WAXI- West African Exploration Initiative

IXOA- L'Initiative d'Exploration Ouest Africaine

Metamorphic evolution of the southern West African Craton

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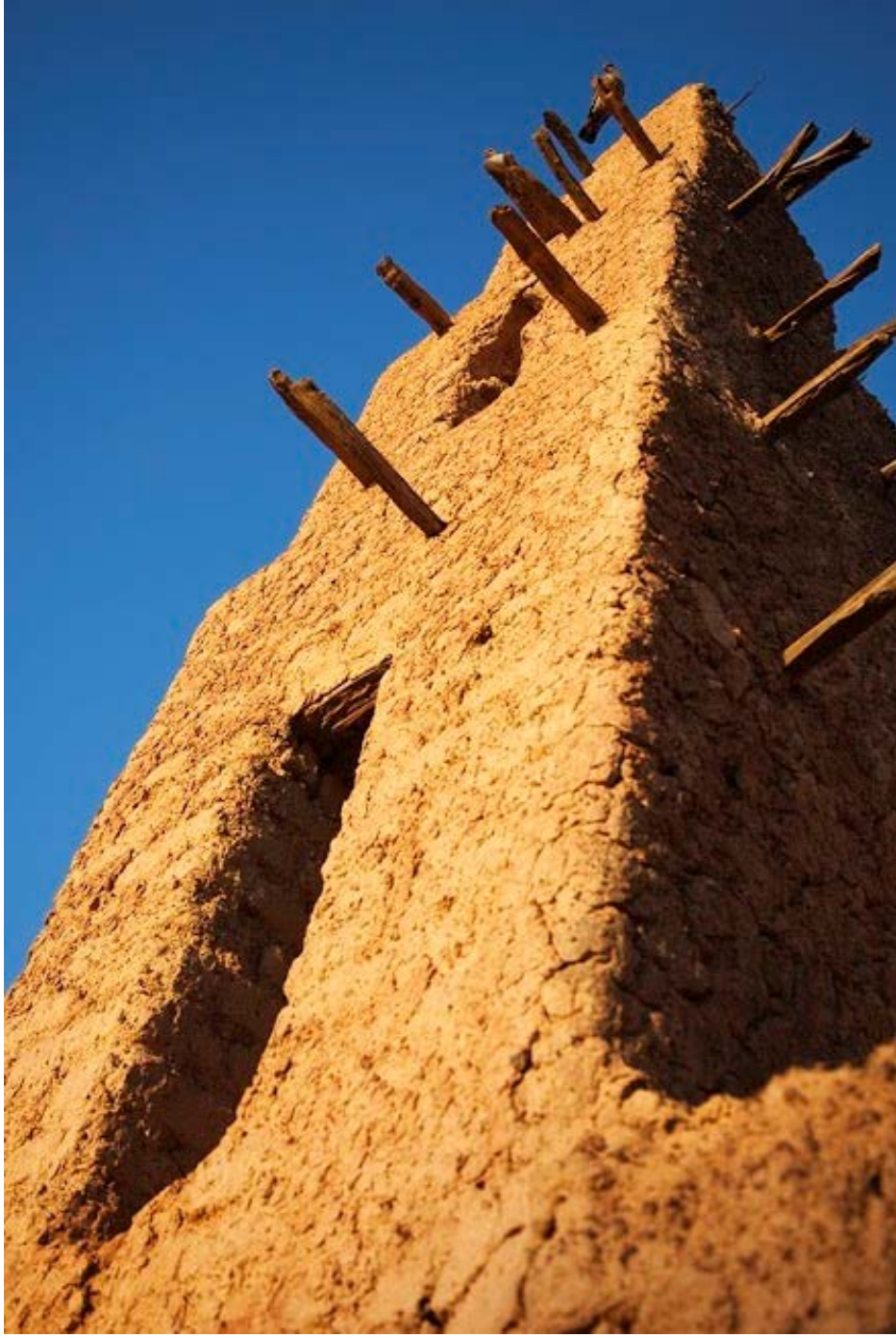
[1]GET IRD UPS, [2]IFAN, [3]Uni Lorraine, [4]UCAD, [5]UWA



IRD Institut de recherche pour le développement

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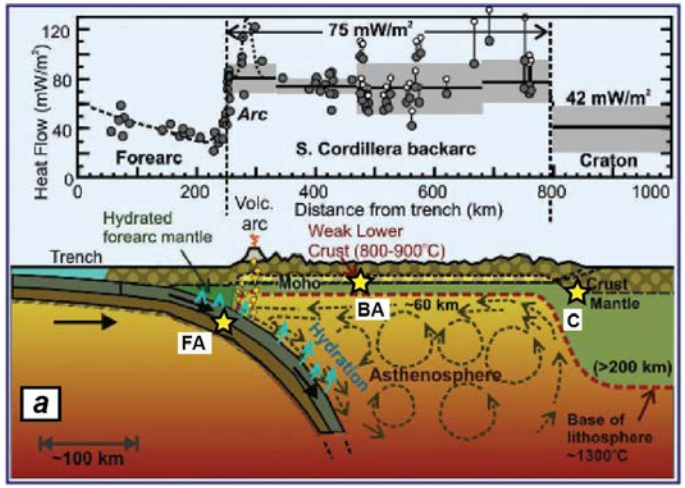
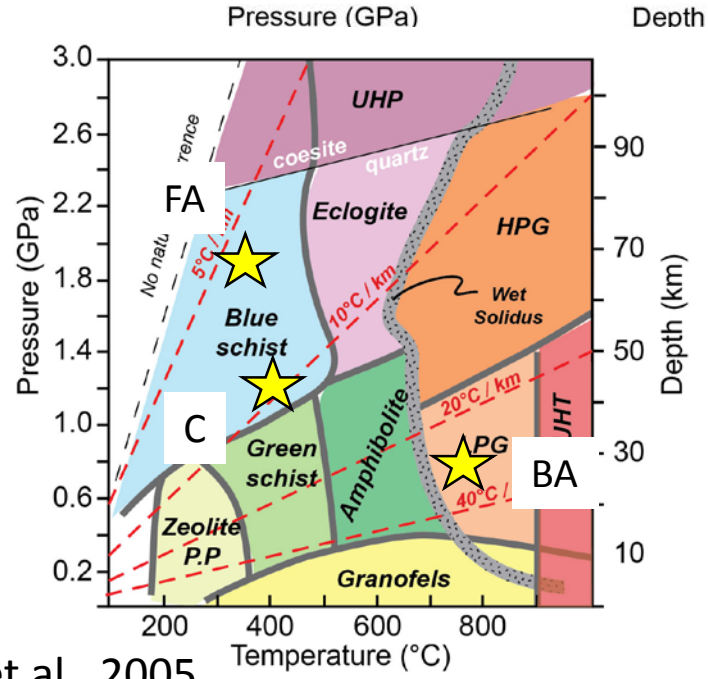
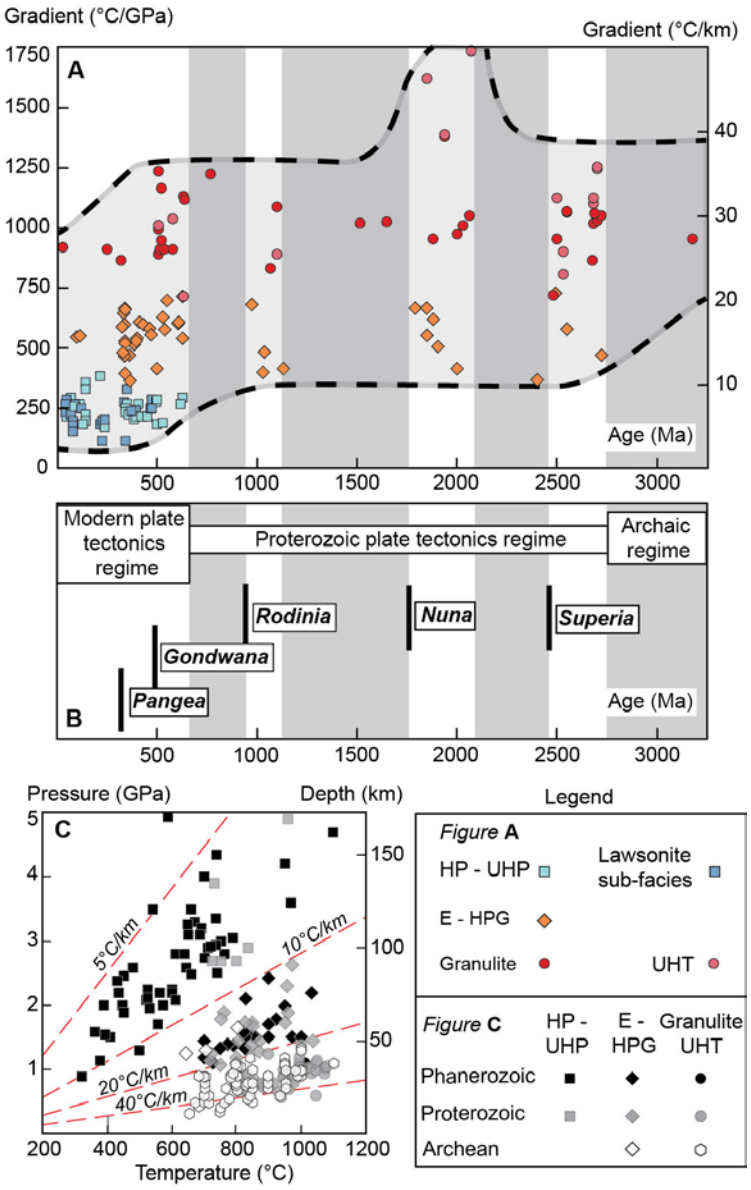
Metamorphism is key to understanding geodynamic evolution of the orogen



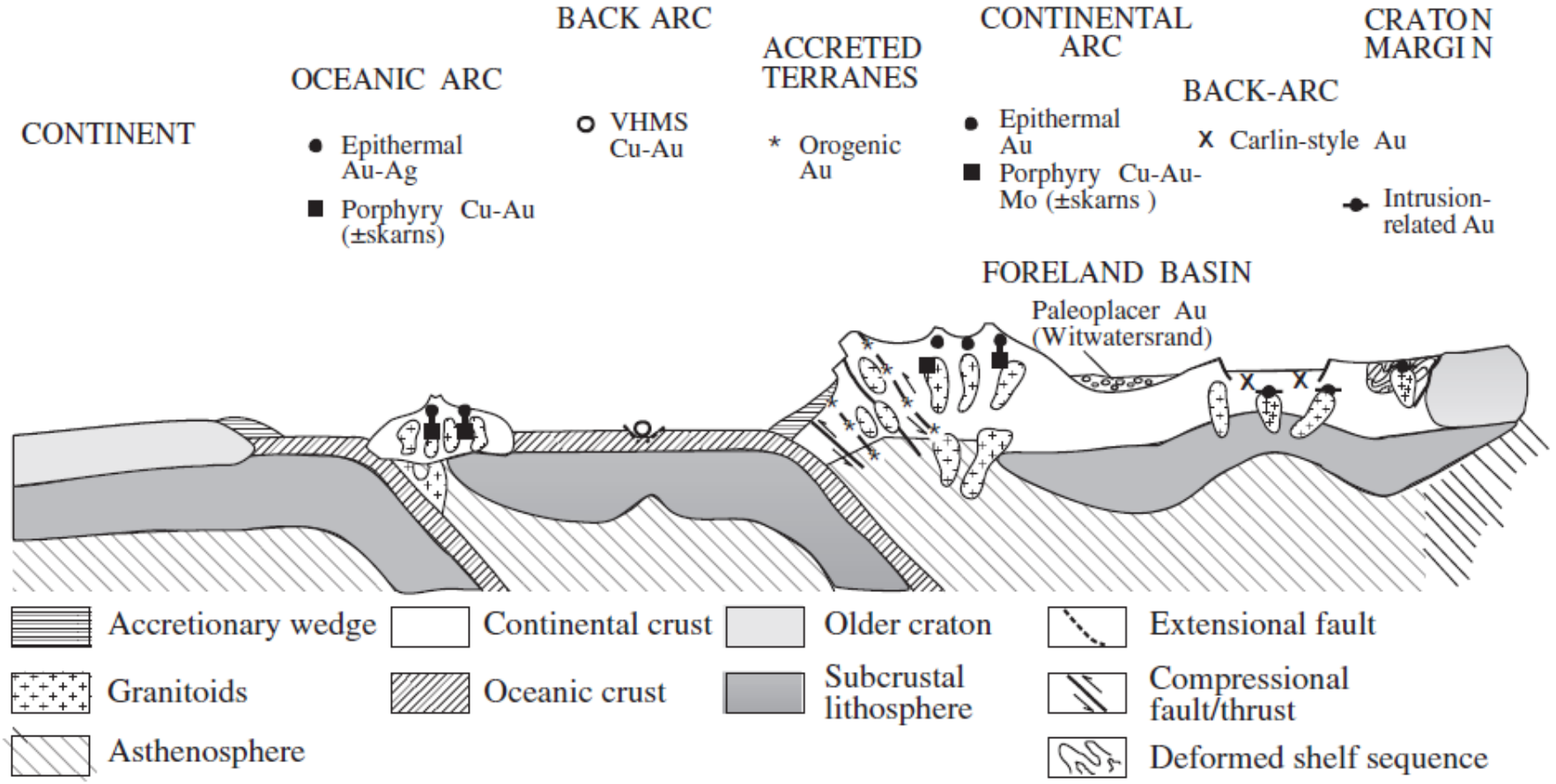


Hyndman et al., 2005



Brown, 2007

Ore deposits form in various geodynamic settings



Groves et al., 2005

Archean vs. modern type orogens

Plate tectonics

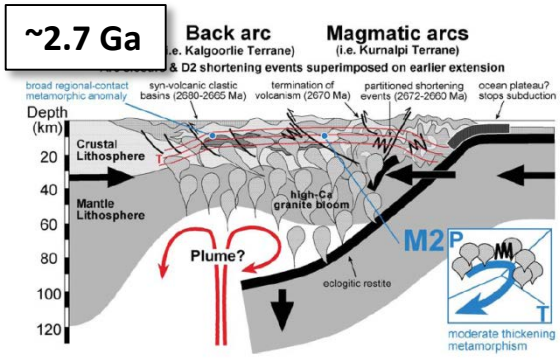
Crustal scale folding

Lateral crustal flow

Vertical tectonics "sagduction"

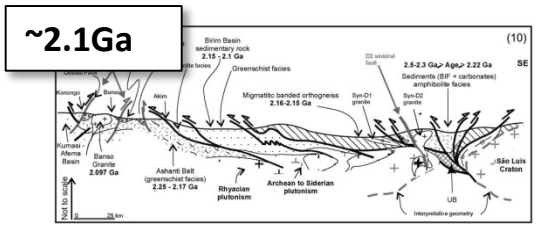
Yilgarn (Australie)
WA (Ghana)

~2.7 Ga



Goscombe et al. (2009)

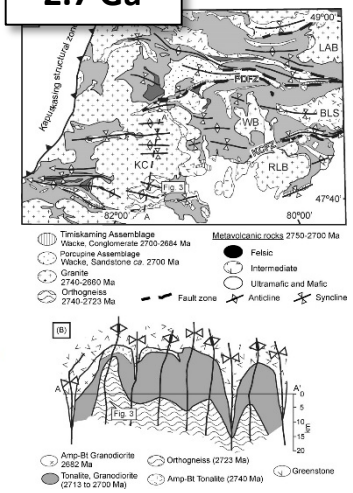
~2.1Ga



Feybesse et al. (2006)

Abitibi (Canada)

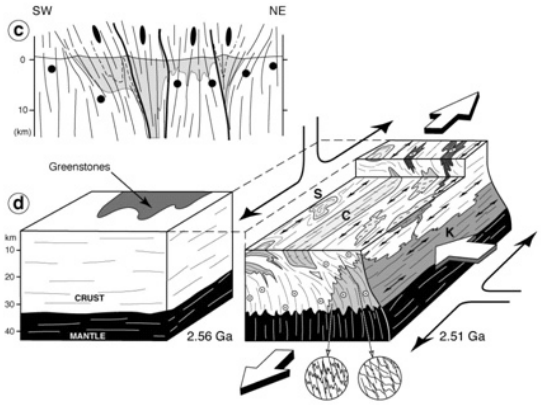
~2.7 Ga



Peschler et al. (2006)

Dharwar (Inde)

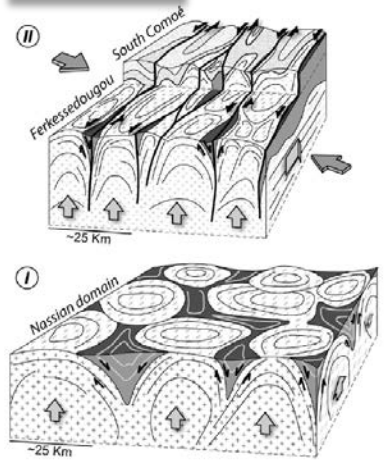
~2.5 Ga



Chardon et al. (2008)

WA (Côte d'Ivoire)

~2.1Ga

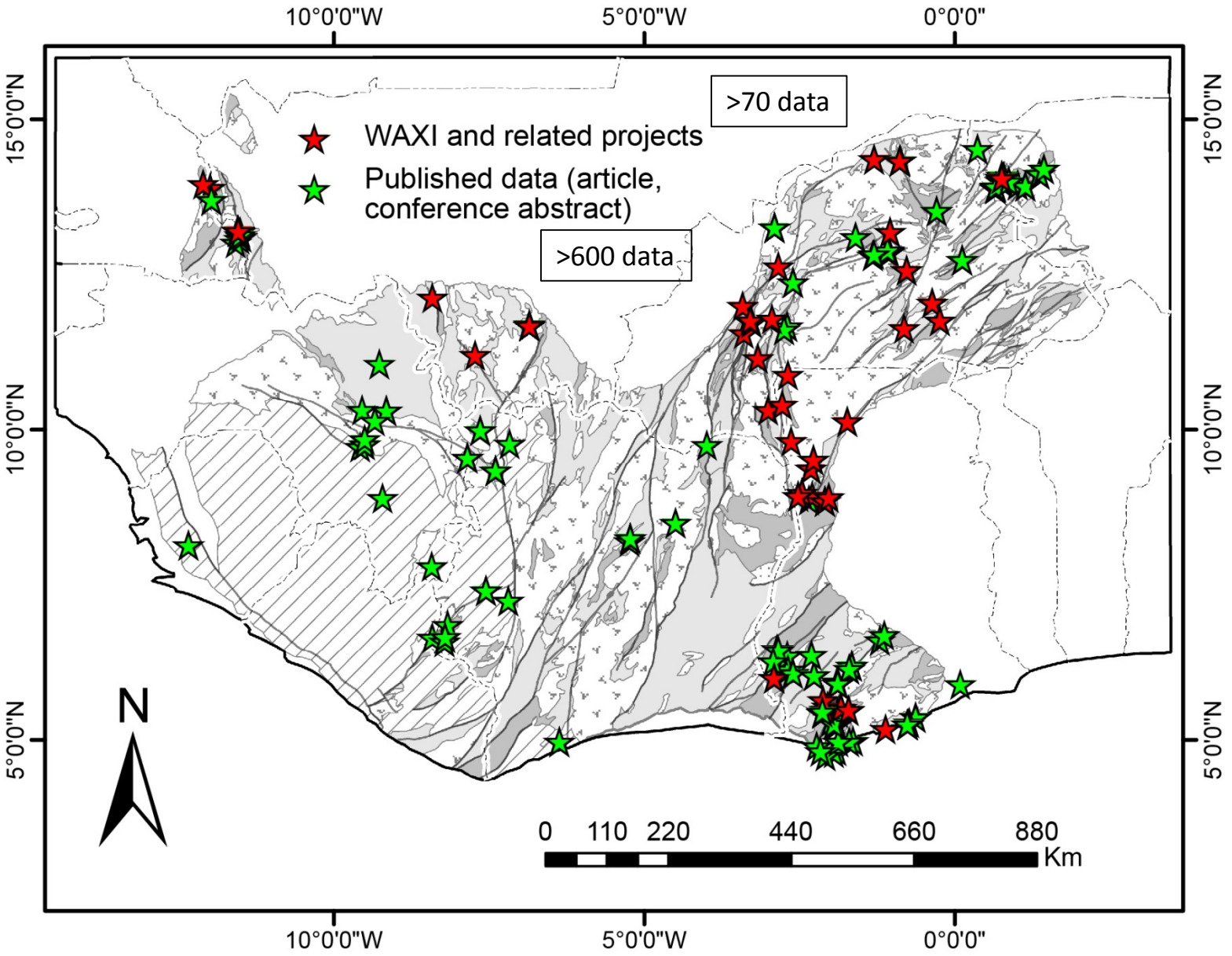


Vidal et al. (2009)

Metamorphism in Precambrian orogens

- Precambrian orogens are “hot” but greenschist to amphibolite facies rocks are very common
- Upper crustal levels predominate, lower (granulite facies) crust only rarely exposed: example of Dhawar craton, India (tilted) (e.g. Jayananda et al., 2013)
- Eclogite facies metamorphism (Barberton, e.g. Moyen et al., 2006) (subduction - exhumation)
- Contrasted metamorphic P-T paths and non-unique geodynamic setting (Yilgarn, e.g. Goscombe et al., 2009)
- Paleoproterozoic rocks of the West African Craton: the youngest “Archean-type” orogen or one the oldest modern-type orogen?

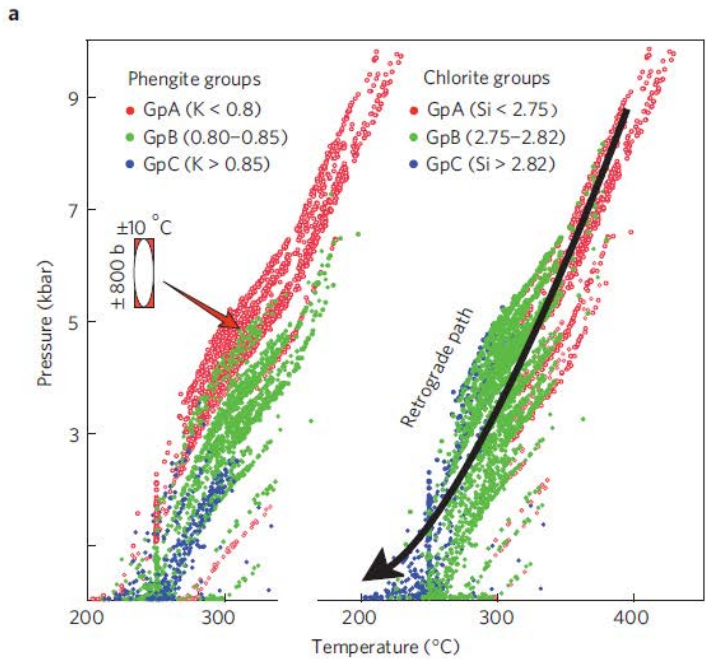
WAXI 2 Metamorphic database

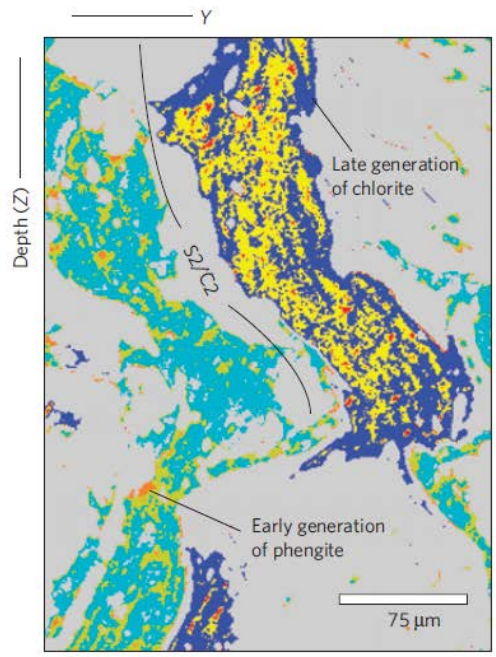


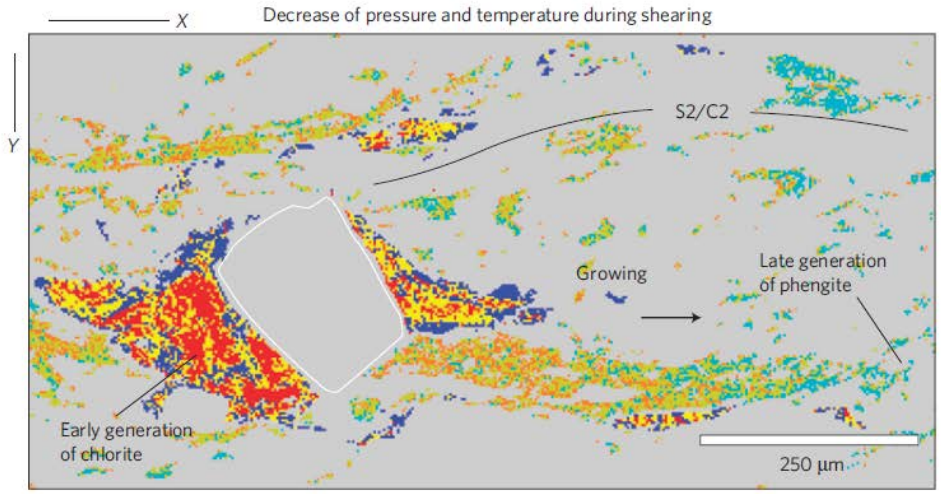
Metamorphism of the WAC

- Greenschist facies prevailing, amphibolite facies only within the contact aureoles of the plutons (e.g. Debat et al., 2003, Vidal et al., 2009)
- Migmatites (T > 650 °C) found in S Ghana, Ivory Coast (Opare-Addo et al., 1993)
- High grade metamorphism (PT) limited to the Archean-Proterozoic boundary – collision zone (Pitra et al., 2010)

E Burkina Faso





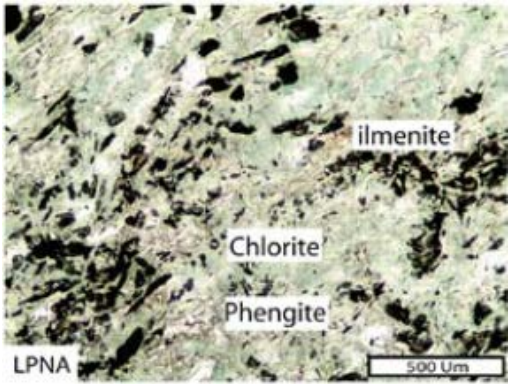


Chlorite GpC	GpB	GpA
Si > 2.82	2.75–2.82	Si < 2.75
Phengite GpC	**GpB**	**GpA**
K > 0.85	0.80–0.85	K < 0.80
(*T* < 300 °C) (*P* < 2.5 kbar)	(250–350 °C) (2.5–5 kbar)	(*T* > 320 °C) (*P* > 5 kbar)

Chlorite-mica multiequilibria

Cold geothermal gradient

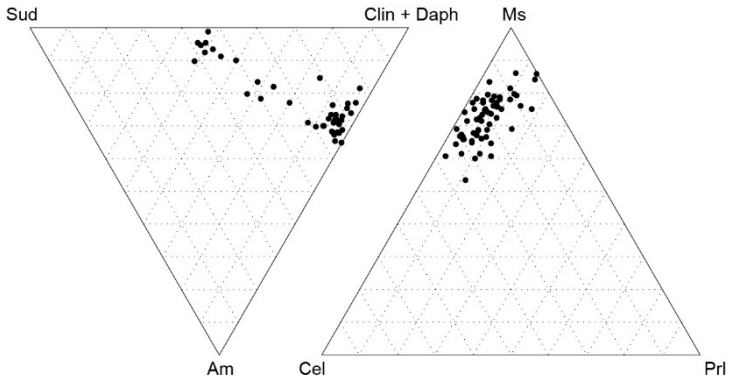
Subduction setting

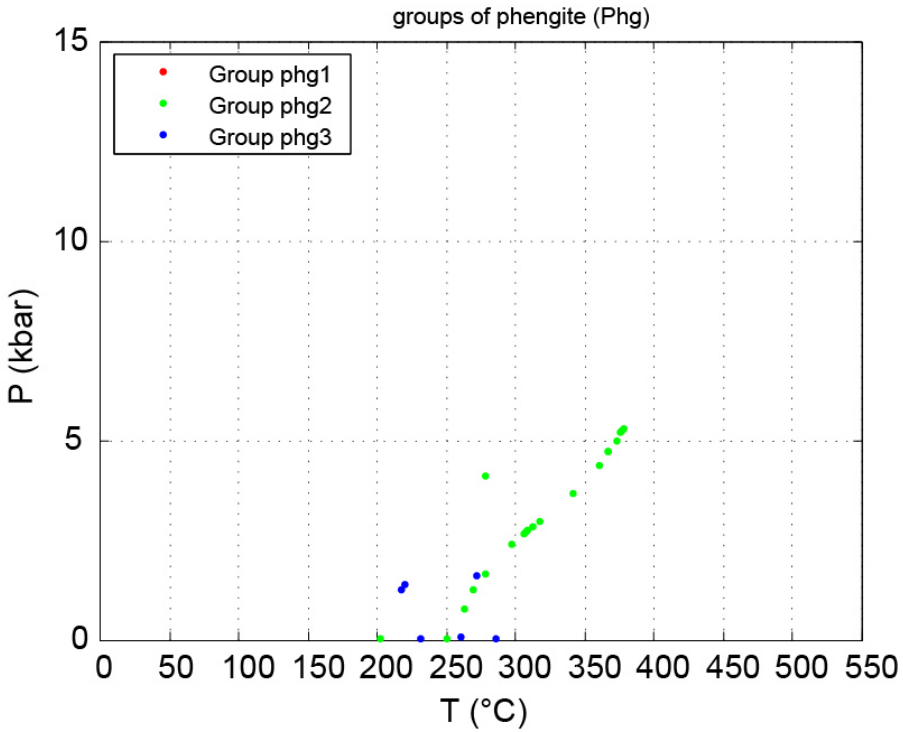


Ganne et al., 2012

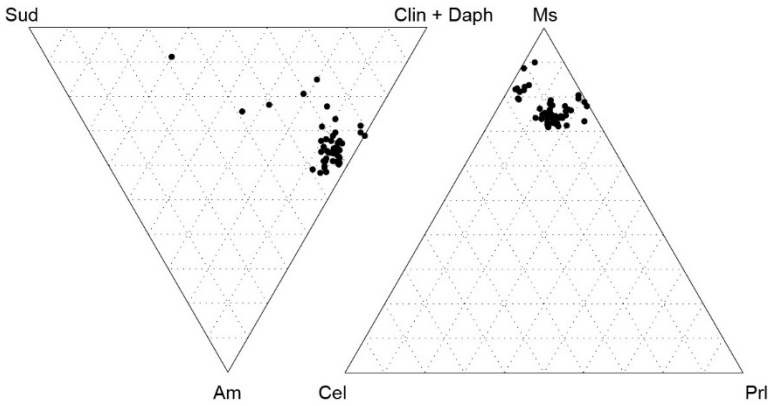
S Ghana

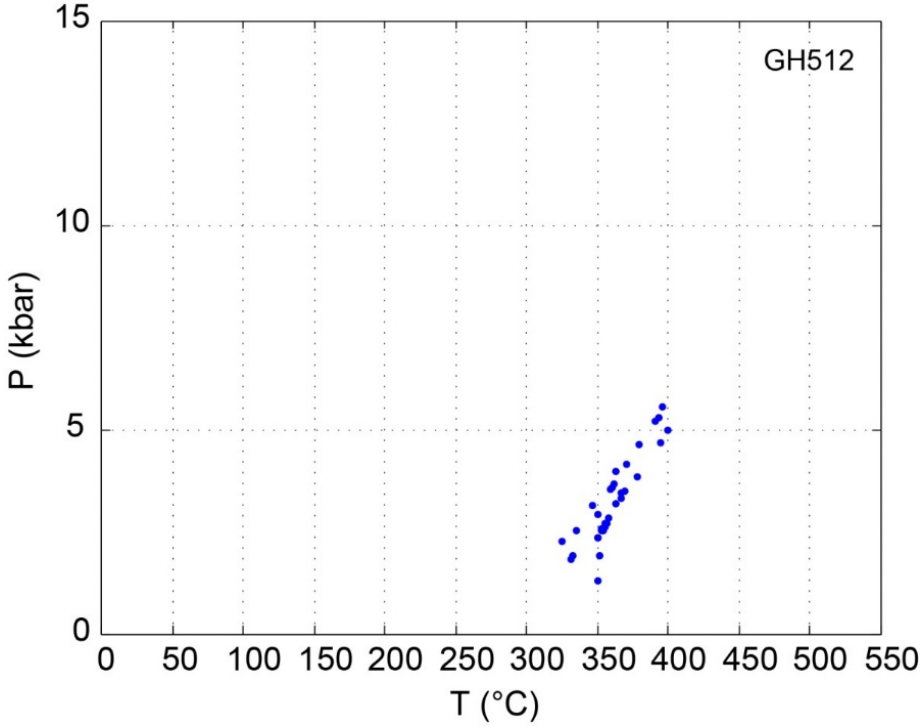
Birimian volcano-sediment from Wassa gold deposit



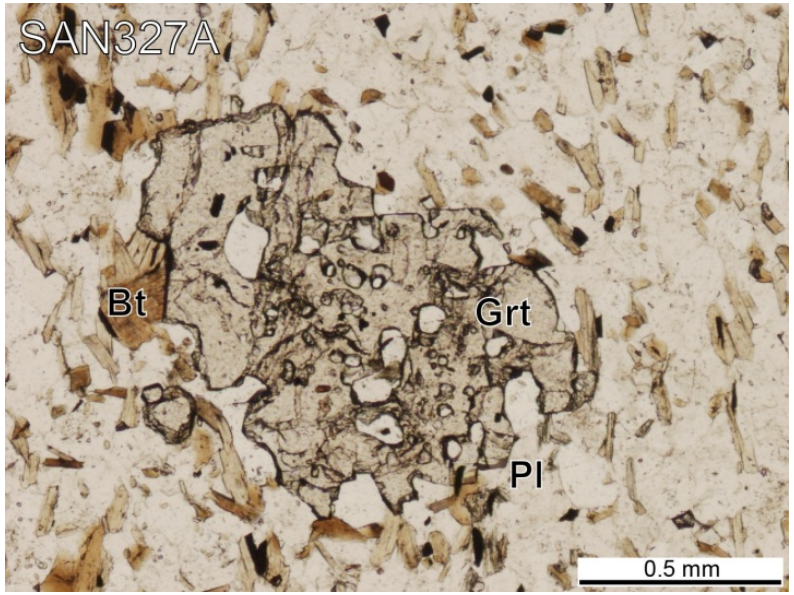


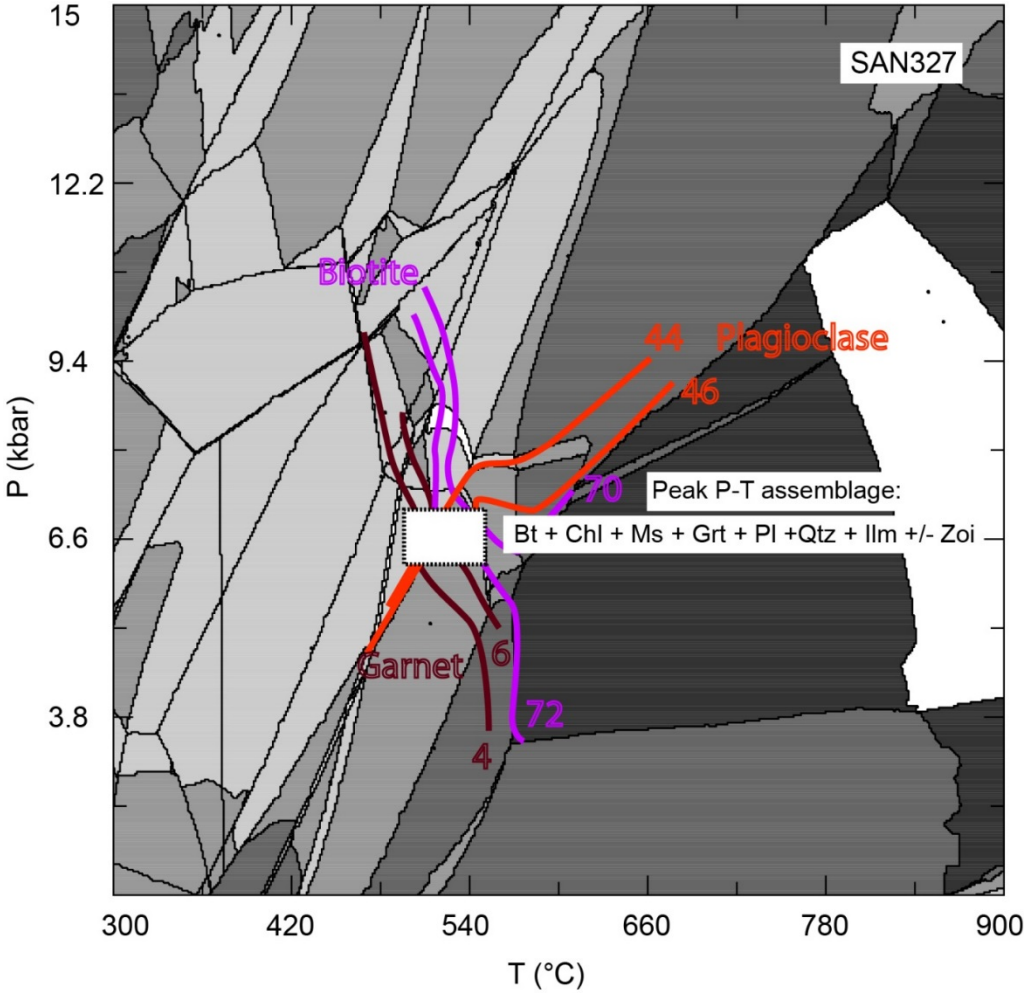
Tarkwaian metasediment from Damang gold deposit



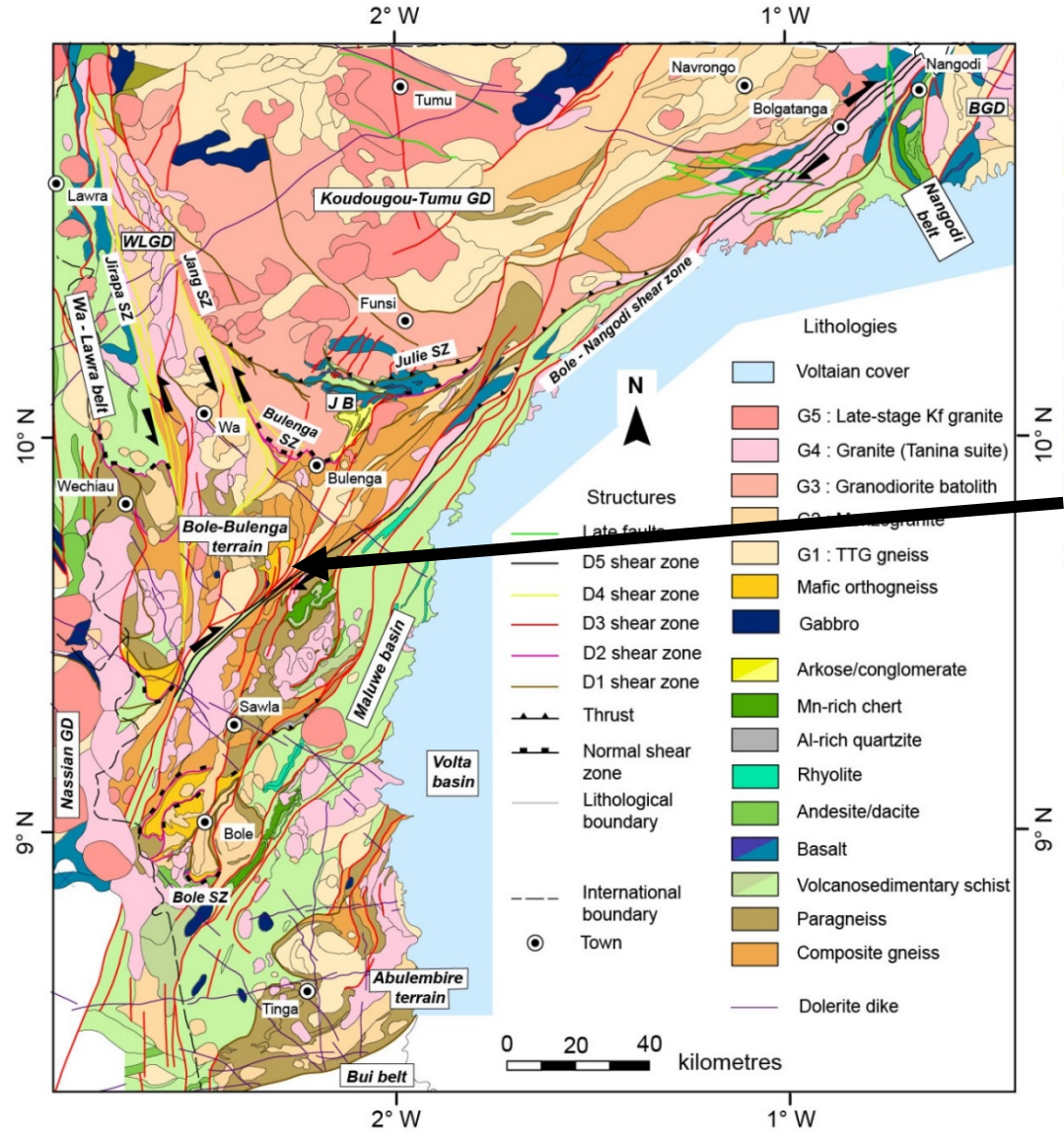


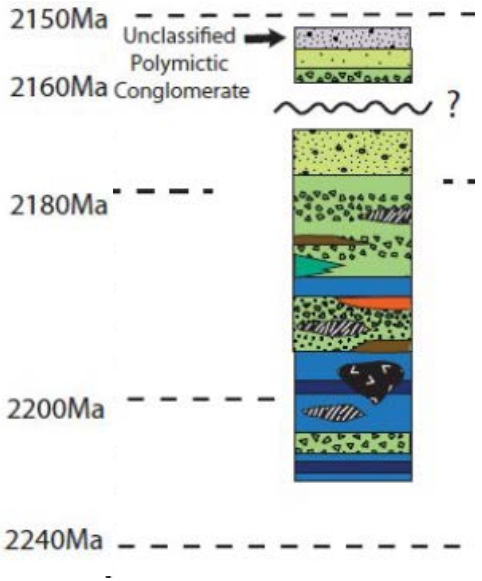
S Mali – Morila gold deposit





N Ghana

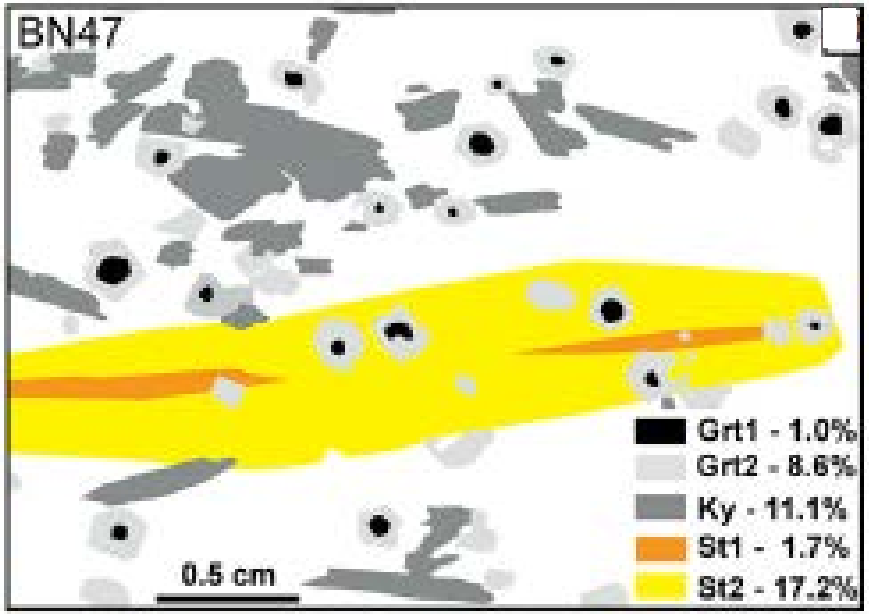


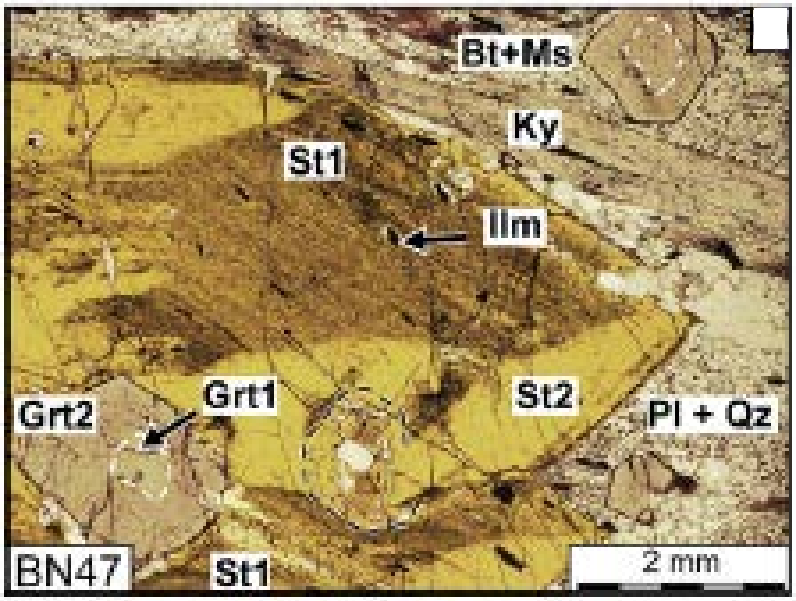


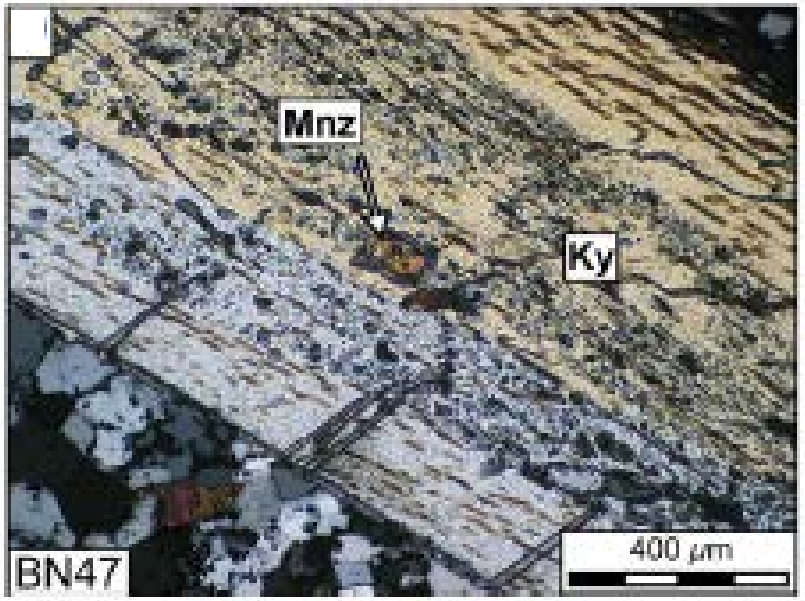
Block et al., in review

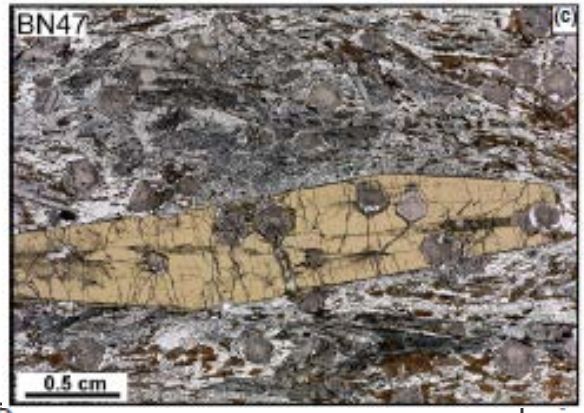
N Ghana

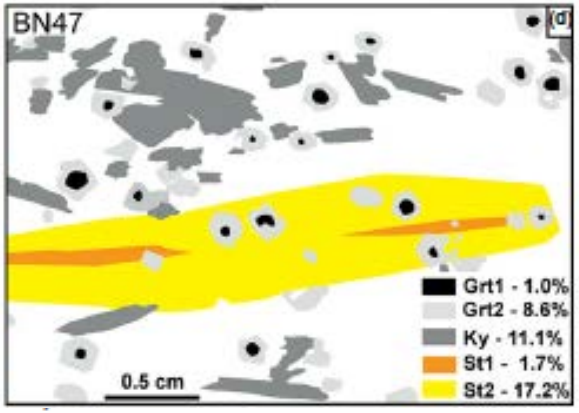

BN47
0.5 cm

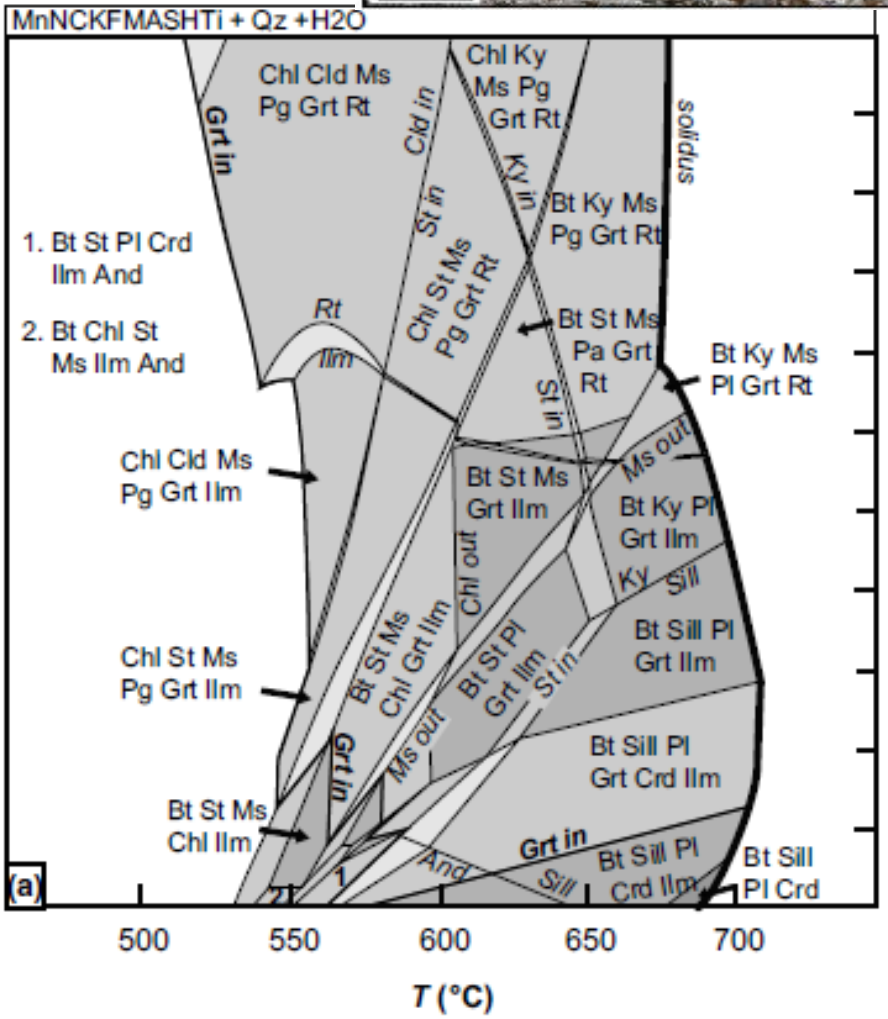

BN47
0.5 cm
Grt1 - 1.0%
Grt2 - 8.6%
Ky - 11.1%
St1 - 1.7%
St2 - 17.2%

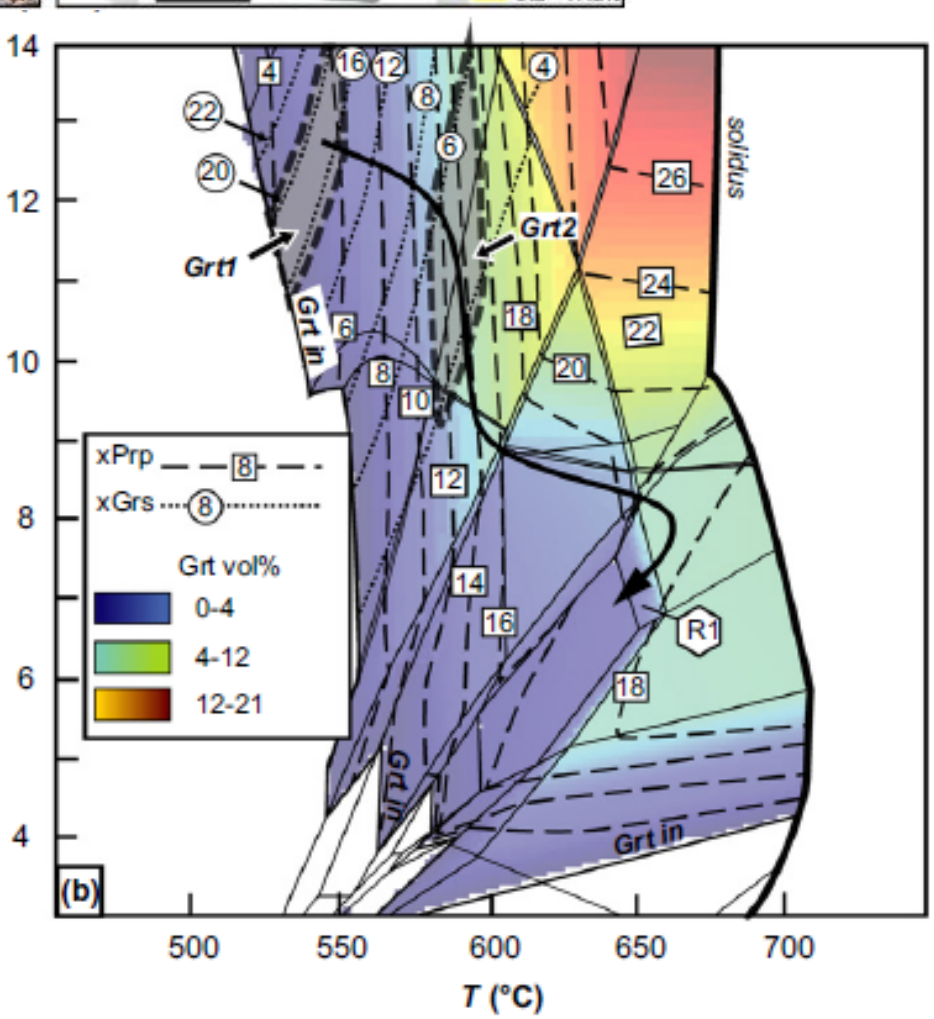

Bt+Ms
Ky
St1
Ilm
Grt2
Grt1
St2
Pl + Qz
BN47
St1
2 mm


Mnz
Ky
BN47
400 µm

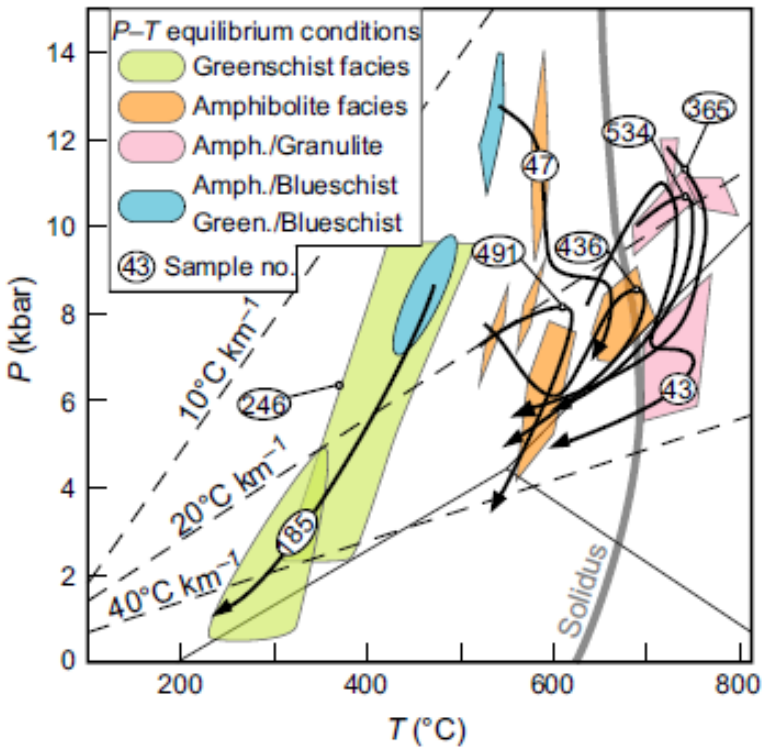

BN47
(c)
0.5 cm

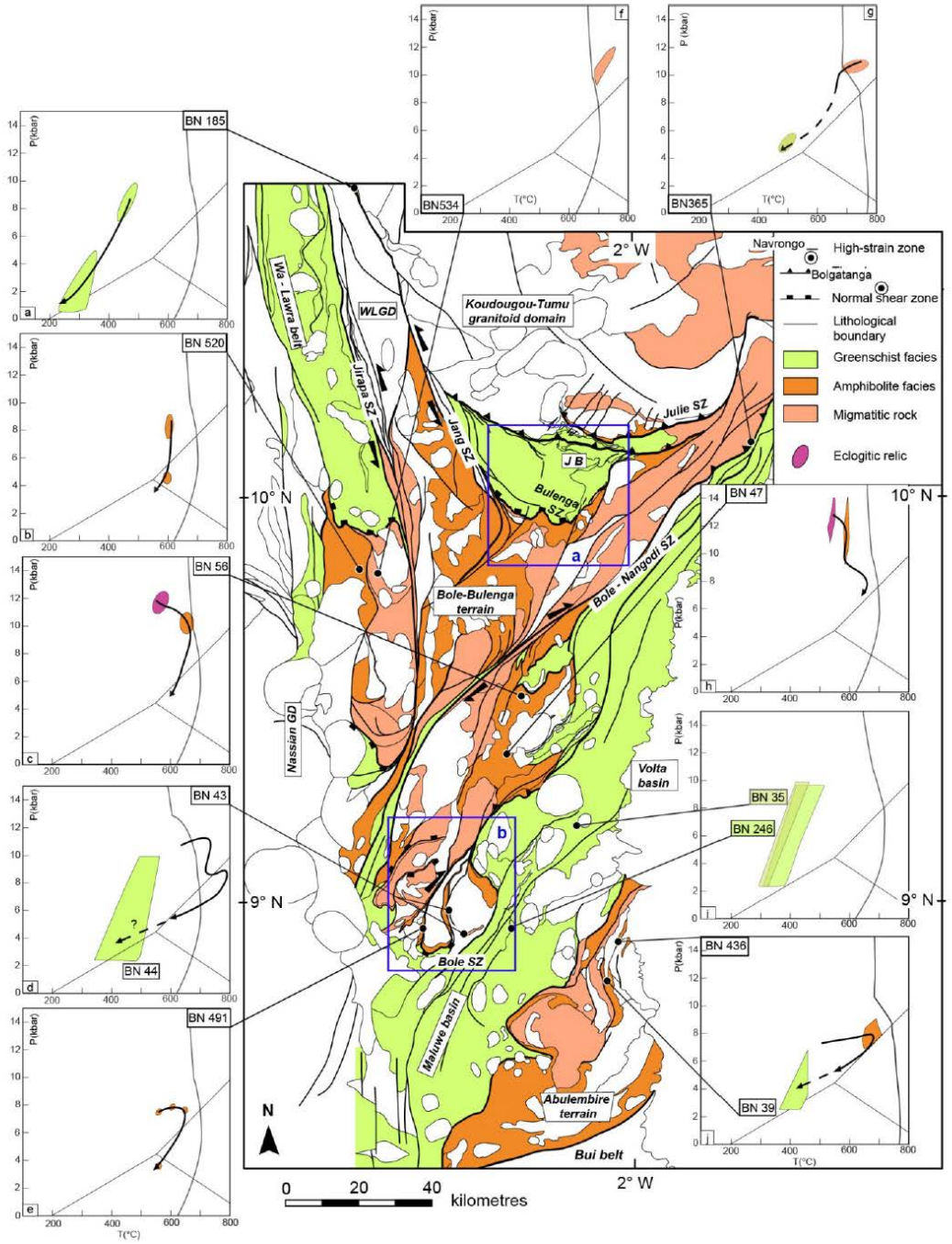

BN47
(d)
Grt1 - 1.0%
Grt2 - 8.6%
Ky - 11.1%
St1 - 1.7%
St2 - 17.2%
0.5 cm

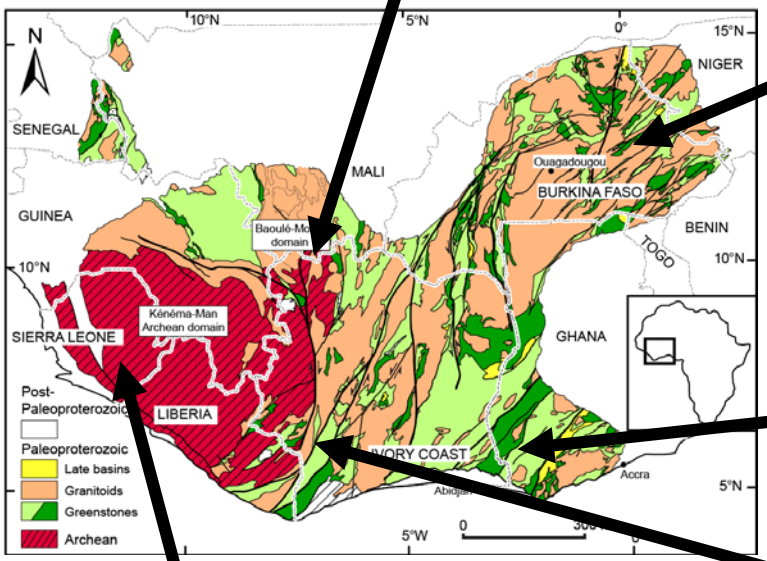

MnNCKFMASHTi + Qz +H2O
Chl Cld Ms Pg Grt Rt
Chl Ky Ms Pg Grt Rt
Grt in
Cld in
Ky in
St in
solidus
1. Bt St Pl Crd Ilm And
2. Bt Chl St Ms Ilm And
Rt
Ilm
Chl St Ms Pg Grt Rt
Bt Ky Ms Pg Grt Rt
Bt St Ms Pa Grt Rt
Bt Ky Ms Pl Grt Rt
Chl Cld Ms Pg Grt Ilm
Bt St Ms Grt Ilm
Ms out
Bt Ky Pl Grt Ilm
Chl out
Ky
Sill
Chl St Ms Pg Grt Ilm
Bt St Ms Chl Grt Ilm
Bt St Pl Grt Ilm
Bt Sill Pl Grt Ilm
Grt in
Bt Sill Pl Grt Crd Ilm
Bt St Ms Chl Ilm
And
Sill
Bt Sill Pl Crd Ilm
Bt Sill Pl Crd
(a)
2
1
500
550
600
650
700
T (°C)

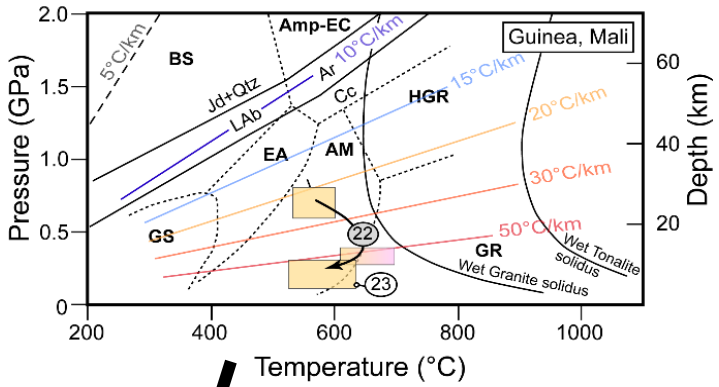

14
12
10
8
6
4
22
20
16
12
8
4
6
26
Grt2
Grt1
24
18
22
Grt in
6
8
20
10
12
xPrp
xGrs
Grt vol%
0-4
4-12
12-21
14
16
R1
18
solidus
Grt in
(b)
500
550
600
650
700
T (°C)

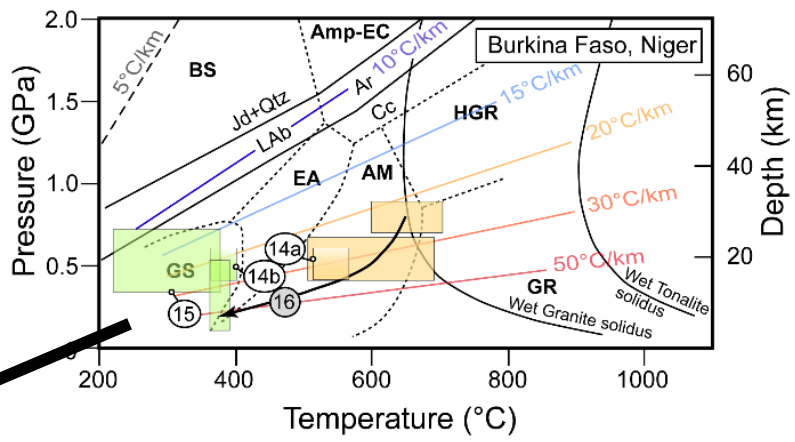
N Ghana

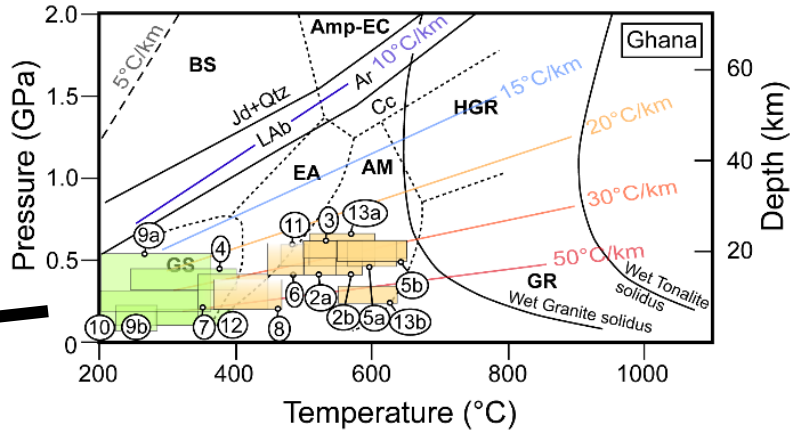

P–T equilibrium conditions
Greenschist facies
Amphibolite facies
Amph./Granulite
Amph./Blueschist
Green./Blueschist
43 Sample no.
10°C km⁻¹
20°C km⁻¹
40°C km⁻¹
Solidus
P (kbar)
T (°C)
47
534
365
491
436
43
246
185

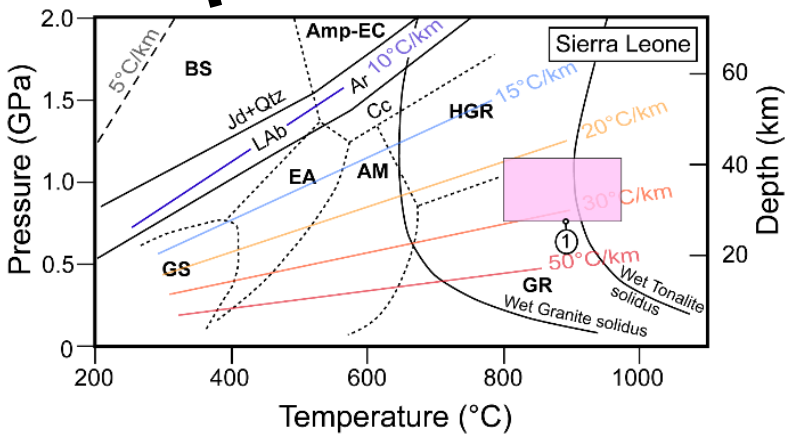

BN 185
BN 520
BN 56
BN 43
BN 44
BN 491
BN534
BN365
BN 47
BN 35
BN 246
BN 436
BN 39
Navrongo
Bolgatanga
2° W
10° N
9° N
High-strain zone
Normal shear zone
Lithological boundary
Greenschist facies
Amphibolite facies
Migmatitic rock
Eclogitic relic
Wa - Lawra belt
WLGD
Koudougou-Tumu granitoid domain
Jirapa SZ
Jaru SZ
Julie SZ
J B
Bulenga SZ
Bole-Bulenga terrain
Bole - Nangodi SZ
Nassian GD
Volta basin
Bole SZ
Maluwe basin
Abulembire terrain
Bui belt
N
0 20 40
kilometres

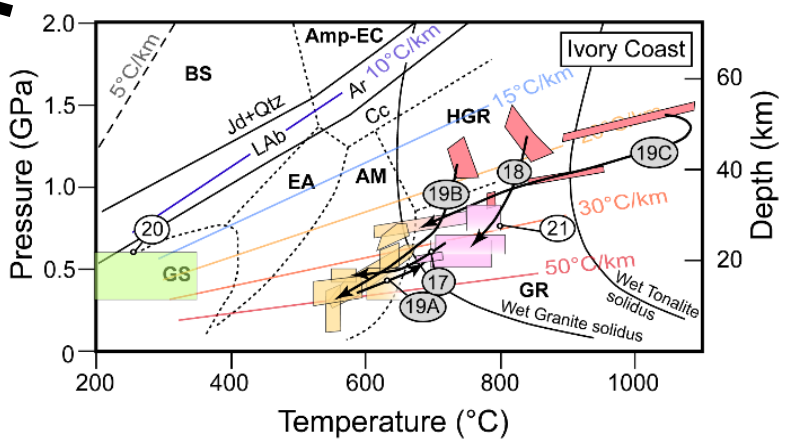

N
SENEGAL
GUINEA
MALI
BURKINA FASO
NIGER
BENIN
TOGO
GHANA
SIERRA LEONE
LIBERIA
IVORY COAST
Ouagadougou
Accra
Abidjan
Baoulé-Mo domain
Kénéma-Man Archean domain
10°N
5°N
0°
15°N
5°W
Post-Paleoproterozoic
Paleoproterozoic
Late basins
Granitoids
Greenstones
Archean


Guinea, Mali
Pressure (GPa)
Temperature (°C)
Depth (km)
BS
Amp-EC
Jd+Qtz
LAb
Ar
Cc
HGR
EA
AM
GS
GR
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
22
23

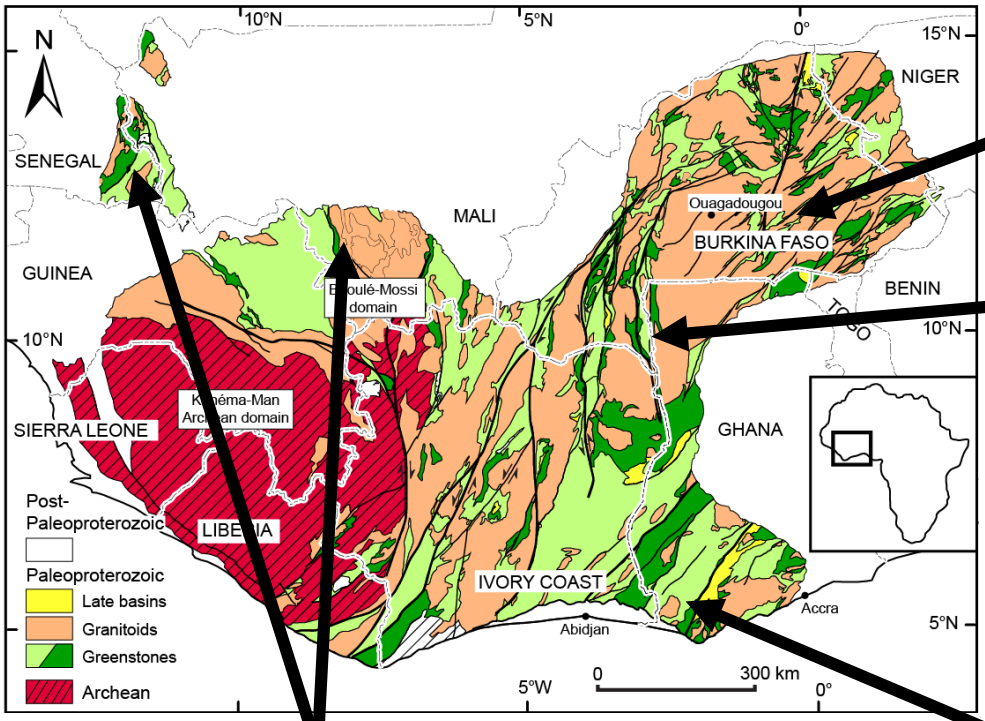

Burkina Faso, Niger
Pressure (GPa)
Temperature (°C)
Depth (km)
BS
Amp-EC
Jd+Qtz
LAb
Ar
Cc
HGR
EA
AM
GS
GR
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
14a
14b
15
16

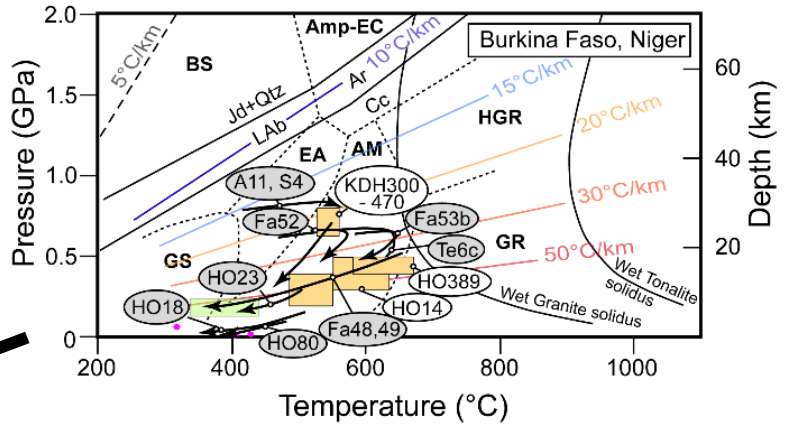

Ghana
Pressure (GPa)
Temperature (°C)
Depth (km)
BS
Amp-EC
Jd+Qtz
LAb
Ar
Cc
HGR
EA
AM
GS
GR
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
9a
4
11
3
13a
6
2a
5b
2b
5a
13b
10
9b
7
12
8

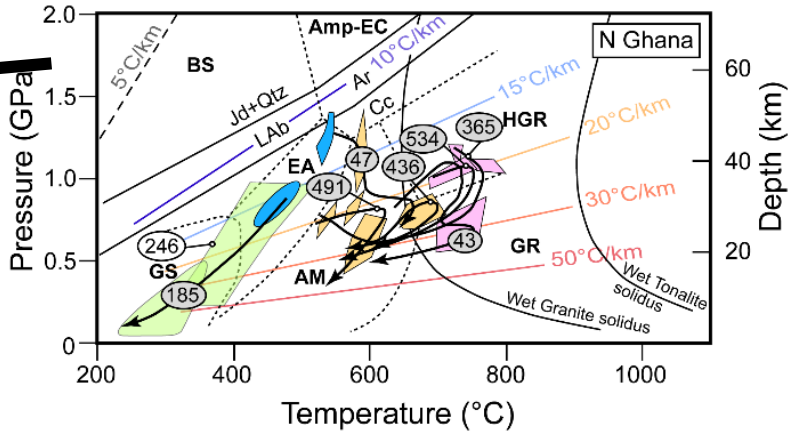

Sierra Leone
Pressure (GPa)
Temperature (°C)
Depth (km)
BS
Amp-EC
Jd+Qtz
LAb
Ar
Cc
HGR
EA
AM
GS
GR
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
1

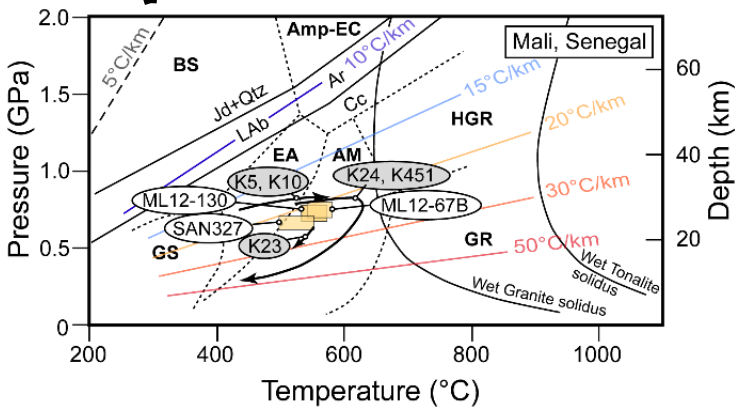

Ivory Coast
Pressure (GPa)
Temperature (°C)
Depth (km)
BS
Amp-EC
Jd+Qtz
LAb
Ar
Cc
HGR
EA
AM
GS
GR
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
20
19C
18
19B
21
17
19A

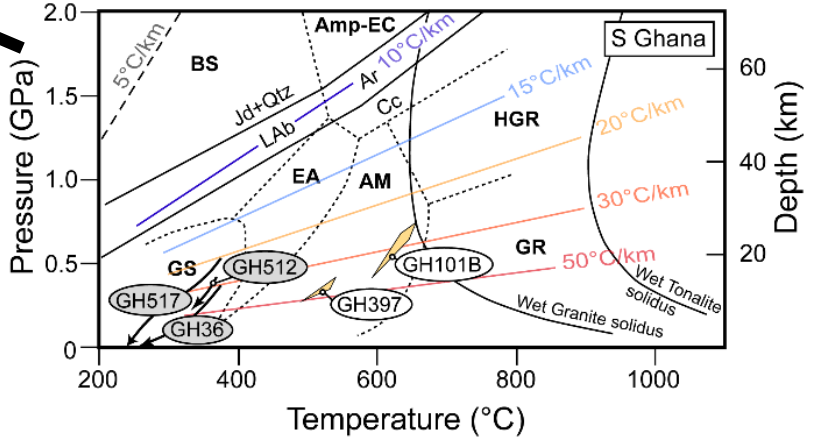
WAXI 2


N
10°N
5°N
0°
15°N
SENEGAL
MALI
NIGER
Ouagadougou
BURKINA FASO
GUINEA
BENIN
Boulé-Mossi domain
Kénéma-Man Archean domain
SIERRA LEONE
GHANA
LIBERIA
IVORY COAST
Accra
Abidjan
5°W
0
300 km
Post-Paleoproterozoic
Paleoproterozoic
Late basins
Granitoids
Greenstones
Archean


Burkina Faso, Niger
Amp-EC
BS
HGR
EA
AM
GS
GR
Jd+Qtz
LAb
Ar
Cc
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
A11, S4
KDH300 - 470
Fa52
Fa53b
Te6c
HO23
HO389
HO18
HO14
Fa48,49
HO80
Pressure (GPa)
Depth (km)
Temperature (°C)


N Ghana
Amp-EC
BS
HGR
EA
AM
GS
GR
Jd+Qtz
LAb
Ar
Cc
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
365
534
47
436
491
246
43
185
Pressure (GPa)
Depth (km)
Temperature (°C)


Mali, Senegal
Amp-EC
BS
HGR
EA
AM
GS
GR
Jd+Qtz
LAb
Ar
Cc
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
K5, K10
K24, K451
ML12-130
ML12-67B
SAN327
K23
Pressure (GPa)
Depth (km)
Temperature (°C)


S Ghana
Amp-EC
BS
HGR
EA
AM
GS
GR
Jd+Qtz
LAb
Ar
Cc
5°C/km
10°C/km
15°C/km
20°C/km
30°C/km
50°C/km
Wet Tonalite solidus
Wet Granite solidus
GH512
GH101B
GH517
GH397
GH36
Pressure (GPa)
Depth (km)
Temperature (°C)

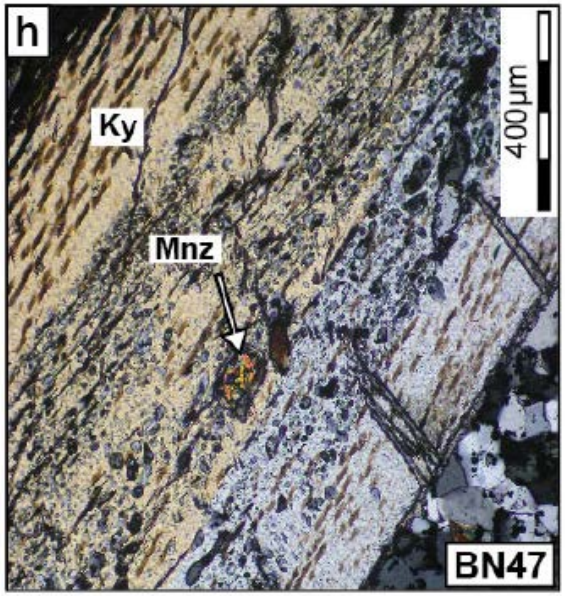
Timing of metamorphism

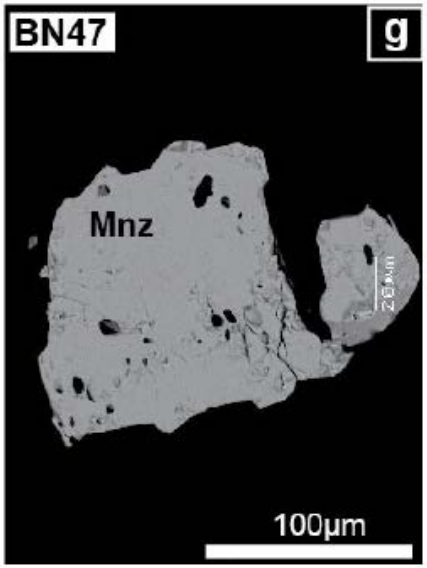
Published metamorphic ages

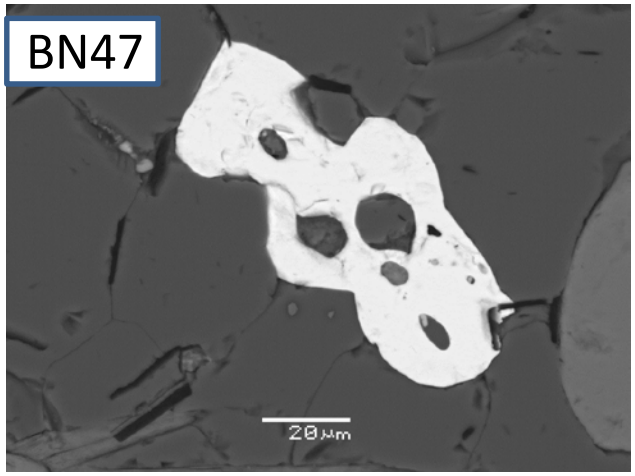
Country	Location	Lithology	Age (Ma)	Mineral dated	Method	Reference
E Senegal	Dialé-Daléma Series	metasediments	2165±1	Zircon	U–Pb	Hirdes and Davis, 2002
E Senegal	Dialé-Daléma Series	metasediments	2156±10	Zircon	Pb–Pb, Zt evaporation	Calvez et al., 1990
N Ghana	Maluwe basin	granodiorite	2105±10	Zircon	U-Pb SHRIMP	de Kock et al., 2009
S Ghana	Kibi belt	BIF paragneiss calc silicate	2104±34	hbl, pl, grt	Sm-Nd	Feybesse et al., 2006
N Ghana	Bolé-Navrongo belt	monzogranite	2104±31	Zircon	U-Pb SHRIMP	Thomas et al., 2009
N Ivory Coast	Haute Comoé	granodioritic gneiss	2100±3	Titanite	U–Pb TIMS	Hirdes et al., 1996
S Ghana	Ashanti belt	granitoid	2098±7	Rutile-galena	Pb–Pb	Oberthür et al., 1998
N Ghana	Bolé-Navarongo belt	granite	2098±4	Zircon	U-Pb SHRIMP	Thomas et al., 2009
E Senegal	Dialé-Daléma Series	metasediments	2096±8	Zircon	Pb–Pb, Zt evaporation	Milési et al., 1989
S Ghana	Sefwi Group	amphibolite	2095±34	Hornblende	K–Ar	Feybesse et al., 2006
S Ghana	Ashanti belt	grantoid	2092±3	Sphene	U–Pb TIMS	Oberthür et al., 1998
S Ghana	Ashanti belt	granitoid	2086±4	Rutile-galena	Pb–Pb	Oberthür et al., 1998
E Senegal	Saraya Pluton	granite	2064±4	Monazite	U–Pb	Hirdes and Davis, 2002
S Ghana	Tarkwa strata	metasediments	2063±9	Xenotime (hydrothermal)	U-Pb SHRIMP	Pigois et al., 2003
S Ghana	Tarkwa strata	metasediments	2034±4	Biotite	Ar–Ar	Pigois et al., 2003
SW Ivory Coast	Ity-Toulepleu area	metasediments	2031±9	Grt, WR	Sm-Nd	Koumelan et al., 1997
S Ghana	Tarkwa strata	metasediments	2029±4	Biotite	Ar–Ar	Pigois et al., 2003

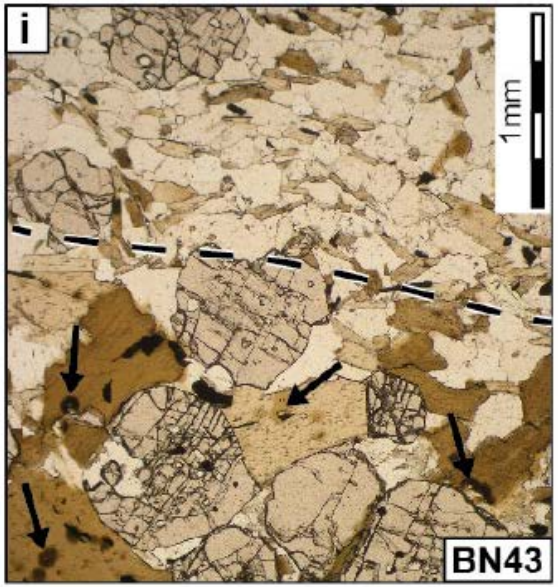
- Many of the metamorphic ages come from granitoids
- Only three ages related to a metamorphic study (Kouamelan et al., 1997; Pitra et al., 2010) (Feybesse et al., 2006) (Block et al., 2015)
- Several ages have very high errors, K-Ar and Ar-Ar systems often remobilized
- No age from Burkina Faso, Mali, Niger, Guinea…

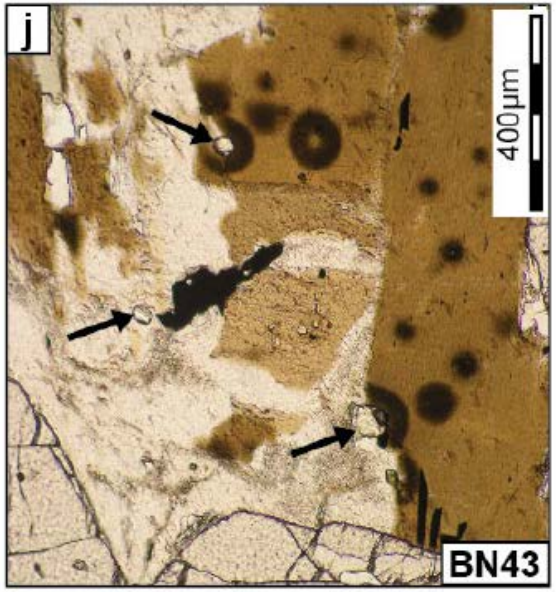
Monazite dating

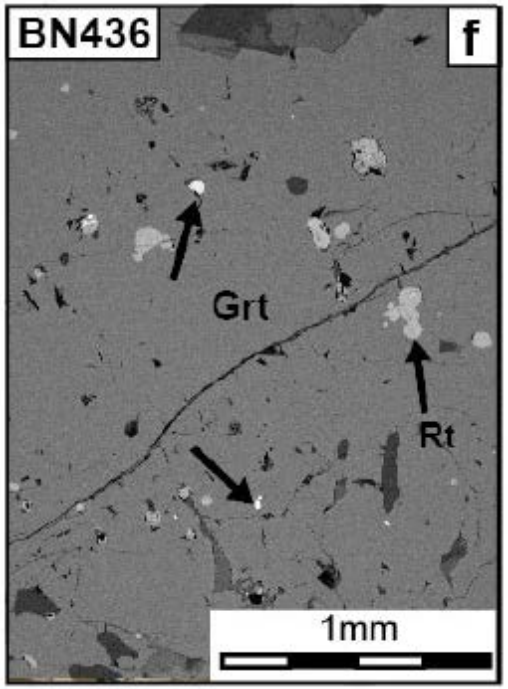








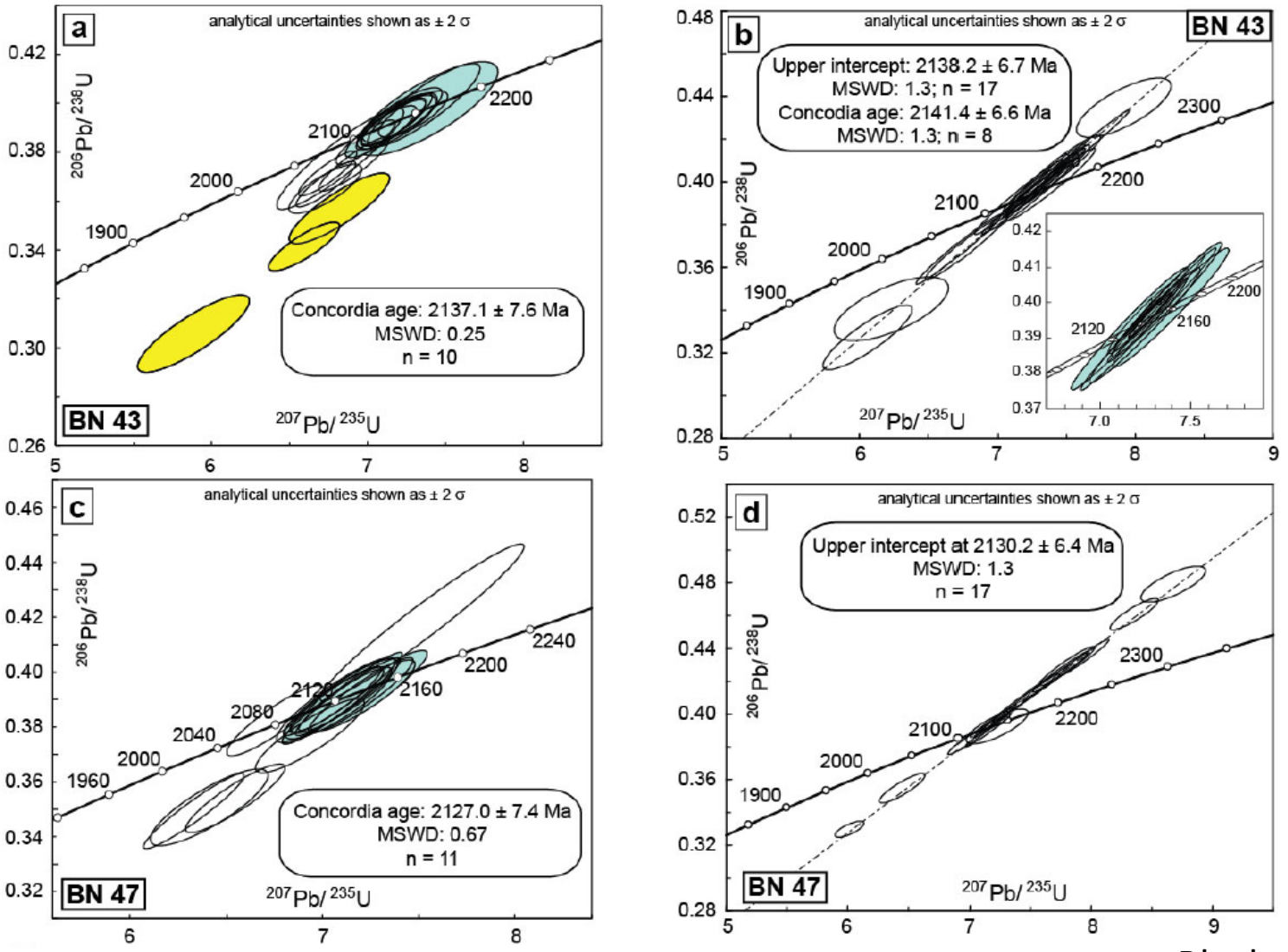




Monazite dating

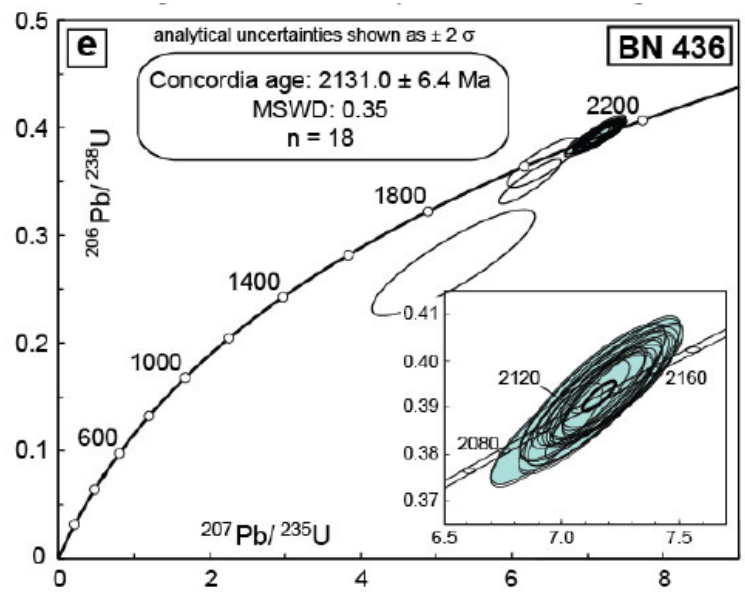
In situ LA ICP-MS

In situ SHRIMP

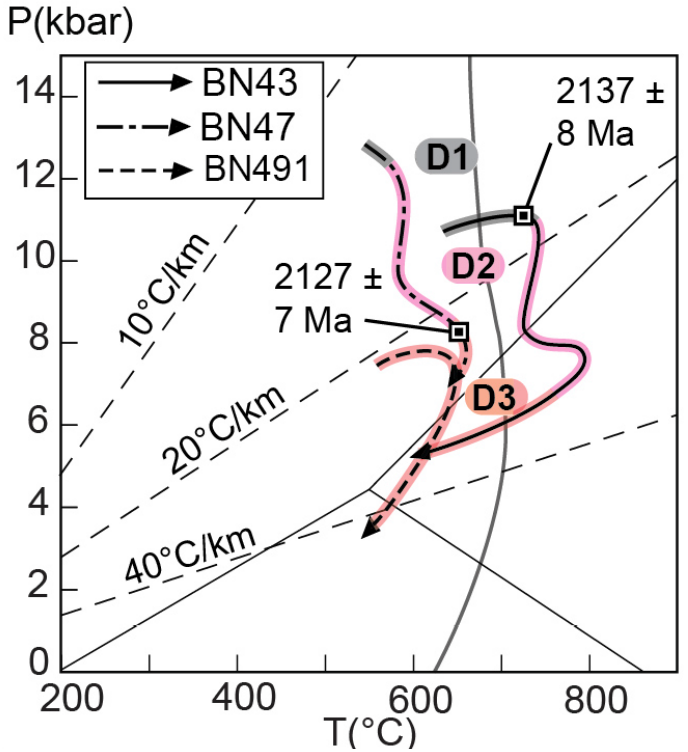


Block et al., 2015

Monazite dating



In situ LA ICP-MS

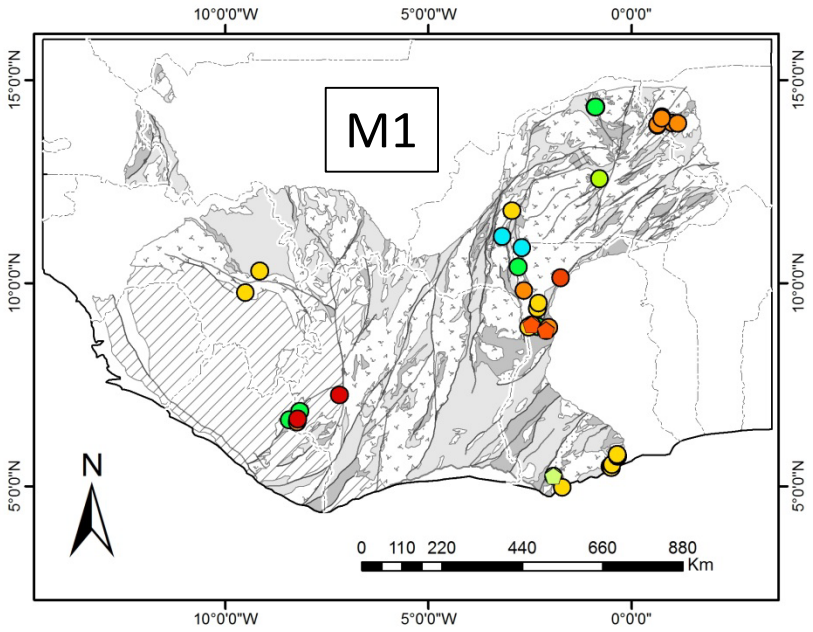


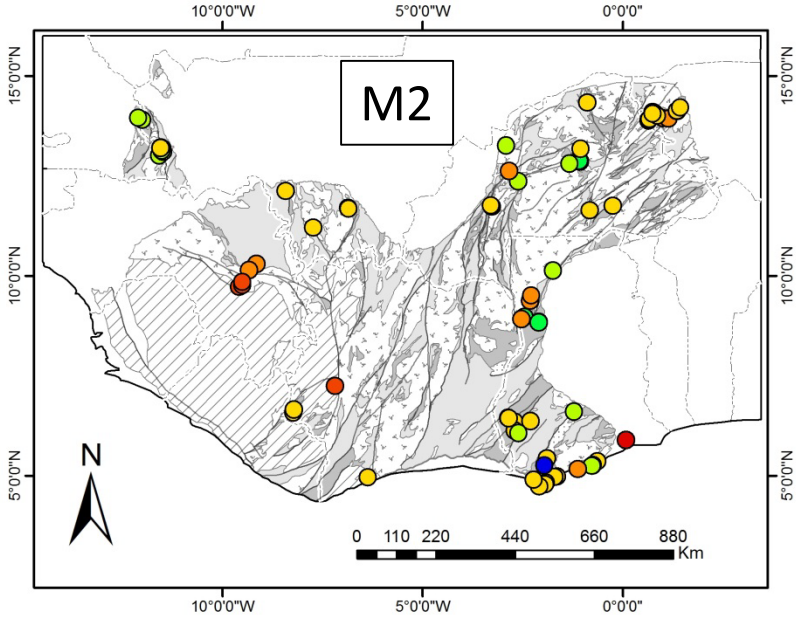
- BN43 – 2137 ± 8 Ma ; 2138 ± 7 Ma
- BN47 – 2127 ± 7 Ma ; 2130 ± 6 Ma
- BN436 – 2131 ± 6 Ma

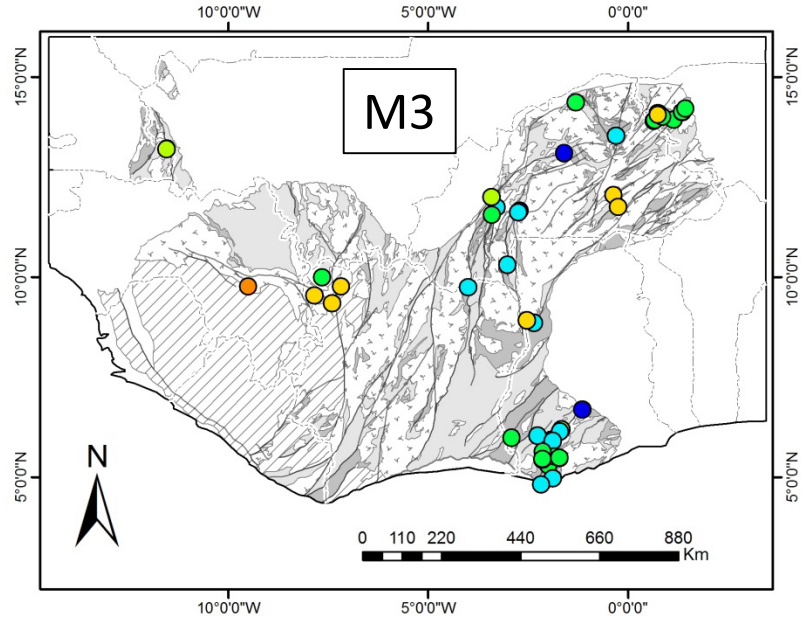
-> age of HT metamorphic phase

Block et al., 2015

Temperatures







Legend

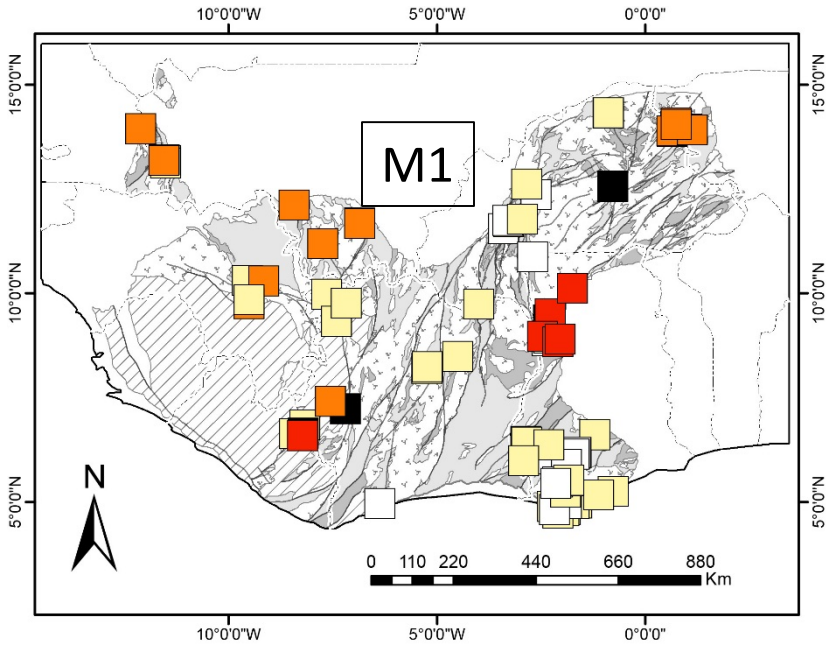
Temperature (°C)

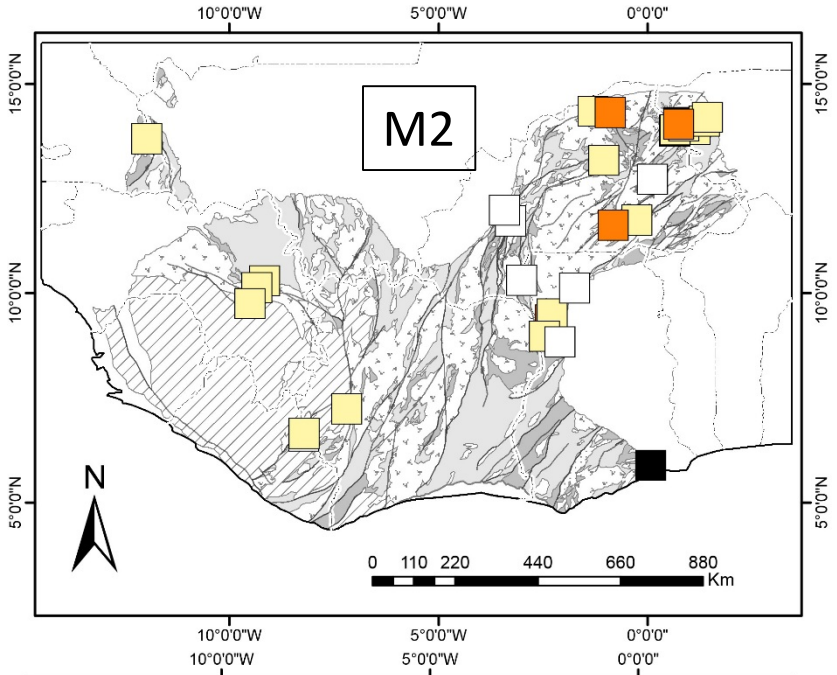
- < 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 600
- 601 - 700
- 701 - 800
- 801 - 1000

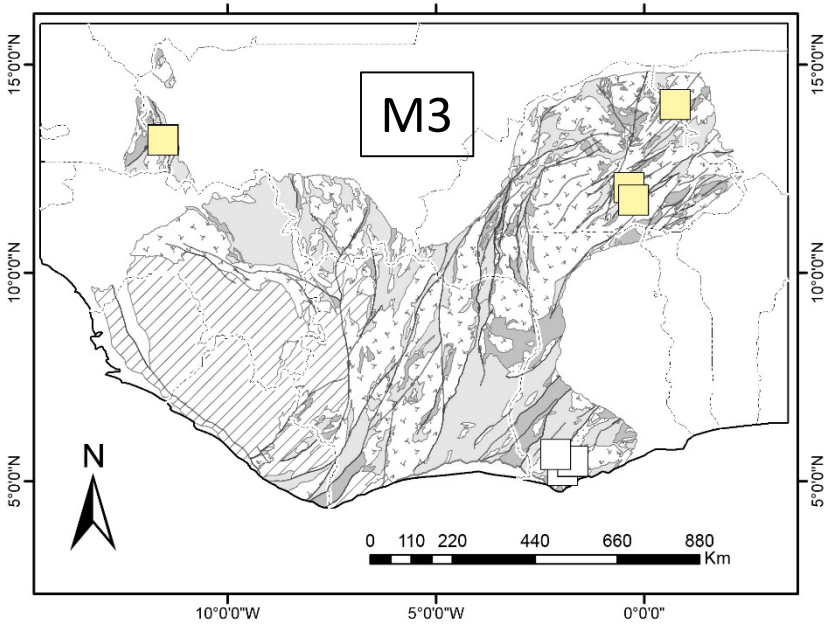
Facies

- Greenschist
- Upper greeschist
- Amphibolite
- Upper amphibolite facies
- Contact metamorphism / granulites

Pressures



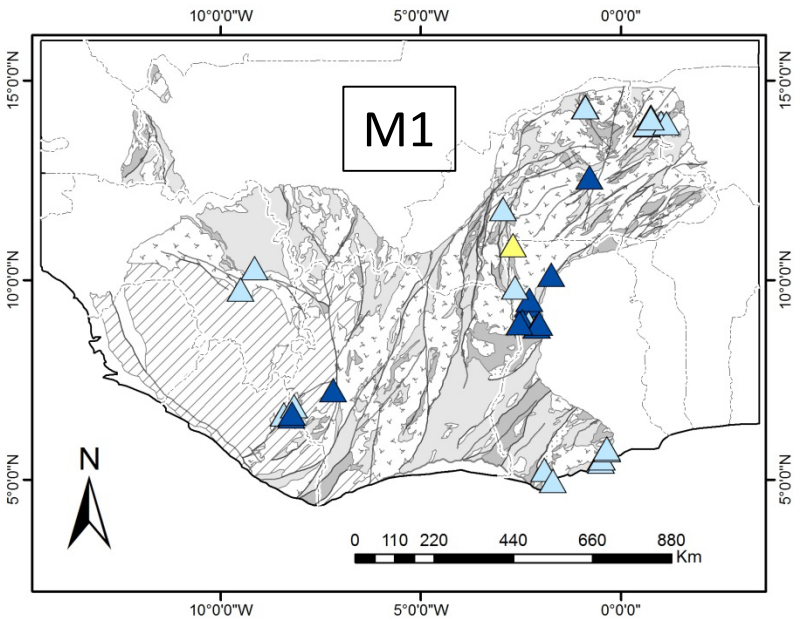


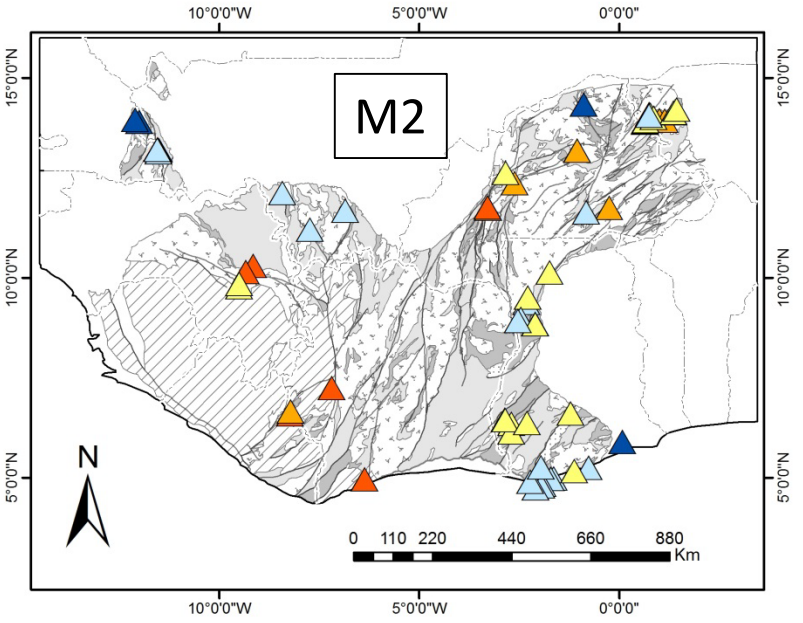


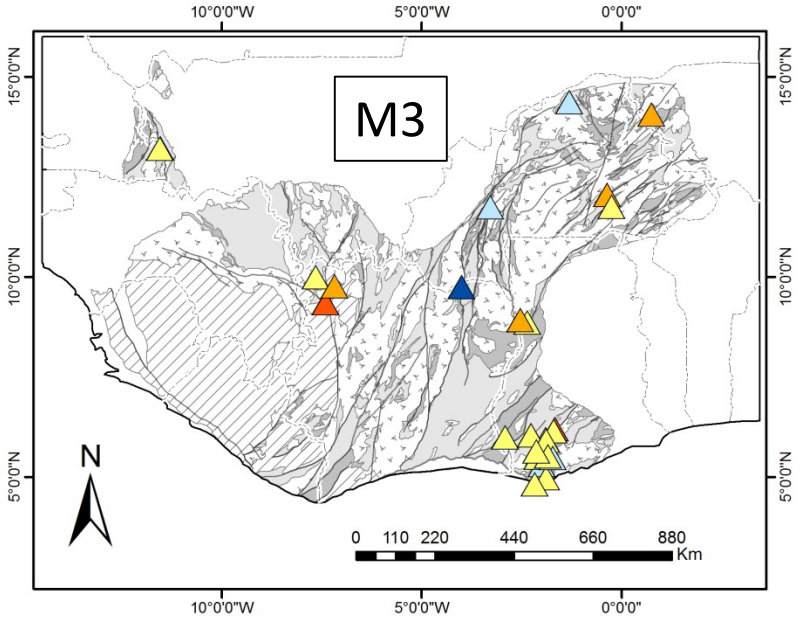
Pressure (kbar)

- < 3
- 3.1 - 6
- 6.1 - 9
- 9.1 - 12
- 12.1 - 15

Apparent geothermal gradients



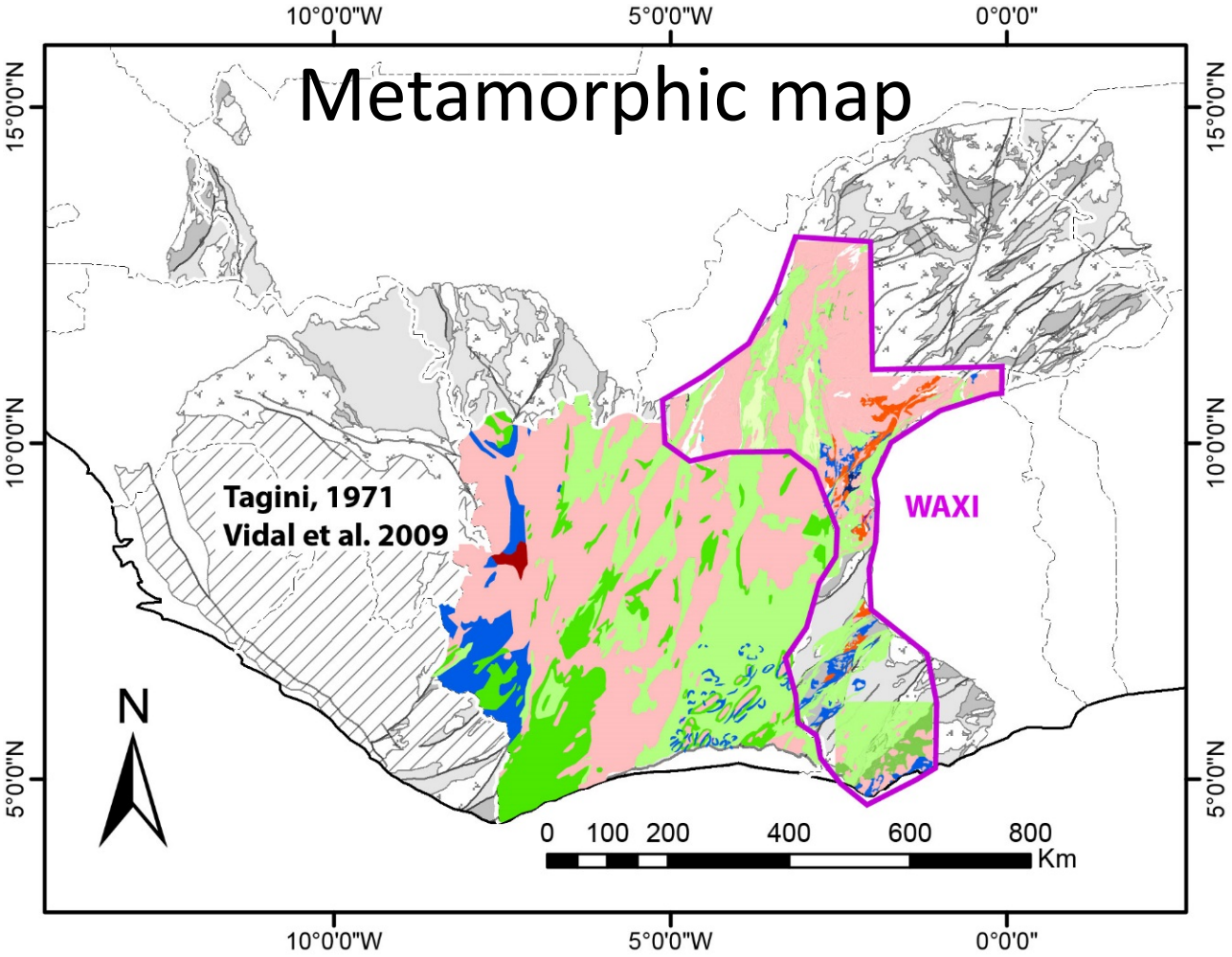




Legend

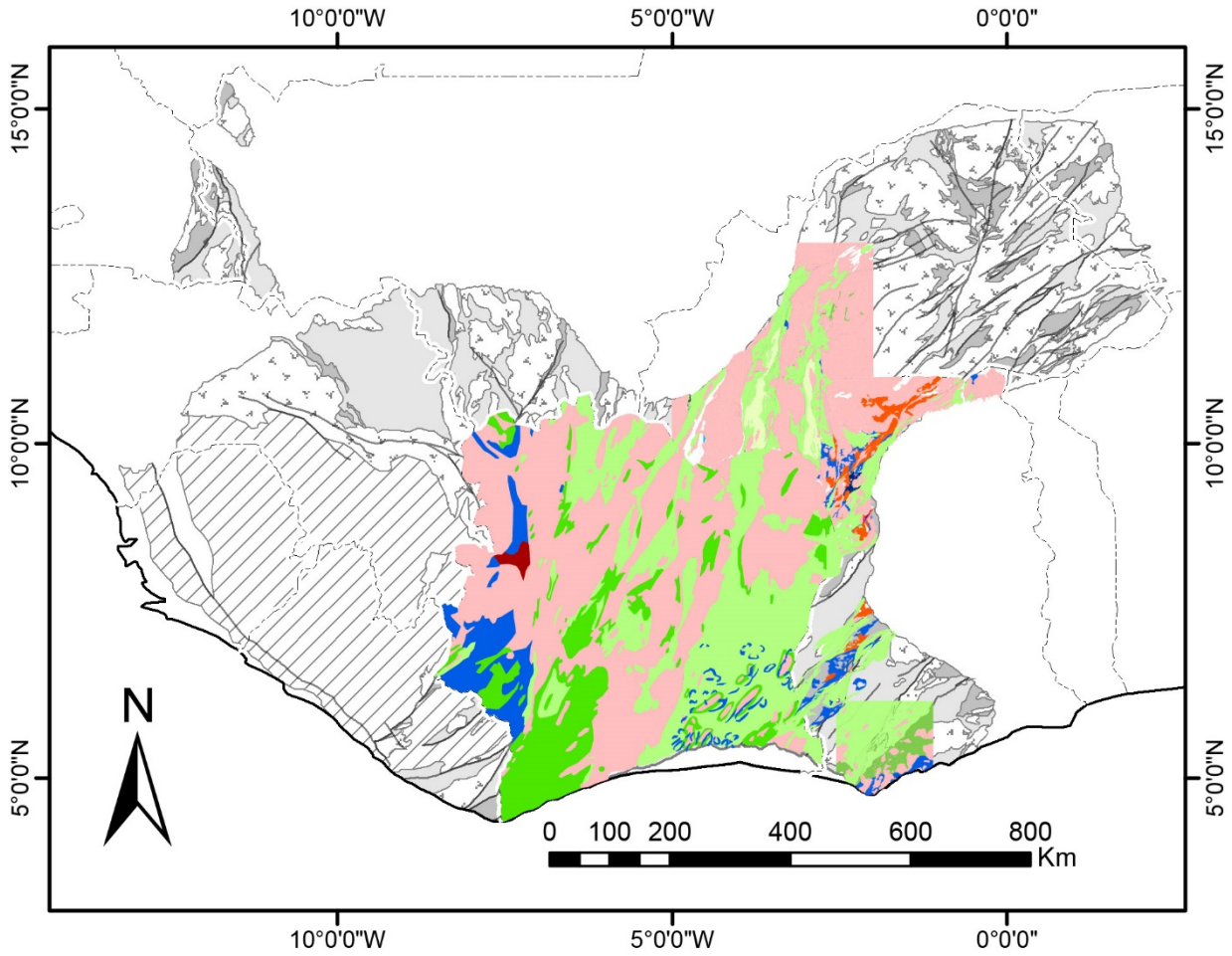
Metamorphic gradient (°C/km)

- < 20
- 21 - 30
- 31 - 40
- 41 - 50
- 51 - 60



Legend

- Lower greenschist facies
- Greenschist facies
- Upper greenschist facies
- Epidote - amphibolite facies
- Amphibolite facies
- Sill-Crd
- Kyanite zone
- High pressure amphibolite facies
- Upper amphibolite facies
- Migmatite facies
- Granitoid



Legend

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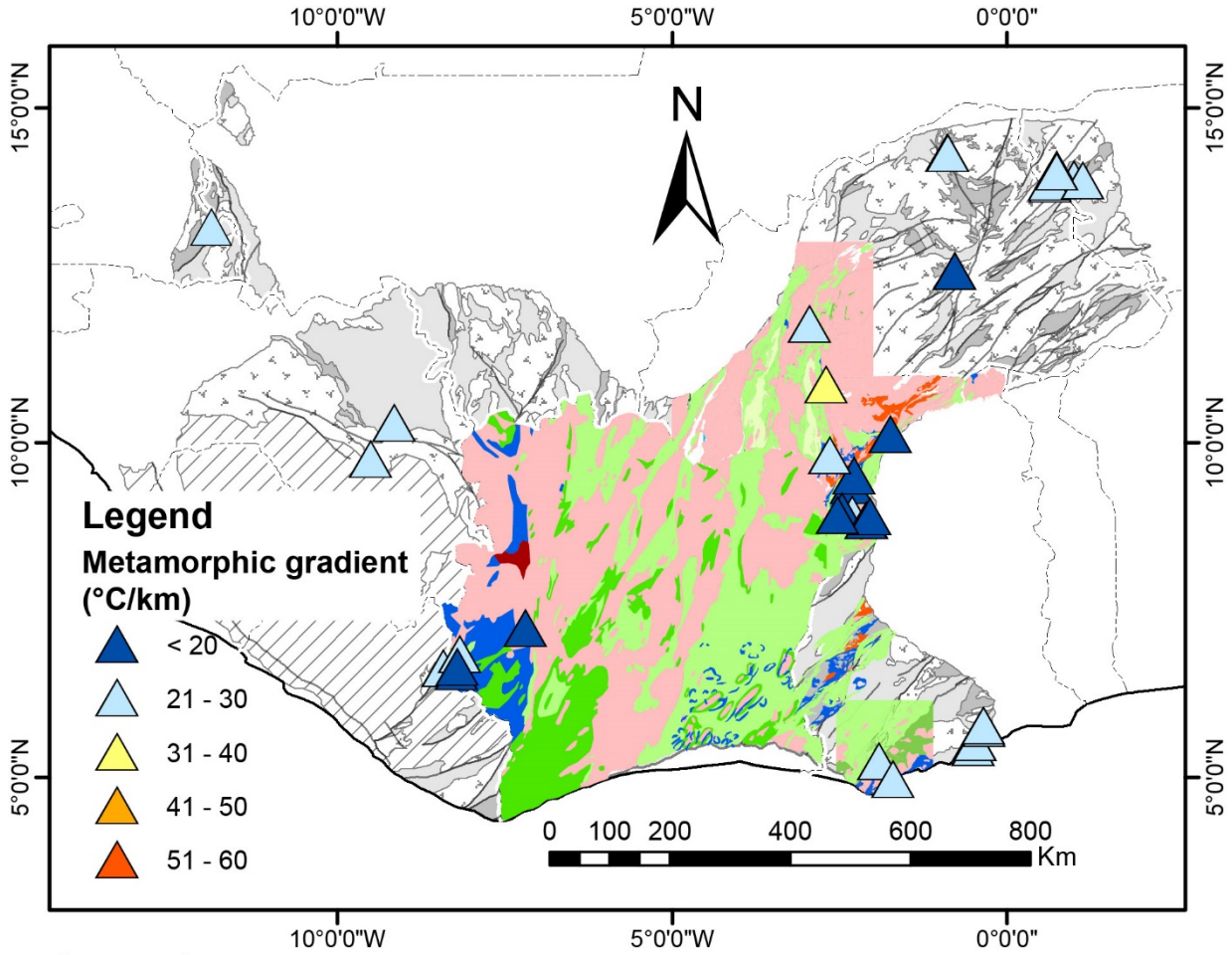

Legend

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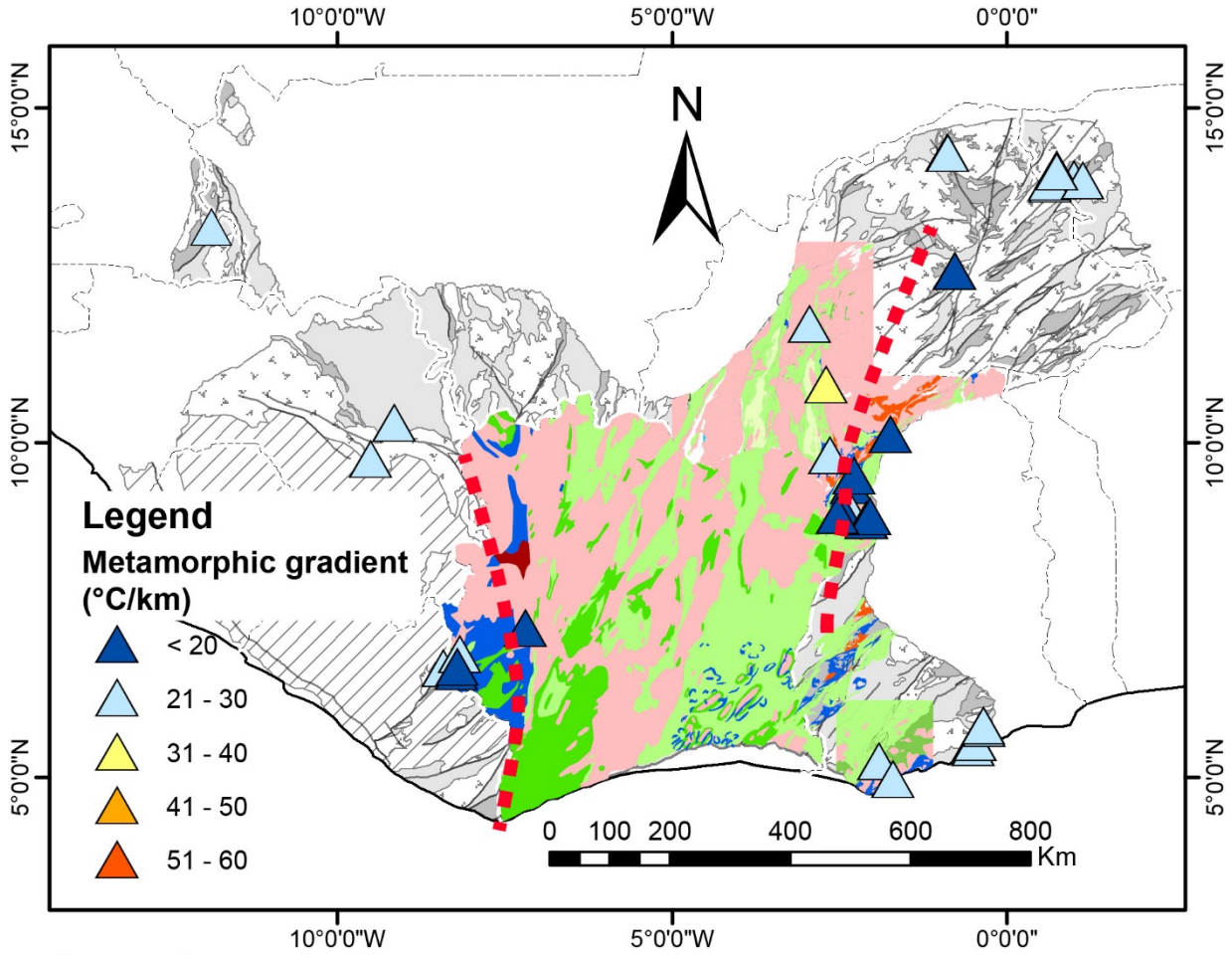

Legend

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- Epidote - amphibolite facies
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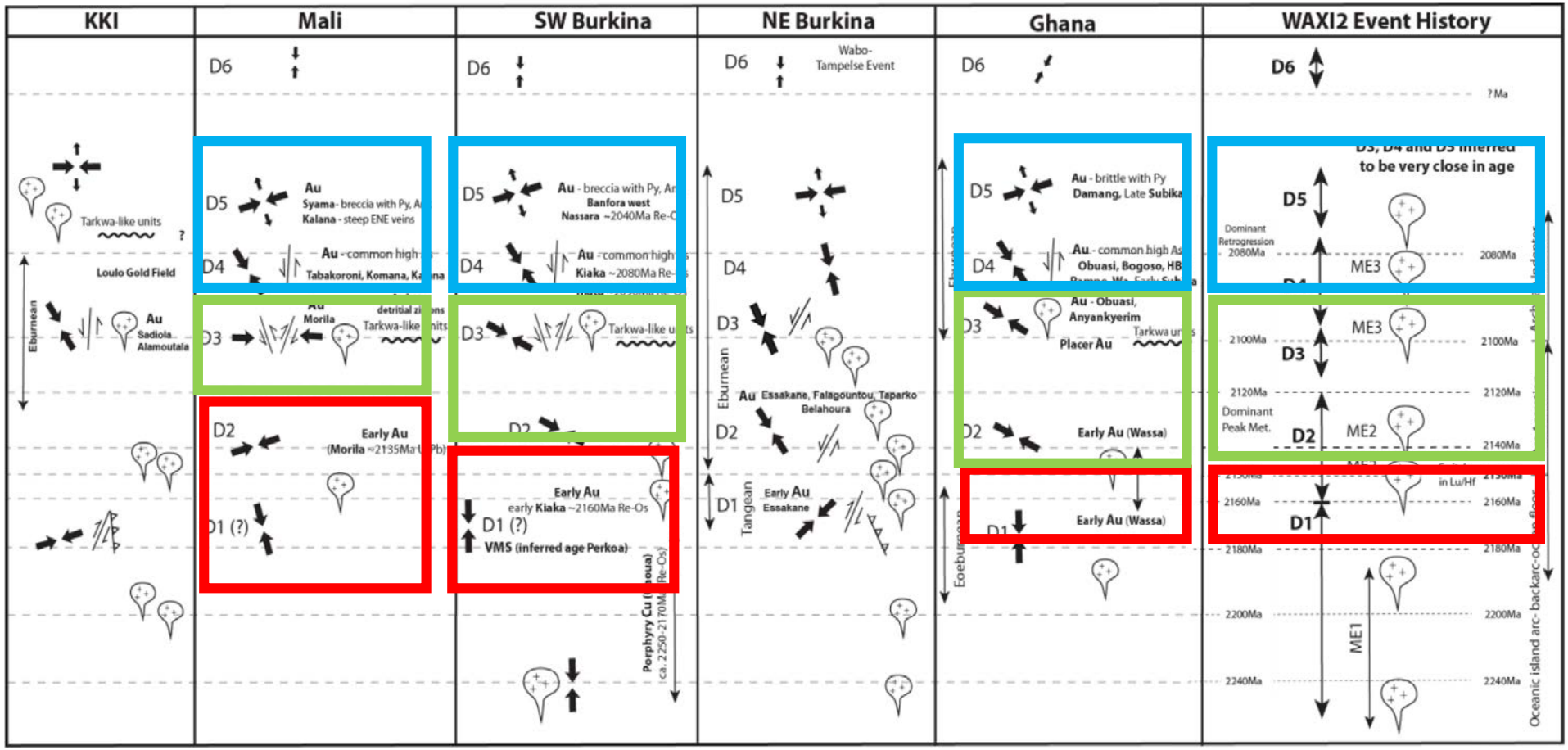
- Upper amphibolite facies
- Migmatite facies
- Granitoid

Tectono-metamorphic evolution



M1 **M2** **M3**

Miller et al., in prep.

Conclusions

- Cold apparent geothermal gradients suggest **subduction/collisional setting** (E Burkina Faso, N Ghana)
- **Mineral deposits** occur form over a **wide range of metamorphic conditions**
- Target for **subduction, collision, back-arc and ocean floor related deposits**
- Evidence for zones of **crustal thickening** (up to 40 km), **rock burial and exhumation** during Eburnean orogenesis

Conclusions

- **Greenschist facies rocks** occur in upper crustal levels and their metamorphism may be **contemporaneous** with that of the **high grade rocks**. The **contacts** with mid- to lower crustal rocks are often **tectonic** (N Ghana)
- We can find zones of **contact metamorphism**… but in most of the cases, it **overprints previous regional metamorphism**
- Correlation of metamorphic events across the craton is difficult due to the **lack of precise geochronological data**

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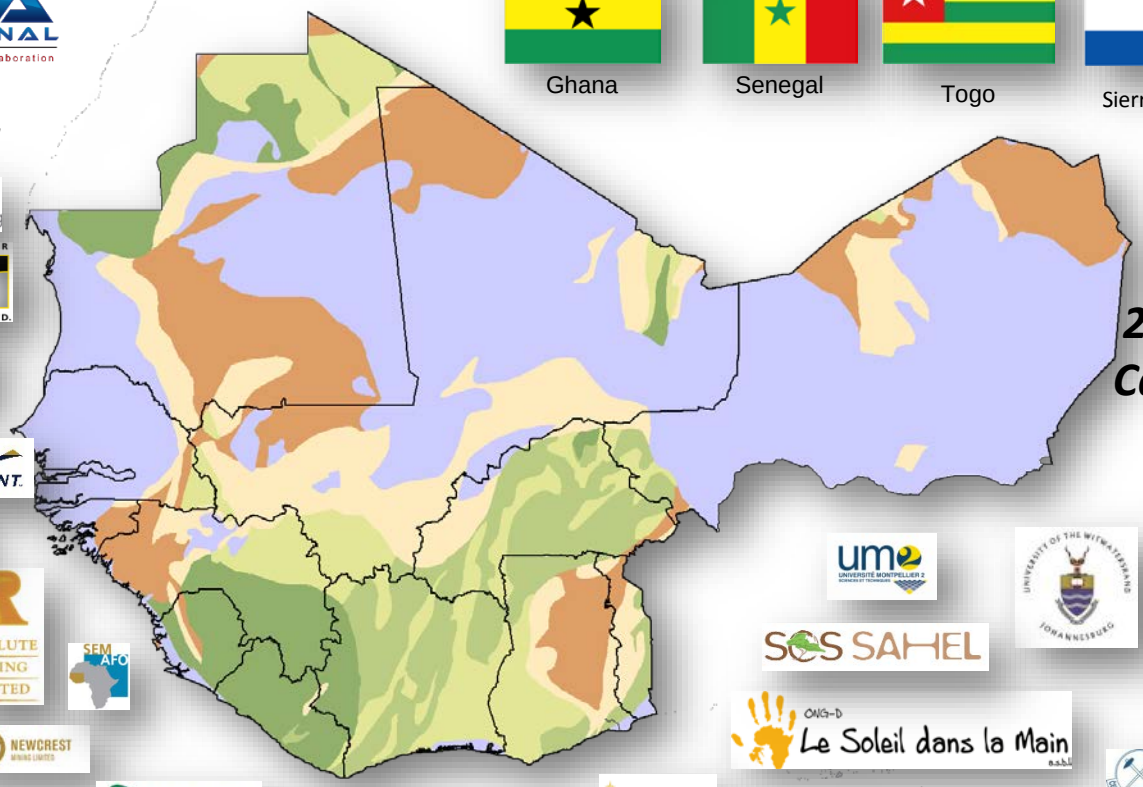

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