# Paleoproterozoic crustal growth and differentiation :
## *a guide for understanding Au mineral system*

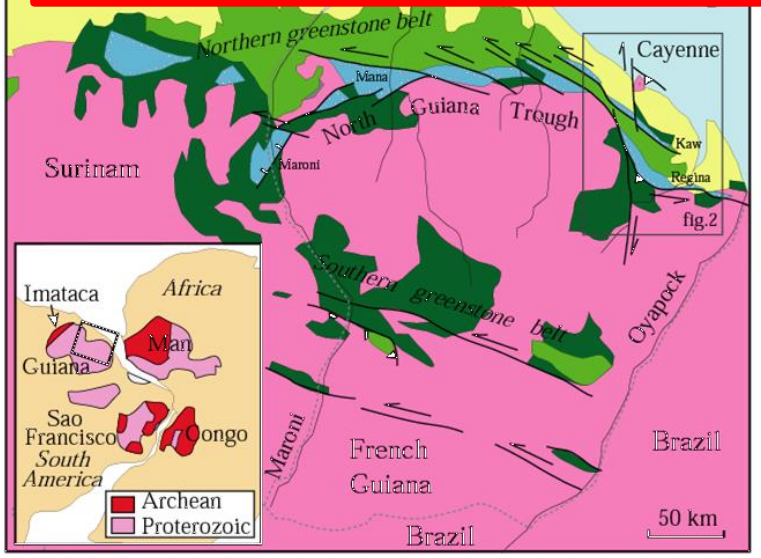
**Vanderhaeghe O.**
**Ledru P.**

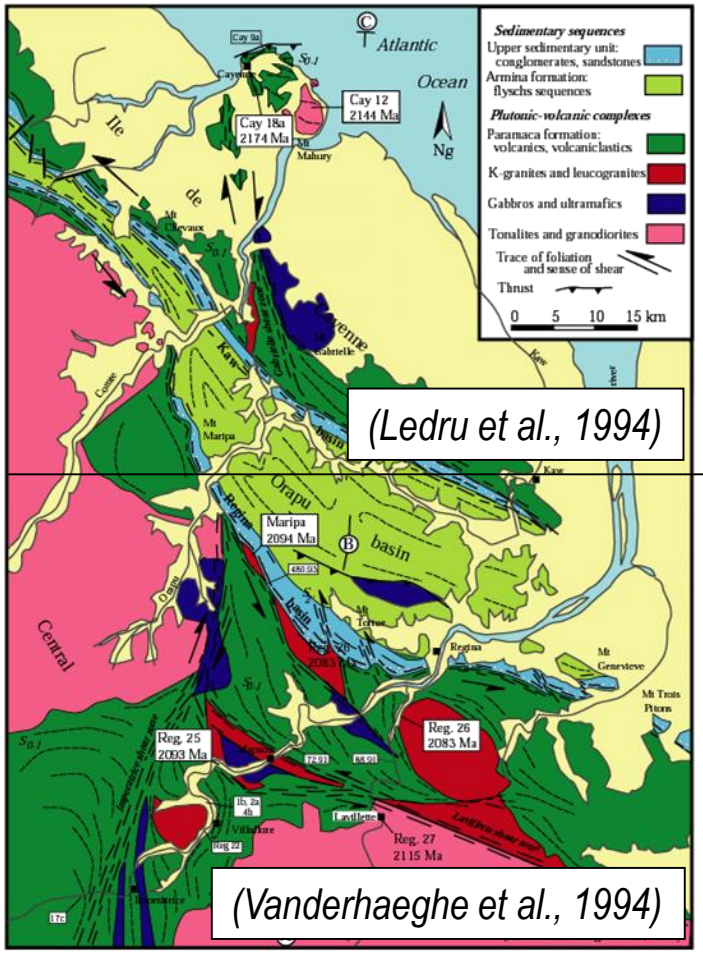
11th Inter Guiana Geological Conference:
The Tectonics & Resource Potential of NE South America

## Personnal context

***1991-1993*** **BRGM Guyane**

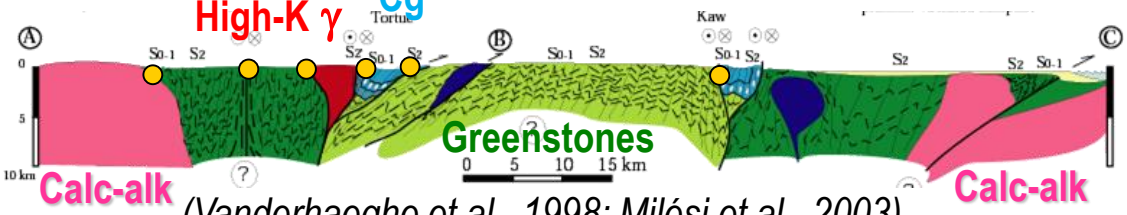
In memory of **Gaston Brugnot**
gone with the secrets of greenstone belts




(Ledru et al., 1994)

(Vanderhaeghe et al., 1994)




(Vanderhaeghe et al., 1998; Milési et al., 2003)

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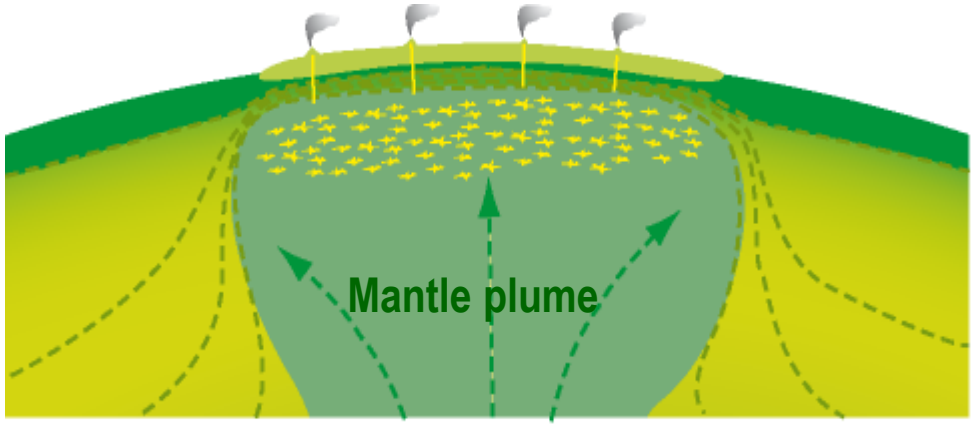
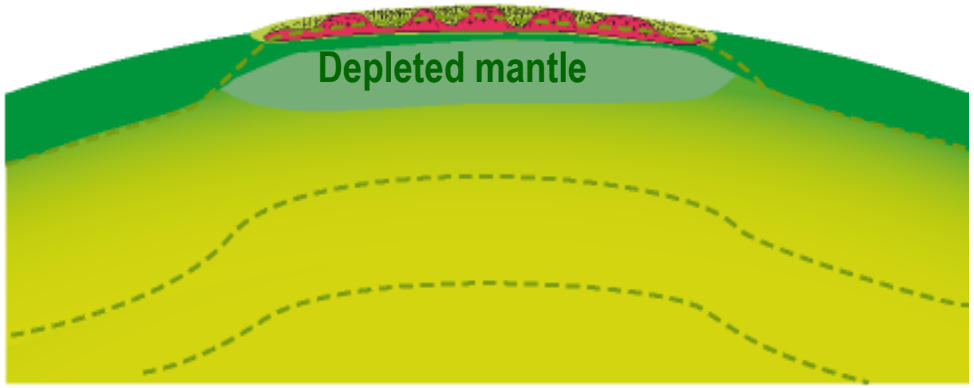
## Geodynamics of lithospheric construction and crustal-growth

### Mantle plume model

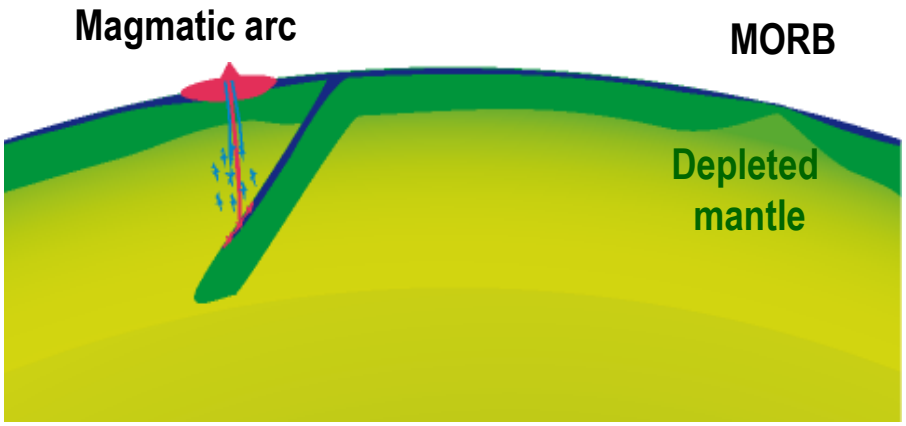
1. Oceanic plateau




2. Granite-Greenstone




### Subduction model



# Gold mineralization:

*a guide for understanding crustal growth-differentiation*

**Vanderhaeghe O.**
**Ledru P.**

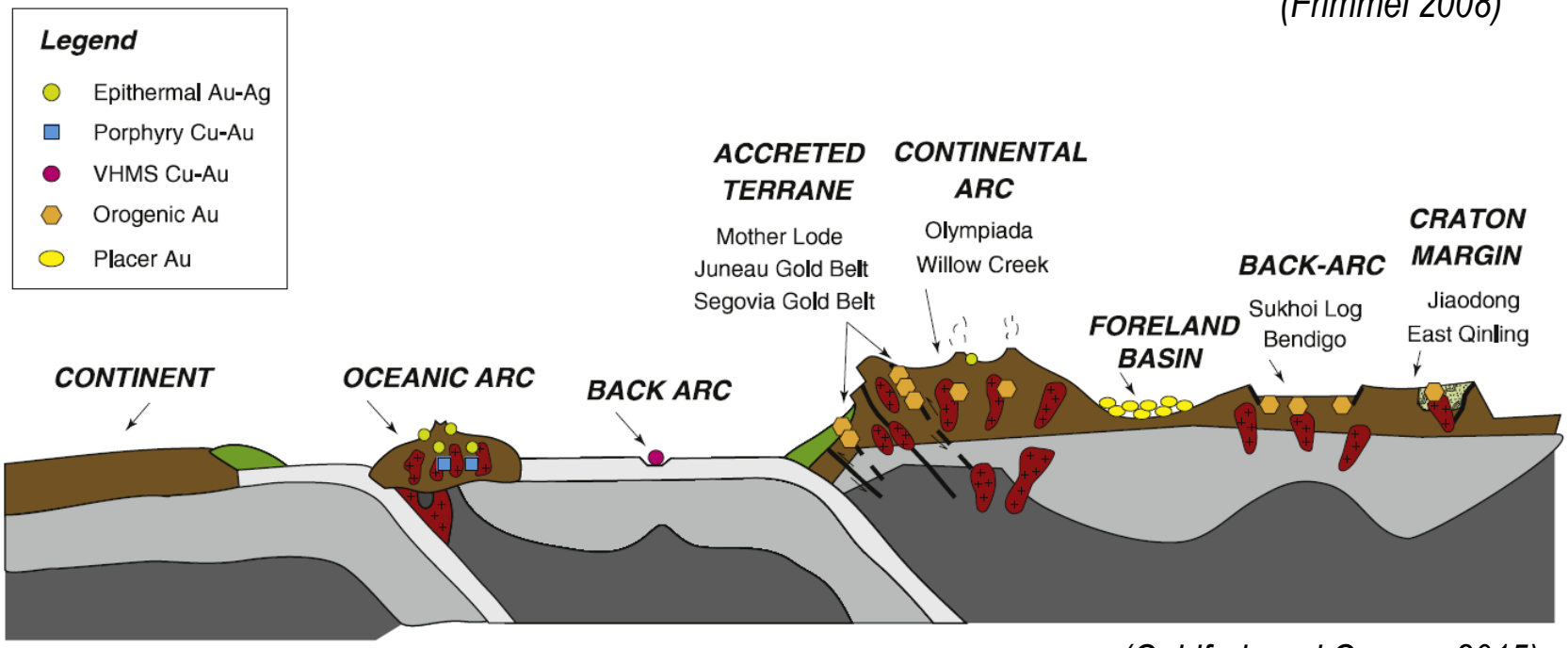
## Gold mineral system

**Gold (Au):**

- Siderophile element with little chemical affinity to oxygen
- Mobile in hydrothermal fluids enriched in sulfur and salt (Cl)
- Concentrates in ultramafic rocks or forms disseminated and/or vein-type ore-bodies
- Traces mantle/crust transfers and fluid generation-migration within the lithosphere

**“Gold was added to the continental crust during a giant Mesoarchaean gold event at 3 Ga”**
**“Gold was remobilized and concentrated during subsequent crustal reworking”**

*(Frimmel 2008)*




*(Goldfarb and Groves, 2015)*

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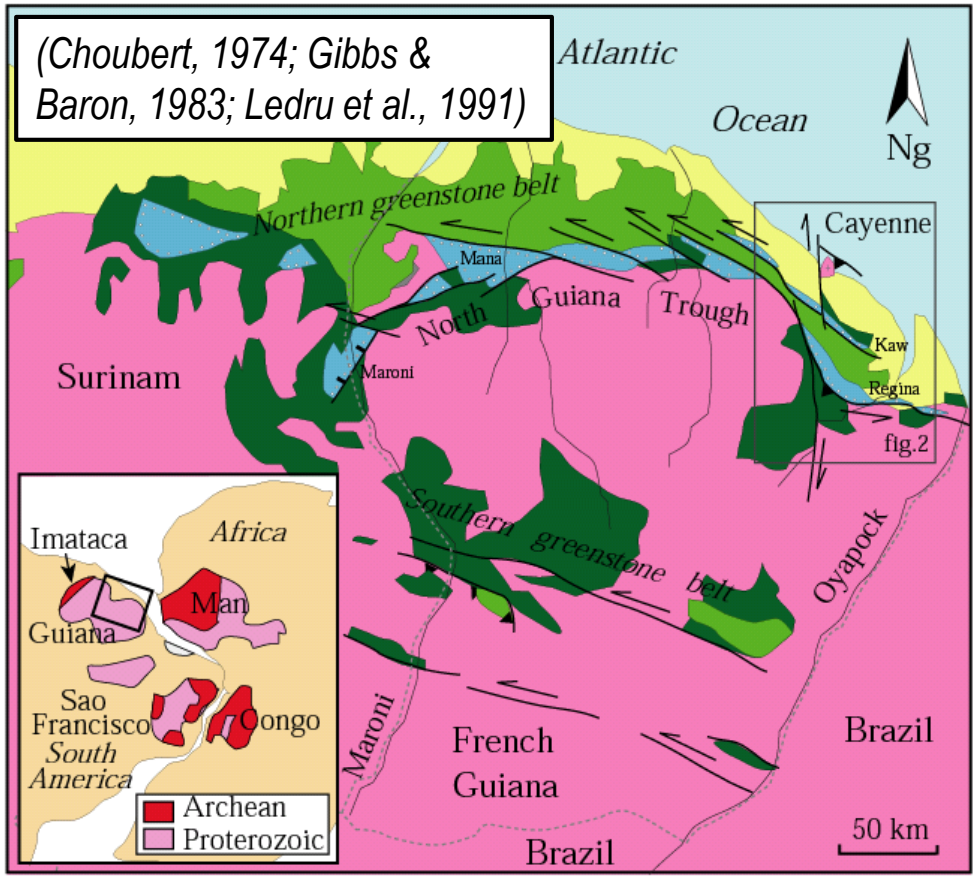
## Geological setting




**Paleoproterozoic sequences**

***Sedimentary sequences***

- Upper Sedimentary Unit conglomerates and sandstones
- Armina formation flyschs sequences

***Plutonic-volcanic complexes***

- Paramaca formation volcanics and volcaniclastics
- Granitoids, gneisses

## Strategy

**Source of magmatic rocks?**
- Mantle (depleted or enriched)
- Crust (mafics, felsic, sediments, …)

**Context of melting?**
- Plume (plateau)
- Subduction
- Orogenic belt

**Significance of deformation?**
- Plate kinematics
- Pluton emplacement
- Gravity-driven flow

**Significance of metamorphism?**
- Burial, exhumation
- Contact metamorphism

**Sedimentation/erosion?**

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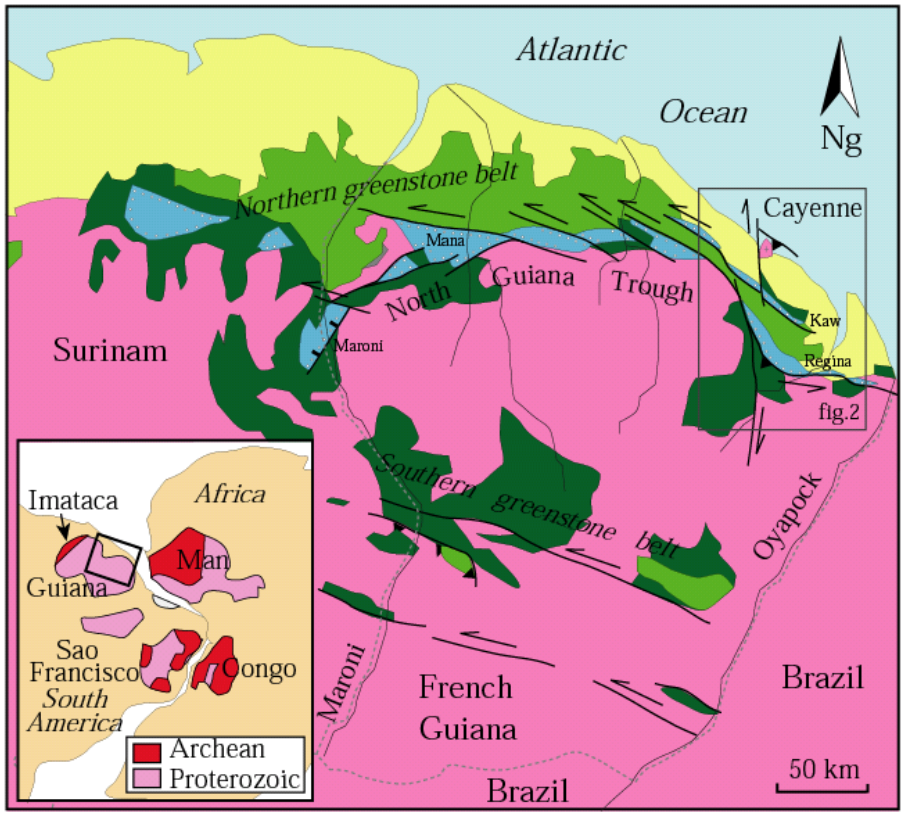
**Ledru P.**
*(Vanderhaeghe et al., 1998)*

## Geological setting

- Domes, plutons, belts, shear zones
- Gold mineralizations

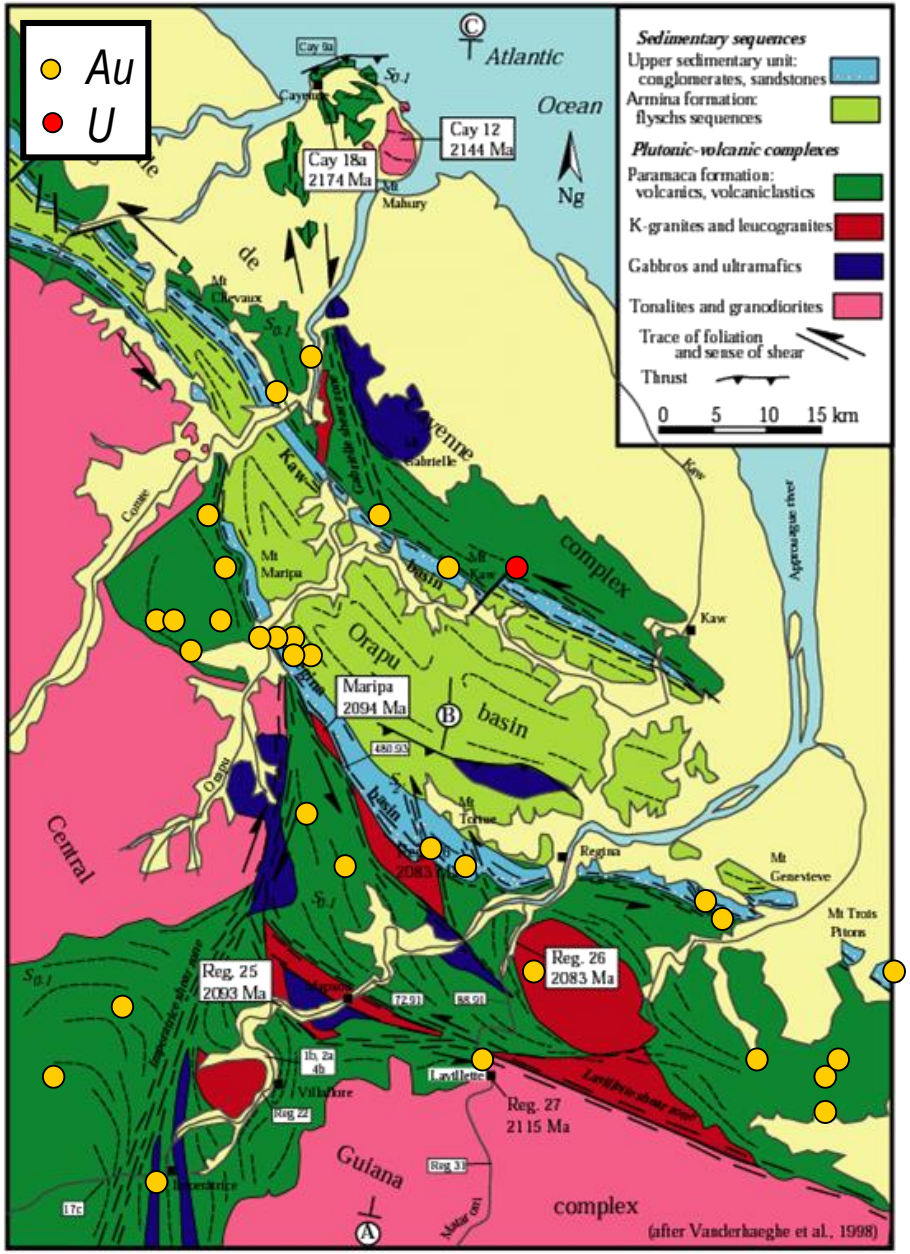



**Neoproterozoic juvenile contribution**

*(Gruau et al., 1985)*

$\varepsilon_{Nd}$ : +2.1±1.8

**Sm–Nd isochron 2.11±0.09 Ga**



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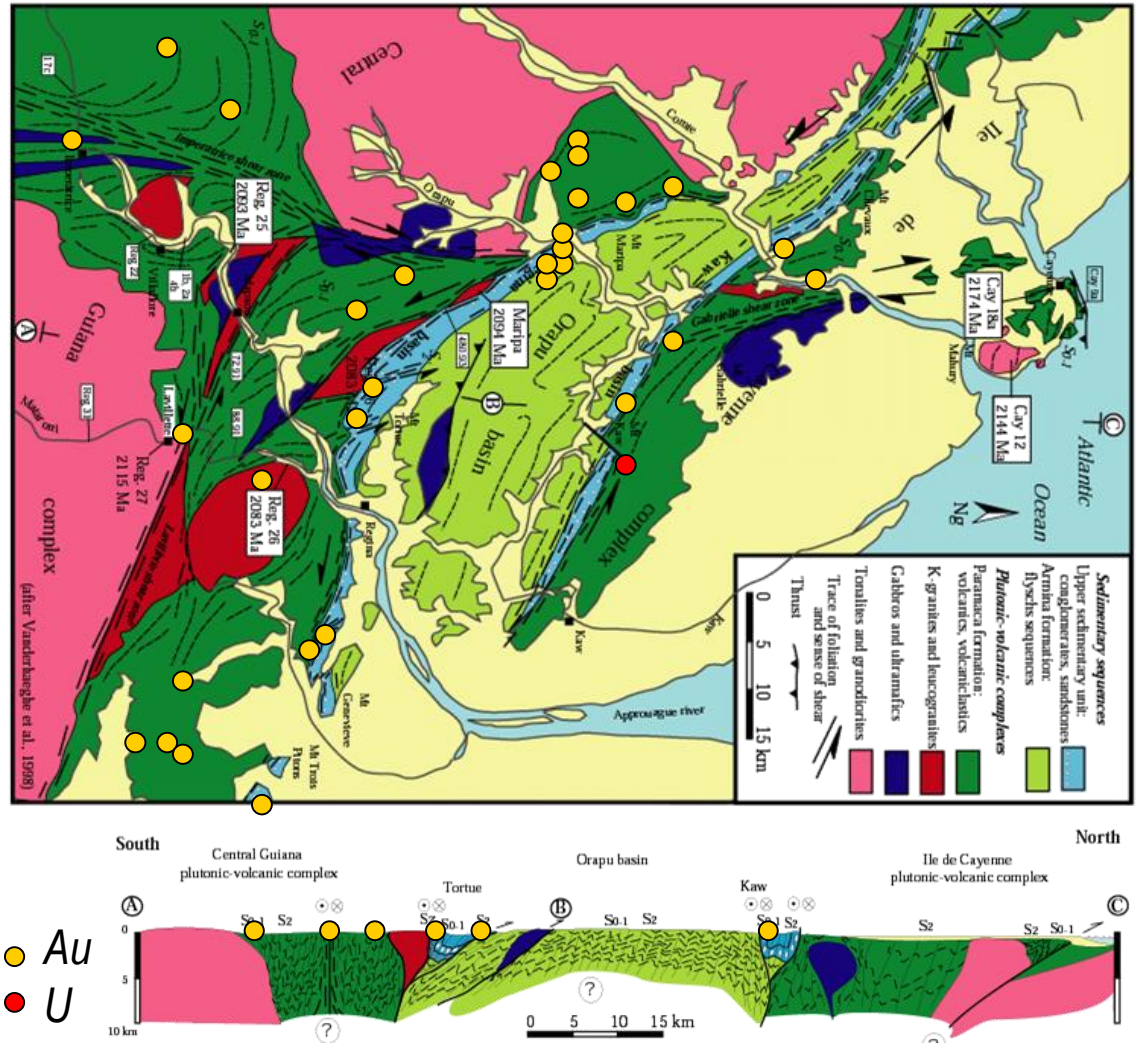
## Geological setting



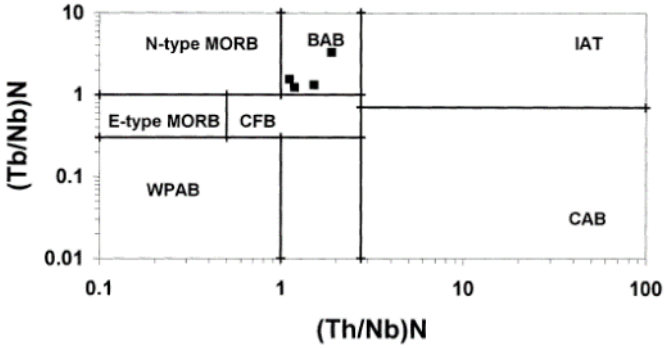


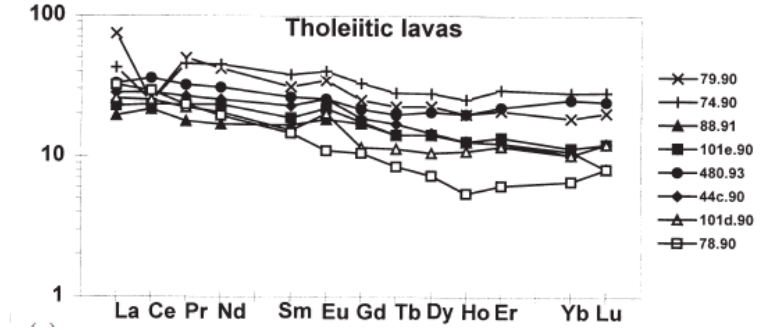


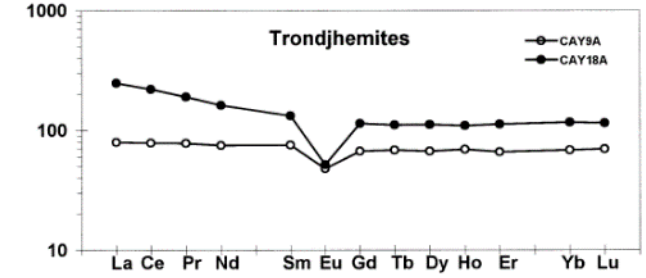
- *Au*
- *U*

*(Vanderhaeghe et al., 1998; Milési et al., 2003)*

## Metavolcanics (Paramaca)




- **Tholeitic magmatism**

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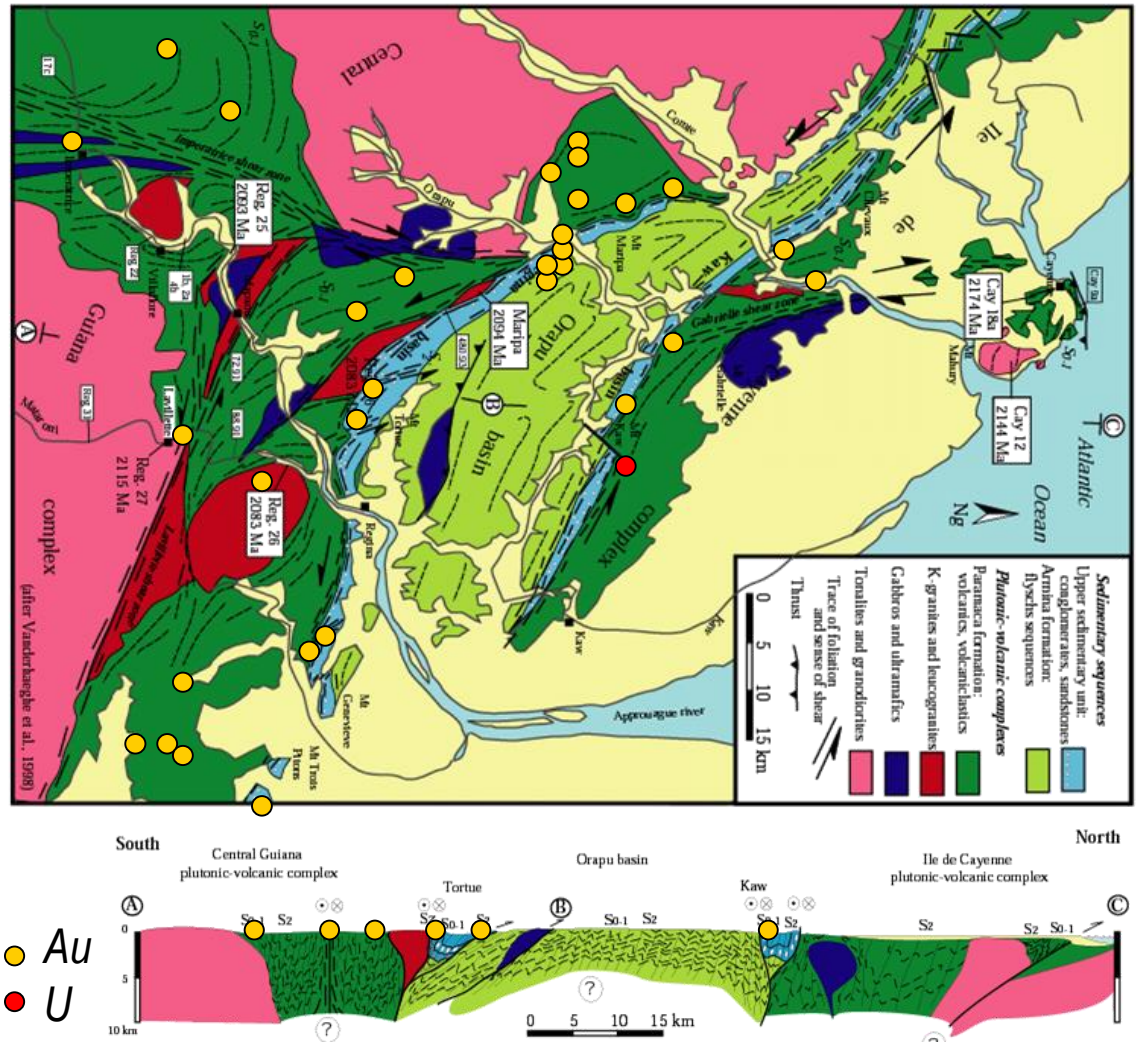


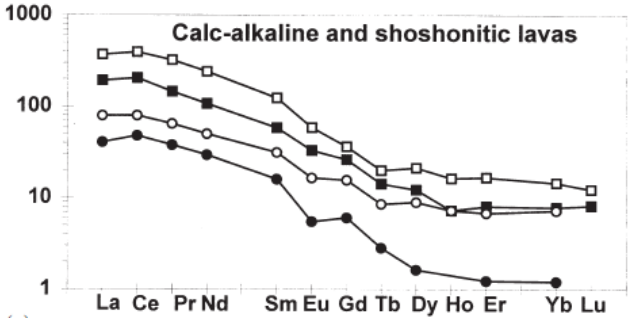


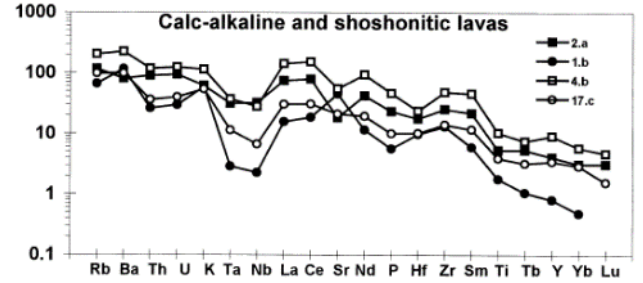


- Au
- U

*(Vanderhaeghe et al., 1998; Milési et al., 2003)*

## Metavolcanics (Paramaca)




- **Calc-alkaline magmatism**

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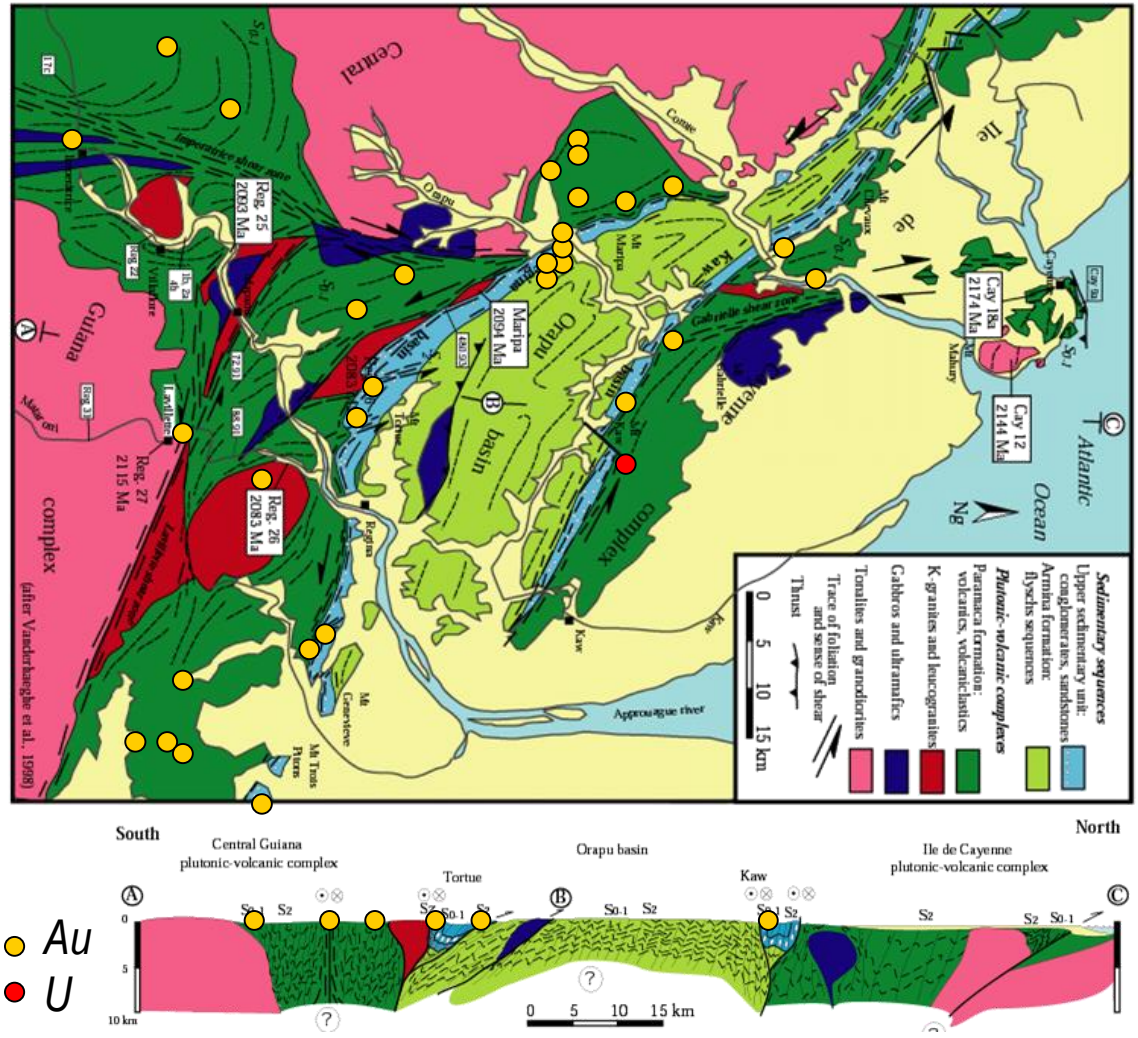
## Geological setting



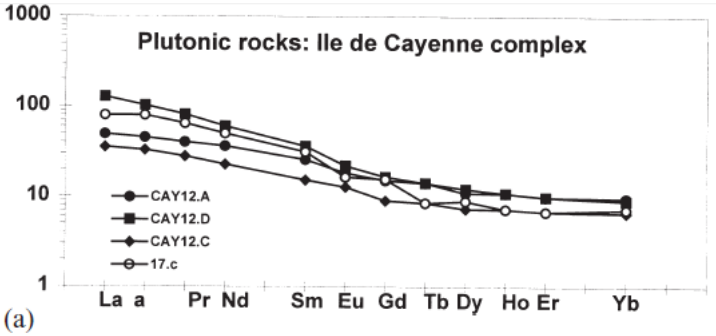


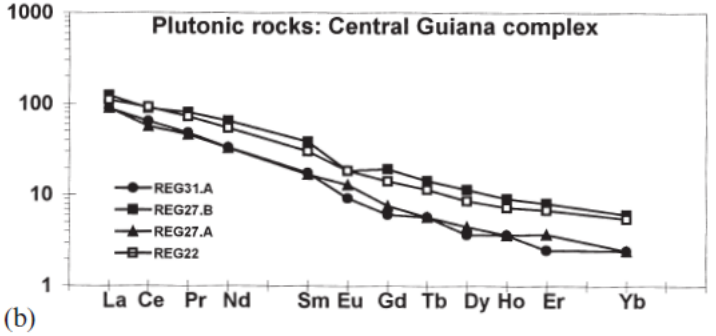


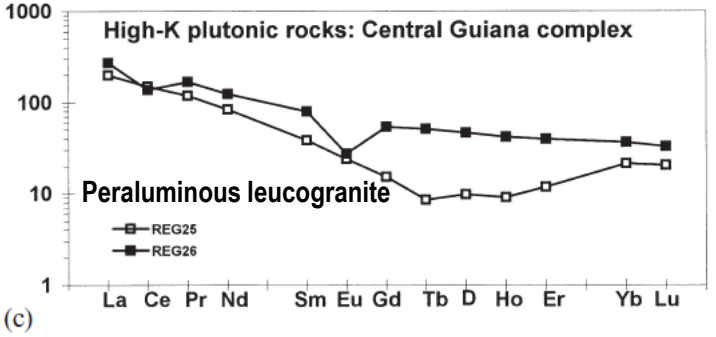
- Au
- U

*(Vanderhaeghe et al., 1998; Milési et al., 2003)*

## Plutonics (Ile de Cayenne, Central Guiana)




- **Calc-alkaline, high-K and peraluminous magmatism**

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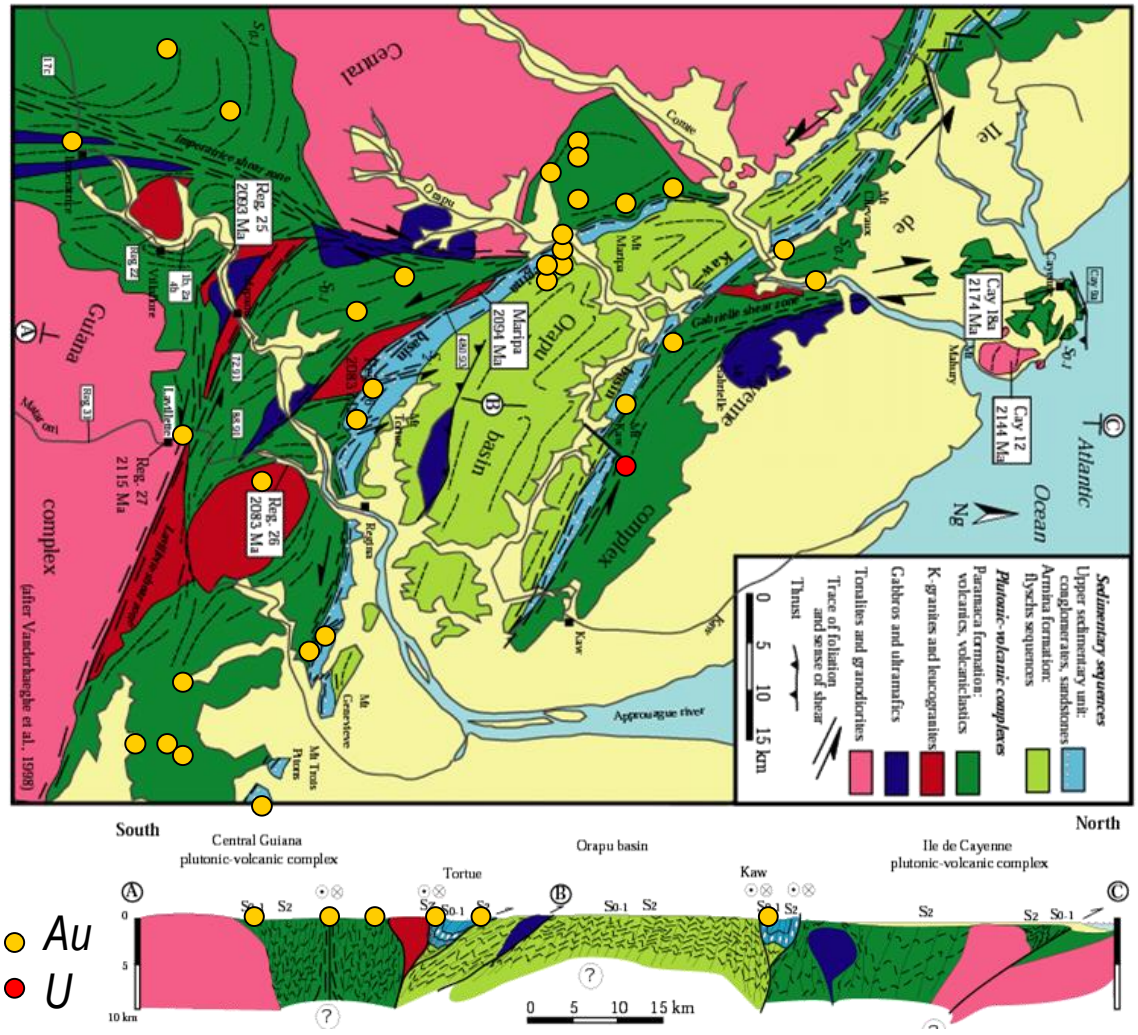
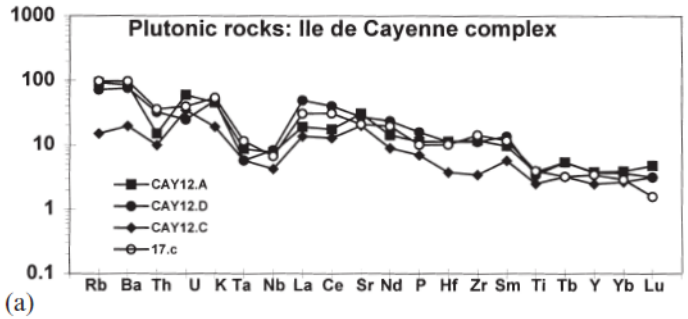
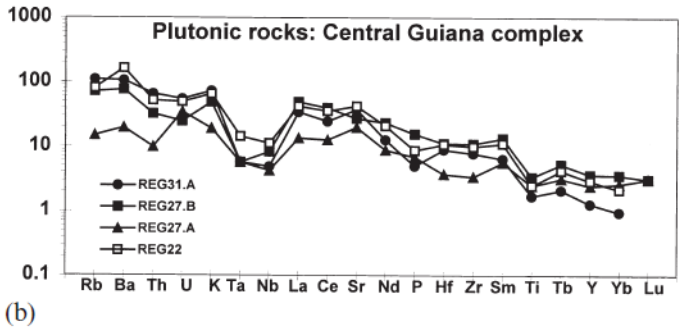
## Geological setting

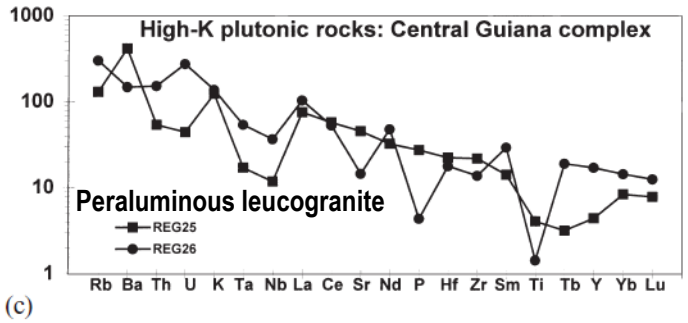



*(Vanderhaeghe et al., 1998; Milési et al., 2003)*

## Plutonics (Ile de Cayenne, Central Guiana)




- **Calc-alkaline, high-K and peraluminous magmatism**

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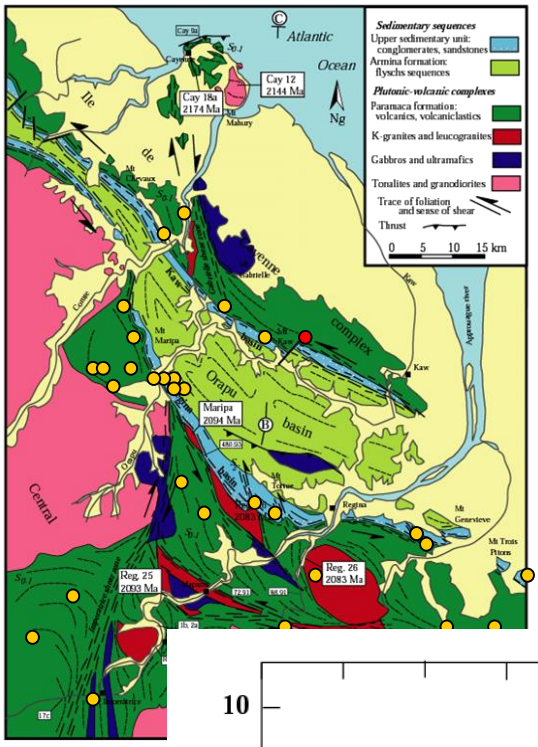
*(Vanderhaeghe et al., 1998; Milési et al., 2003)*

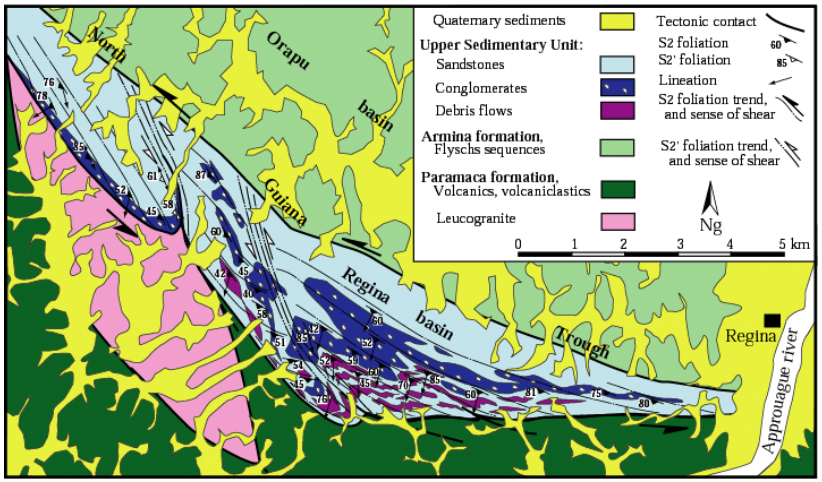
## Geological setting



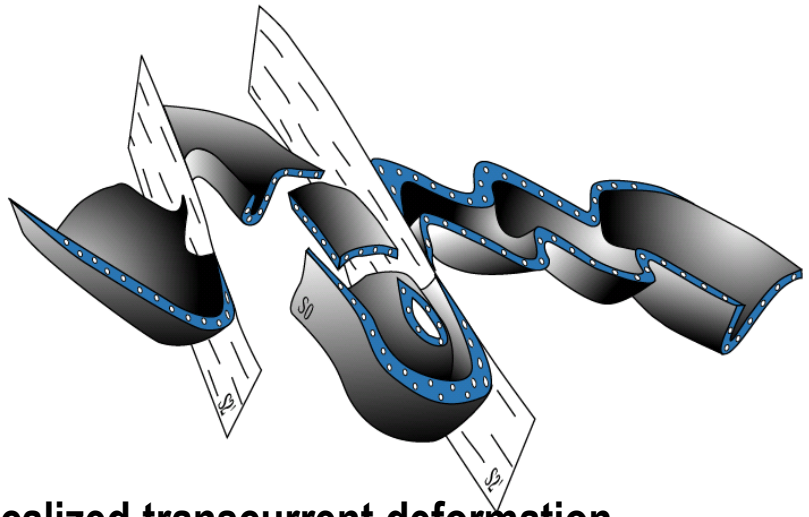

- *Au*
- *U*

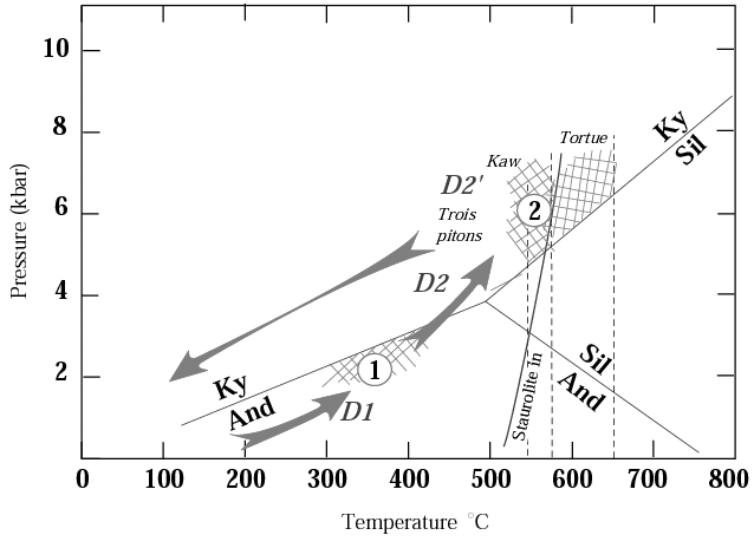
### D1:

- **Domes cored by plutonic rocks**
- **Pervasive deformation of the greenstone belts**
- **HT/LP metamorphism**




Style of folding of the bedding plane in the Tortue area.




### D2:

- **Localized transcurrent deformation**
- **Pull-apart basins**
- **HT metamorphism**

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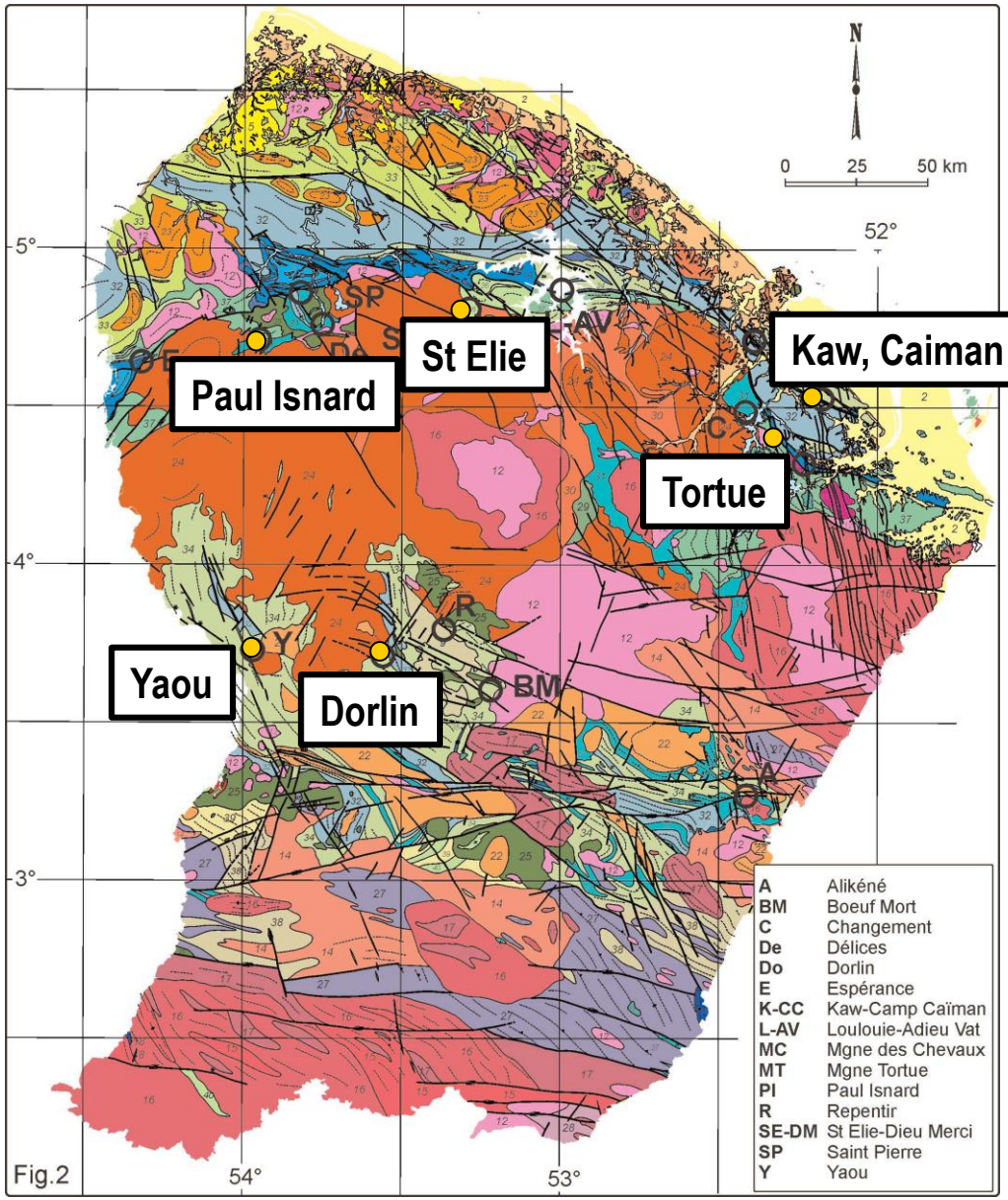

Fig.2

## Gold mineralizations

### Reworked paleoplacers

**Montagne Tortue:**
Paleoplacers, monogenic-polygenic conglomerates
Au mesothermal veins

**Montagne de Kaw:**
Syn-D2 mesothermal veins

### Hydrothermal shear zones

**Saint Elie :**
Au mesothermal veins
6t @ 4.2 g/t

**Paul Isnard :**
Au mesothermal veins
46t @ 2.5 g/t

### Reworked volcanic-hydrothermal Au

**Dorlin :**
Au stratiform, mesothermal veins
11t @ 1.3 g/t

**Yaou :**
Au stratabound, mesothermal veins, syn-$D_2$ $\gamma$
24t @ 2.2 g/t

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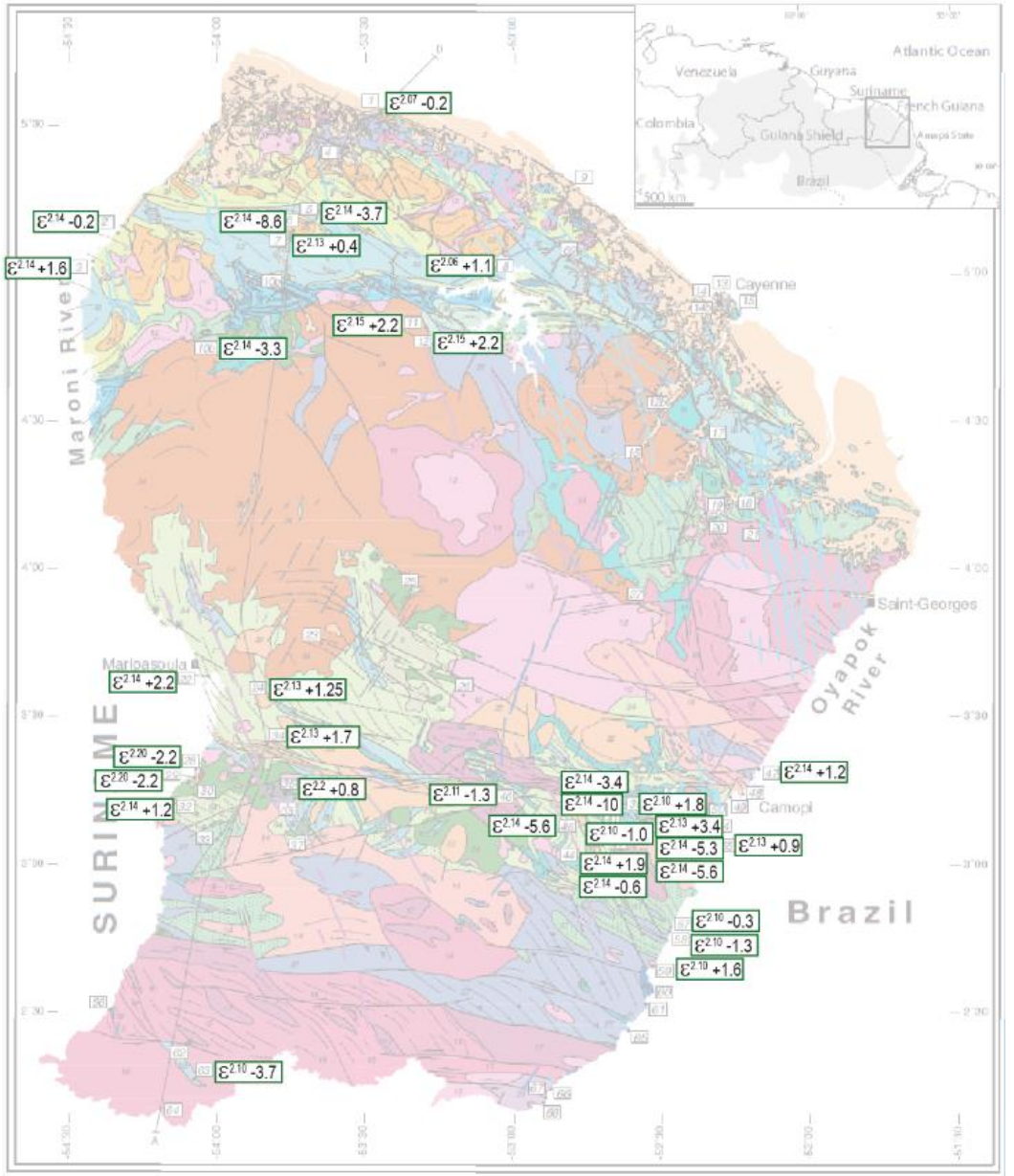
## Geochronological data

$\varepsilon_{Nd}$:

- + for most rocks
- - for few detrital & inherited cores

⇨ Dominant input of juvenile rocks

Needs Lu-Hf datas on zircon!



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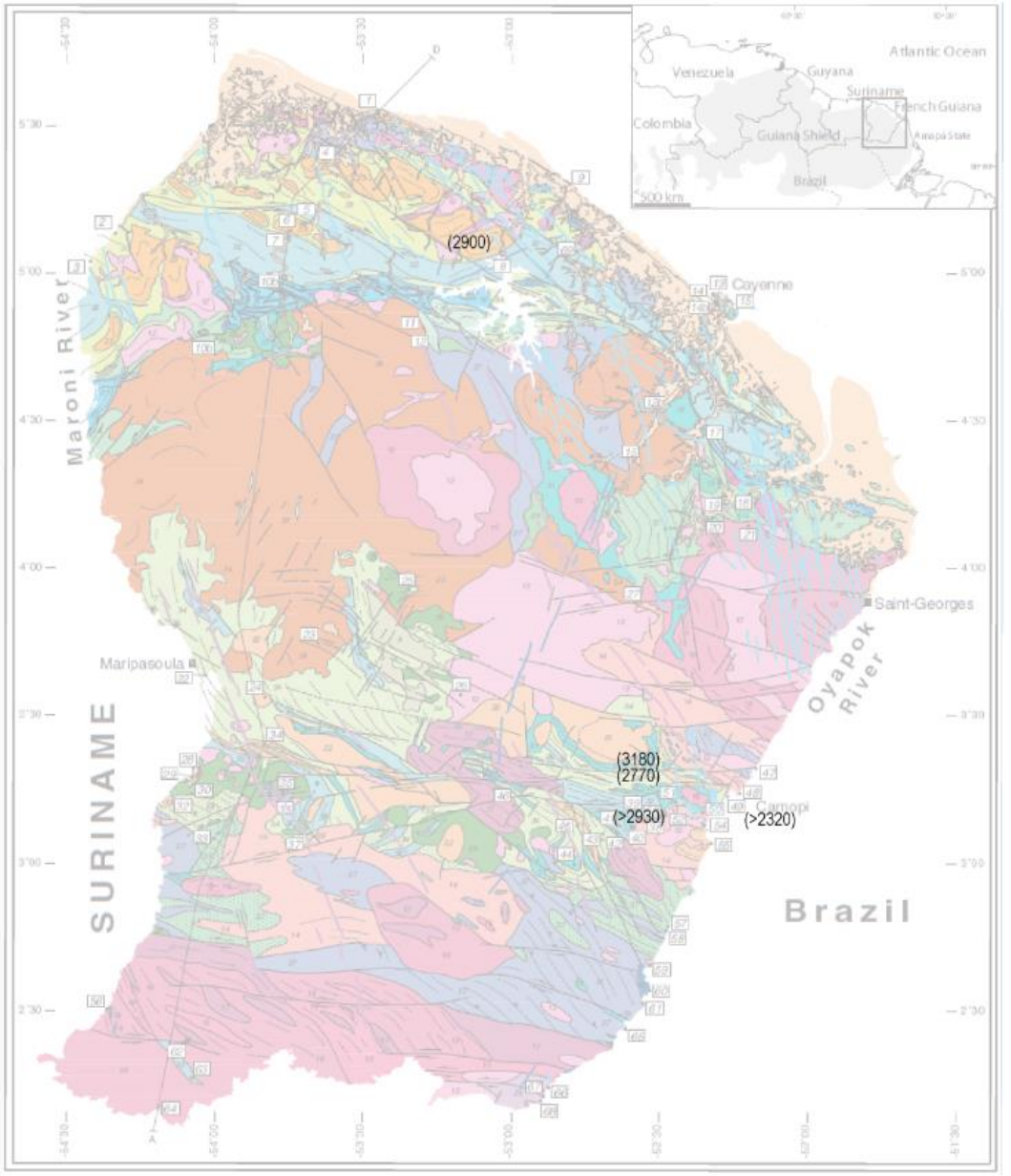
## Geochronological data

**U-Pb > 2.6 Ga**

- **Inherited cores**

**⇨Little input of Archean rocks**

**Needs careful in situ dating!**



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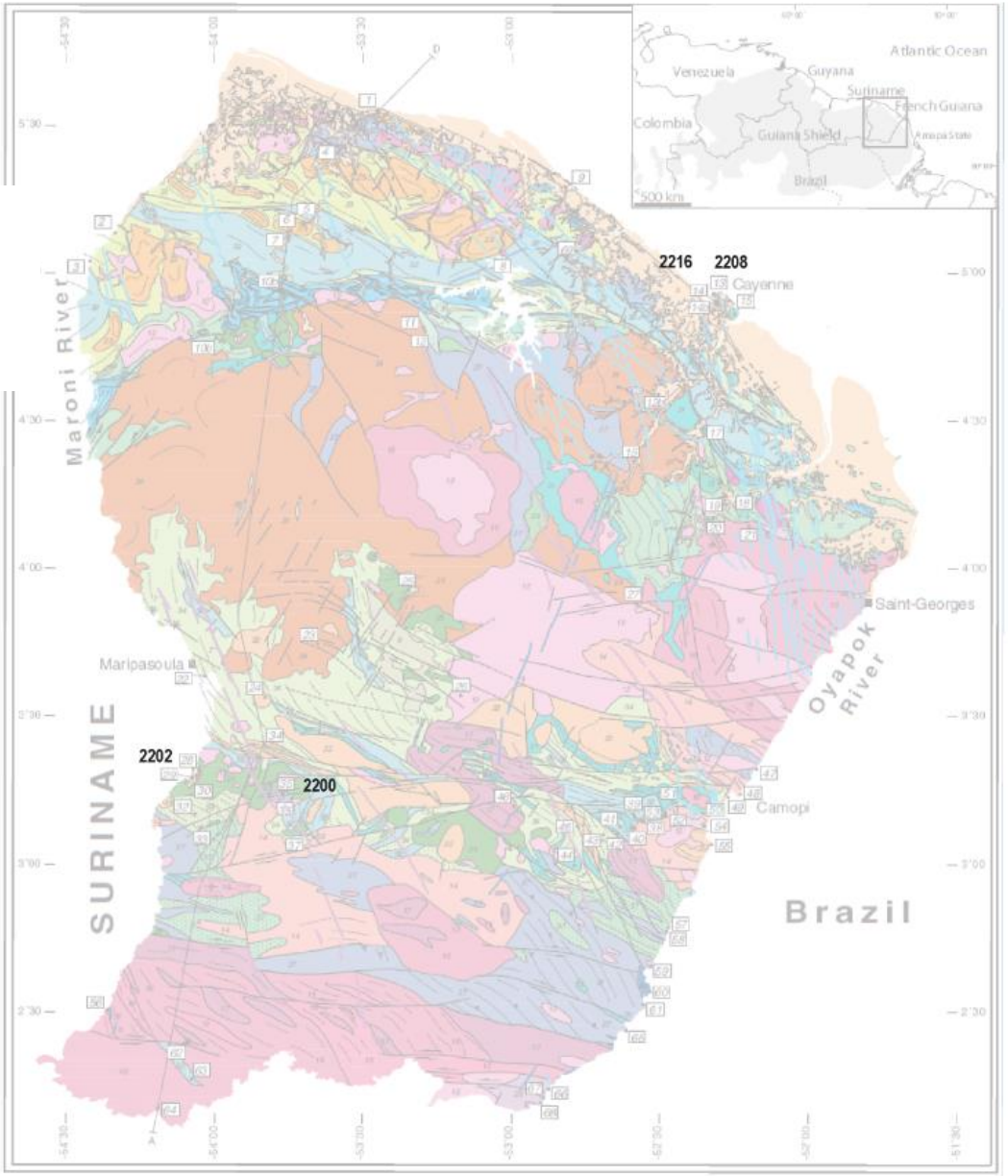
## Geochronological data

**U-Pb 2.22-2.20 Ga**

- **Tholeitic trondjhemites**

**⇨ One or several oceans?**

**Needs more data!**



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## Geochronological data

**U-Pb 2.18-2.12 Ga**

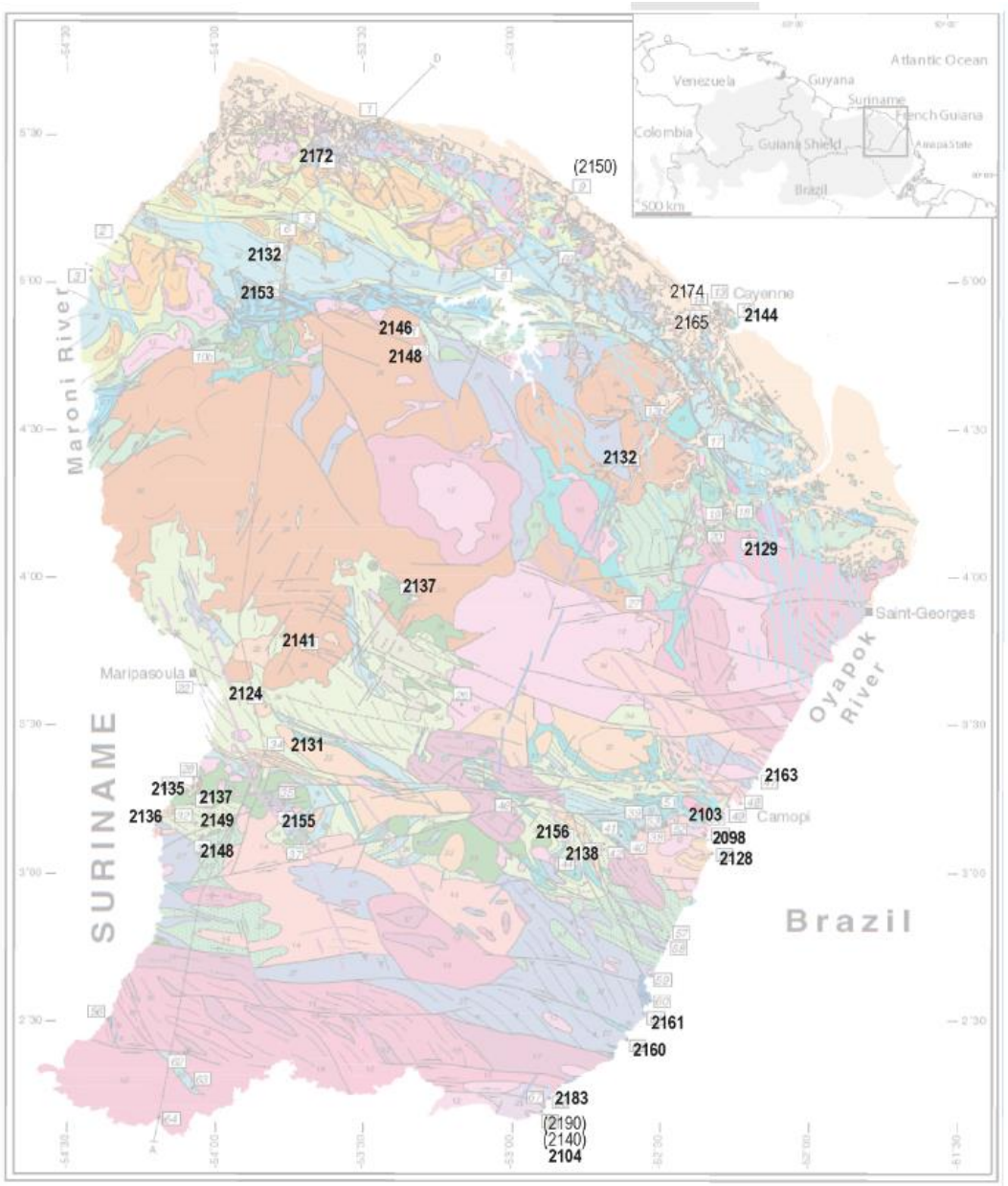
- **Calc-alkaline plutonics-metavolc.**

⇨ **Widespread magmatism?**

⇨ **Partial melting of mafics?**

⇨ **Partial melting of enriched mantle?**

**Needs combined isotopic tracing and in situ geochronological dating!**



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## Geochronological data

**U-Pb 2.11-2.08 Ga**

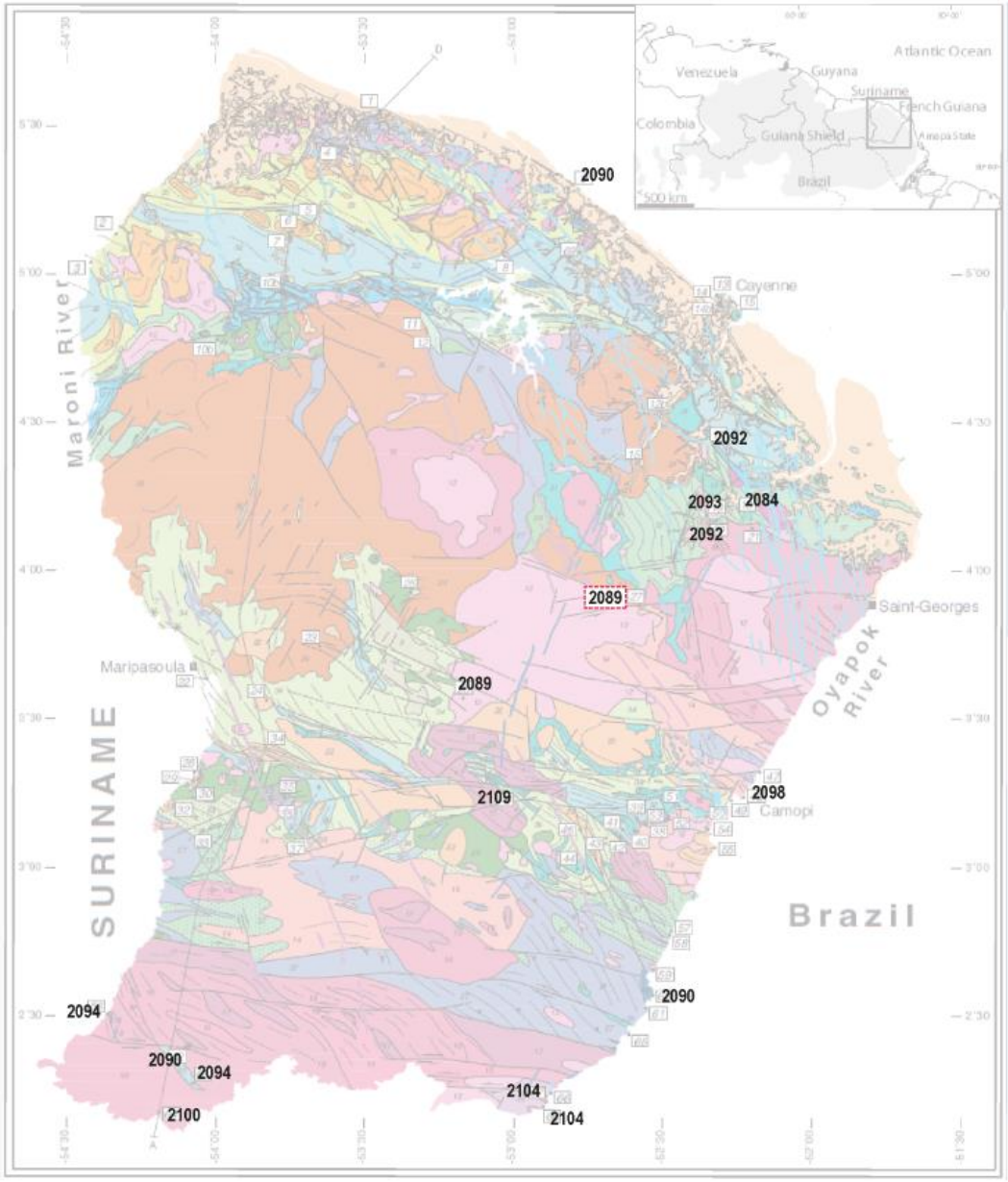
- **High-K granites**

⇨ **Widespread magmatism**

⇨ **Partial melting of mafics?**

⇨ **Partial melting of enriched mantle?**

**Needs combined isotopic tracing and in situ geochronological dating!**



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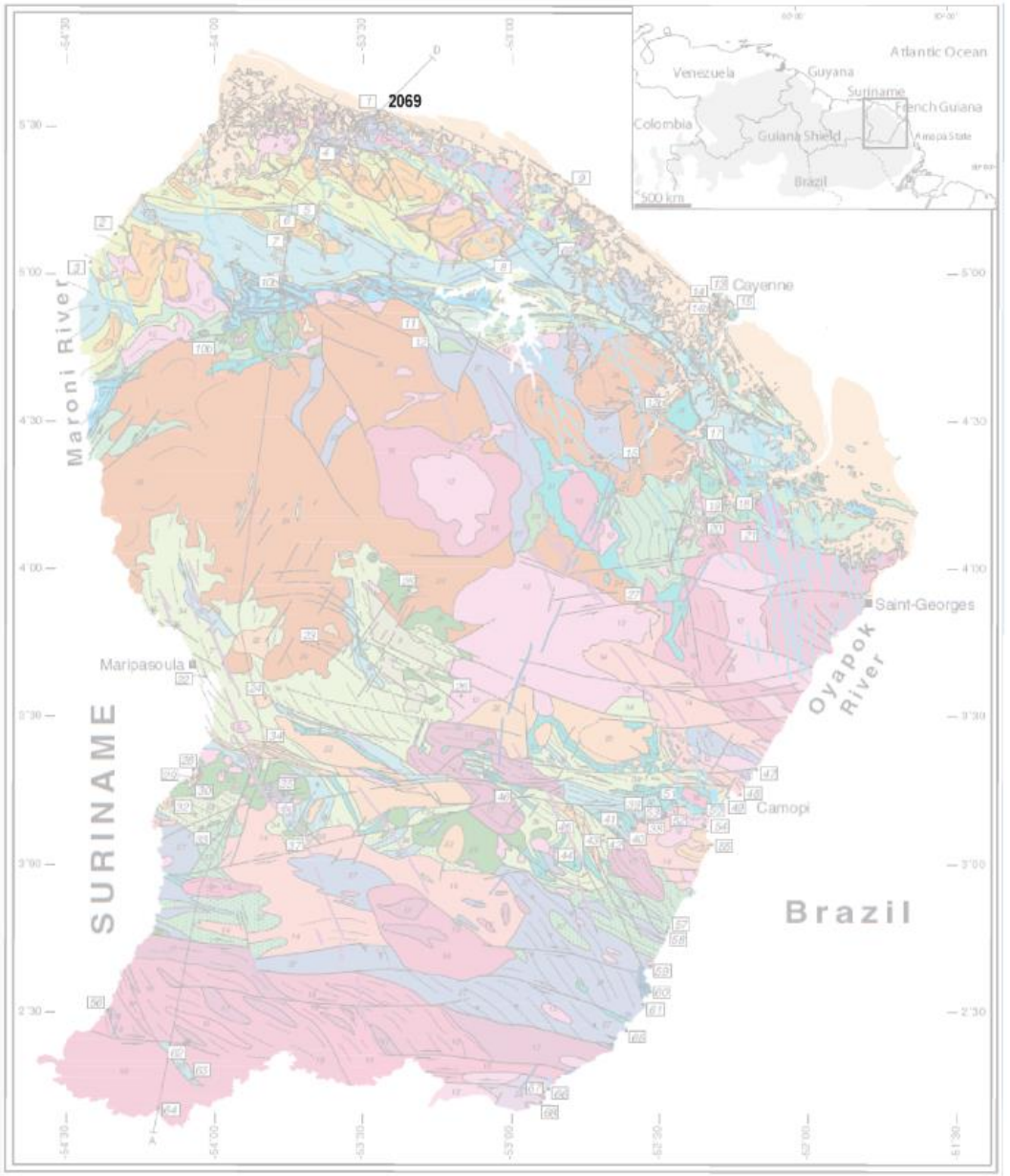
## Geochronological data

**U-Pb ~2.07 Ga**

- **Peraluminous granites**

⇨ **Partial melting of metasediments?**

**Needs more data!**



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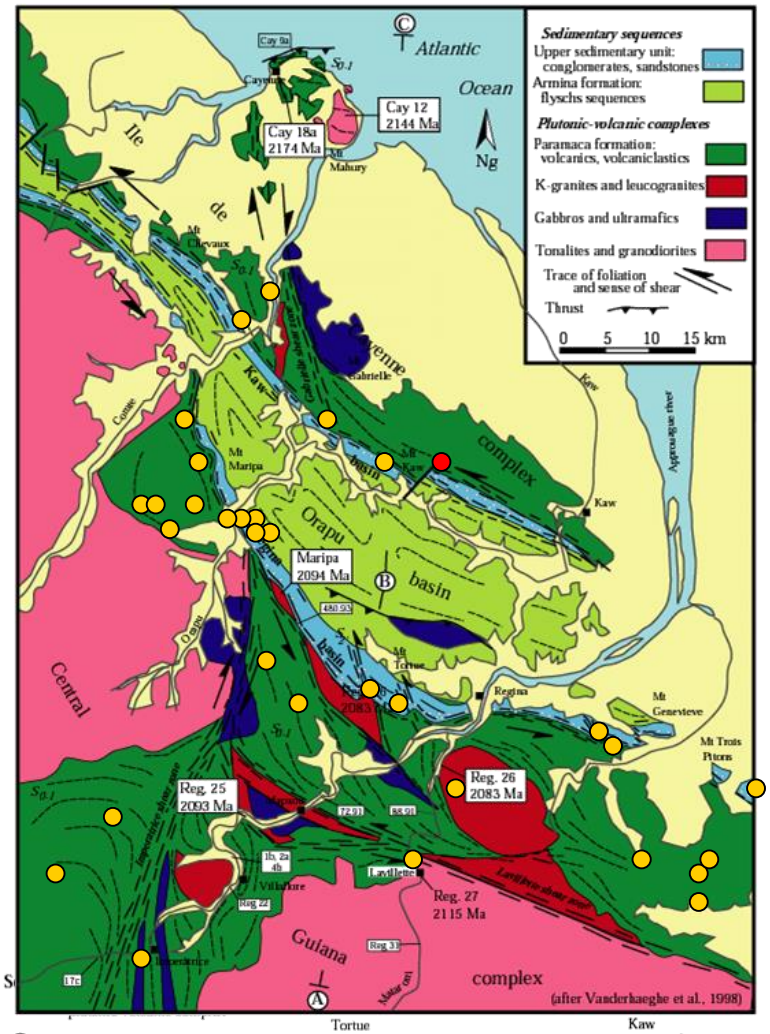
## Tectonics-geodynamics

*(Vanderhaeghe et al., 1998; Milési et al., 2003)*

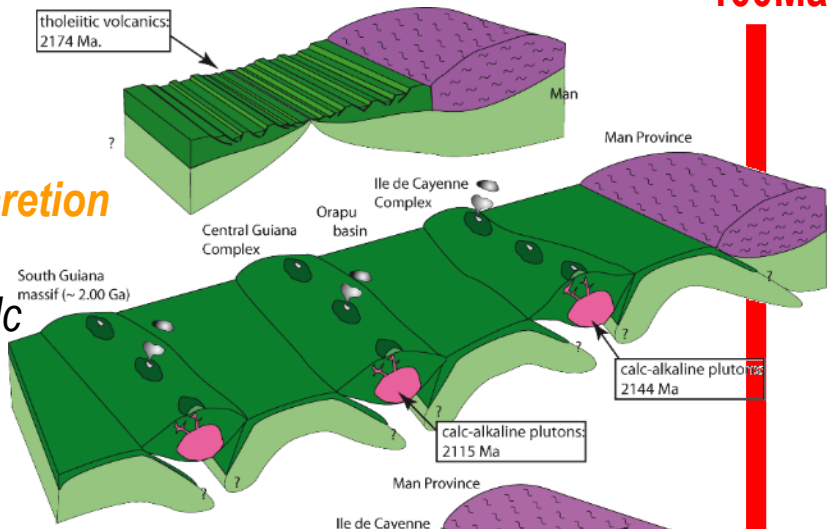
**150km**
**~100Ma**




- *Au*
- *U*

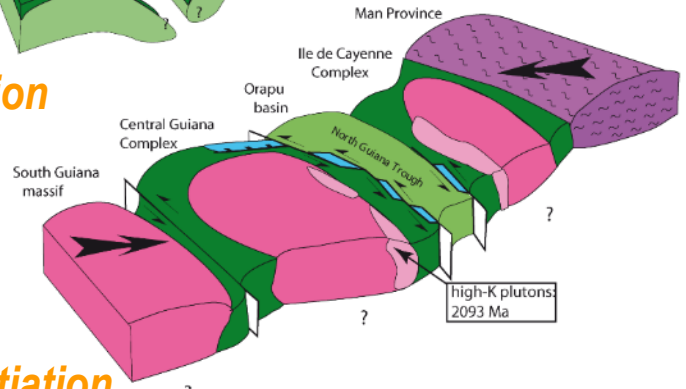
### 1. Magmatic accretion

- *Tholeites volc.*
- *Calc-alk plut-volc*



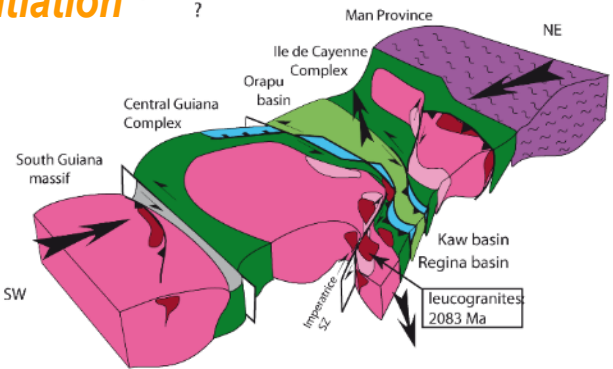

### 2. Tectonic accretion

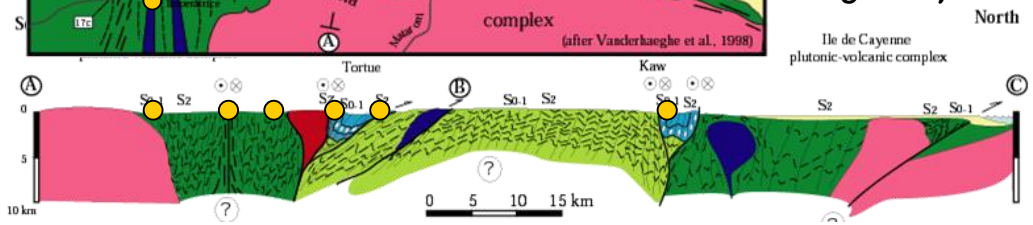
- *strike-slip SZ*
- *Horizontal L*




### 3. Crustal differentiation

- *S-type $\gamma$*
- *high-K $\gamma$ ?*



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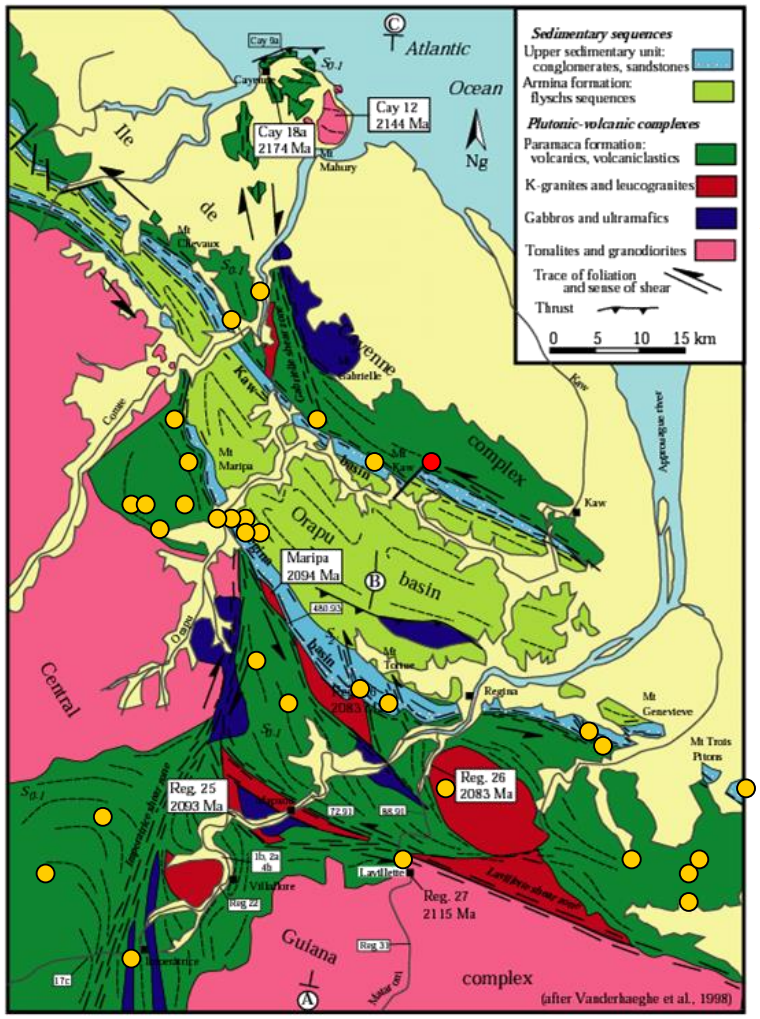
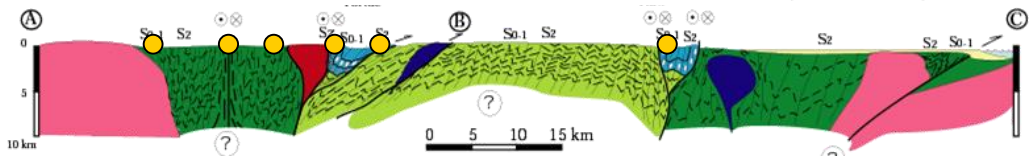
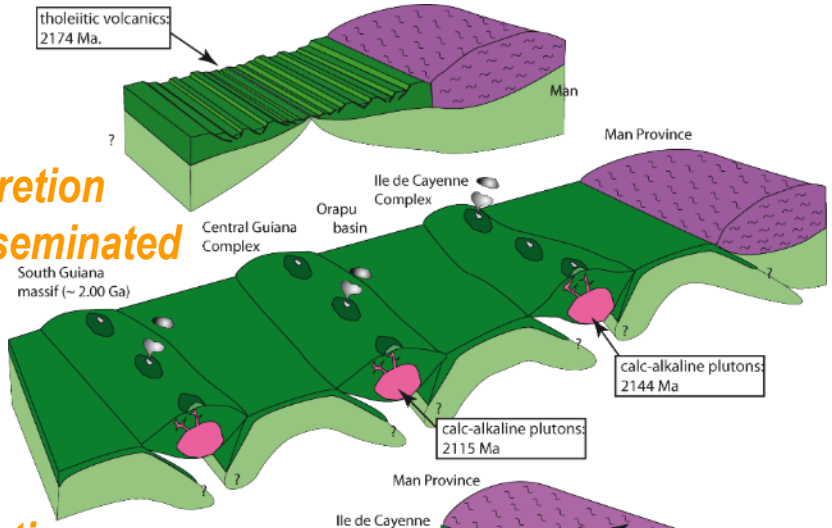
*(Vanderhaeghe et al., 1998; Milési et al., 2003)*

## Tectonics-geodynamics

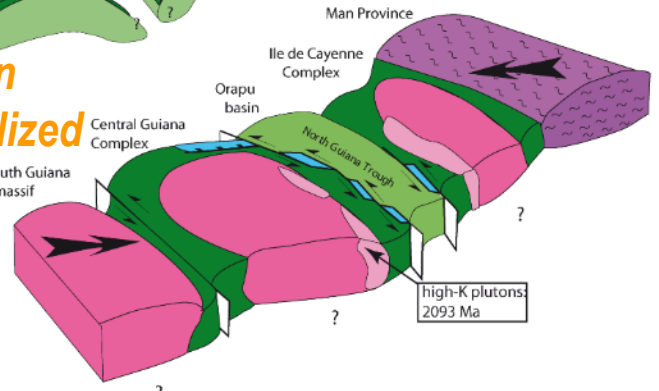


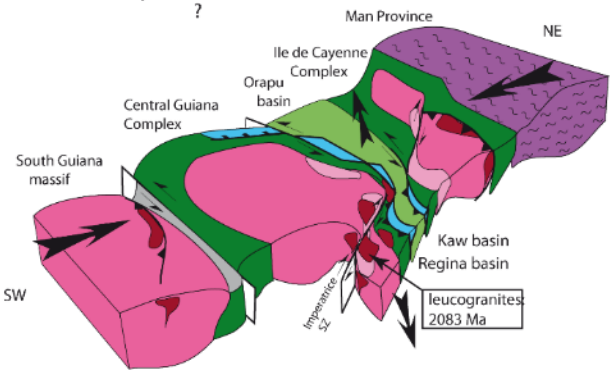

**1. Magmatic accretion**
**Au deposits disseminated**
- *Hydrothermal*




**2. Tectonic accretion**
**Au deposits remobilized**
- *Paleoplacers*
- *Hydrothermal veins*
- *Shear zones*




- *Au*
- *U*



# Paleoproterozoic crustal growth and differentiation :

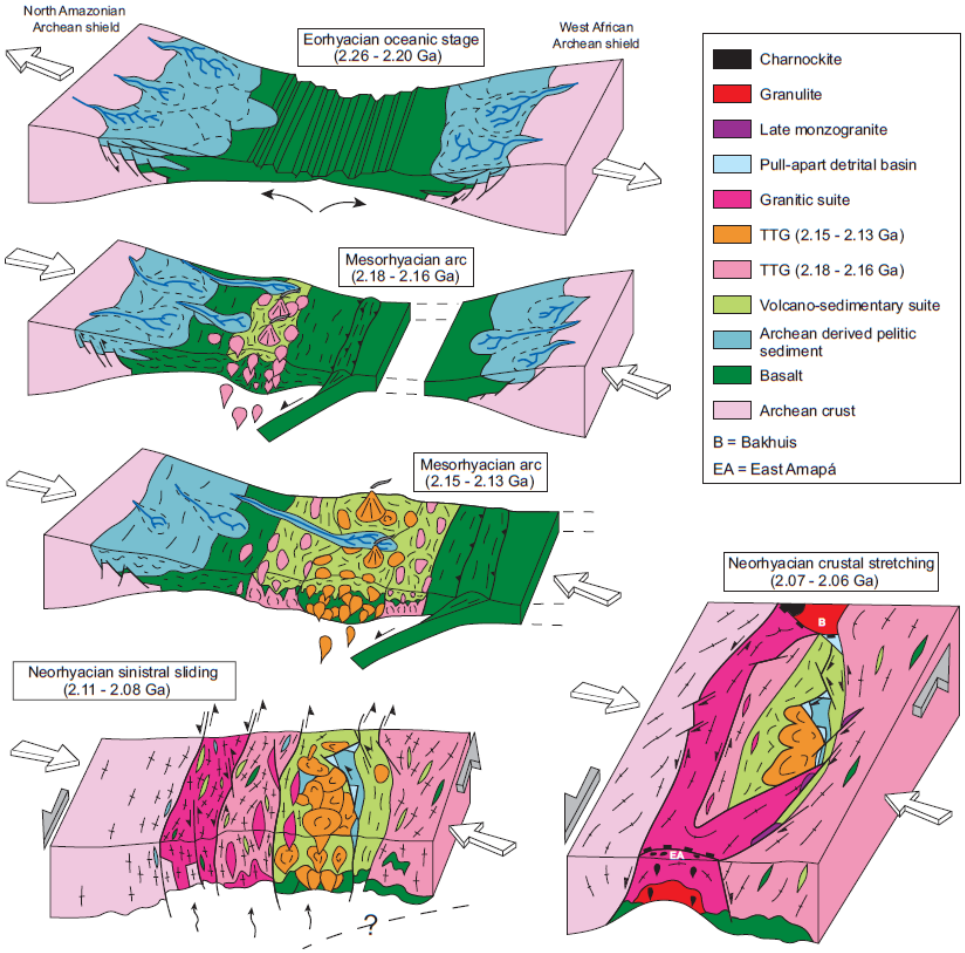
*a guide for understanding Au mineral system*

Vanderhaeghe O.
Ledru P.

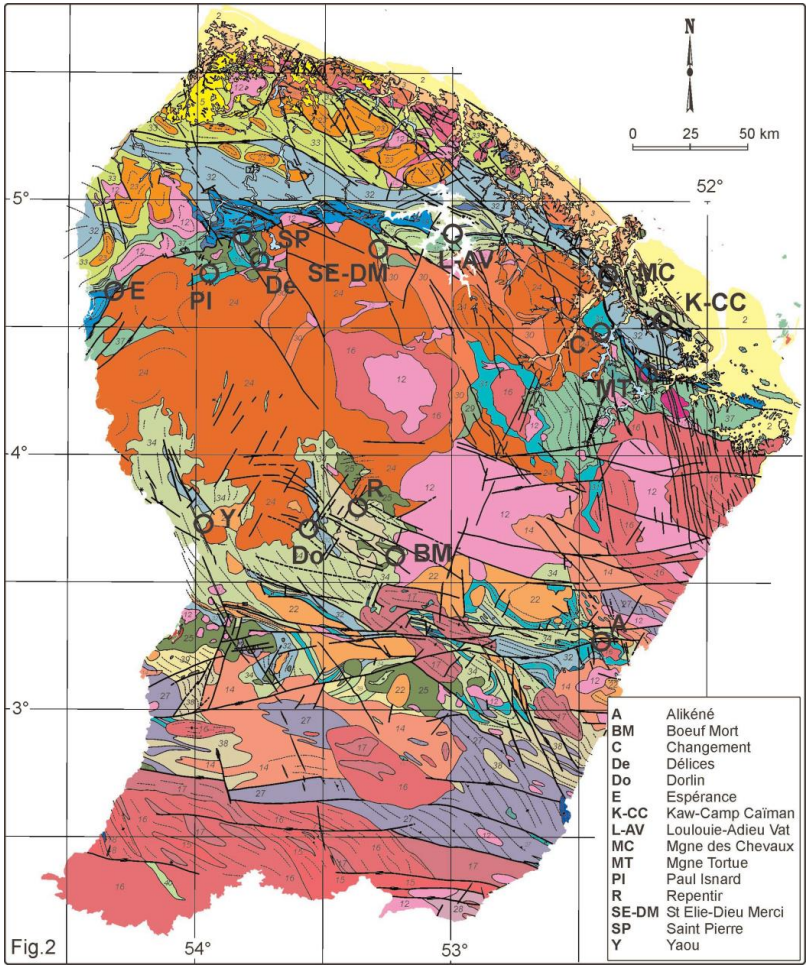
## Tectonics-geodynamics

### Generalization of the model to French Guiana

*(Delor et al., 2003)*




300km
~120Ma



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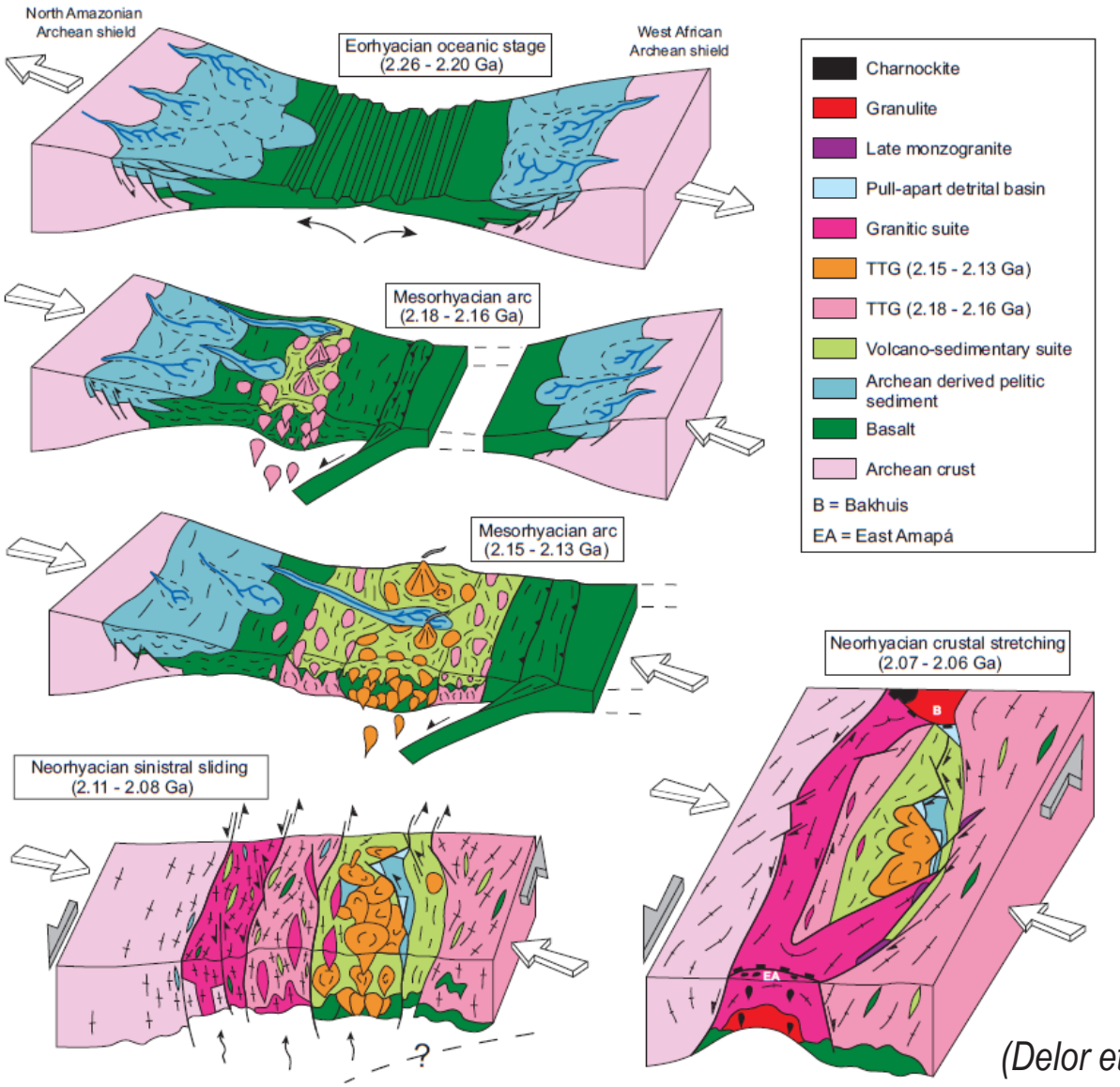
**Ledru P.**

## Tectonics-geodynamics




*(Delor et al., 2003)*

**~300km**
**~120 Ma**

1. **Tholeites :** depleted mantle
2. **Calc-alc:** amphibolites pm
3. **High-K :** enriched mantle and/or mafic crust
4. **Peraluminous:** metasediments

**► A single differentation trend!**

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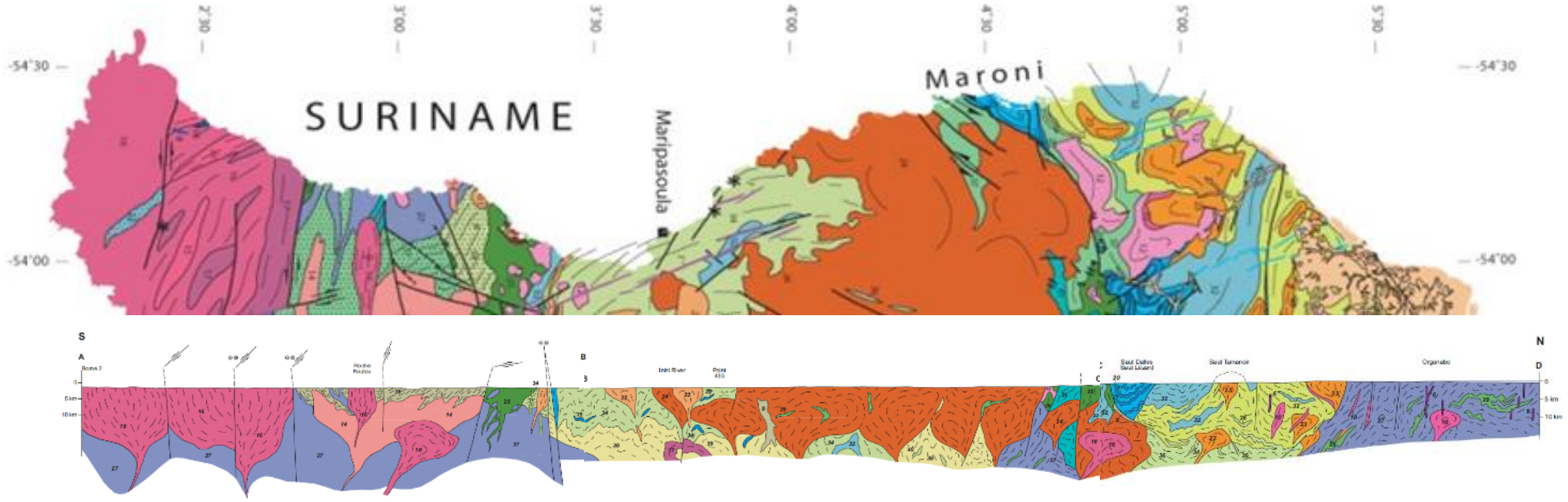
## Debated issues

- **Greenstone belts : single ocean or mutiple sutures-arcs?**
- **Calc-alkaline, high-K, peraluminous magmatic complexes?**
- **HT/LP metamorphism (no HP/LT?): tectonic-thermal context?**
- **Relationships between greenstones, plutonics and migmatitic gneisses?**
- **Nature of the lower crust and of the subcontinental lithosphere?**
- **Mineral systems, source of metals and of mineralizing fluids?**

*(Delor et al., 2003)*



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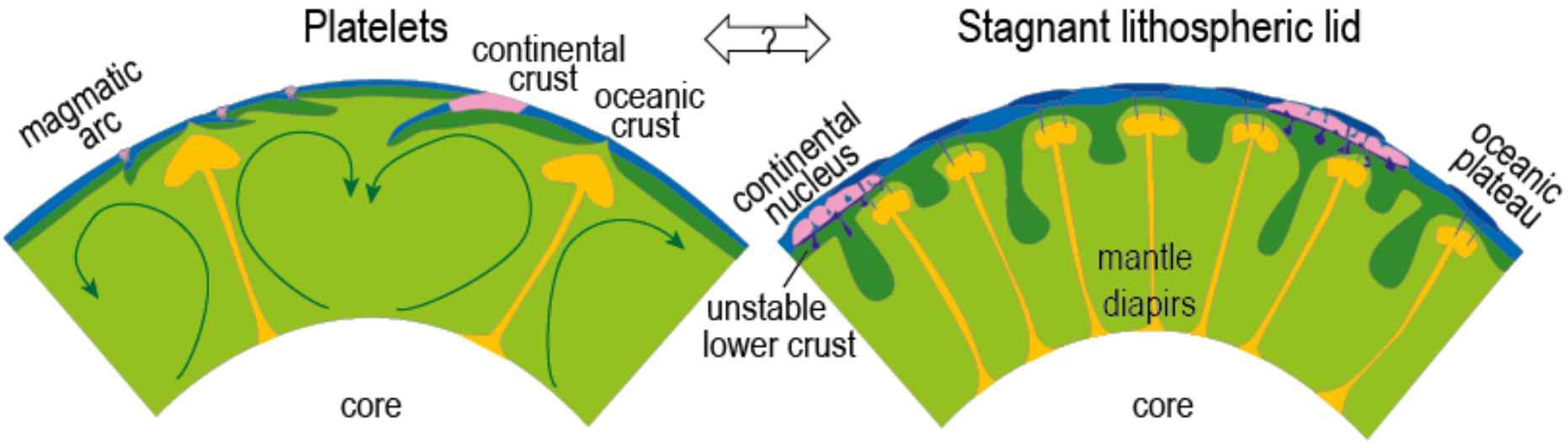
## Conclusion

**Major gold extraction associated with Paleoproterozoic crustal growth and reworking**

"Gold was added to the continental crust during a giant Mesoarchaean gold event at 3 Ga"
*(Frimmel 2008)*

⇨ **Inefficient Archean gold extraction or subsequent recycling of crust (and gold) into the mantle?**
⇨ **Geodynamic context of Paleoproterozoic crustal growth and reworking?**



# Paleoproterozoic crustal growth and differentiation :
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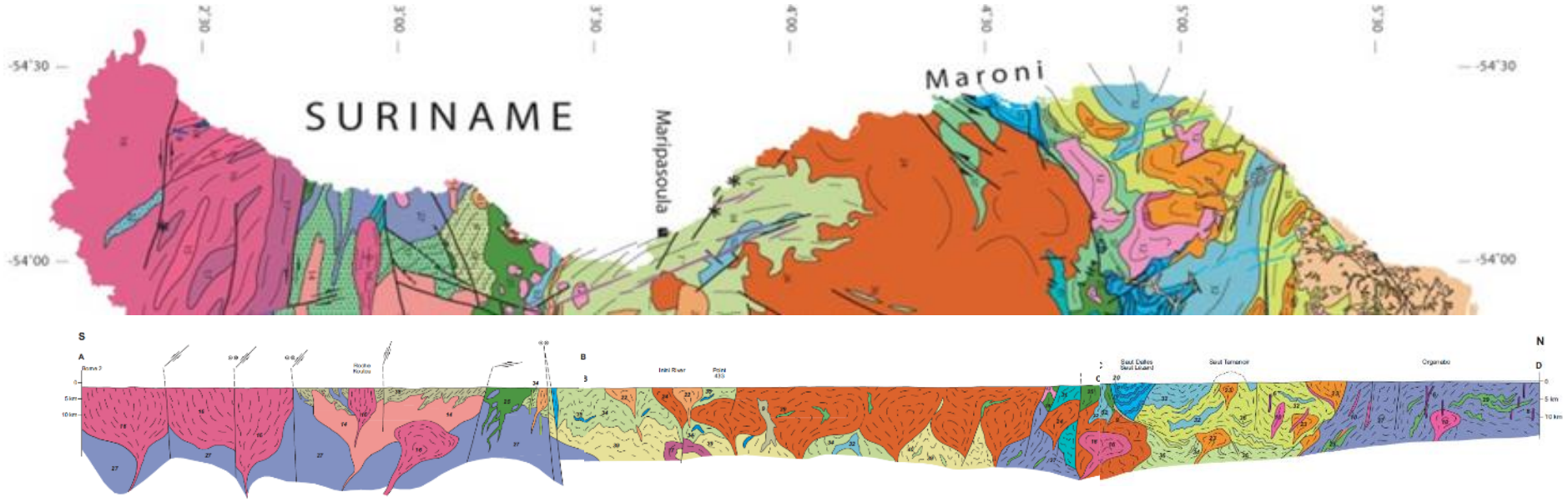
**Ledru P.**

## Perspectives

**Linking crustal growth-differentiation and mineral systems:**

- **Lithostratigraphy of volcanic-sedimentary sequences**
- **Metamorphic-structural record**
- **Petrology-geochemistry-geochronology of magmatic complexes**
- **Petrology-geochemistry-geochronology of mineralizations and their host rocks**

*(Delor et al., 2003)*



# Paleoproterozoic crustal growth and differentiation :
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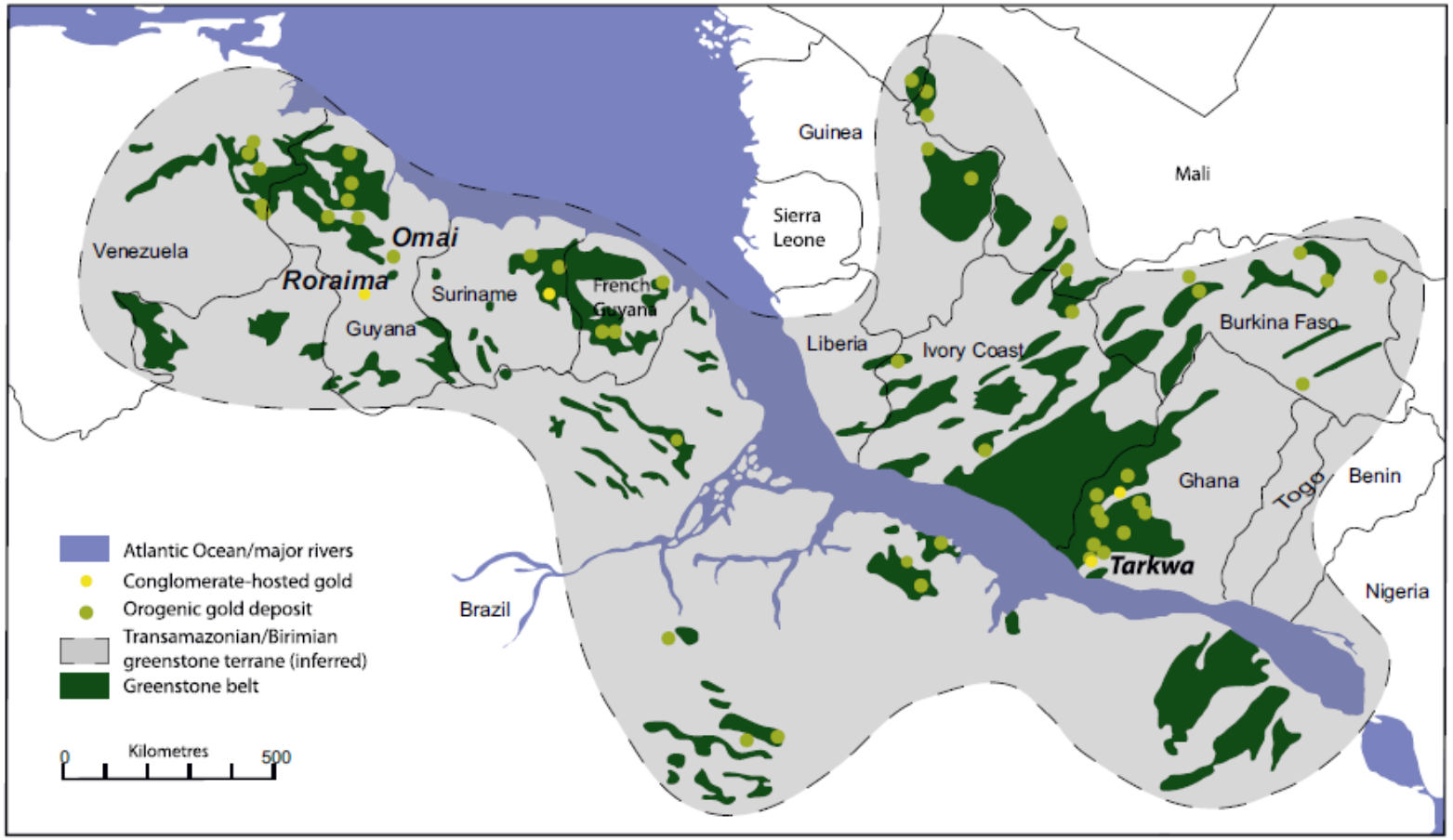
**Ledru P.**

## Perspectives

**WAC-Guiana shield correlation…**

*(Frimmel et al., 2014)*




**… but not with pre-Atlantic reconstruction!**

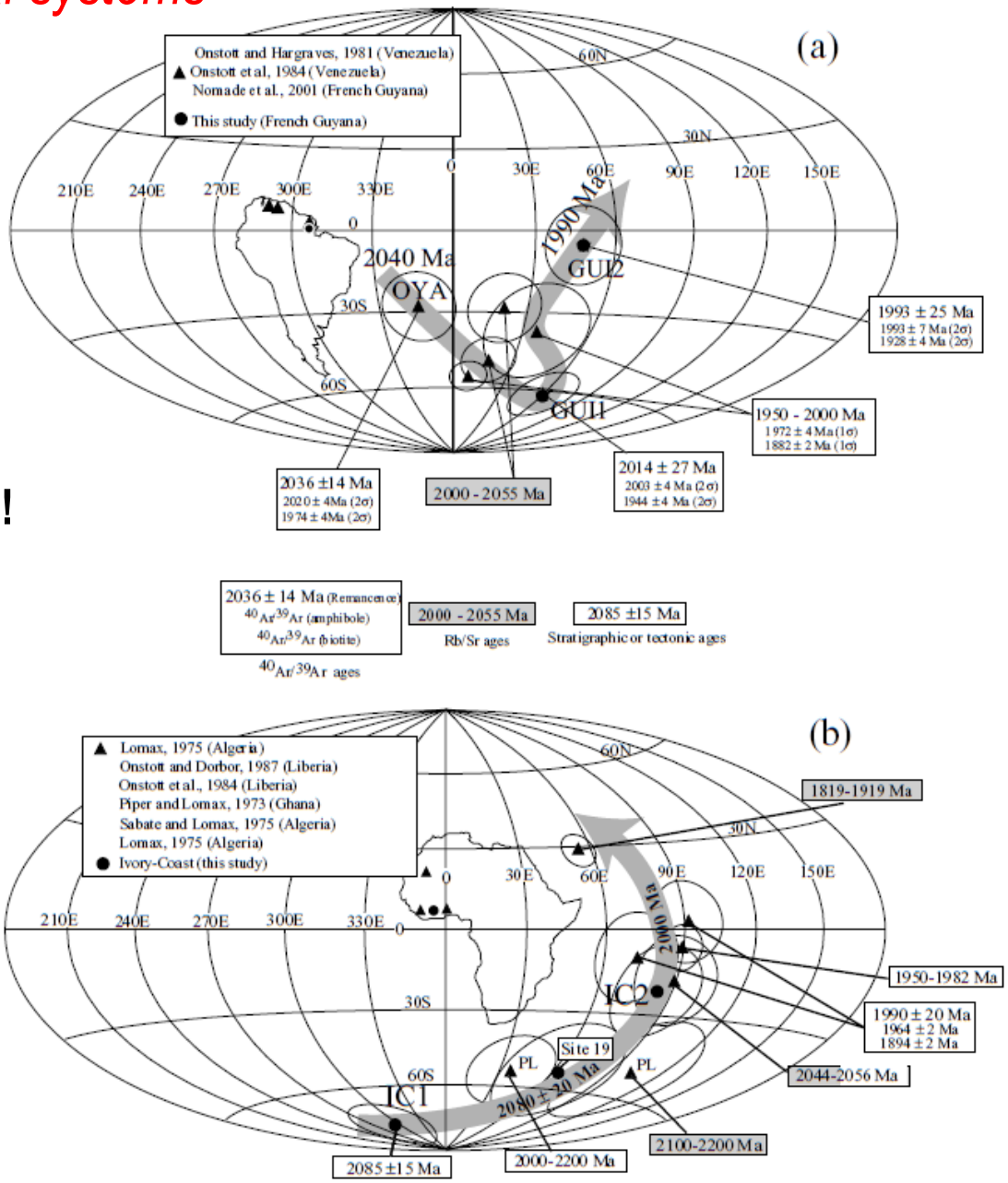
# Paleoproterozoic crustal growth and differentiation :

*a guide for understanding mineral systems*

## Perspectives

**WAC-Guiana shield correlation**

**~2.1 Ga: 3000 km wide ocean between Guiana shield and the WAC!!**




*(Nomade et al., 2003)*

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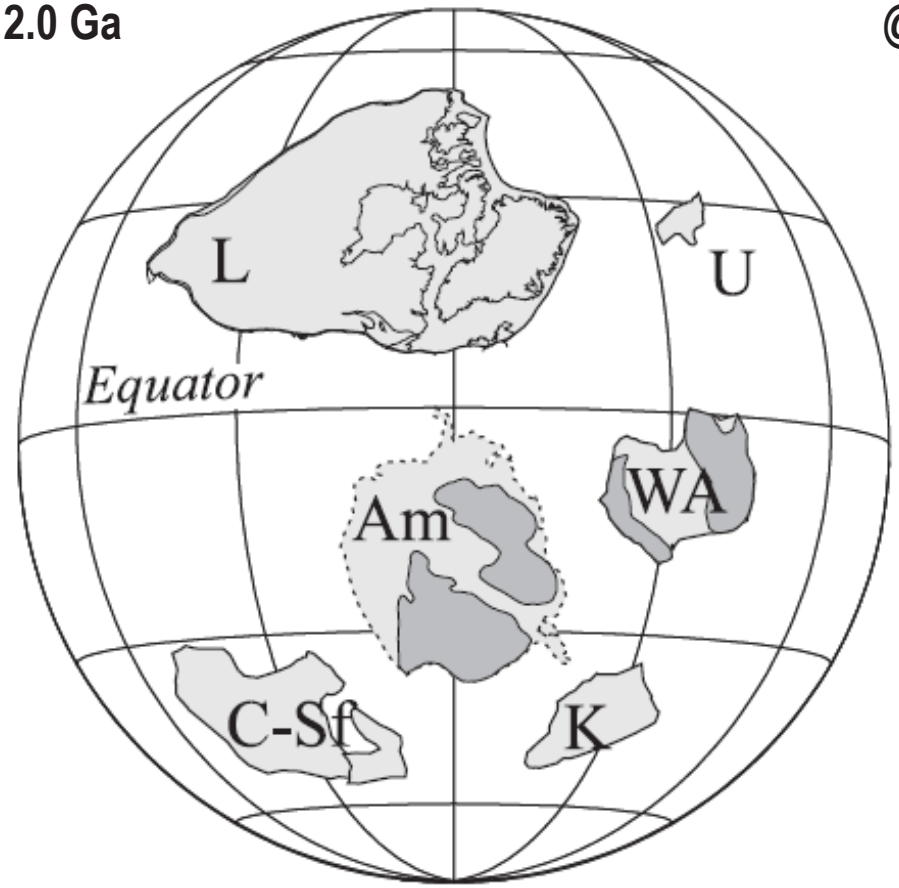
## Perspectives

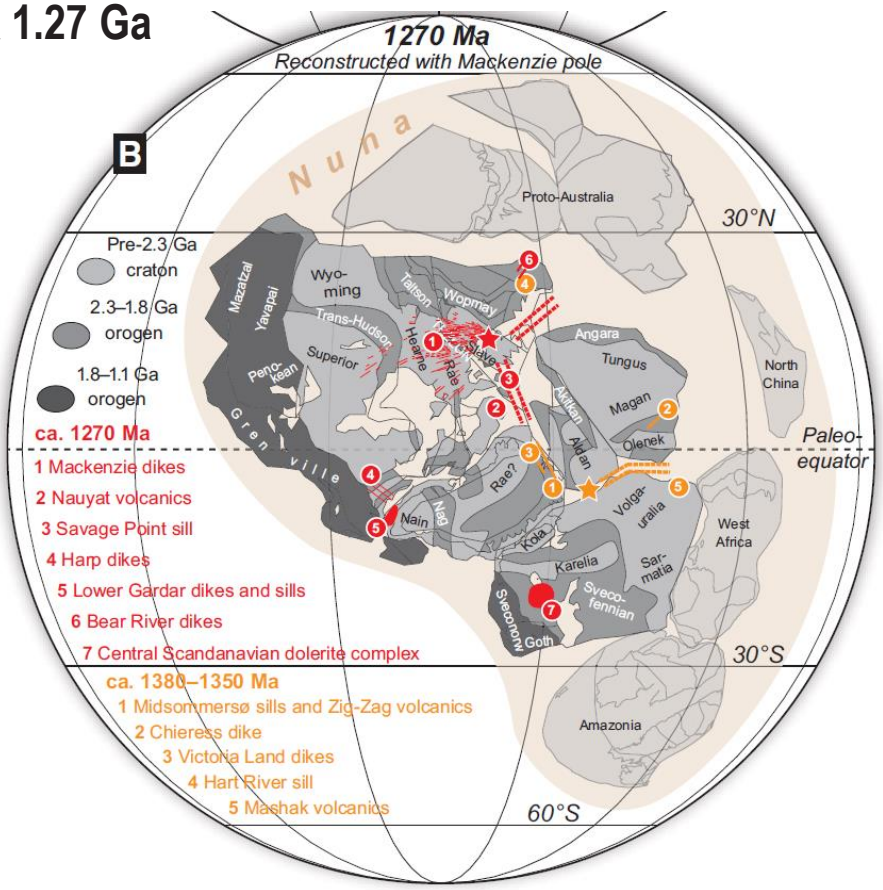
### WAC-Guiana shield correlation

**@ 2.0 Ga**




*(Pesonen et al., 2003)*

**@ 1.27 Ga**




*(Evans & Mitchell, 2011)*

**… but paleogeographic reconstructions are still a bit uncertain**

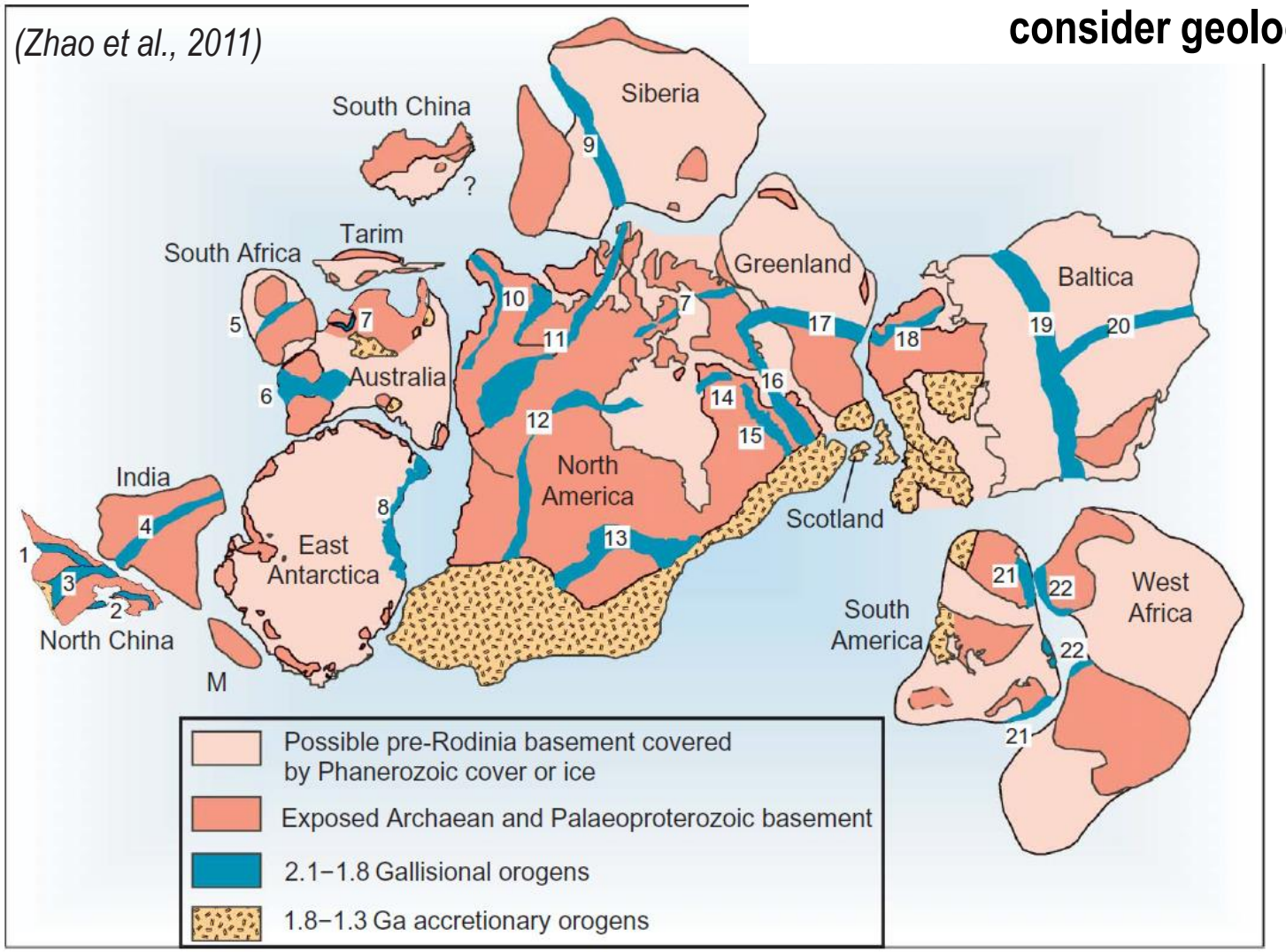
# Paleoproterozoic crustal growth and differentiation :

*a guide for understanding mineral systems*

## Perspectives

**WAC-Guiana shield correlations are uncertain**

**… and only approximately consider geology!**



Gold is a good tracer of mantle-crust and intracrustal transfers

Understanding these transfer provides guides for mineral exploration

# Questions?