Metamorphic evolution of the southern West African Craton

L. Baratoux\textsuperscript{1,2}, S. Block\textsuperscript{1}, J. Ganne\textsuperscript{1}, S. Perrouty\textsuperscript{1}, L. Siebenaller\textsuperscript{1}, D. Béziat\textsuperscript{1}, J. Davis\textsuperscript{1}, E. Dioh\textsuperscript{2}, A. Fontaine\textsuperscript{3}, P.M. Ndiaye\textsuperscript{4}, J. Miller\textsuperscript{5}, M. W. Jessell\textsuperscript{1,5}

\textsuperscript{1}GET IRD UPS, \textsuperscript{2}IFAN, \textsuperscript{3}Uni Lorraine, \textsuperscript{4}UCAD, \textsuperscript{5}UWA
Metamorphism is key to understanding geodynamic evolution of the orogen

Hyndman et al., 2005

Brown, 2007
Ore deposits form in various geodynamic settings
Archean vs. modern type orogens

**Plate tectonics**
- Yilgarn (Australie)
- WA (Ghana)
  - ~2.7 Ga
- Chardon et al. (2008)
- Peschler et al. (2006)
- Vidal et al. (2009)
- Feybesse et al. (2006)

**Crustal scale folding**
- Abitibi (Canada)
  - ~2.7 Ga
- Chardon et al. (2008)

**Lateral crustal flow**
- Dharwar (Inde)
  - ~2.5 Ga
- Goscombe et al. (2009)

**Vertical tectonics “sagduction”**
- WA (Côte d’Ivoire)
  - ~2.1 Ga
- 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

- >70 data
- >600 data

WAXI and related projects
Published data (article, conference abstract)
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-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

groups of phengite (Phg)

\[ P \text{ (kbar)} \]

\[ T \text{ (°C)} \]

GH512
S Mali – Morila gold deposit

[S image of rock sample with labels Bt, Grt, Pl]

[Temperature-pressure (P-T) diagram with peaks and mineral assemblages]

[Graphical representation of mineral assemblages and peak P-T conditions]

Peak P-T assemblage:
Bt + Chl + Ms + Grt + Pl + Qtz + IIm +/- Zoi
N Ghana

Block et al., in review
N Ghana

![Diagram showing P-T equilibrium conditions and geological map of N Ghana](image-url)

- **P-T equilibrium conditions**
  - Greenschist facies
  - Amphibolite facies
  - Amph./Granulite
  - Amph./Blueschist
  - Green./Blueschist

- **Geological map**
  - High-strain zone
  - Normal Shear zone
  - Greeneschist facies
  - Amphibolite facies
  - Migmatitic rock
  - Eclogitic relic

- **Location**
  - National Center for Geomatics, NPM
  - Bui belt
  - Ahulembire terrain
  - Volta basin

- **Geological Features**
  - Birrimian Belt
  - Whittemore Belt
  - Nsuaem Belt
  - Navrongo-Tama granulite domain
  - Kossiogho-Tamale granulite domain

- **Map Scale**
  - 1:500,000
  - 1:200,000

- **Legend**
  - Lithological boundary
  - P-T data points

### Timing of metamorphism

#### Published metamorphic ages

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

- 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*

- **BN 43**
  - Concordia age: $2137.1 \pm 7.6$ Ma
  - MSWD: 0.25
  - $n = 10$

- **BN 47**
  - Concordia age: $2127.0 \pm 7.4$ Ma
  - MSWD: 0.87
  - $n = 11$

*In situ SHRIMP*

- **BN 43**
  - Upper intercept: $2138.2 \pm 6.7$ Ma
  - MSWD: 1.3
  - $n = 17$
  - Concordia age: $2141.4 \pm 6.6$ Ma
  - MSWD: 1.3
  - $n = 8$

- **BN 47**
  - Upper intercept at $2130.2 \pm 6.4$ Ma
  - MSWD: 1.3
  - $n = 17$

Block et al., 2015
Monazite dating

- 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

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Facies</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 200</td>
<td>Greenschist</td>
</tr>
<tr>
<td>201 - 300</td>
<td>Upper greenschist</td>
</tr>
<tr>
<td>301 - 400</td>
<td>Amphibolite</td>
</tr>
<tr>
<td>401 - 500</td>
<td>Upper amphibolite facies</td>
</tr>
<tr>
<td>501 - 600</td>
<td>Contact metamorphism / granulites</td>
</tr>
<tr>
<td>601 - 700</td>
<td></td>
</tr>
<tr>
<td>701 - 800</td>
<td></td>
</tr>
<tr>
<td>801 - 1000</td>
<td></td>
</tr>
</tbody>
</table>
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
Tectono-metamorphic evolution

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**
Liberia  Mali  Guinea  Niger  Burkina Faso
Senegal  Togo  Sierra Leone  Mauritania  Côte d'Ivoire

Project Broker & Coordinator

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