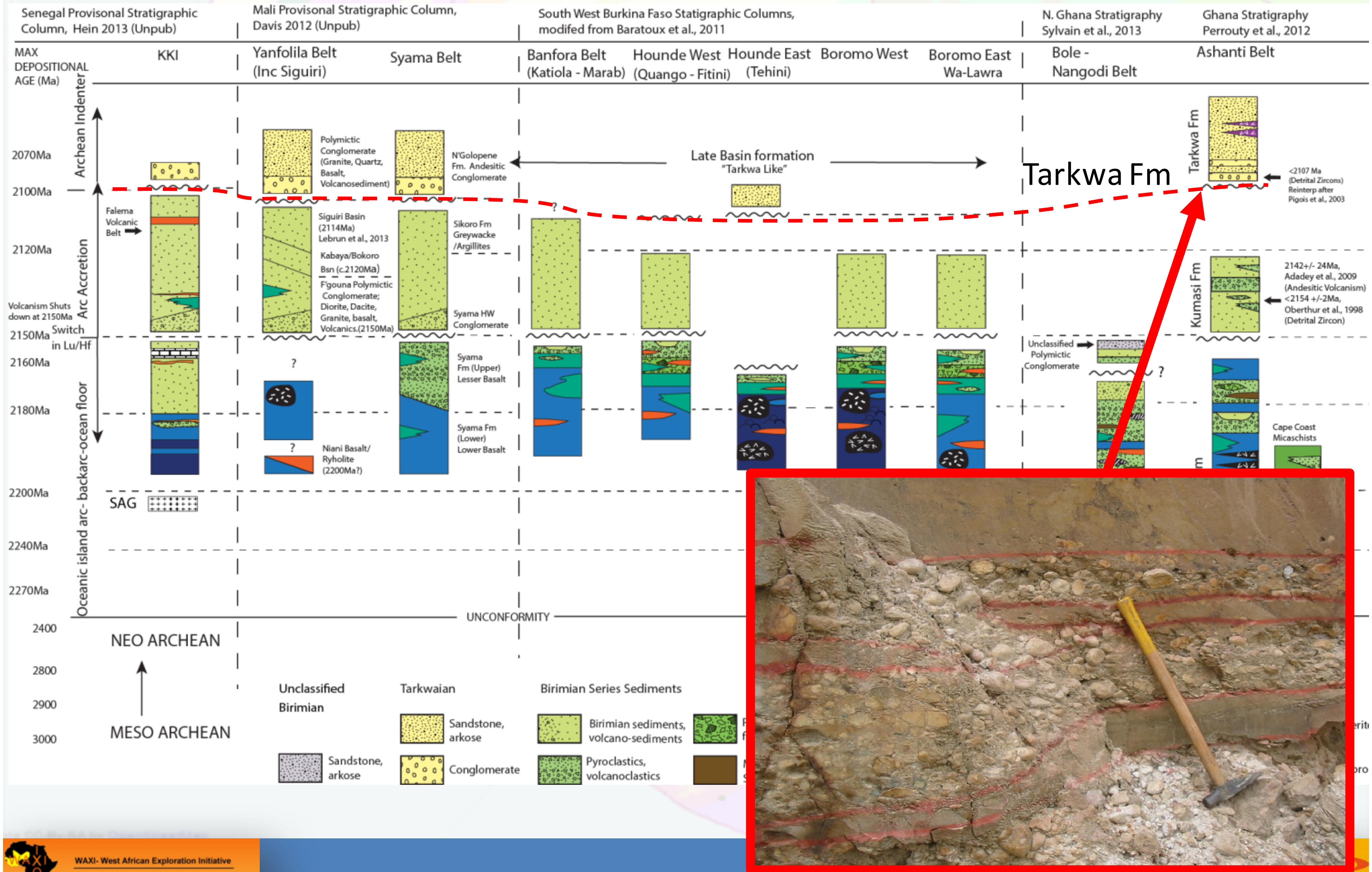
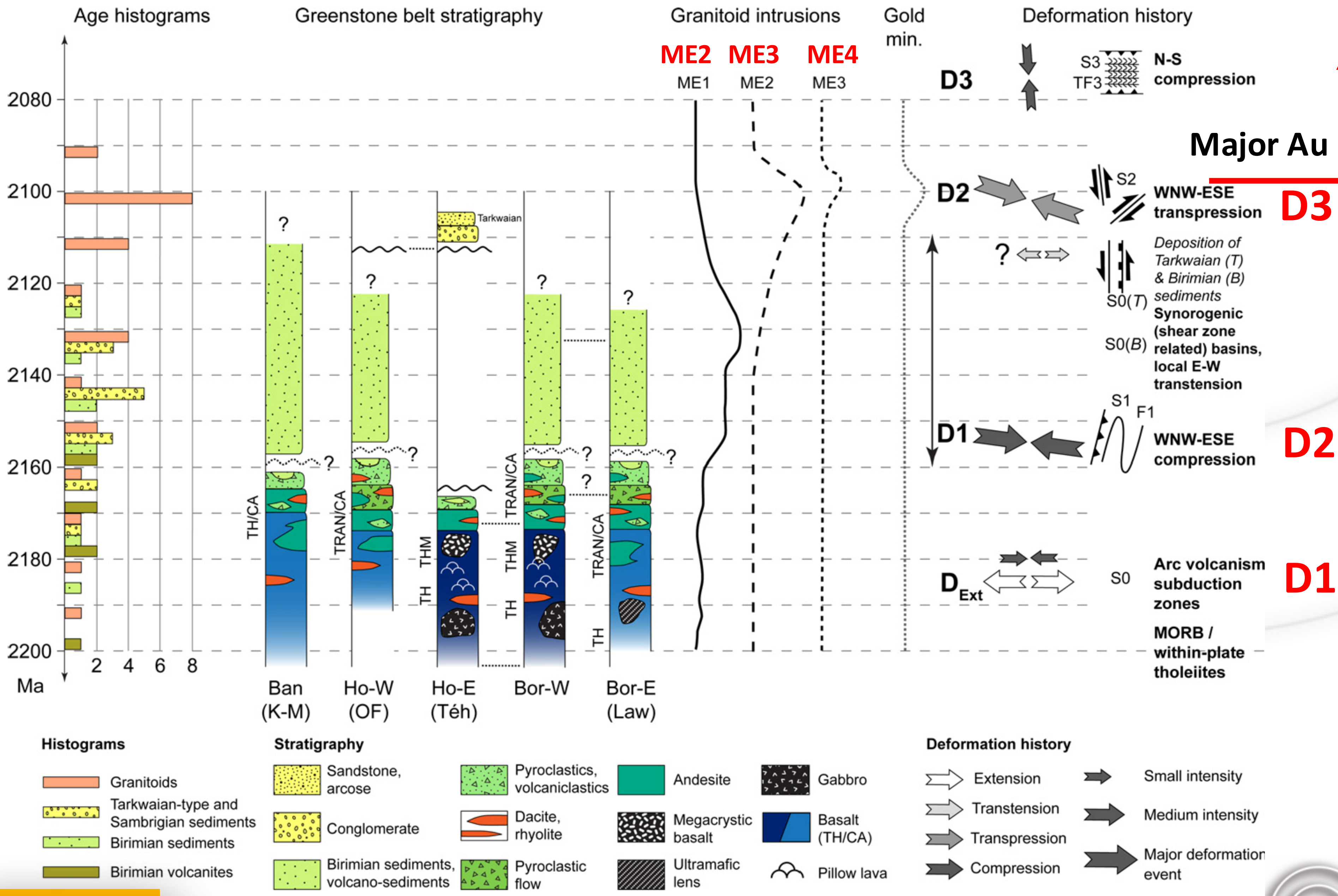
WAXI2 New 1:200,000 maps



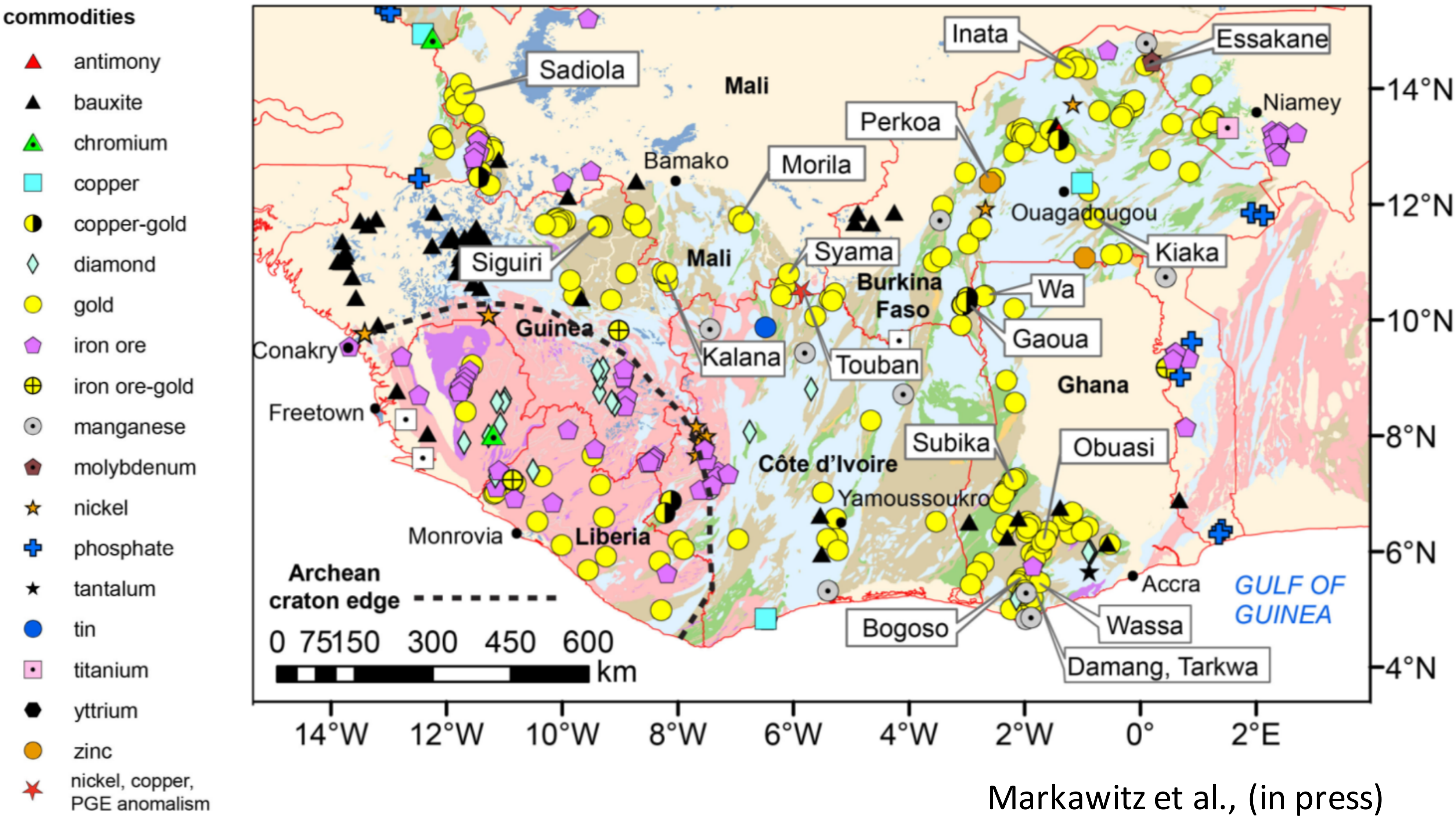
WAXI2 Stratigraphic Synthesis



Original framework used for the interpretations in Mali, Guinea and Ghana



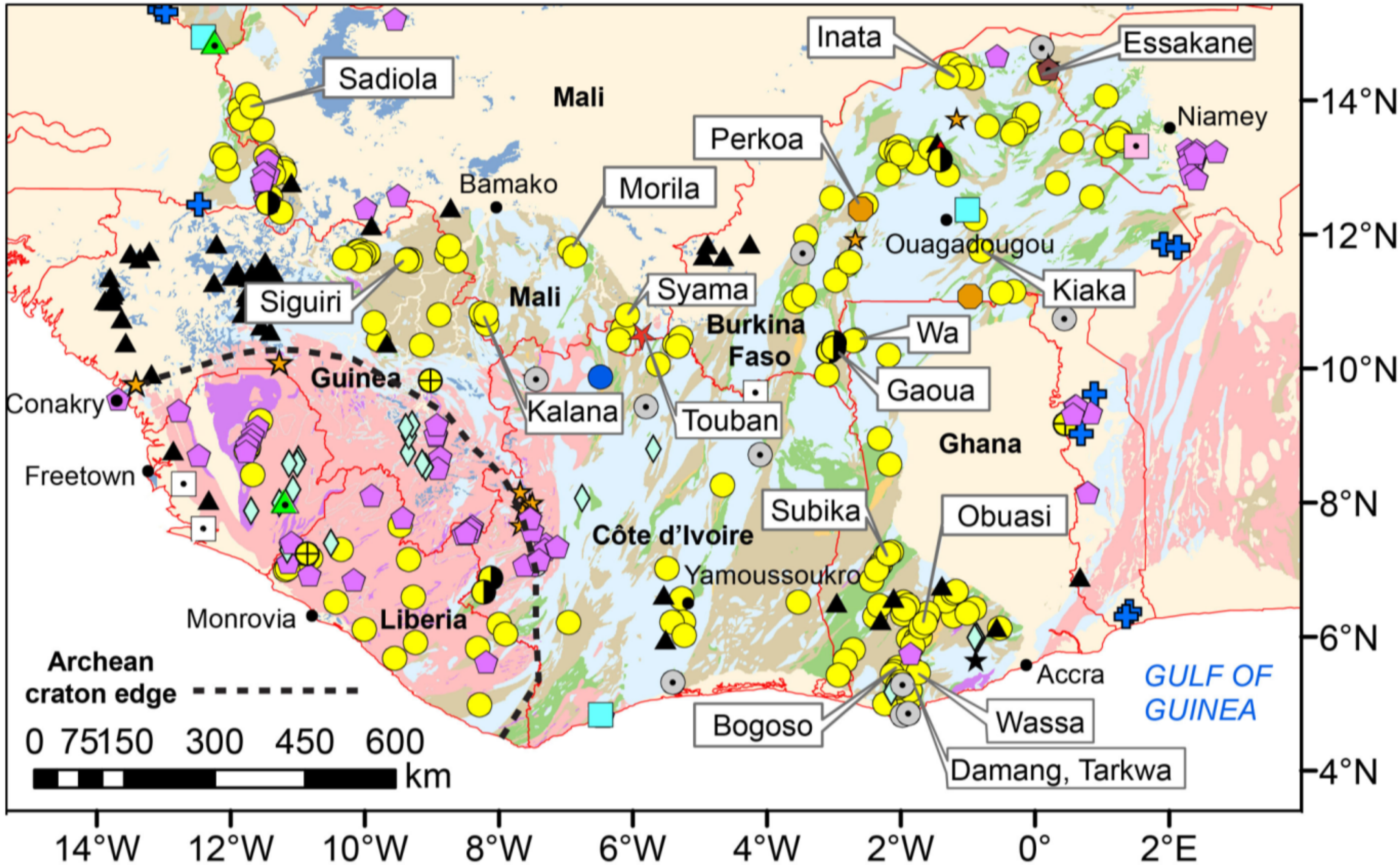
Baratoux et al., 2011, PreCambrian Research 191, 18-45



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 – note broad geographic spread

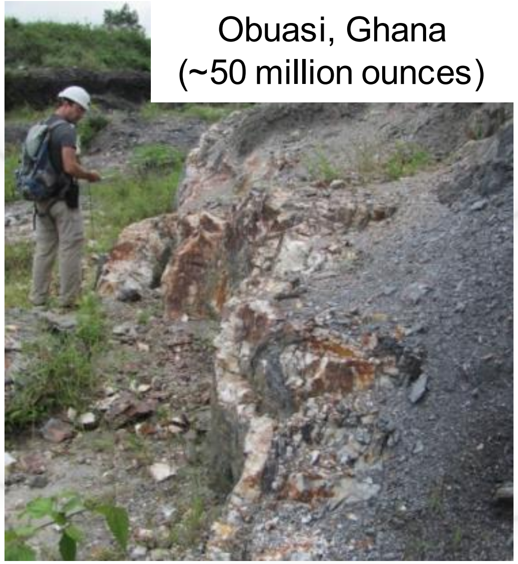

Siguiri, Guinea
(~7 million ounce)


Komana, Mali

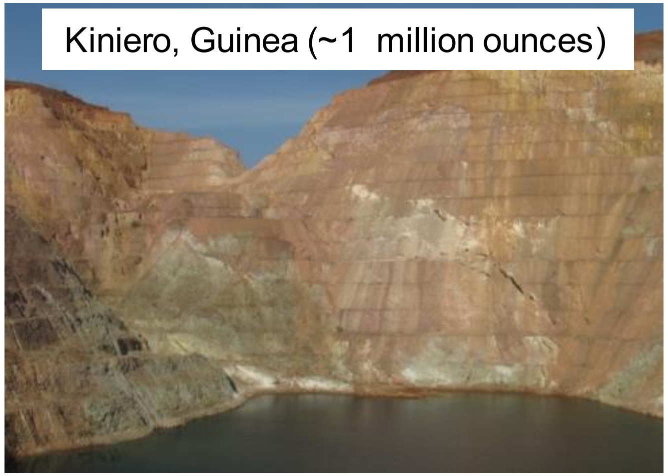

Mana ~ 2 million ounces
Burkina Faso


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)

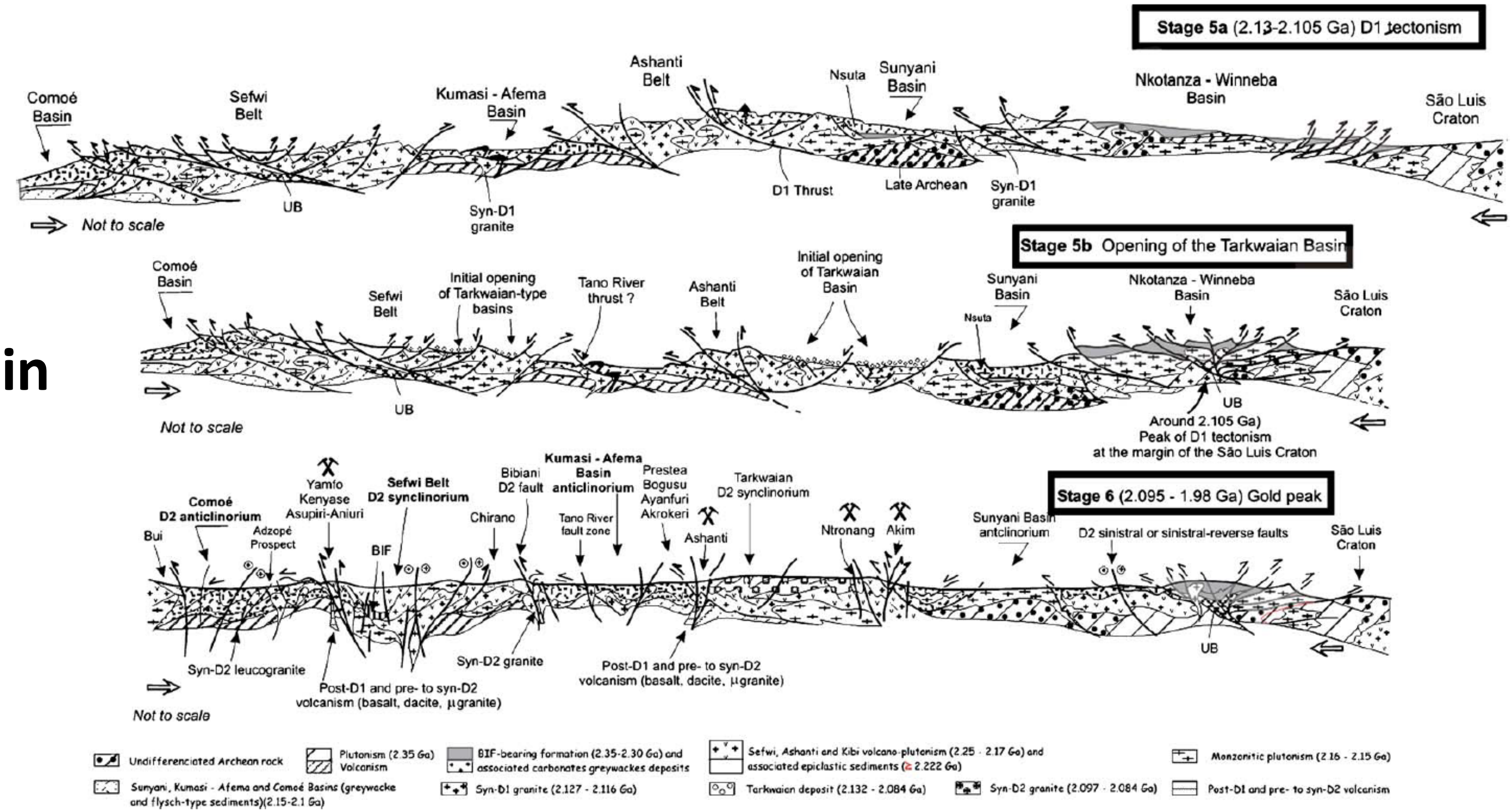
High profile and cited model for Ghana - Feybesse et al., (2006)

- **D1 (2.13 to 2.105 Ga)** = The D1 thrust tectonism, crustal thickening
- **Tarkwaian Basin** contemporaneous with this D1, infill continued during D2 tectonism.
- **D2–3 events (2.095 to 1.98 Ga)** = strike-slip movement. Peak D2 was sinistral to reverse-sinistral shearing.
- Structures active in D2 channelled and trapped gold-bearing hydrothermal fluids

D1

Tarkwaian Basin

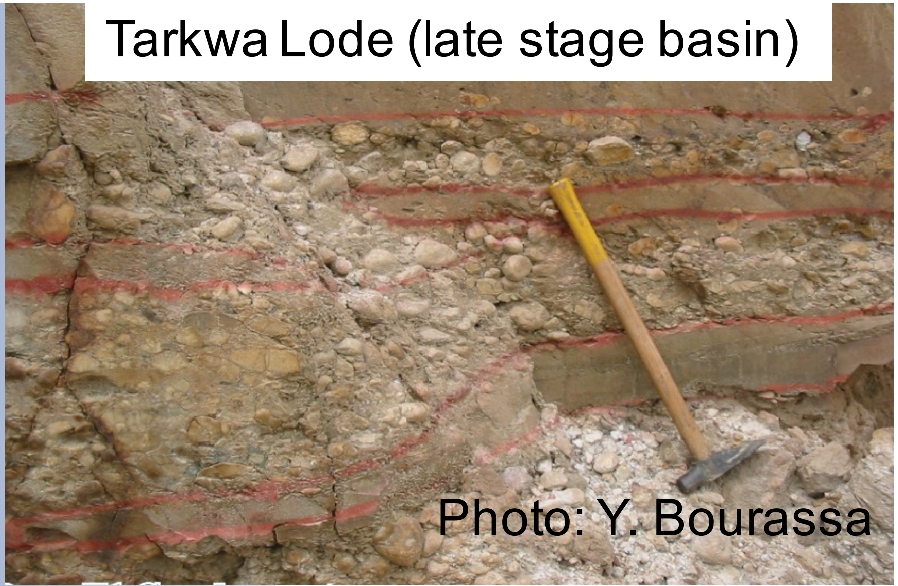
D2-3



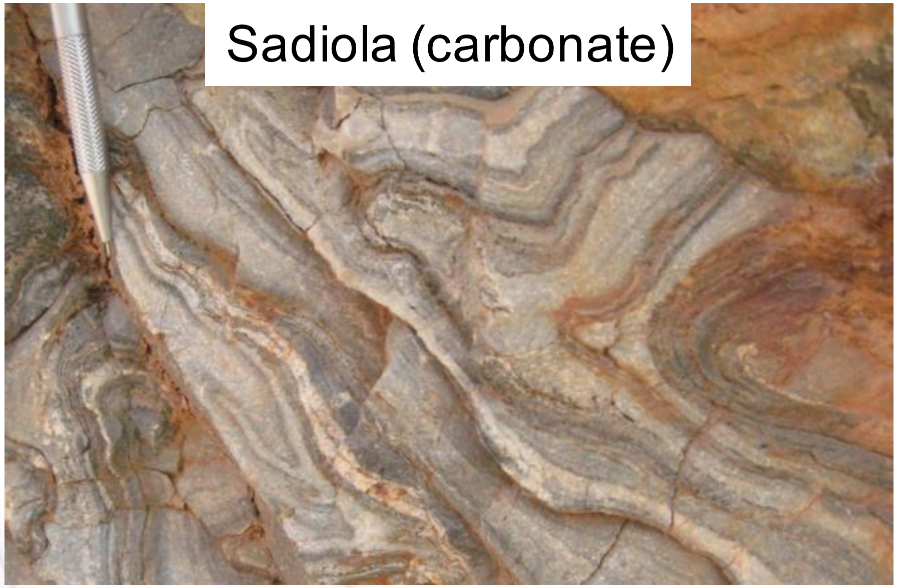
Gold deposit host rocks (2.2-2.1 Ga)

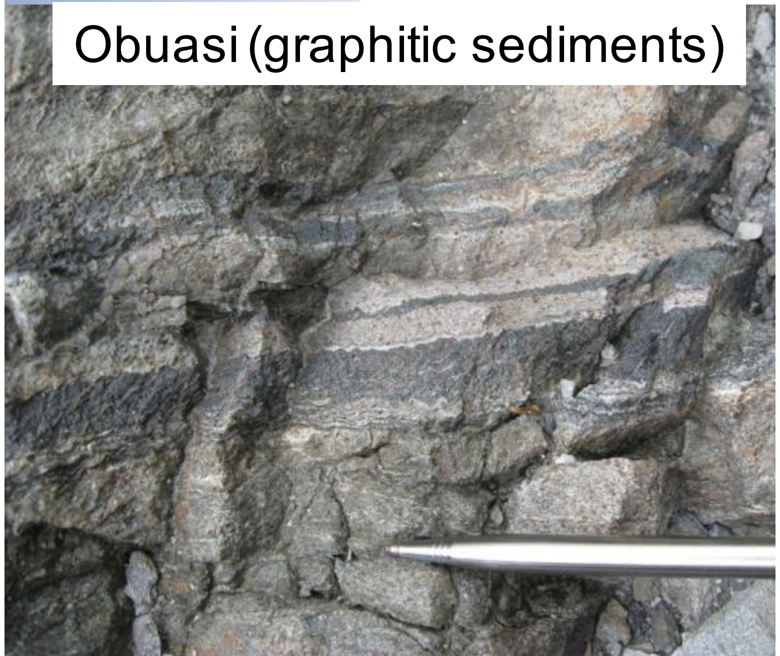
Host rock types range from;

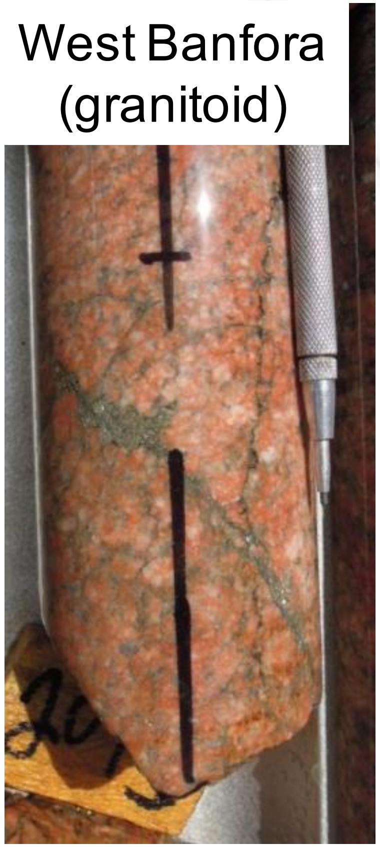
- carbonate-hosted (Sadiola)
- sediment-hosted (Siguiri, Obuasi)
- sediment and granitoid hosted (Kalana)
- mafic intrusive hosted (e.g., Syama)
- mafic volcanic hosted (e.g. Kiniero)
- granitoid hosted (e.g. Banfora, Subika)
- placer deposits in quartz-pebble conglomerates (Tarkwa).

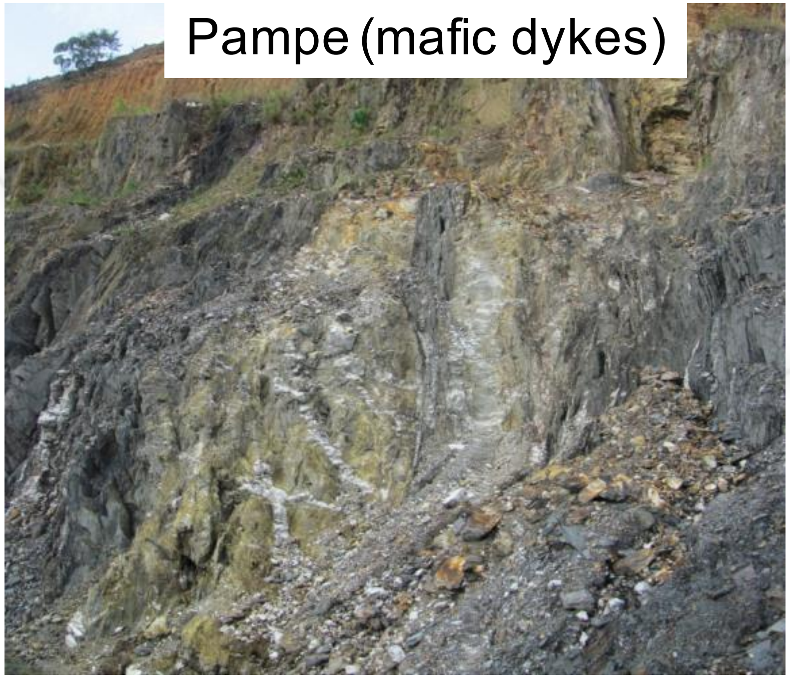


Tarkwa Lode (late stage basin)


Sadiola (carbonate)


Obuasi (graphitic sediments)


West Banfora (granitoid)


Pampe (mafic dykes)

Deposit styles/ models

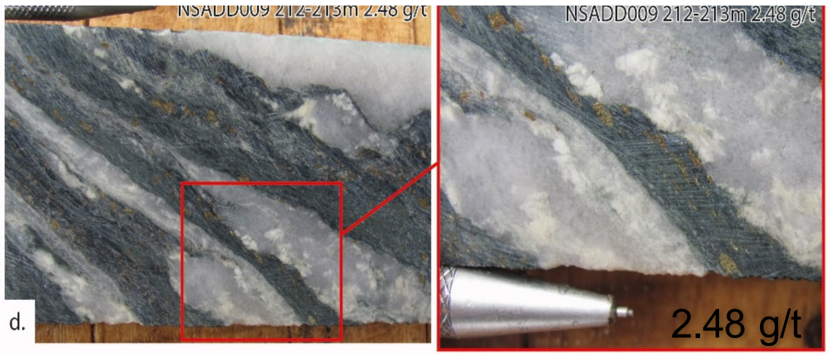
- Intrusion-related (e.g. ~8 Moz Morila deposit; McFarlane et al., 2011)
- Classic fault-valve orogenic gold models (e.g. > 5 Moz Damang deposit; Tunks et al., 2004) with regional fluid flow focussed into low stress domains (Feybesse et al., 2006)
- Paleoplacer systems (e.g. >28 Moz Tarkwa deposit; Pigois et al. 2003) age ca. 2100 to 2110 Ma
- 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).

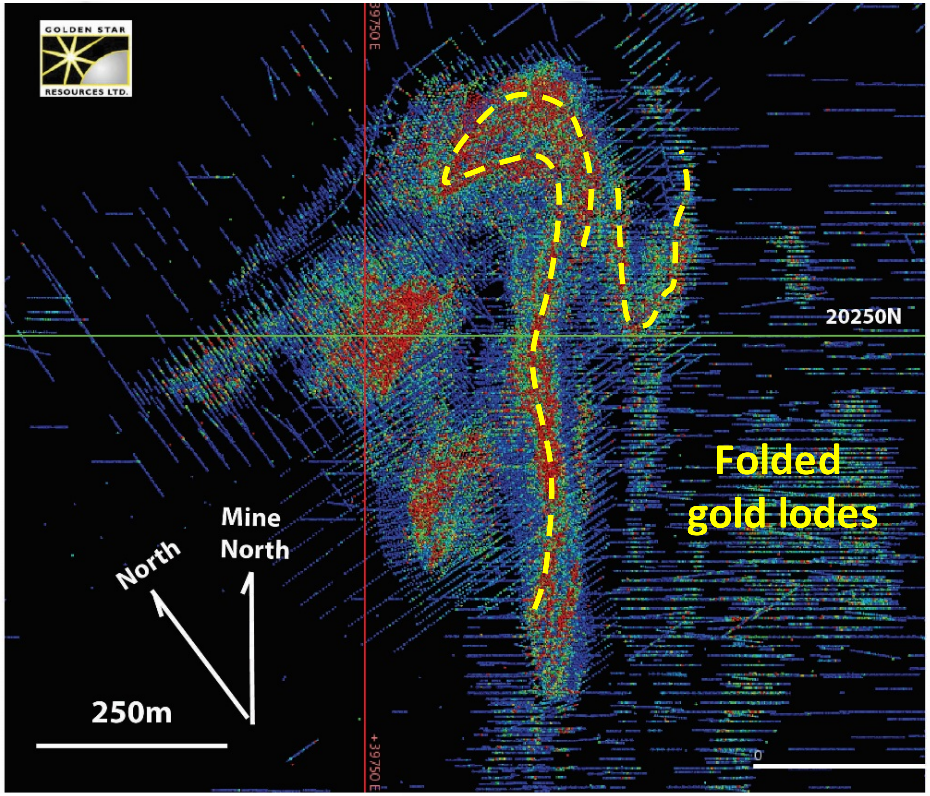
Morila: high T with partial melts

Syama: low –T breccia (mafic intrusive)

Damang: low angle veins

Wassa: folded ductile shear zone (mafic volc.)





WAXI2 Ore Deposit Synthesis – won't cover today

type	Company	Deposit name	host rock	metam	mode of occurrence	deformation	specific alteration	sulphides		Au association	apy T	Re-Os dating		
								principal	accessory			mineral	age	error
Morila-type	Volta	Kiaka	metapelites-diorite	upper amphibolite	disseminated and veins	late shear	carb, chl, trm, czo associate to late shear	po, apy	Bi2Te3, cp, gn, ZnS, late Py	VG in shear-related fractures	>450	Po + Py Po	2077 2158	19 16
	Anglogold Randgold	Morila	Sandstone/shale and minor quartz diorite intrusion	upper amphibolite	disseminated in sandstone/shale and diorite	ductile (+veining), bi foliation	muscovite	apy	po, py, loell, Bi	incl. in Apy in contact c loell	460-570			
Pampe-type	Avocet	Inata	blackshale, andesitic dykes	greenschist	veins in shear zone corridor, during D2-D3	ductile and brittle, shear zone, multiple episodes	ab, carb, late musc + chl	py, aspy	gn, cp, ZnS	inv Au in sulphides on vein edges, VG in fractured sulphides	<300-420	Py	2090	29
	Iamgold	Kalana	sandstone, volcano-sedimentary, diorite	upper amphibolite	qtz-carb +- felds veins	shear veins and tension gaps	chl-carb in selvages	py, cpy, apy, po	sph, gn, Bi, xTe	VG in sulphides; free in veins. >Au in fine grained apy+po in altn halos	>350			
	Goldenstar	Pampe	blackshale, mafic dykes	greenschist	veins in shale and dykes	ductile, but brittle in dykes	ab, carb, late musc + chl	py, aspy	gn, cp, xTe, ZnS	inv Au in sulphides, VG in fractured sulphides	375			
	Goldenstar	Bogoso	blackshale	greenschist	dissiminated and veins	ductile/brittle	carb, qz, ab	Py, Apy	PbSbS, Te, Pd	in py as incl or in late fractures	365-380			
	Goldenstar	Buesichem	blackshale and mafic volcanics	greenschist	dissiminated and veins	ductile (mylonite)	carb, qz, ab	Py	Apy, PbSbS, ZnS	in py as incl or in late fractures	375			
	Resolute	Tabakoroni	Sandstone, black shale and chert	greenschist	dissiminated and veins	strong, shear zone	carb	Apy	Py, CuSbS	in Apy as incl or in late fractures	320			
Nassara-type	Resolute	Syama	lamprophyre/blackshale	greenschist	dissiminated and veins	ductile/brittle (several deformation stages)	ab, carb, musc	py	CuSbS, Apy	in py as incl or in late fractures	<300			
	Goldenstar	Benso	diorite quartzitique	upper greenschist	disseminated and veins/shearbands	localized shearzone	ab, chl, qz	po	Py, PbTeS, Cp	associated to sulph., chl, alb and Fk	<300			
	Volta	Nassara	shale, andesite, diorite	lower greenschist	disseminated and veins	ductile and brittle	carb, chl, ab	py	po, cp, gn, ZnS, Apy	in py as incl or in late fractures	<300	Py Py	2038 2153	7 14
		Gaoua, orogenic Au	diorite, andesite	greenshist	shear zones deforming porphyry, cc-qtz veins	ductile shear zone	chl, carb	py	cp, PbTe, AgTe, CuSbS	in sulphides, chl, and in fractures	<300	Au	188	3
Wassa-type	Goldenstar	Wassa	Mafic Volcanics, Felsic porphyry, minor clastic horizons and very rare black shale	greenschist	disseminated and veins	ductile (lenticular py), folding of D1	chl, carb, qz, trm	py	po, cpy, apy, ZnS	inv Au in py, inclusions in py	375			
Tarkwa-type	Goldfields	Damang	Conglo / microdiorite	upper greenschist	placer and hydrothermal disseminated Au and veins	ductile/brittle	carb, Trm, gr	py --> po	Cp	linked to Trm and sulphides	<300			

Didier Béziat, Stefano Salvi, Luc Siebenaller and others

Architectural/ regional structural controls

- Gold-only 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*

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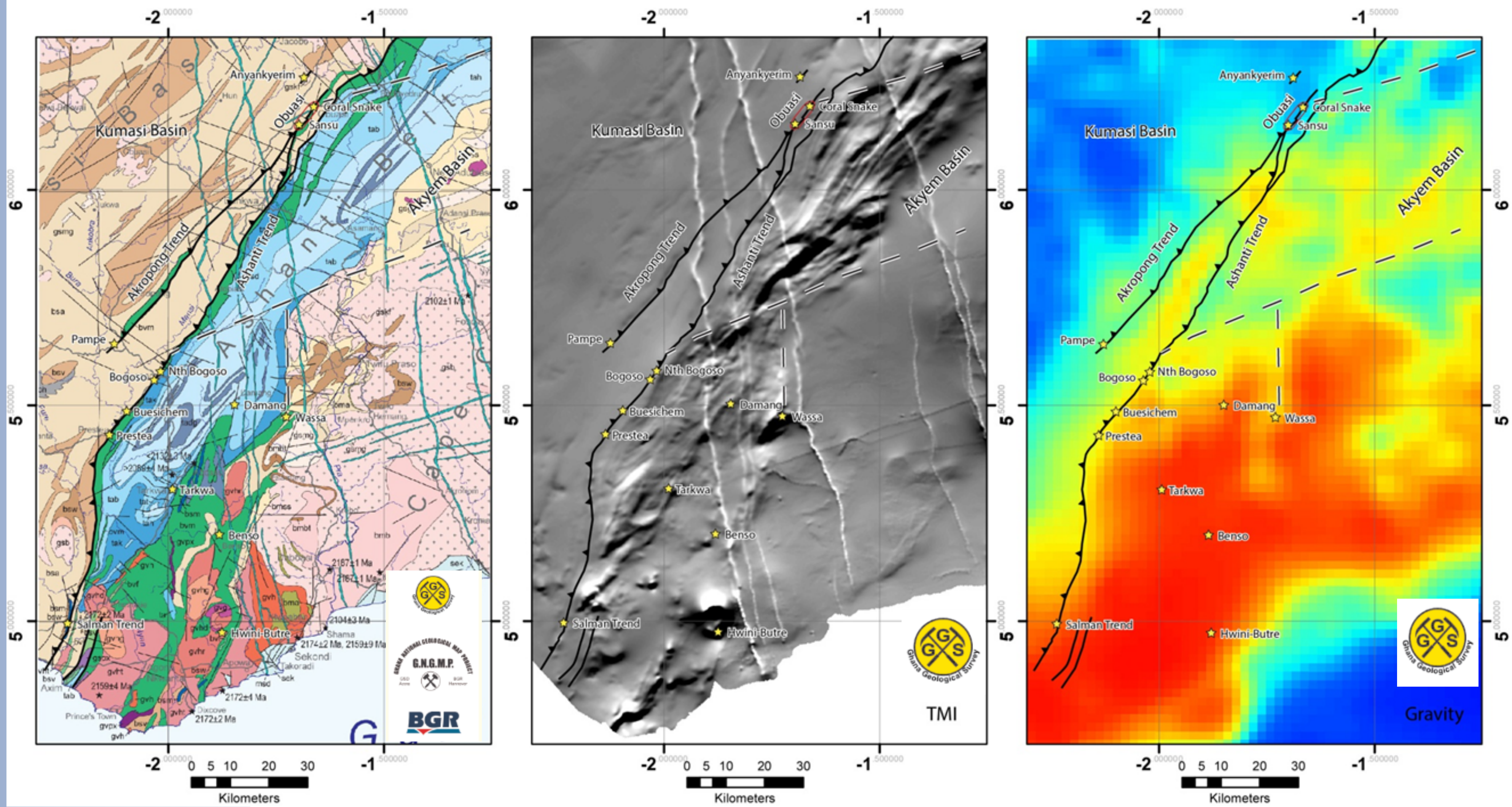
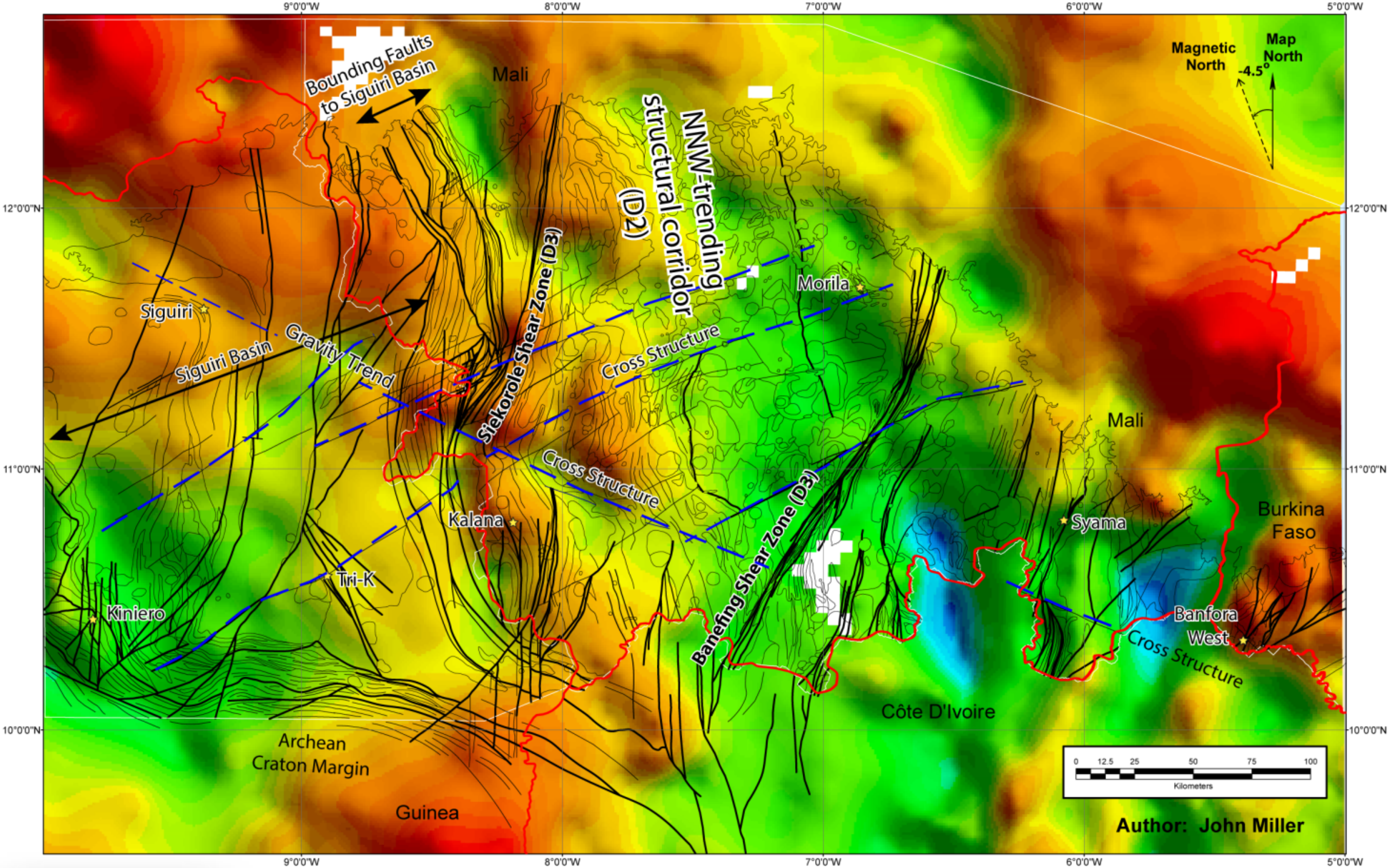
Major variations between individual deposits. Belt scale architectural controls appear to be a control on deposit location.



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

Guinea and Mali (interpretation with gravity data)



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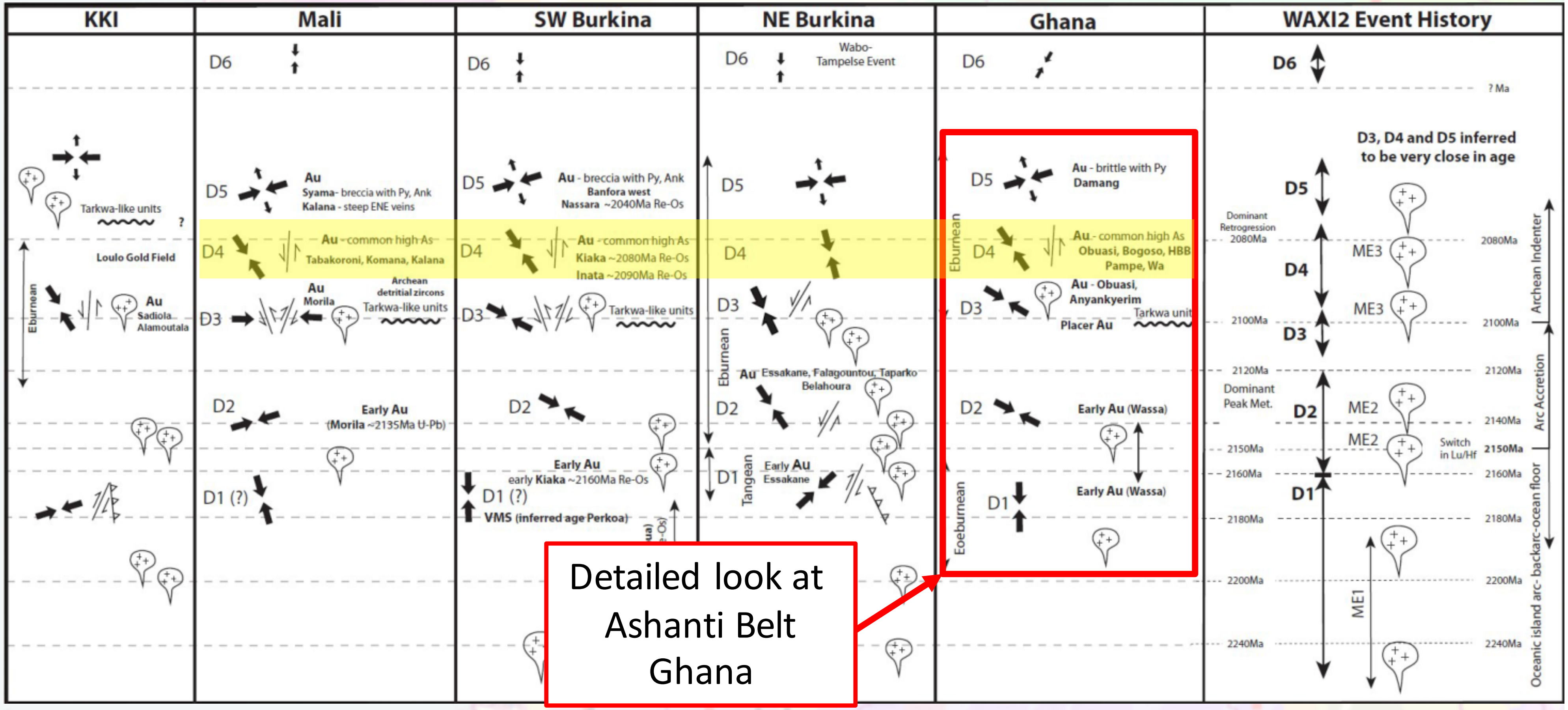
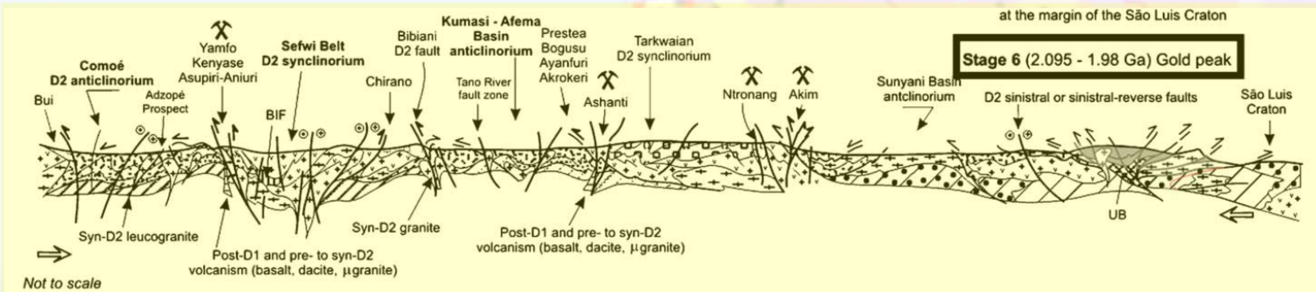
Kinematics and timing

- 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, which is commonly associated with NW-SE shortening, sinistral slip and high arsenic e.g., Obuasi (Allibone et al., 2002; Feybesse et al., 2006).
- Also later stage D5 brittle reverse/ dextral stage (Syama and Damang)
- World class ca. 2100-2110 Ma Tarkwa Formation Paleoplacers in the Ashanti belt predate the D4 gold event – this requires an older pre-Tarkwa deposition 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 Archean Yilgarn craton of Australia)

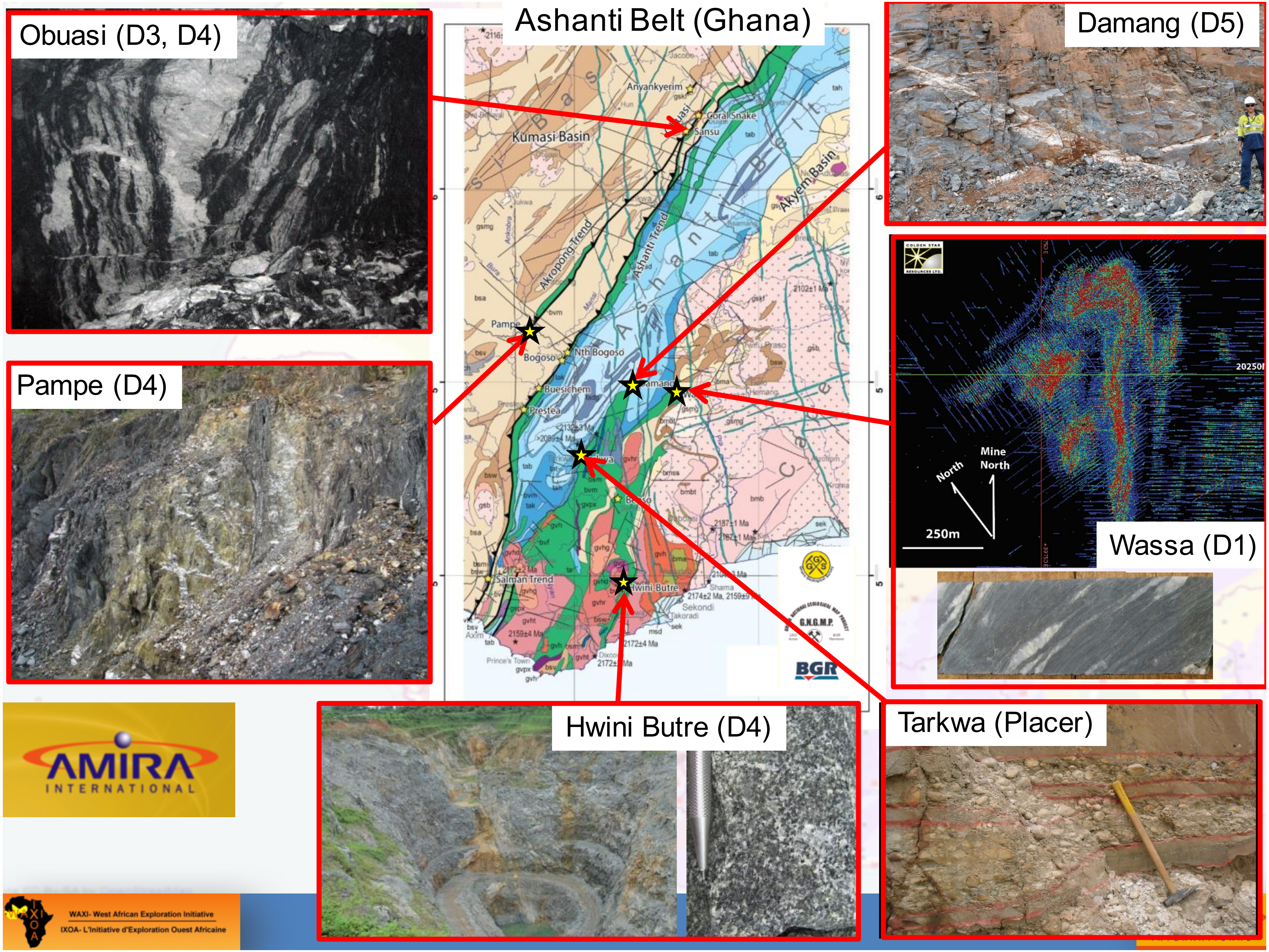
WAXI2 Space-Time Correlation Chart Major D4 gold event highlighted

SENEGAL MALI SW BURKINA FASO NE BURKINA FASO GHANA





Feybesse et al., (2006)
D2–3 events (2.095 to 1.98 Ga)
= sinistral strike-slip movement
& gold (**D4 in WAXI history**)



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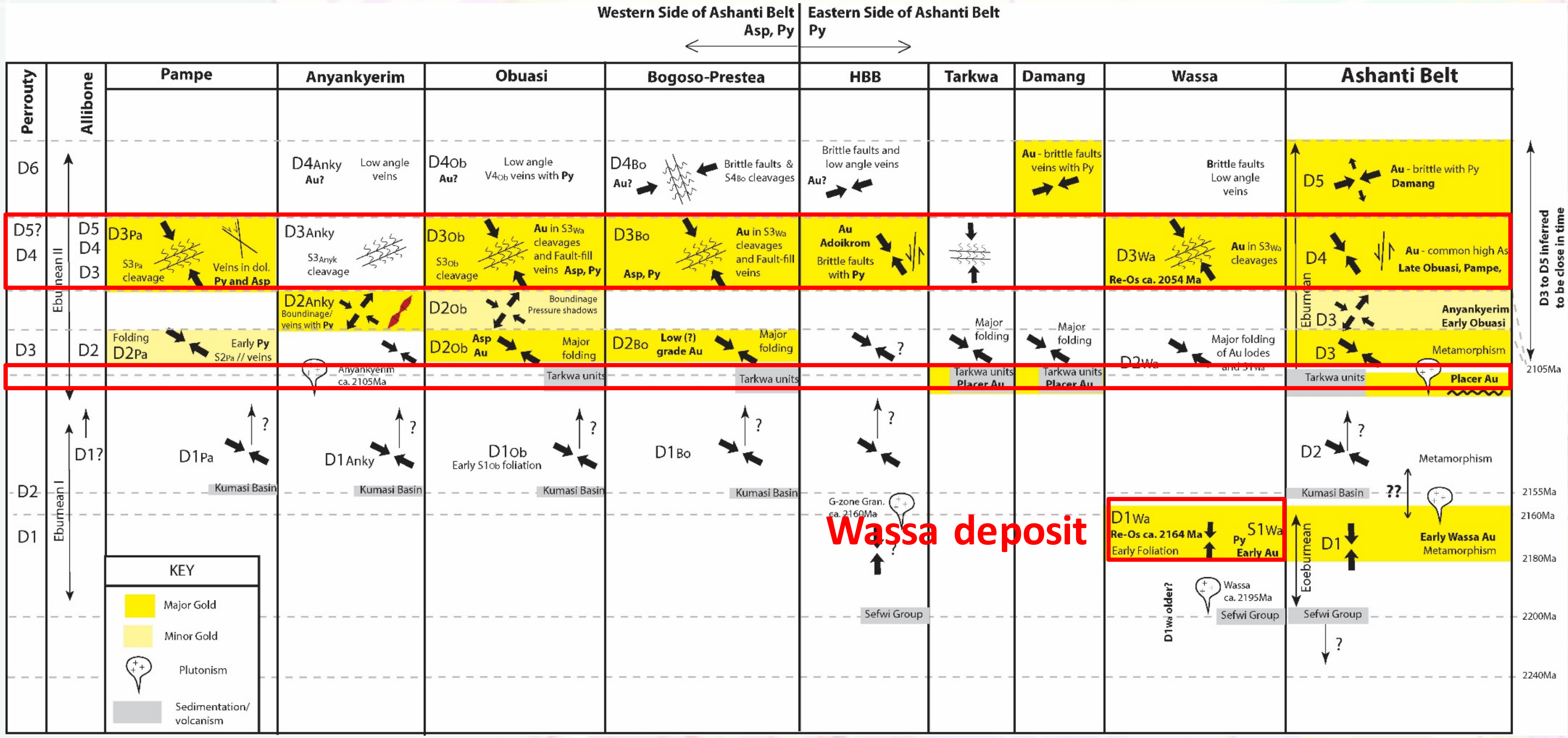
Ashanti Belt (Ghana) – critical study area
Major deformation events and phases of gold

- Poorly defined early events
- Early D1 gold at Wassa – this is pre-deposition of ***Tarkwa unit***
- Deposition of ca. 2100 to 2110 Ma Tarkwa paleoplacers
- Major D3 NW-SE shortening linked to regional folding of all sedimentary sequences (including Tarkwa Fm) and shear development
- D3 Gold related to horizontal stretching and NW-SE shortening
- Regional **D4 event** linked to a ***major phase of gold mineralisation*** with cross cutting ***D4 crenulation cleavages/foliation***, 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)

Ashanti Belt history (deposit by deposit) – linked to WAXI2 event history

NOTE: major late-stage orogenic gold = most common observation in the literature

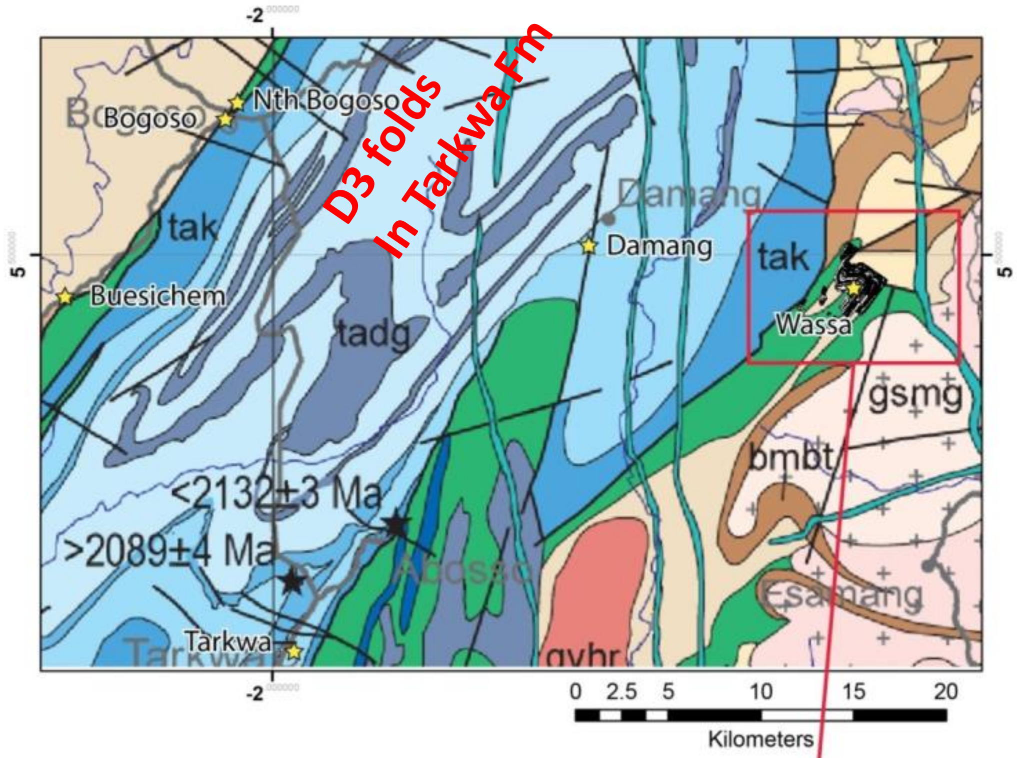


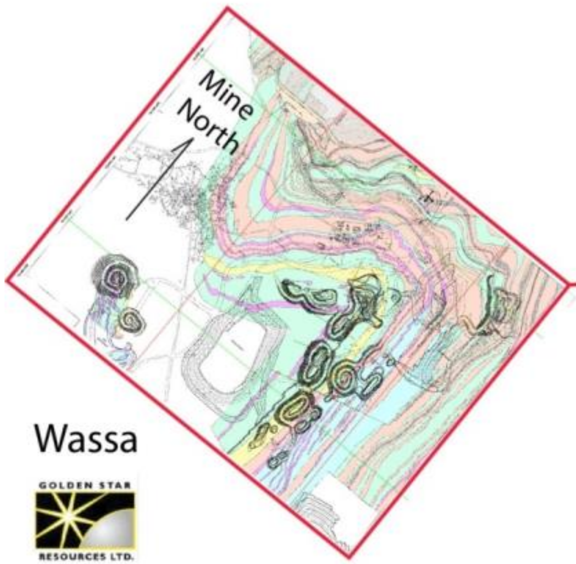
Local events versus WAXI2 event history = will use WAXI2 regional events

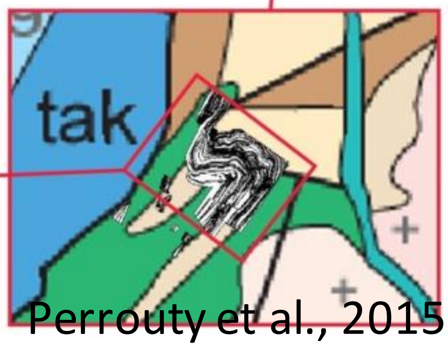
Peak Gold described by Feybesse et al., (2006)

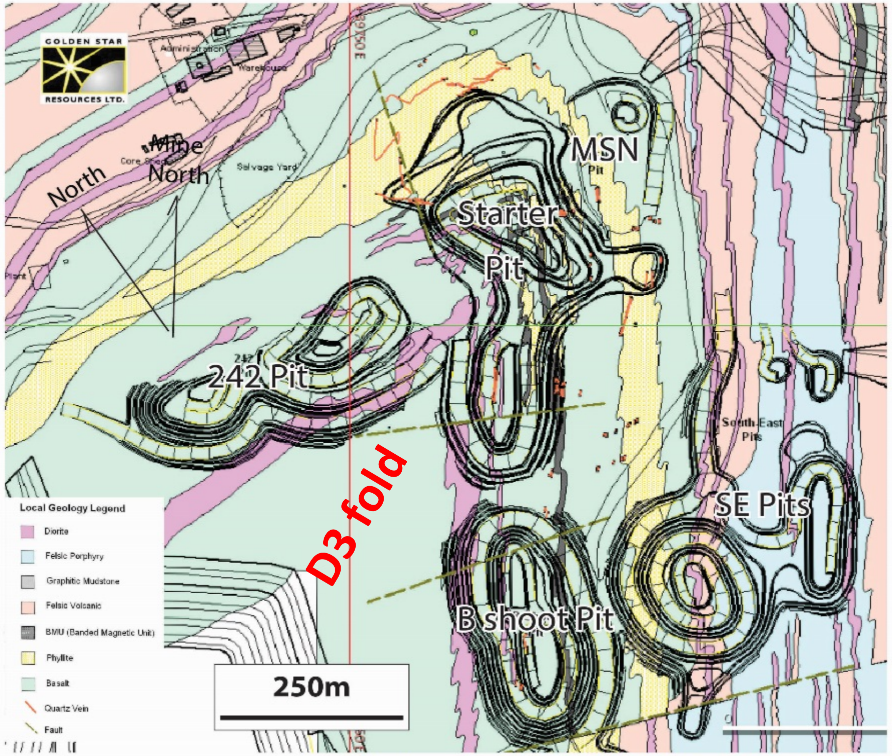
Tarkwa Paleoplacer gold ca. 2100-2110 Ma

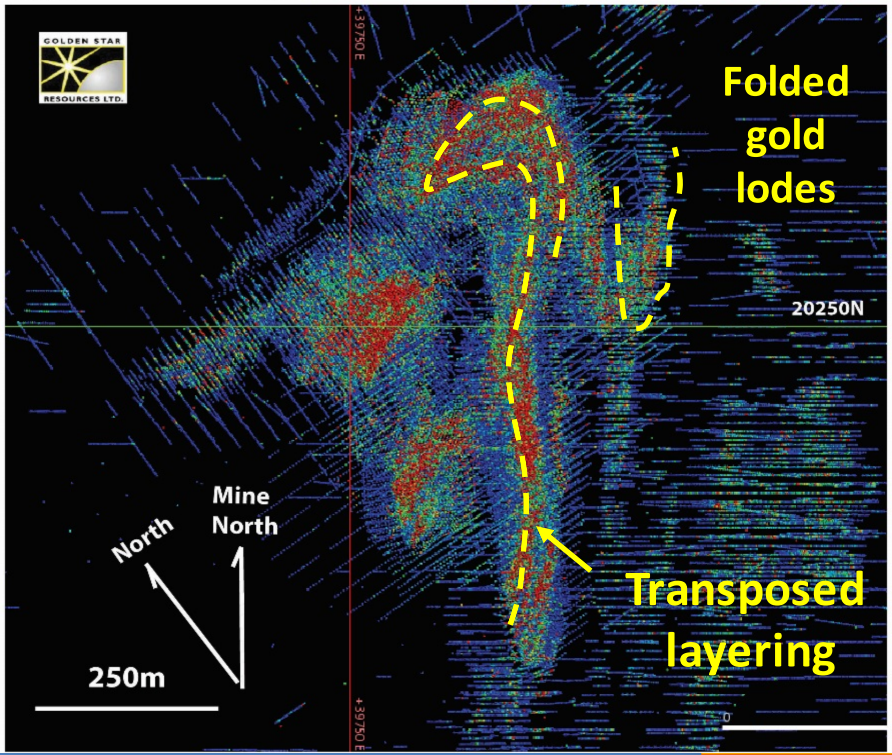
Wassa deposit ~ 5 million ounces gold
(Early Gold, D1 deposit with overprints)



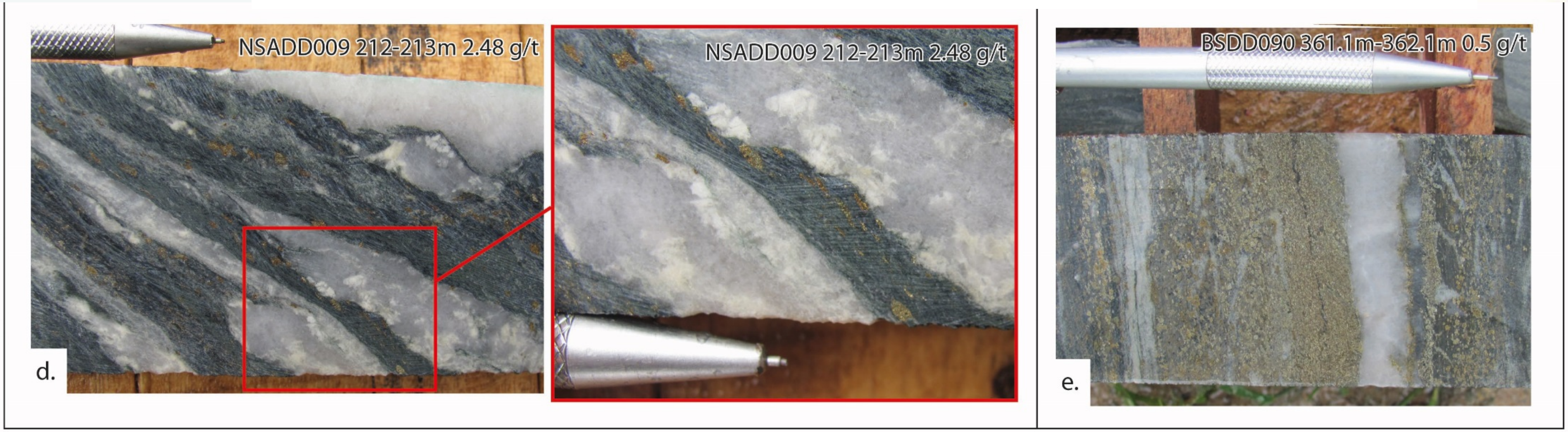


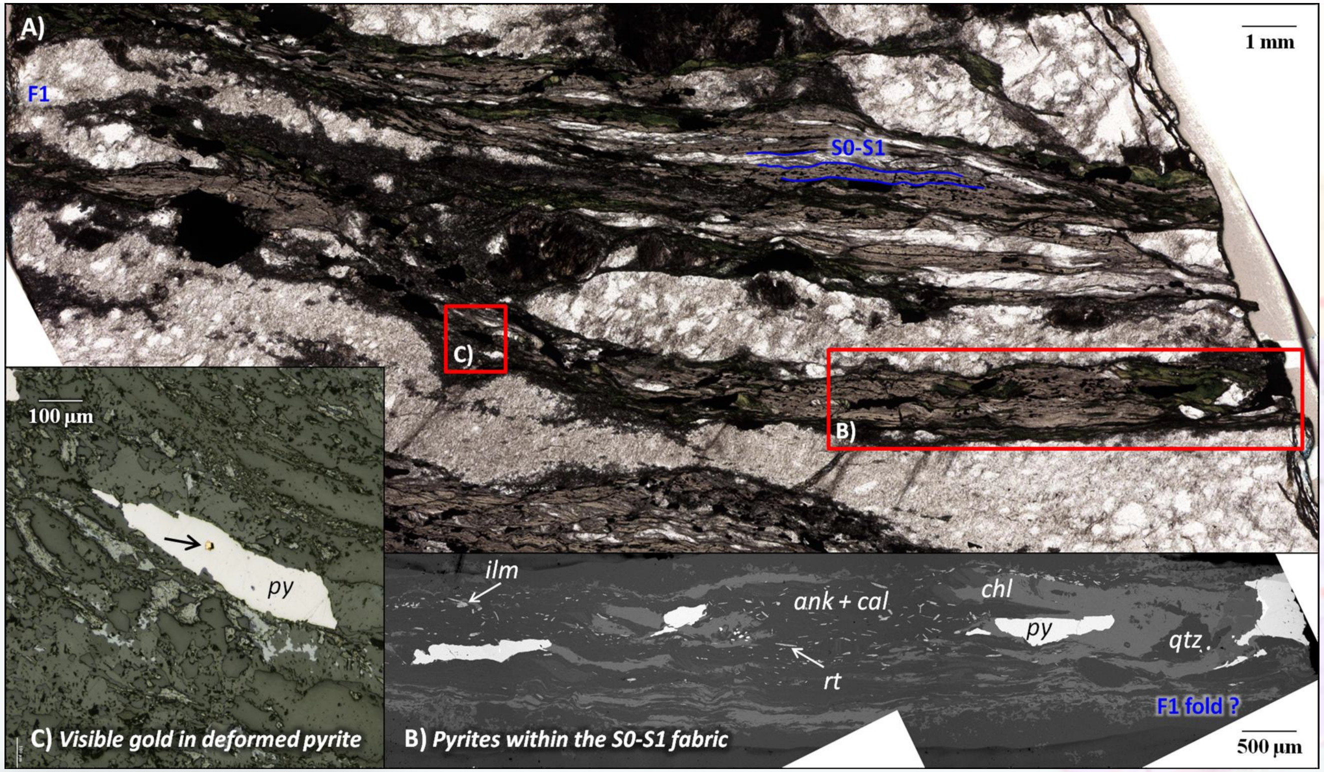






Wassa (Early Gold, interpreted D1, strongly over printed deposit)





C) *Visible gold in deformed pyrite*

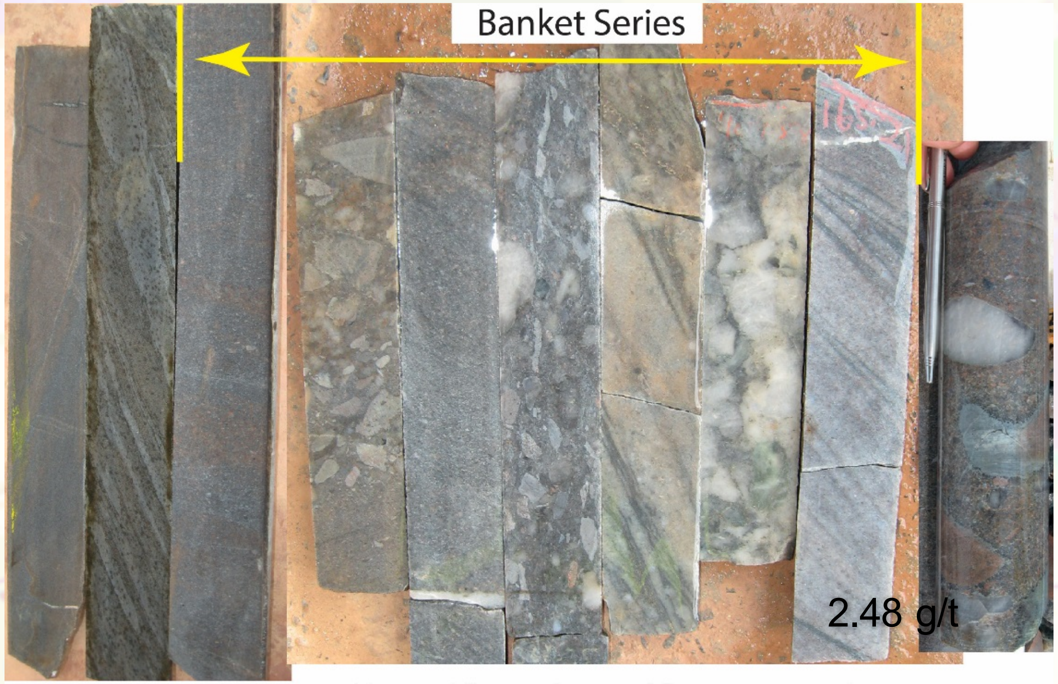
B) *Pyrites within the S0-S1 fabric*

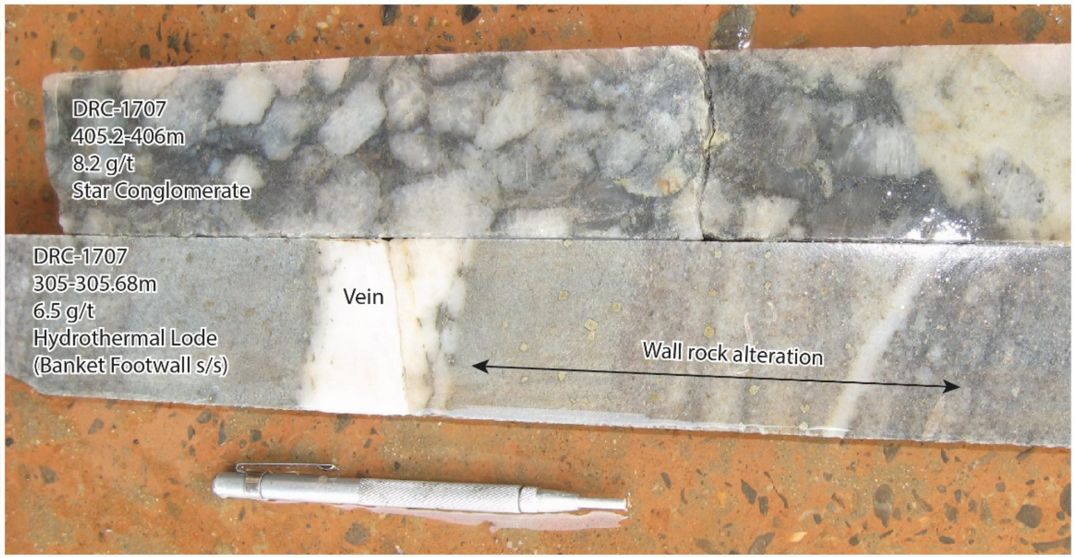
- Texturally early gold
- Grade control data suggests lodes are folded
- Re-Os ages of sulphides from the Wassa deposit produced two ages 2164±22 Ma and 2054±11 Ma (Le Mignot et al., in review).

Tarkwa Unit Paleoplacer (Tarkwa)
ca. 2100 – 2110 Ma

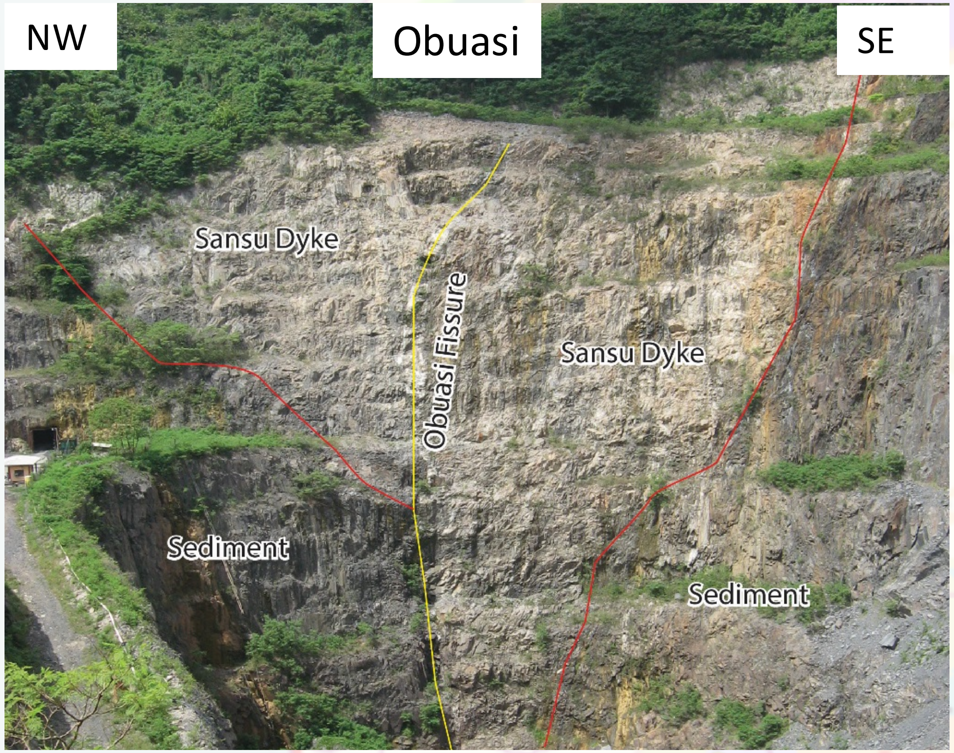
> 28 million ounces of gold

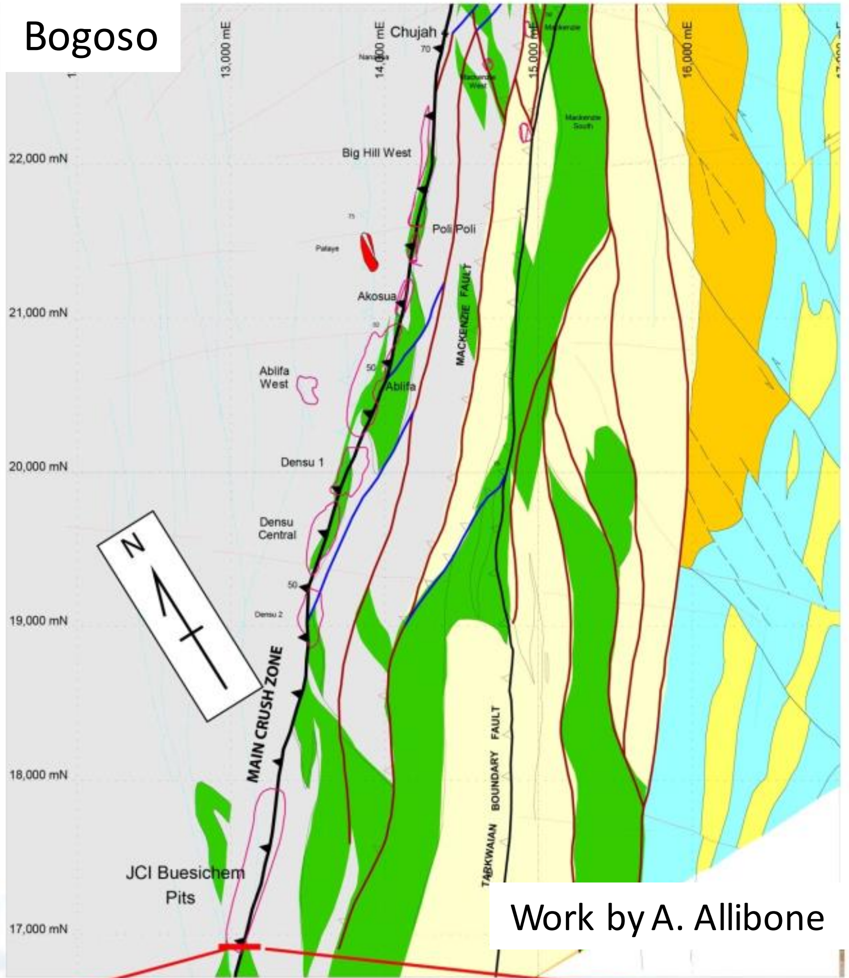
Paleoplacer with hydrothermal overprint (Damang)

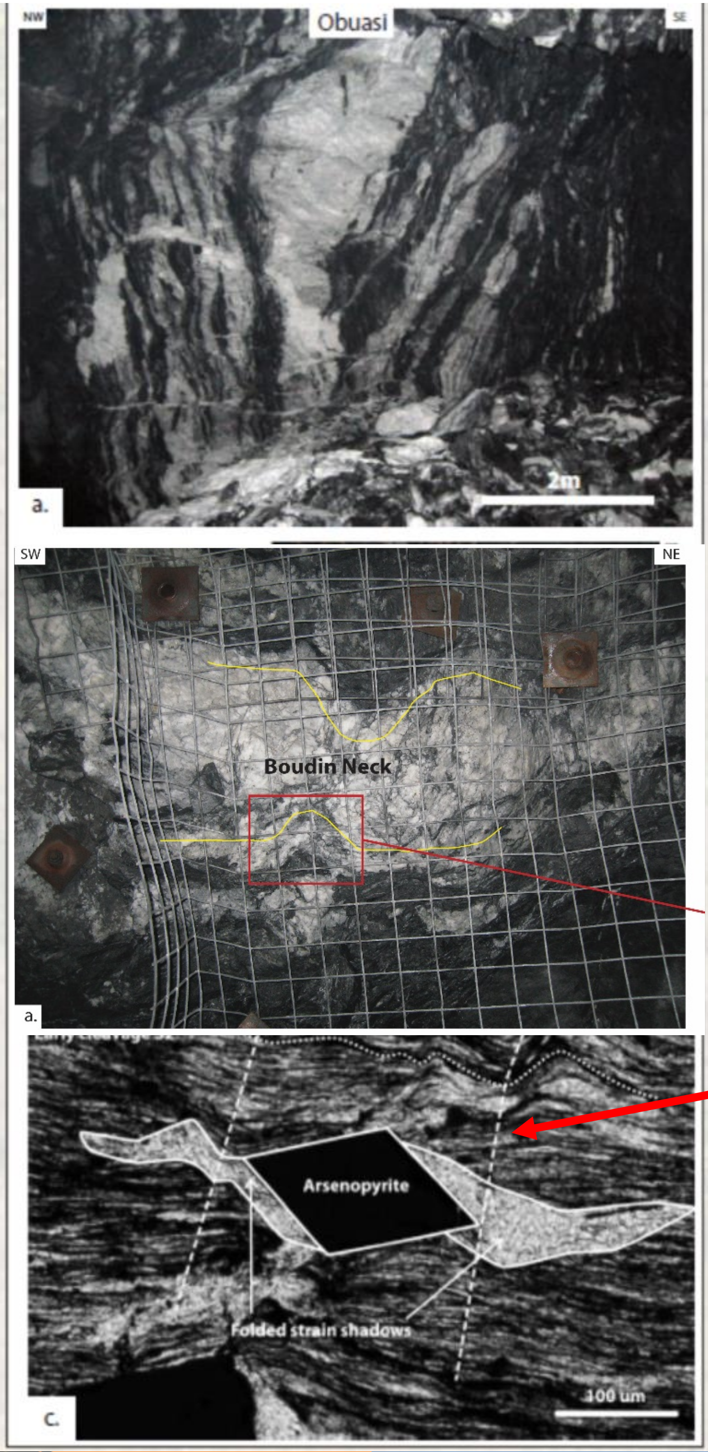




D2/D3 graphitic shears (Obuasi and Bogoso)







Obuasi deposit = > 50 million ounces

Gold at Obuasi prior to the "classic" D4 gold event

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

(pressure shadows folded/ cross cut by D4 foliation).
Junner 1932 noted same relationships.

D4 foliation

Fougerouse et al., (in press)

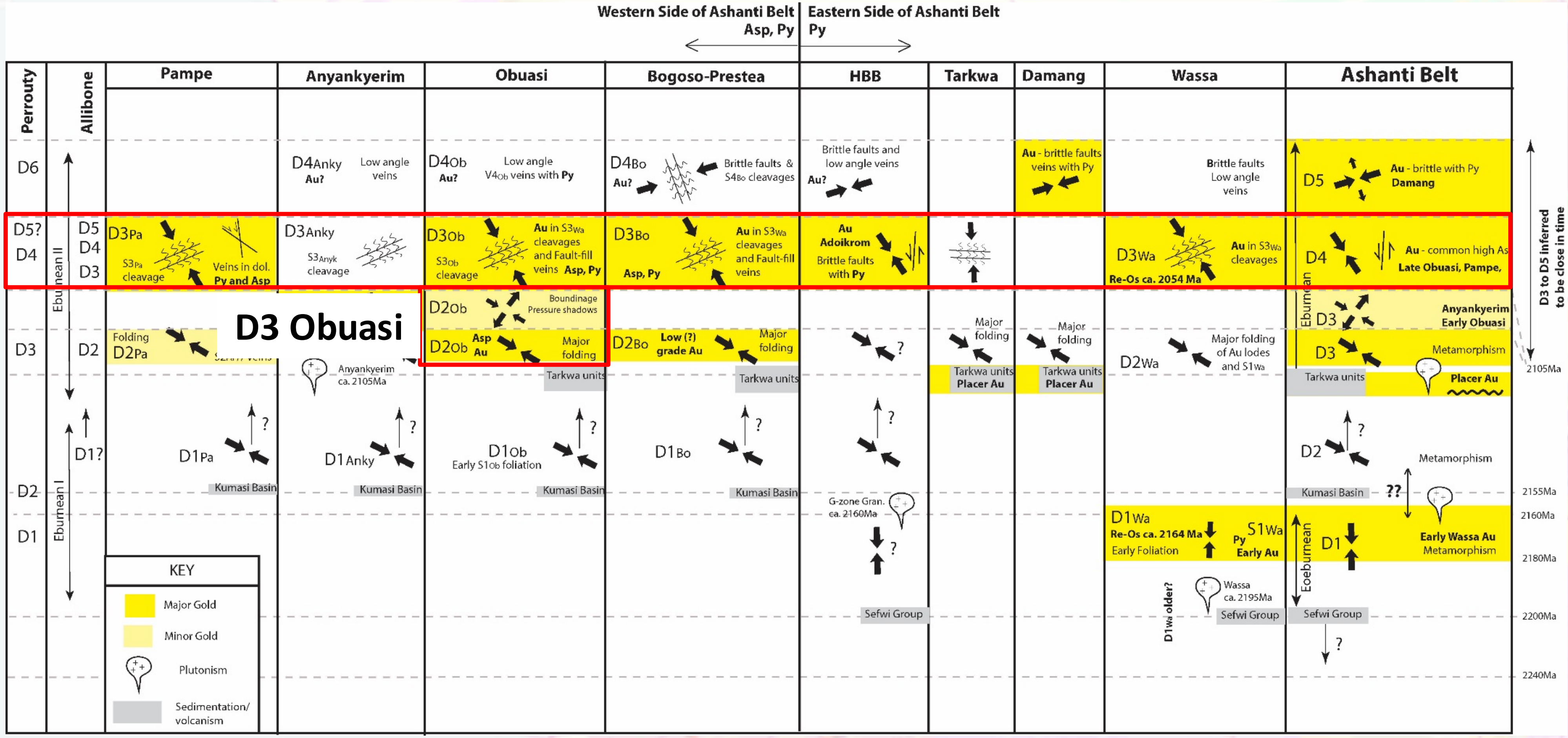
FIG. 4.

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

Junner 1932

Ashanti Belt history (deposit by deposit) – linked to WAXI2 event history

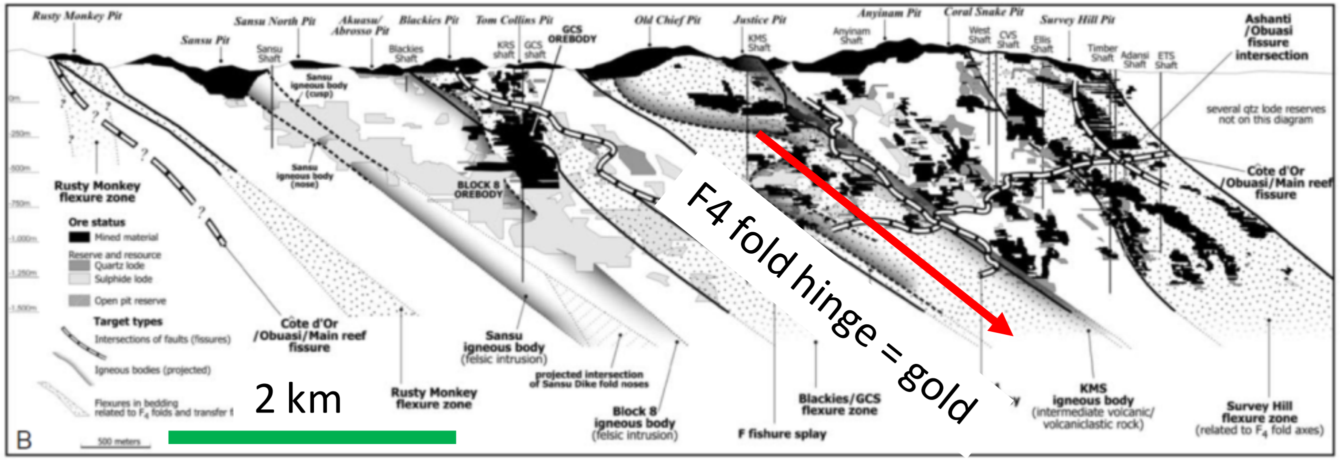
NOTE: major late-stage orogenic gold = most common observation in the literature

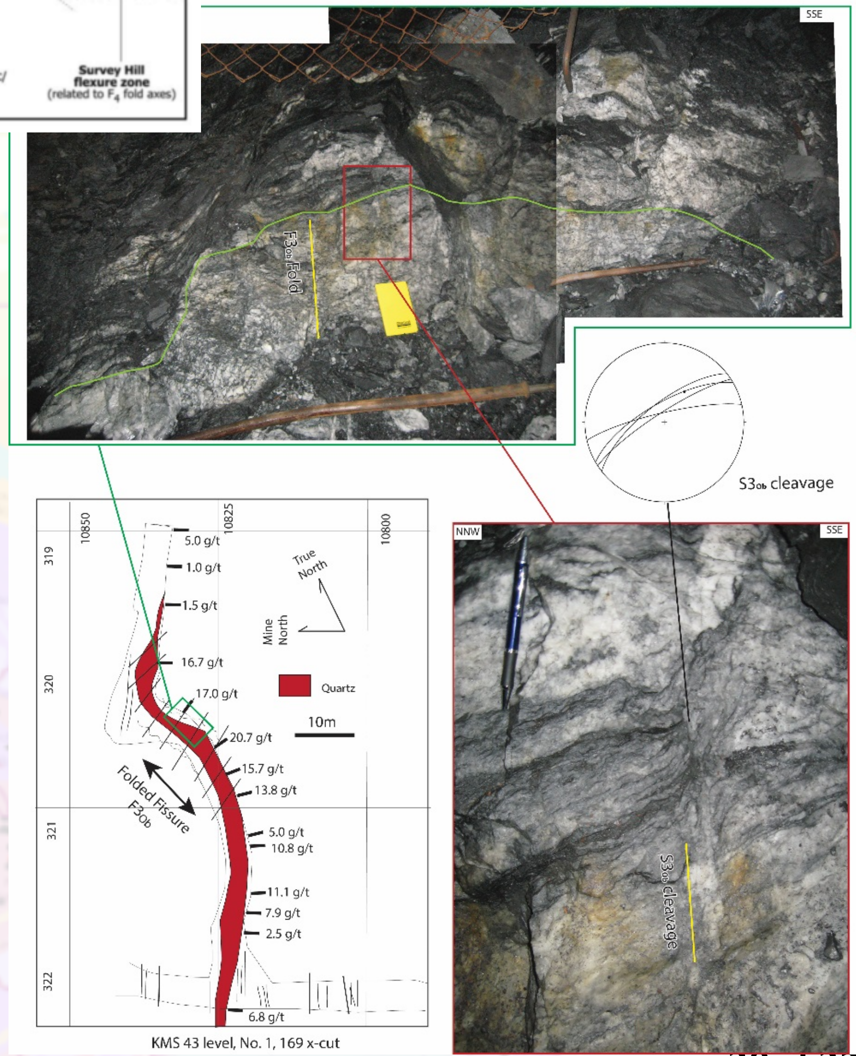


Local events versus WAXI2 event history

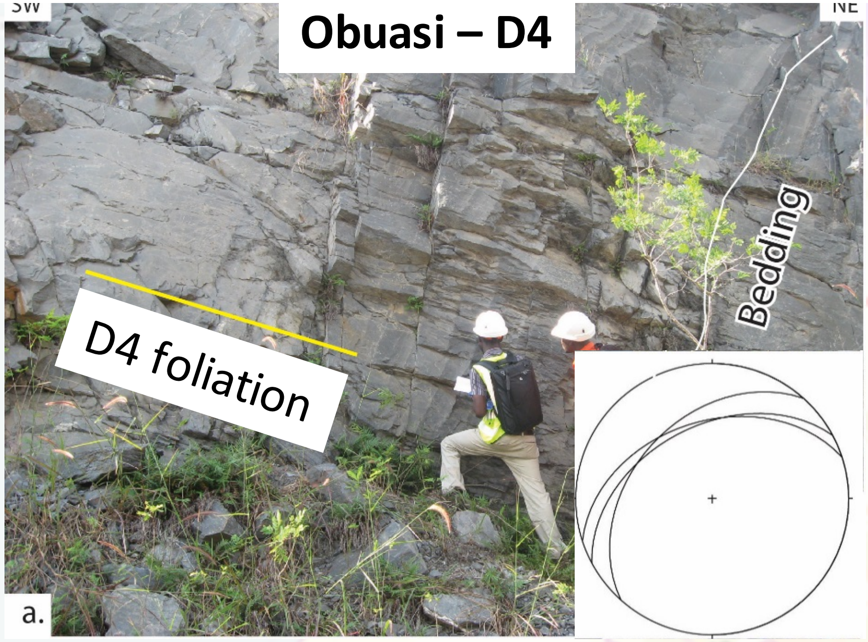
D4 Peak Gold - described by Feybesse et al., (2006)

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

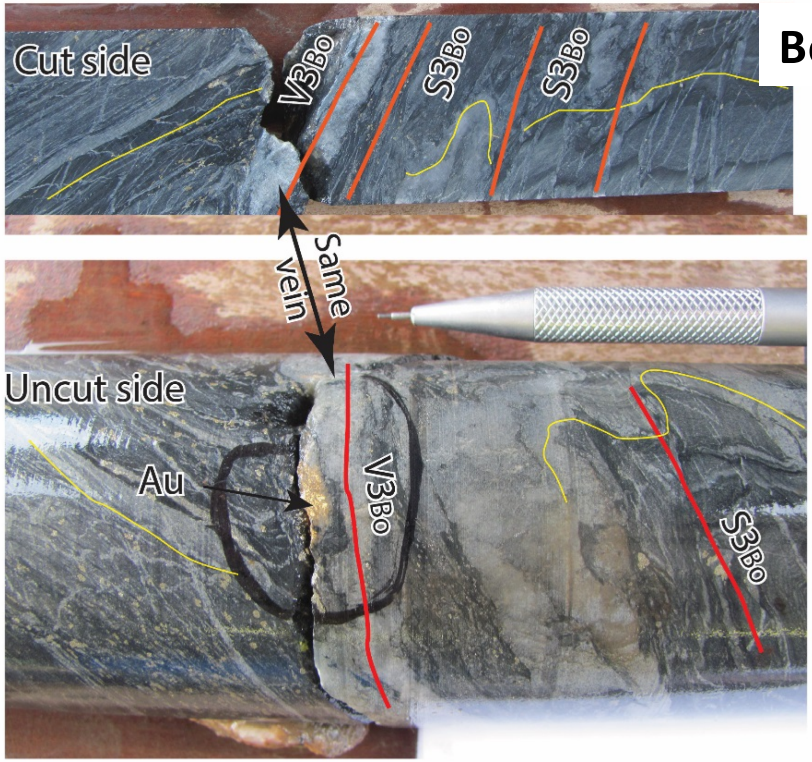




Obuasi – D4

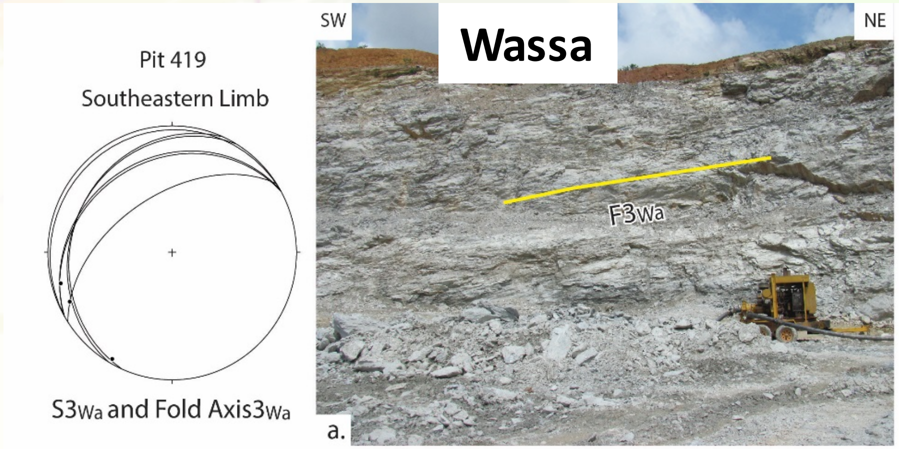


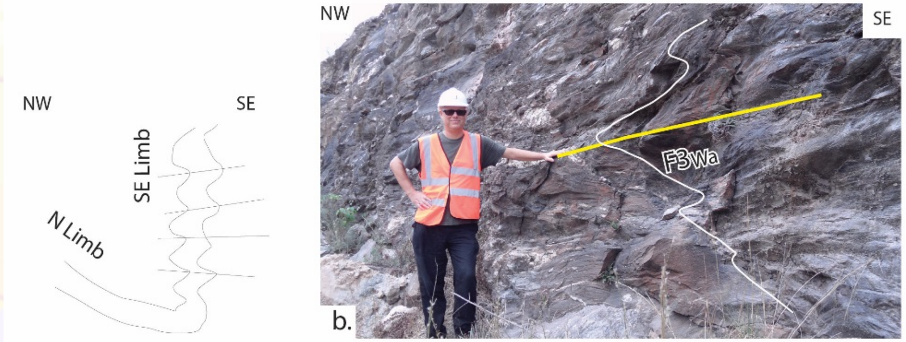
Bogoso

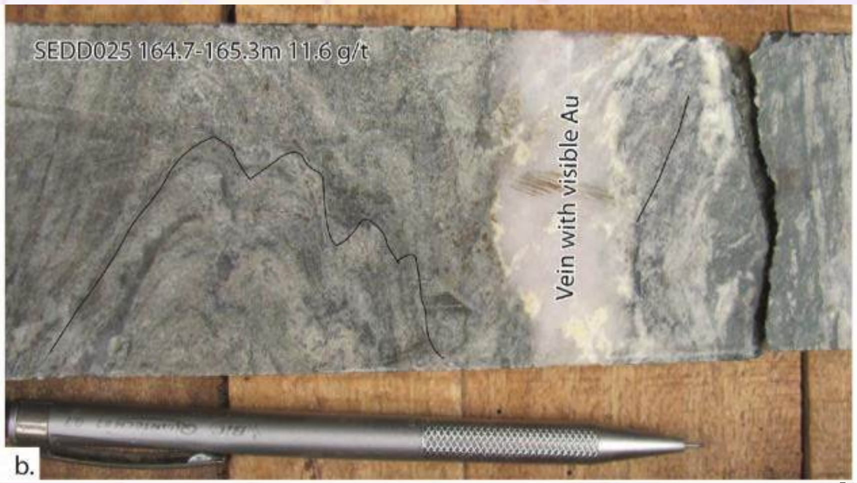


Regional gold-associated D4 cleavage/ foliation

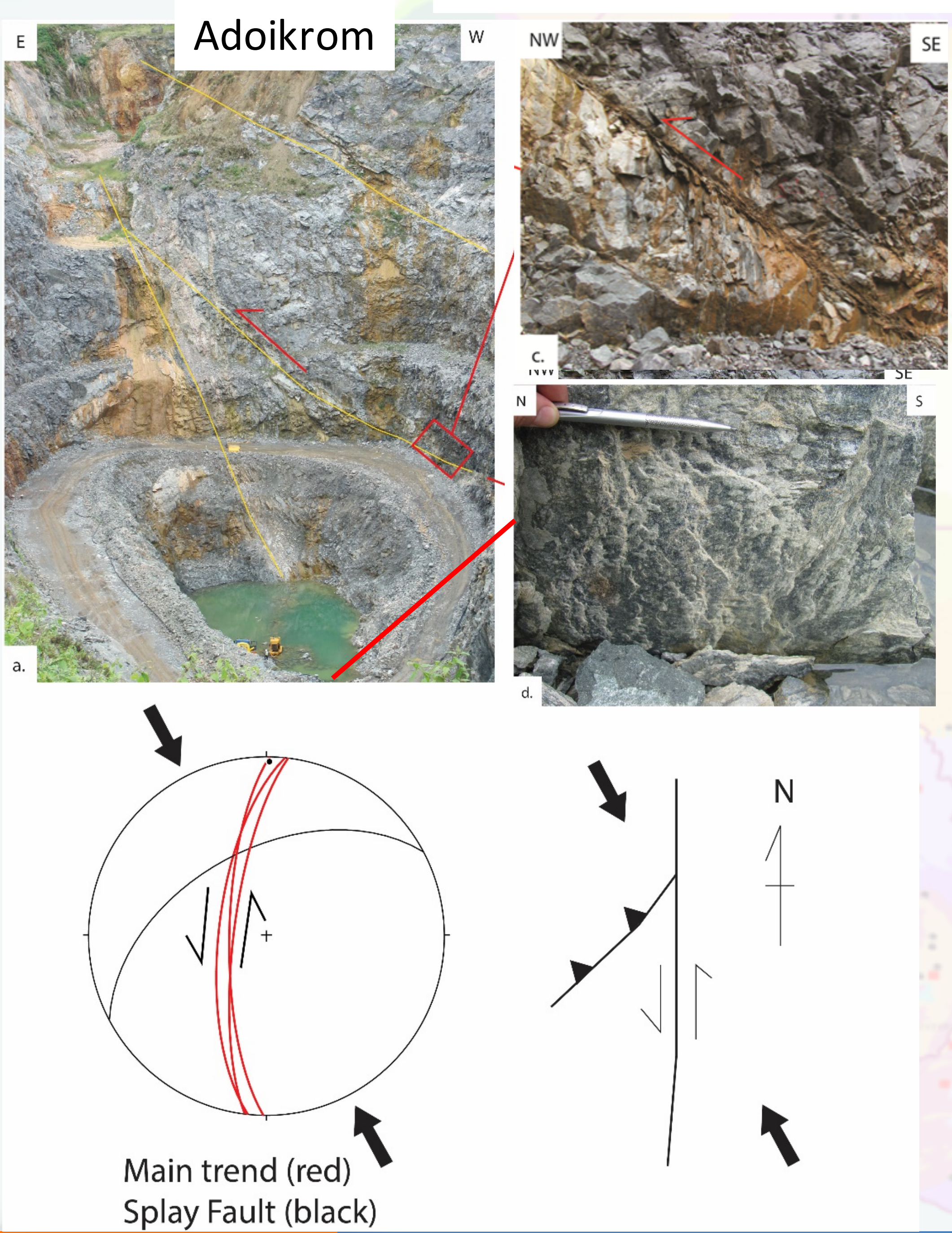
Wassa

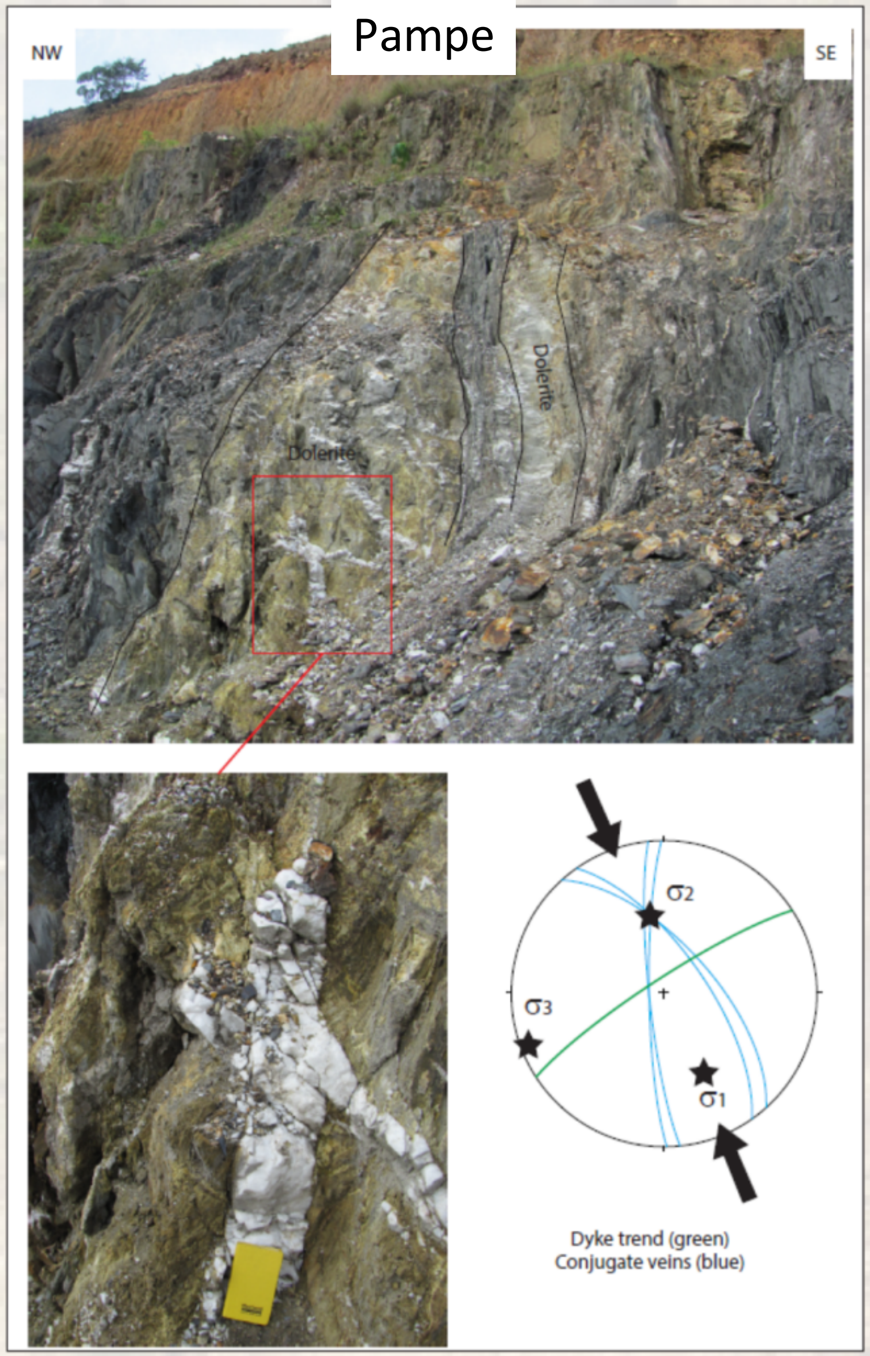




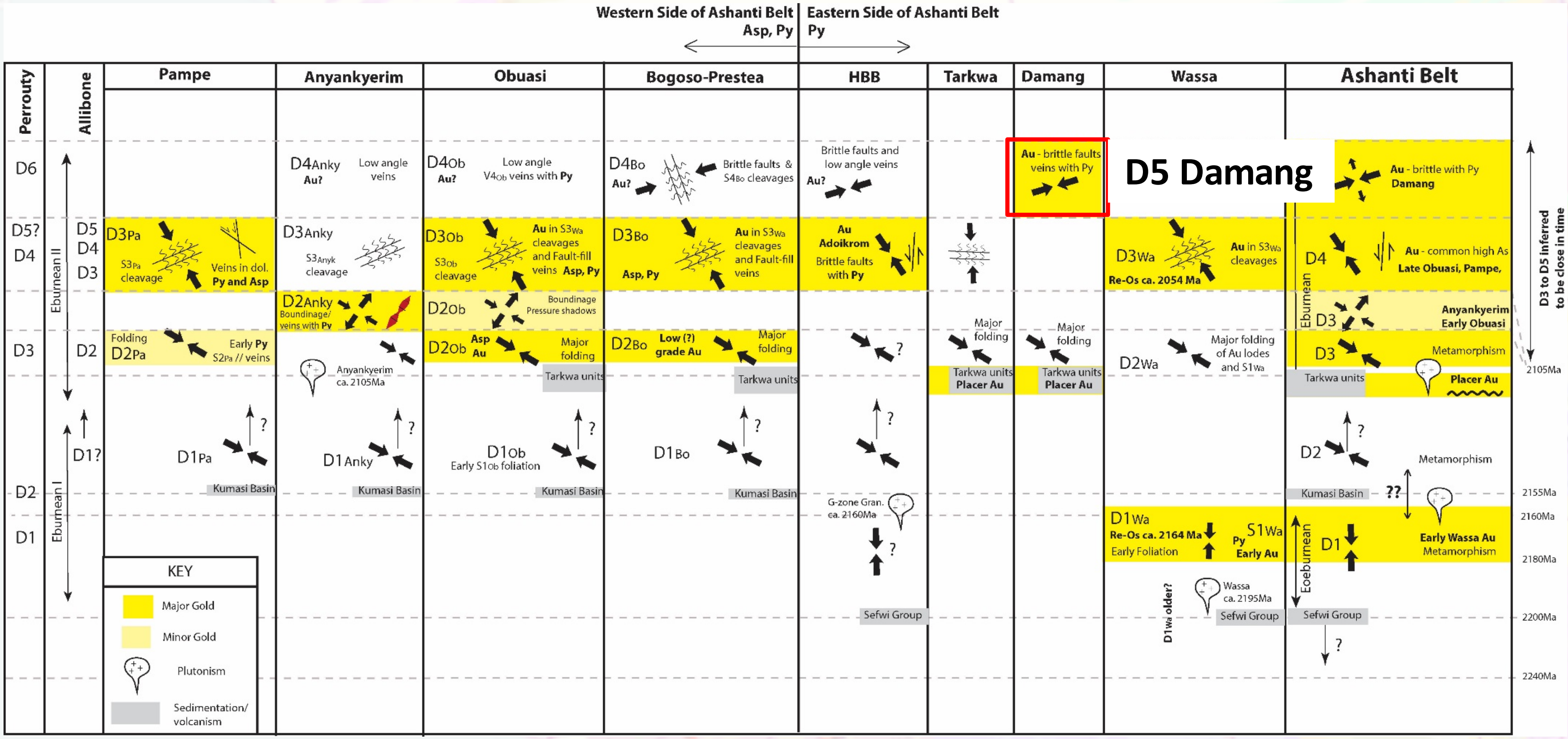


D4 gold mineralisation (gabbro and mafic dyke hosted)





Ashanti Belt – linked to WAXI2 event history
NOTE: major late-stage orogenic gold = most common observation in the literature



Local events versus WAXI2 event history

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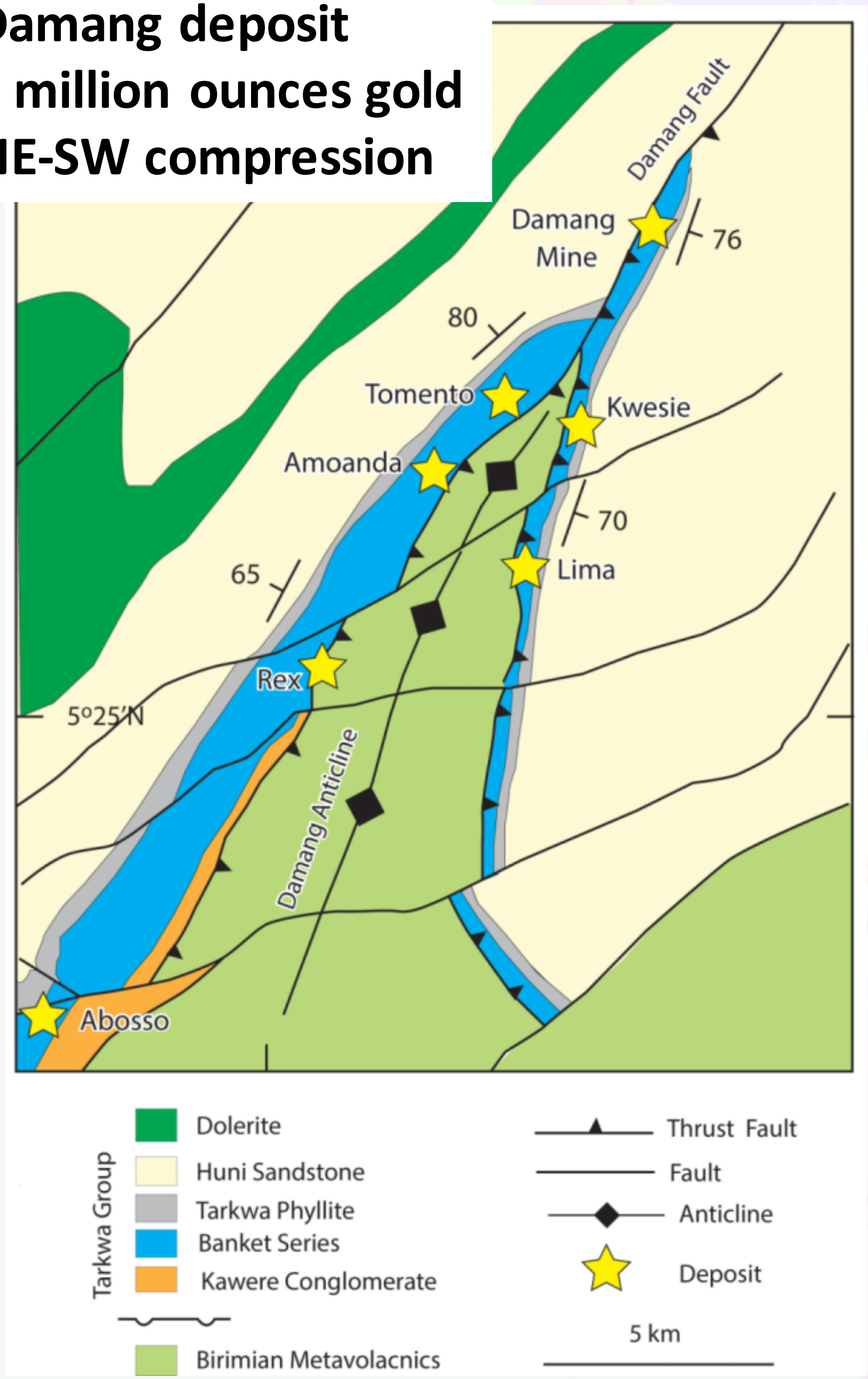
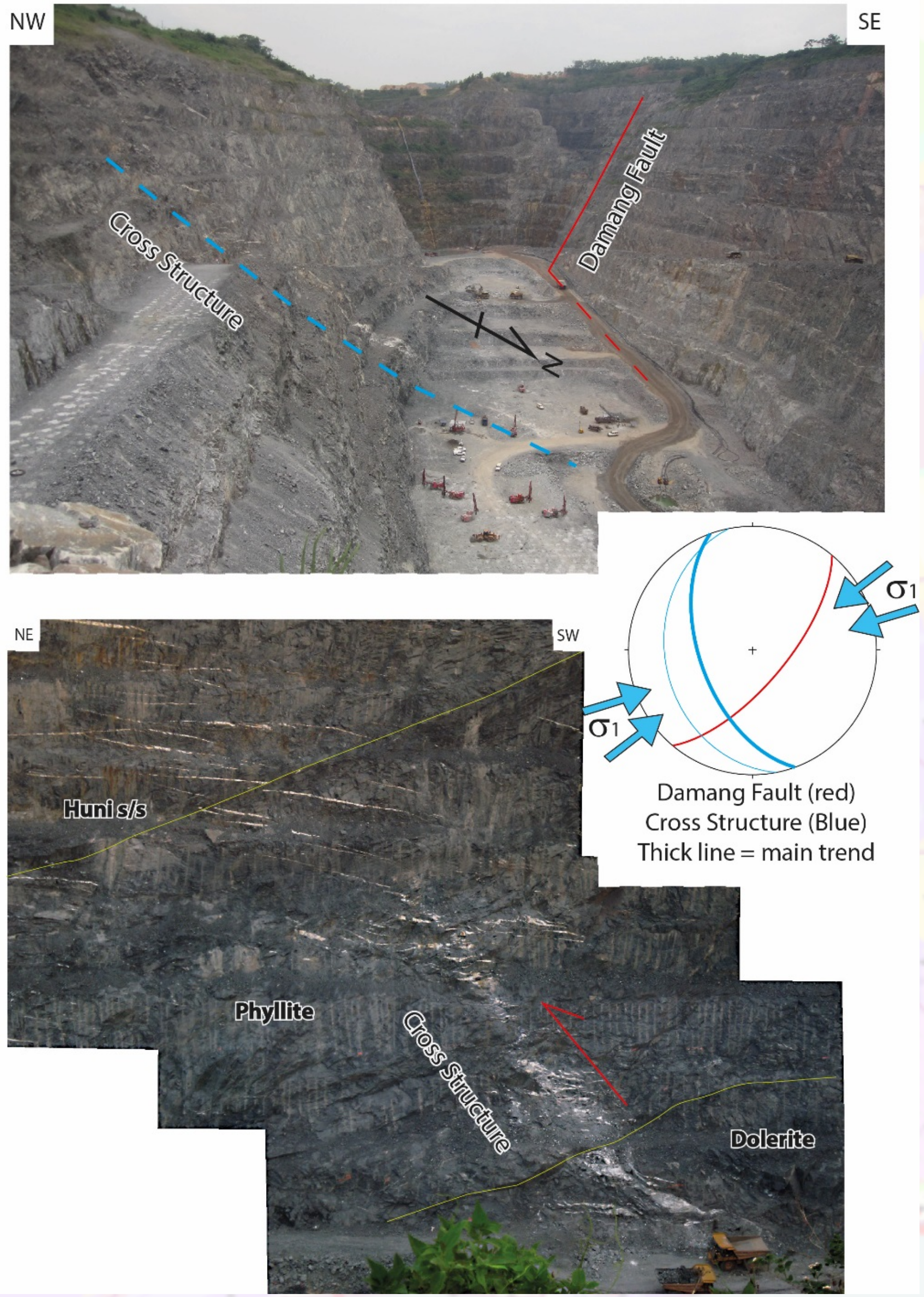
D5 Damang deposit

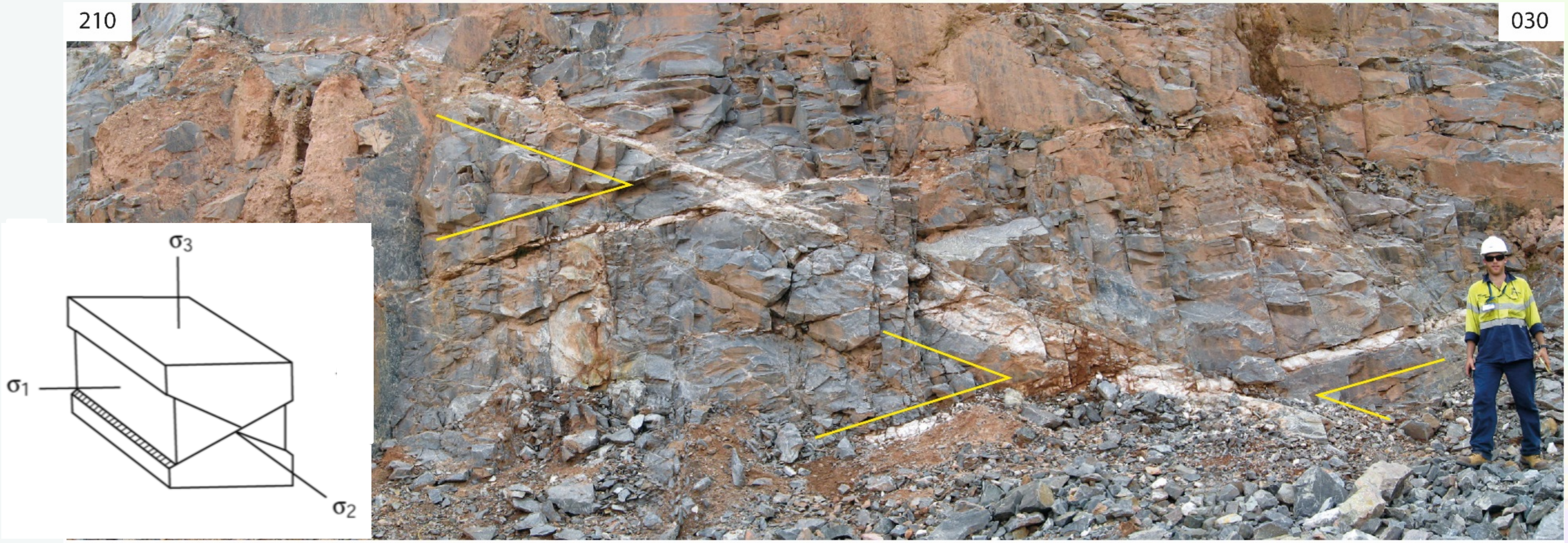
- 5 million ounces gold
- NE-SW compression

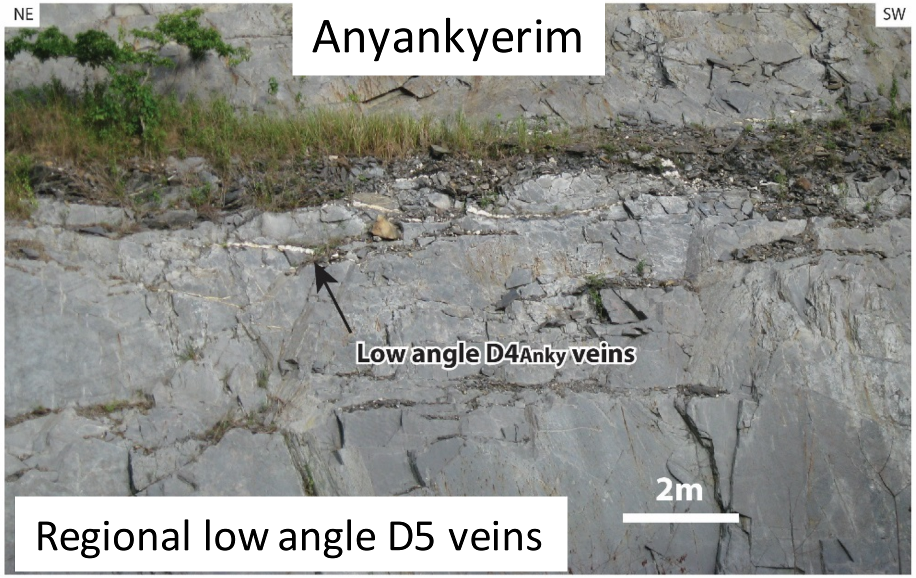


Main Damang Pit

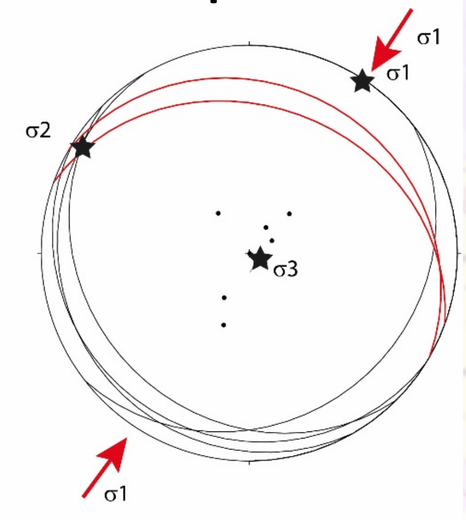


D5 Damang deposit (& late D5 veins at Anyankyerim)



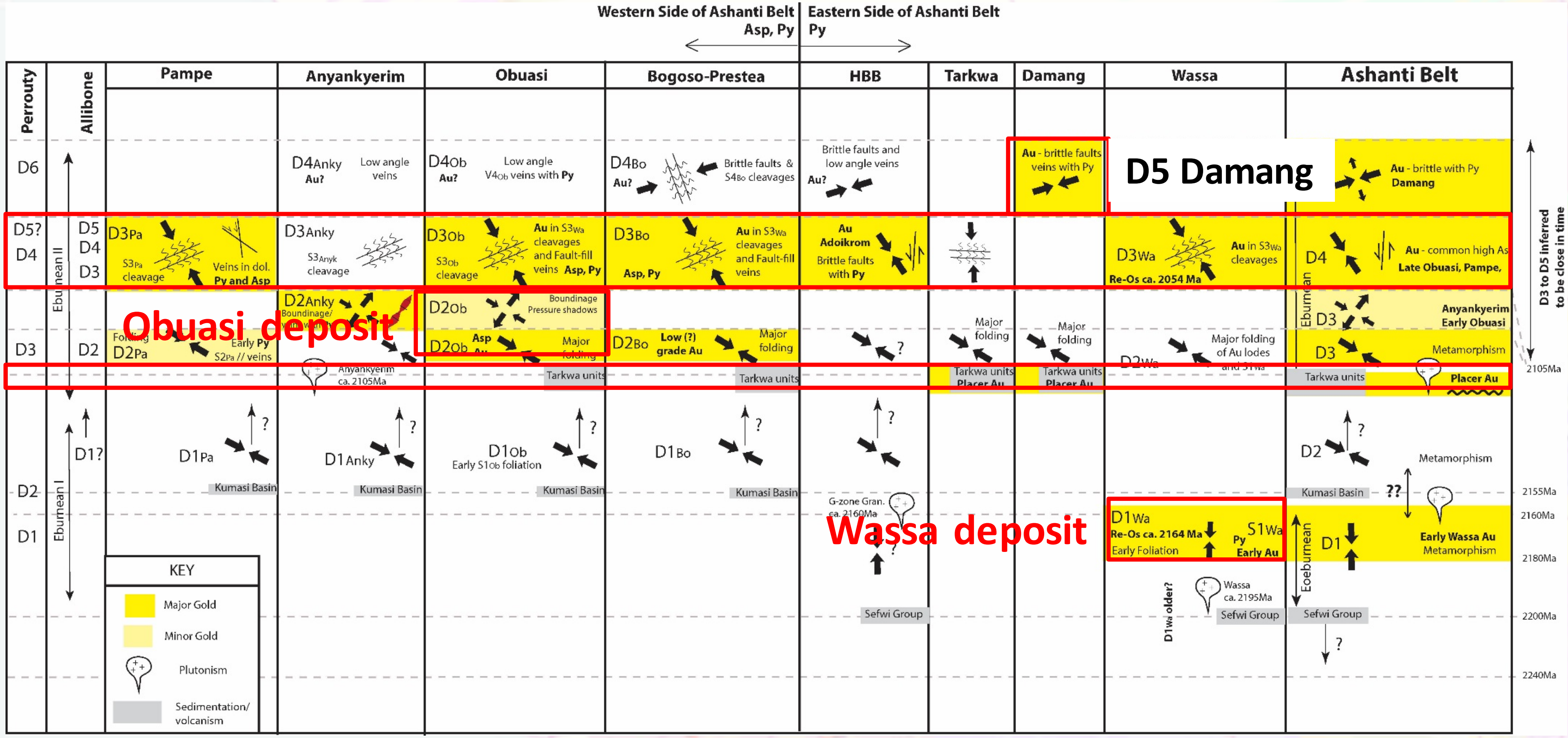


NE-SW compression



Ashanti Belt – linked to WAXI2 event history

NOTE: major late-stage orogenic gold = most common observation in the literature



Local events versus WAXI2 event history

D4 Peak Gold - described by Feybesse et al., (2006)

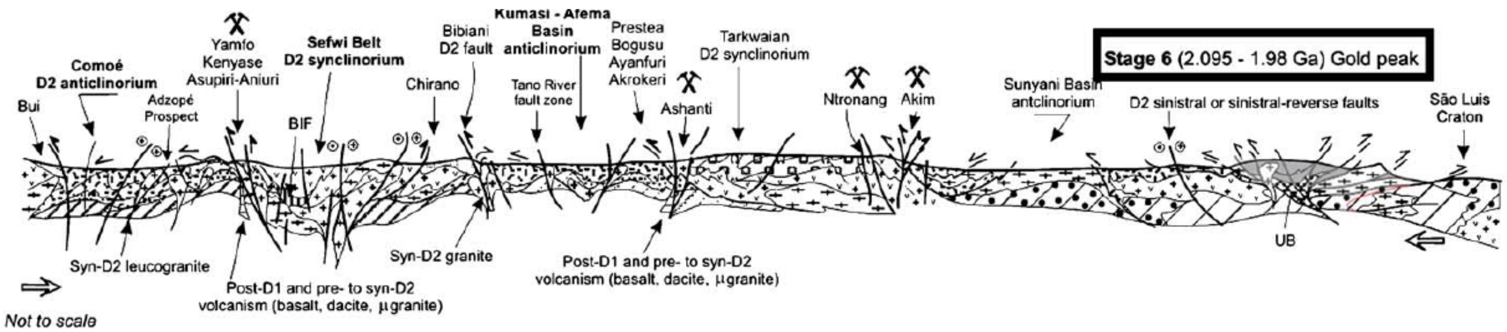
Tarkwa Paleoplacer gold ca. 2100-2110 Ma

High profile and cited model for Ghana - Feybesse et al., (2006)
= Late-kinematic orogenic gold deposits

Circulation of gold-bearing fluids favoured by late-orogenic events that increased crustal permeability caused by;

- change in tectonic style from D1 thrusting to D2 sinistral shearing.
- uplift and erosion to a shallow crustal position enabling D2 brittle behaviour
- period of reduced tectonic activity (= stress quiescence)

D2–3 events
(2.095 to 1.98 Ga)
“GOLD PEAK”



Two key take home points from today’s talk;

1) Main stage or “gold peak” post Tarkwa deposition is very complex
2) Pre-Tarkwaian basin gold events linked to world class deposits exist

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SUMMARY

- Gold deposits have a broad geographic extent and structural styles ranging from early ductile shear zones (Wassa), High-T (Morila), fault-vein arrays (Kalana, Damang), and 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 (3) phases of gold mineralization with different kinematics and alteration occurred post deposition of the Tarkwa Formation (D3, D4, D5)
- There is a dominant D4 gold event, commonly associated with high arsenic mineralization and sinistral-slip kinematics linked to NW-SE shortening.
- **Some** phases of gold predate the deposition of the Tarkwa units (D1 Wassa deposit). These deposits could be potential analogues of the source for the world-class palaeo-placer deposits occurring within the Tarkwa Formation in Ghana. MORE FOCUS ON THESE SYSTEMS IS REQUIRED TO UNDERSTAND CONTROLS ON DEPOSIT LOCATION
- Architectural controls and causes of localisation of early gold deposits versus possible placer systems should be assessed