2nd Mining in European History - Conference

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Ancient mining near the Bibracte oppidum and its nowadays impact on ecosystems:

A multidisciplinary approach

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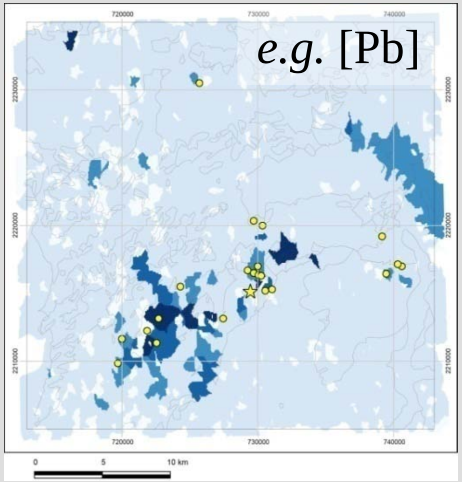
[Heinrich Gross, XVIe s.]

Background project

- Industrial history forgotten by local inhabitants
  - Ancient wastes may still represent a threat (Monna *et al.*, 2011)

- Our project
  - Discovering former mines
    - ⇨ **Prospectivity maps produced from geochemical databases**
    - ⇨ **Field surveys**
  - Assessing their impacts on nowadays aquatic and terrestrial ecosystems
    - ⇨ **Biological survey**



Study site: general presentation

- The Regional Park of Morvan
  - Massif Central chain
  - Protected by constraining environmental policies

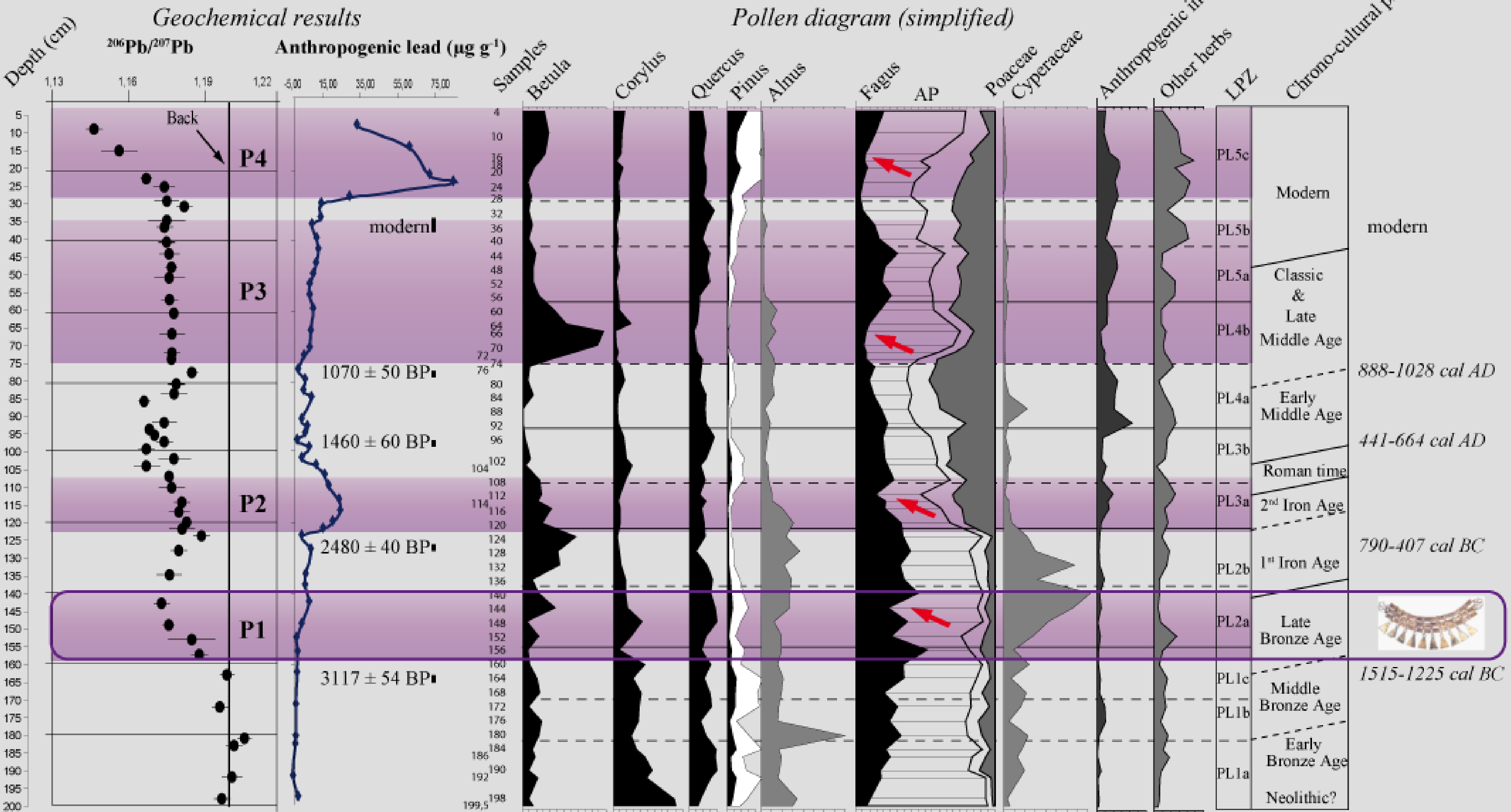
- Experienced active metal mining and smelting activities from prehistory onwards

- The Bibracte oppidum
  - Iron Age major economic center
  - Largest settlement of the Aeduan Celtic tribe
    - ⇨ **ca. 180 BC – 25 AD**

Peat archives: Port-des-Lamberts (Morvan, 710 m)

- Early metallurgy: Late Bronze Age

(I. Jouffroy-Bapicot *et al.*, 2007 - F. Monna *et al.*, 2004)

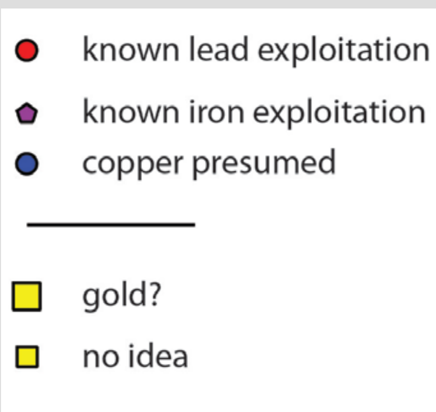


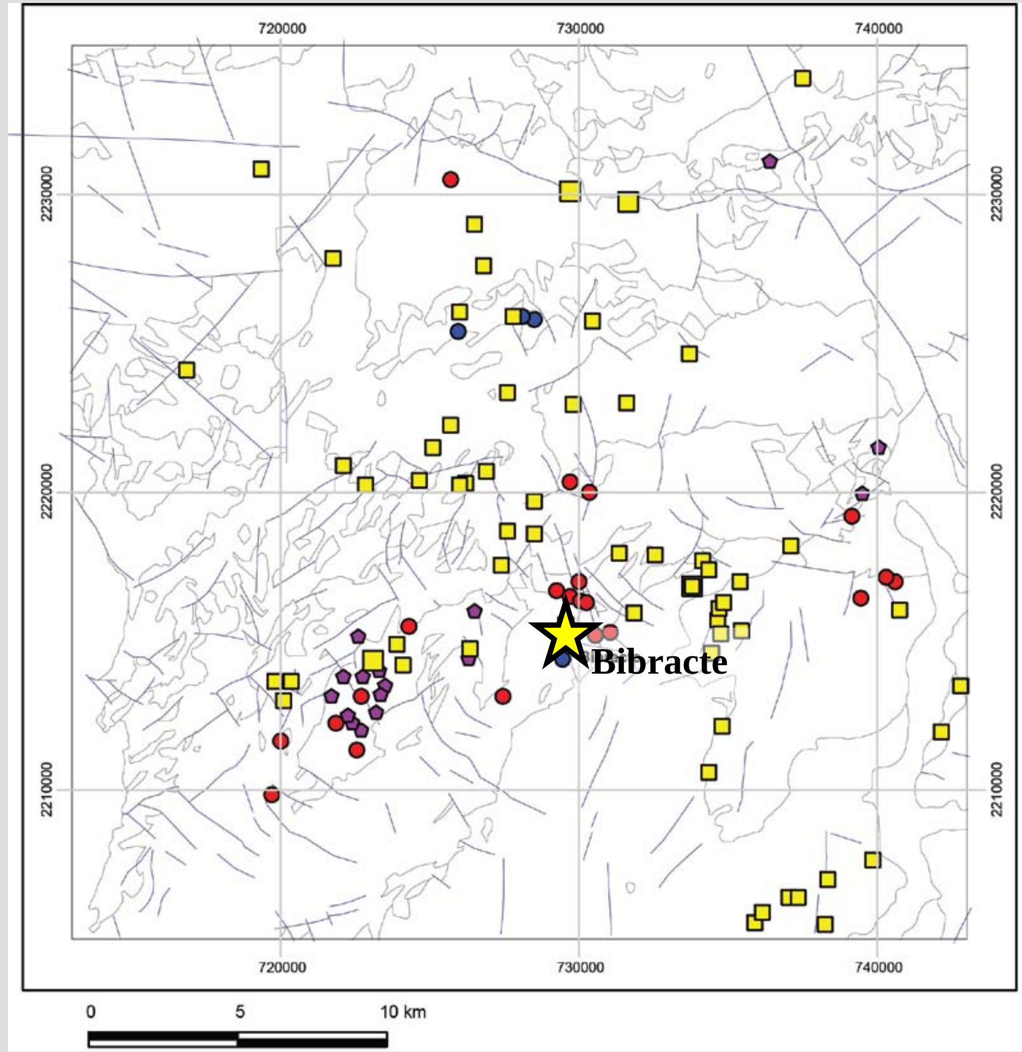
geochemistry : F. Monna, C. Blanchot

Main phases of atmospheric metallic micro-pollutants deposition

pollen : I. Jouffroy-Bapicot

Identifying mining sites



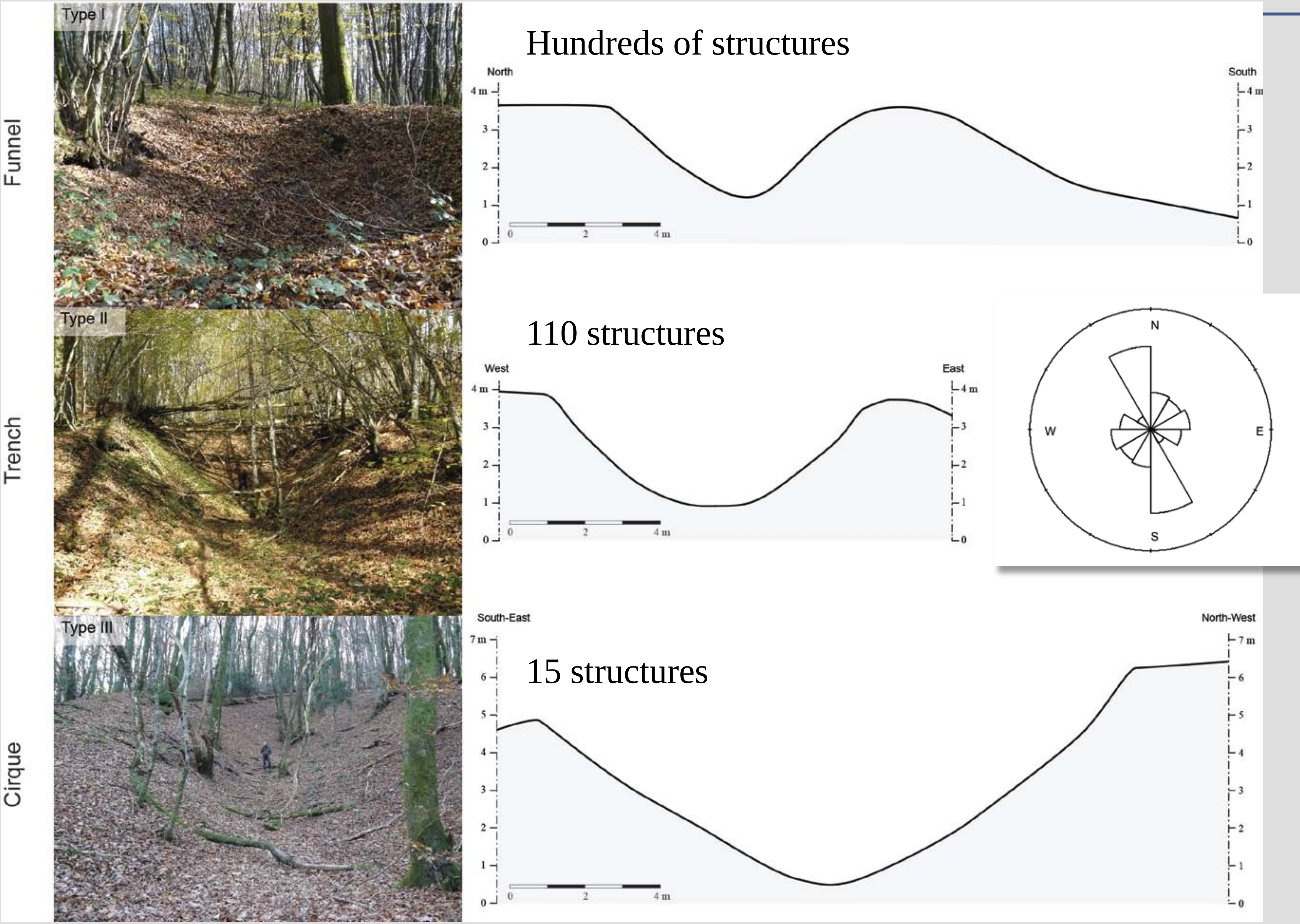


- Field survey
  - ⇨ **A total of 119 past and modern mining sites have been identified**
  - ⇨ **Pilot study area of 900 km²**

(F. Monna et al., IUGS 2012)

Pedestrial prospection

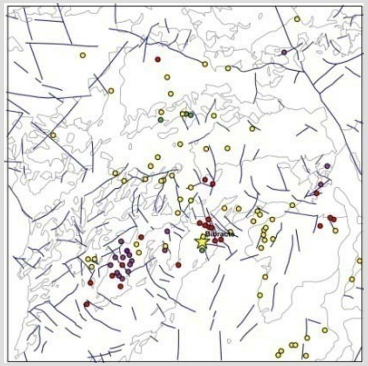
(F. Monna et al., IUGS 2012)



Prospectivity maps: methodology

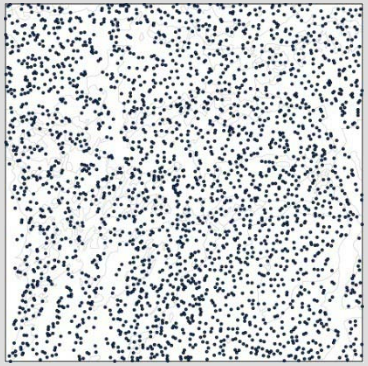
Pilot study area

Systematic prospection in a constrained area



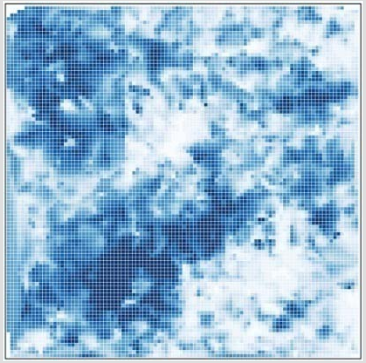
Mapping the mines discovered

Pilot study area



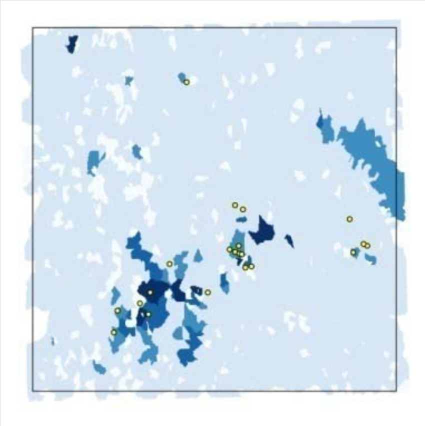
Geochemical database of stream sediments

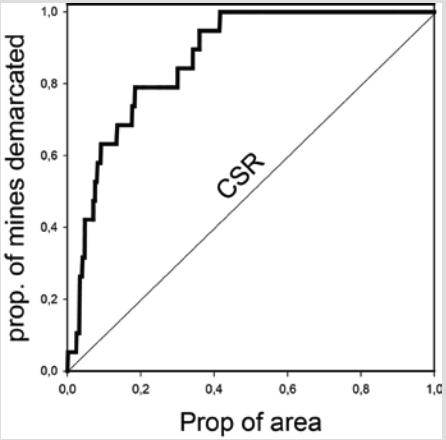
Pilot study area



Treating the data and delineating the geochemical anomalies using a fractal model

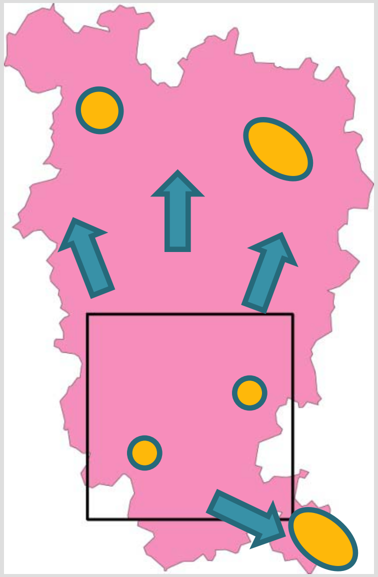
Pilot study area





Crossing the models and the mines discovered.

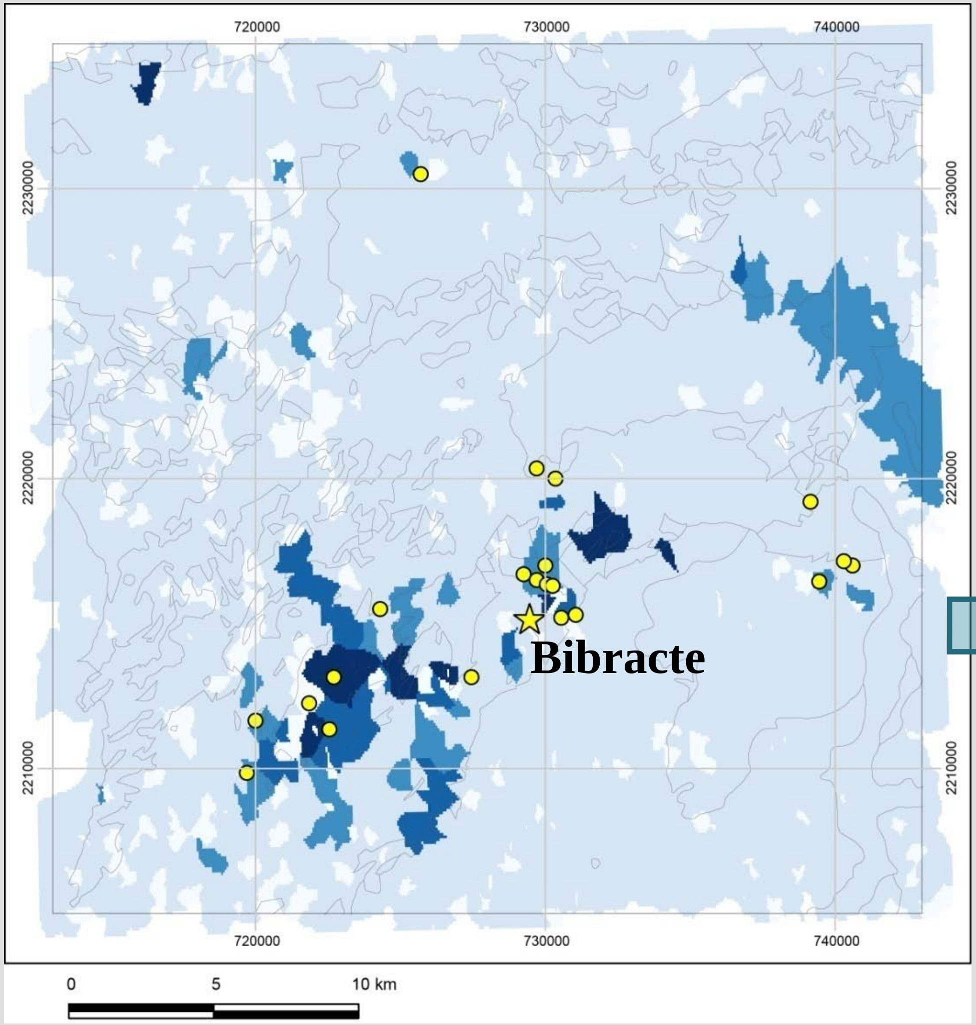
Regional Park of Morvan

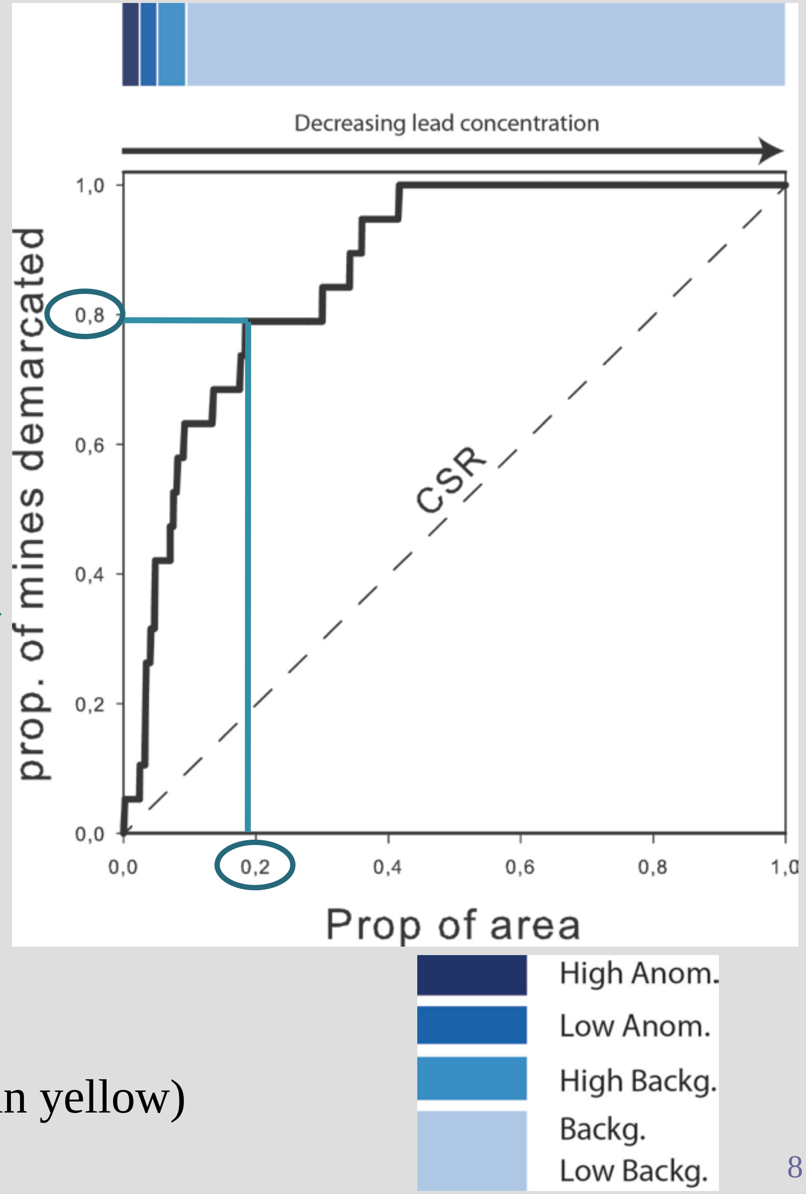


Extrapolating the model to a wider area

(F. Monna et al., IUGS 2012)

Confronting geochemistry and prospection

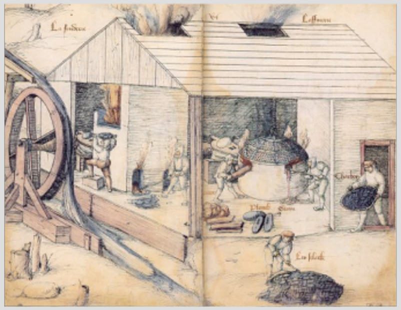




Pb anomalies (fractal model) + known Pb/Ag mines (in yellow)

(F. Monna et al., IUGS 2012)

More precisely…



1. Mining and metallurgical activities

2. Abandoned wastes and tailings

- Local spatial distribution of trace metals in soils affected by past mining?

Pb Zn Cu Cd ?

3. Transfer of metal in soil

Pb Zn Cu Cd ?

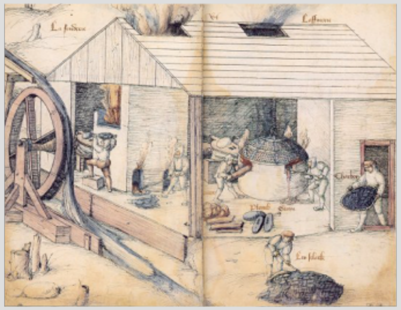
4. Uptake by wildlife

Aquatic ecosystem

Terrestrial ecosystem

More precisely…

- Local spatial distribution of trace metals in soils affected by past mining?



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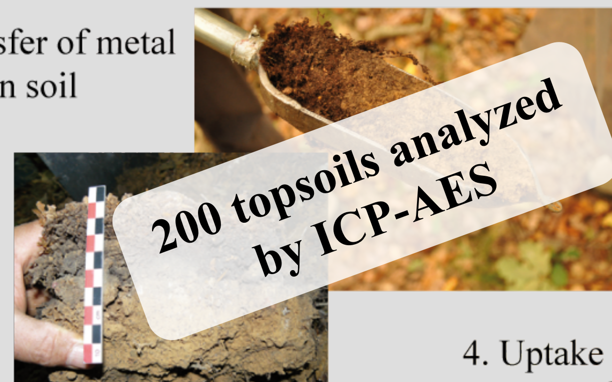

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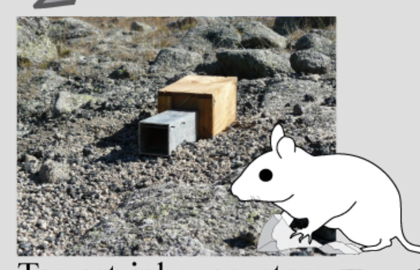
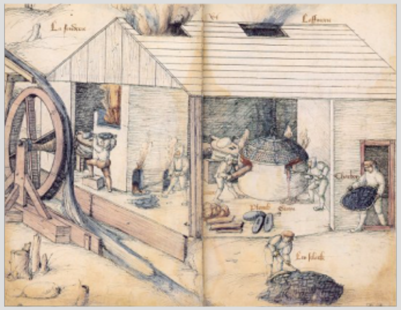
Pb Zn Cu Cd ?

Aquatic ecosystem



Terrestrial ecosystem

More precisely…



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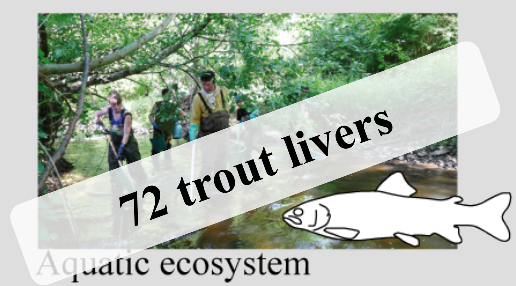

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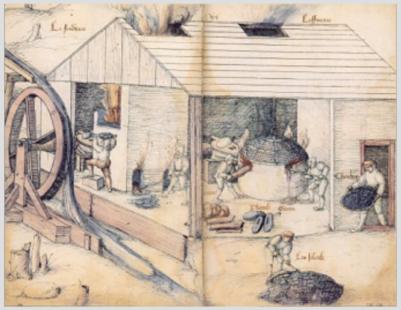

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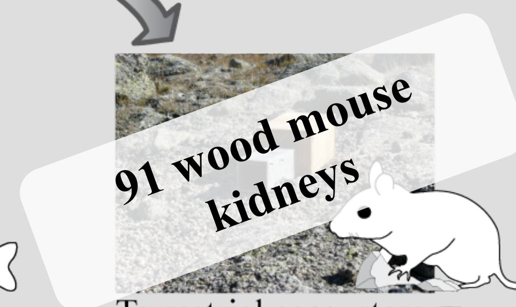

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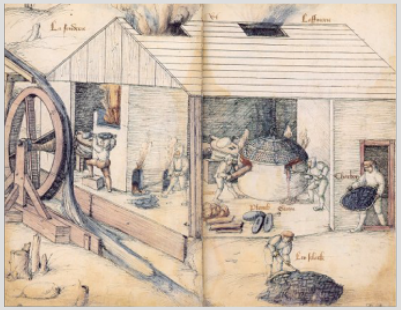

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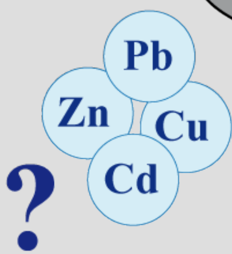
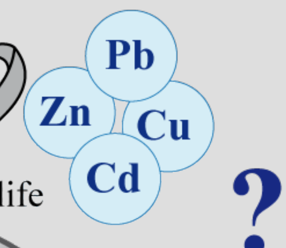


3. Transfer of metal in soil

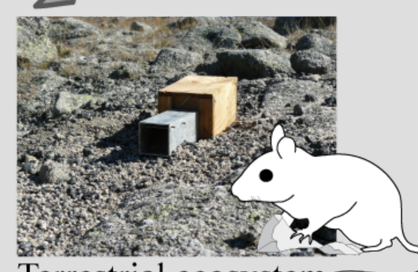


4. Uptake by wildlife

- Consequences of long-term metal in soil on wildlife?
- Impact on ontogenetic development ?

  ⇨ **Fluctuating asymmetry**

Aquatic ecosystem



Terrestrial ecosystem

Study areas for the ecosystems

No mining

Free of mining activity

Discrete mining

Ore exploited: polymetallic sulfide

Type of exploitation: mines and smelting area

Datation: 19^{th} - 20^{th} centuries AD

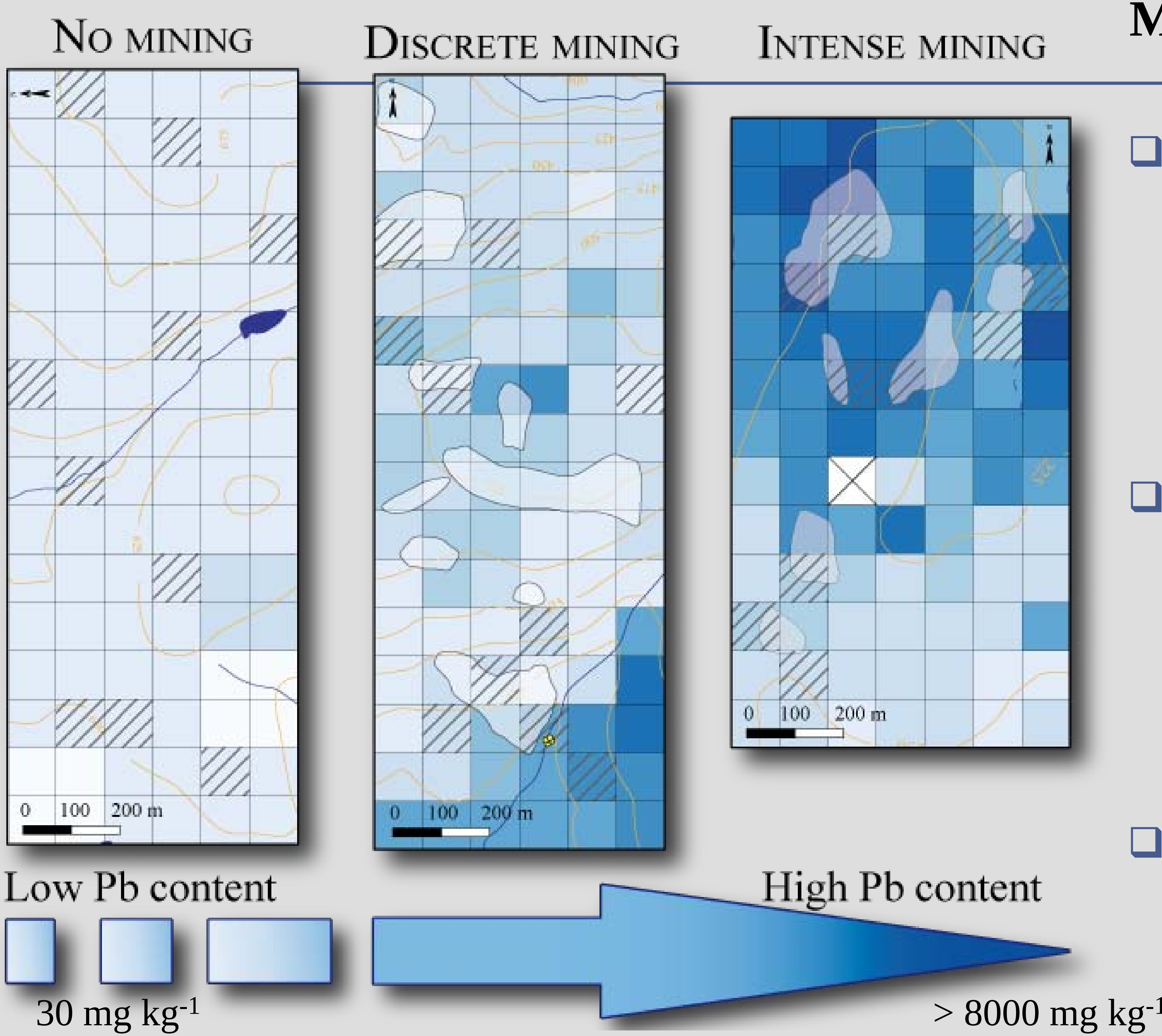
Intense mining

Ore exploited: Galena (PbS)

Type of exploitation: mines

Datation: 15^{th} - 16^{th} centuries AD

Morvan soils: Pb



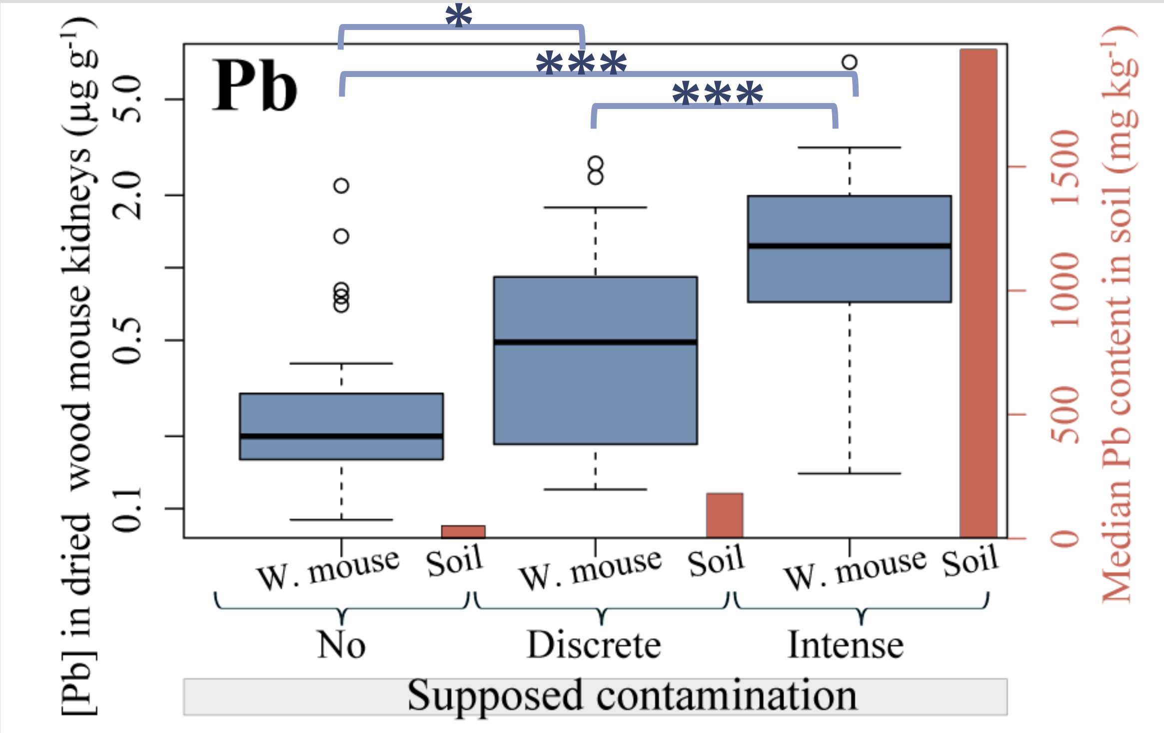
- Good congruence between Pb in soil and the supposed contamination degree
- Pb content mirrors the presence of archaeological sites
- Same pattern for other metals
  - Cd, Cu, Zn

The wood mouse: results at population scale

- Significant statistical differences between sites (Pb, Cd, Zn)
- Pb contents in wood mouse kidneys mirror Pb in soil

Significance level

*	$p < 0.05$
**	$p < 0.01$
***	$p < 0.001$

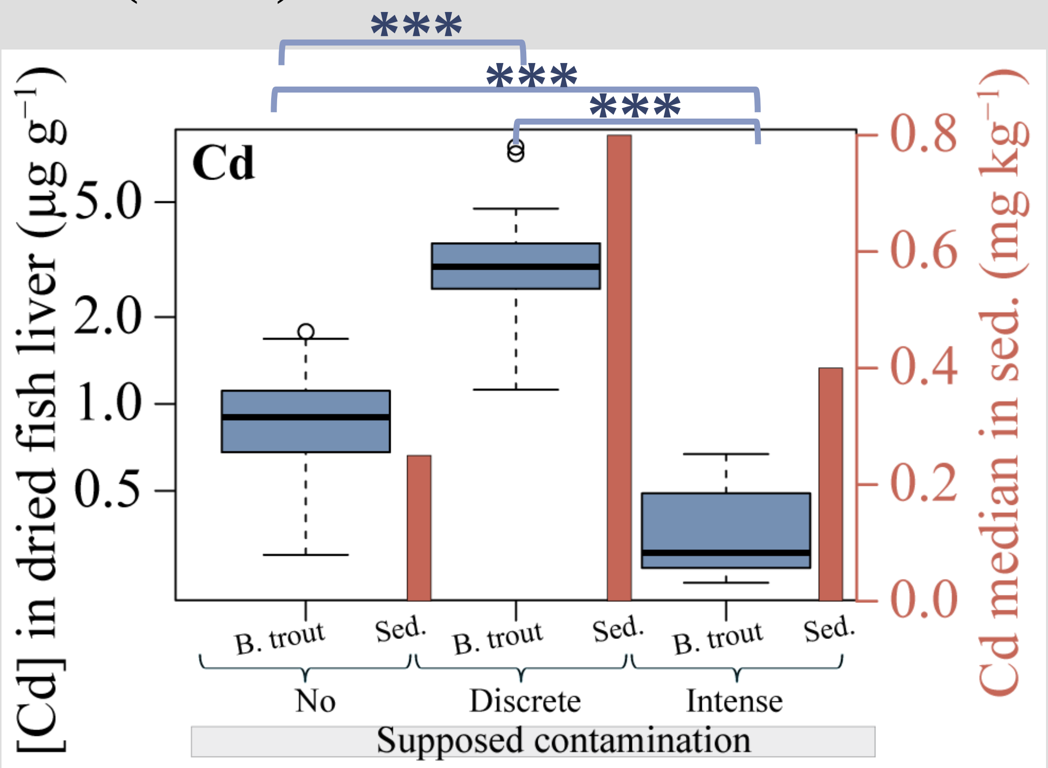


Barplot: median Pb content in soils where wood mice where sampled
Boxplot: Pb distribution wood mouse kidneys

No mining area: n = 30
Discrete mining area: n = 31
Intense mining area: n = 30

The brown trout: results at population scale

- Significant statistical differences between sites (Cu, Cd, Zn)
- Cd contents in fish livers seem to follow Cd in river sediment for the two representative populations ($n > 30$)



Significance level

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**	$p < 0.01$
***	$p < 0.001$

Barplot: median Cd content in river sediment
Boxplot: Cd distribution in Brown trout liver

No mining area: n = 37
Discrete mining area: n = 31
Intense mining area: n = 4

The wood mouse: at individual scale

- Models were performed to test:

Linear model → Sex, Mass, Metal content in soil — ON → Metal content in the wood mouse

	Pb	Zn	Cd	Cu
Sex	-	$p = 0.009$ **	-	$p = 0.01$ *
Mass	-	$p < 0.001$ ***	$p < 0.001$ ***	$p < 0.001$ ***
Metal in soil	$p < 0.001$ ***	-	$p = 0.02$ *	-
Sex:Mass	-	$p = 0.005$ **	-	$p = 0.01$ *
Sex:Metal	-	-	-	-
Mass:Metal	-	-	$p = 0.006$ **	-
↓	*Metal content in soil*	*Mass & sex*	*Metal in soil & mass*	*Mass & sex*

Significance level

*	$p < 0.05$
**	$p < 0.01$
***	$p < 0.001$

The brown trout: at individual scale

- Models were performed to test:

Linear model → Age, Sex, Mass, Metal content in sediment — ON → Metal content in the brown trout

	Pb	Zn	Cd	Cu
Age	-	-	-	-
Sex	-	$p = 0.002$ **	-	-
Mass	-	-	-	-
Metal in sed.	-	$p = 0.04$ *	$p = 0.002$ **	-
Age:Sex	-	$p = 0.02$ *	-	-
Age:Mass	-	-	-	-
Age:Metal	-	-	-	-
Sex:Mass	-	$p = 0.002$ **	$p = 0.003$ **	-
Sex:Metal	-	$p = 0.001$ **	-	-
Mass:Metal	-	-	$p = 0.006$ **	-
	No effect	*Sex, metal & interactions*	*Metal & interactions*	*No effect*

Significance level

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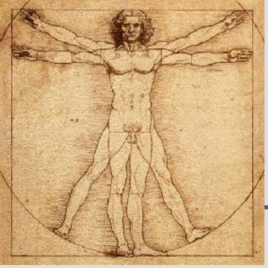
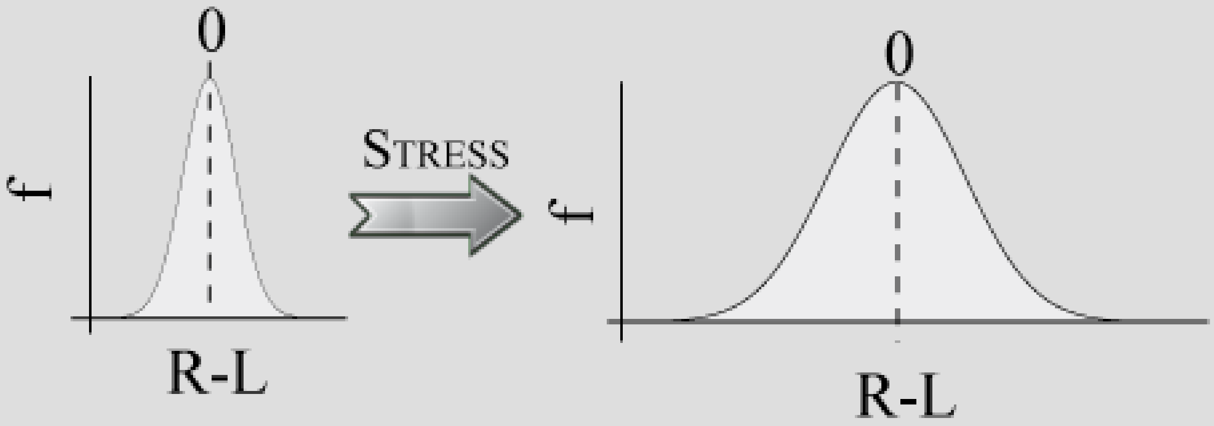
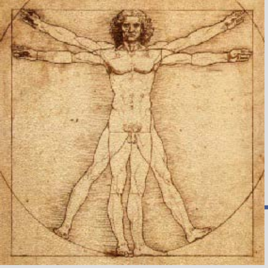


Fluctuating asymmetry (FA): principles

- Developmental instability
  - Reflects the inability of organisms to correct errors occurring during their development
  - Assessed by fluctuating asymmetry (FA)
    - ⇨ **Difference between Right-Left (R-L) sides**

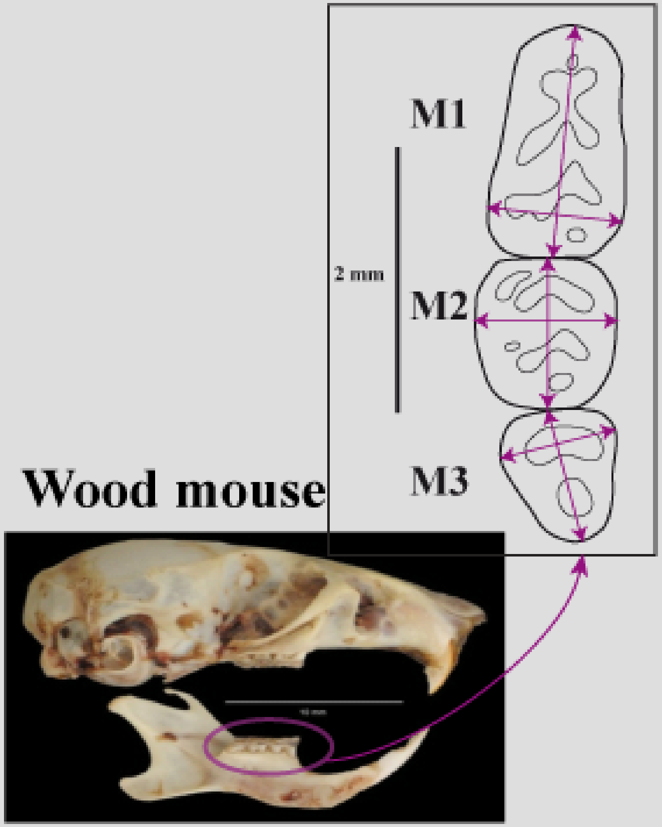


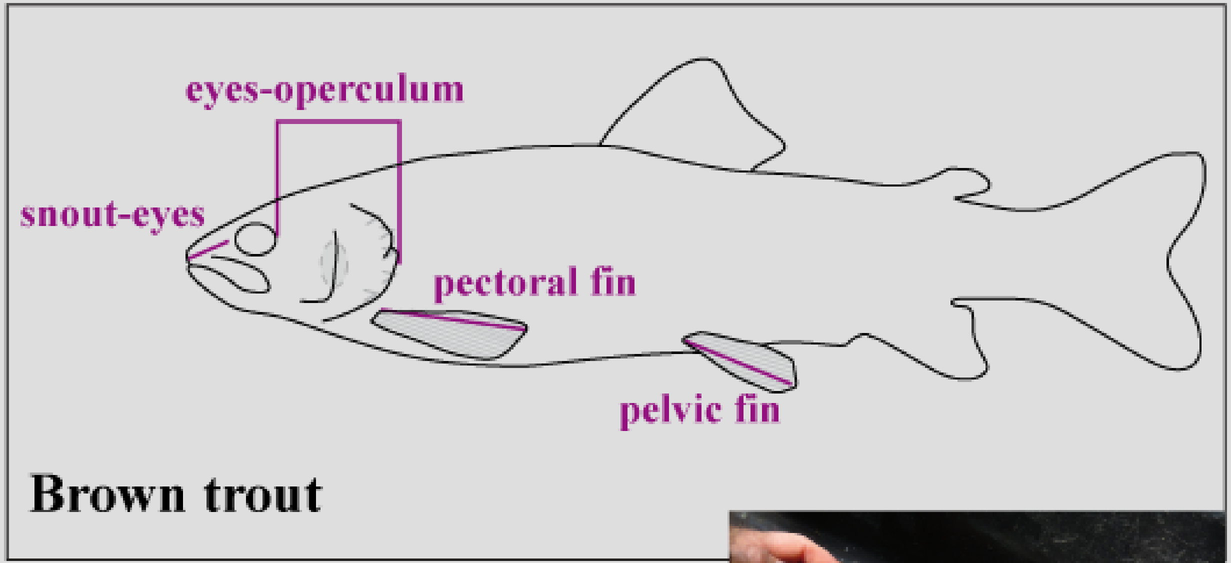
- Indicator of environmental stress (Polak, 2003, Leary and Allendorf, 1989)

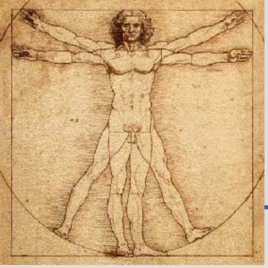


Fluctuating asymmetry (FA): parameters

- 6 metrical traits for the Wood Mouse
  - Length and width of the three lower molars
- 4 metrical traits for the Brown Trout
  - Length of the pectoral and pelvic fins, snout to eyes, eyes to operculum

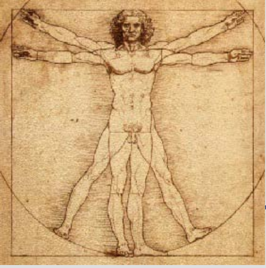






Fluctuating asymmetry (FA): results

- Usual tests were performed
  (Palmer, 1994)
  - Data compatible with the fluctuating asymmetry study



Fluctuating asymmetry (FA): results

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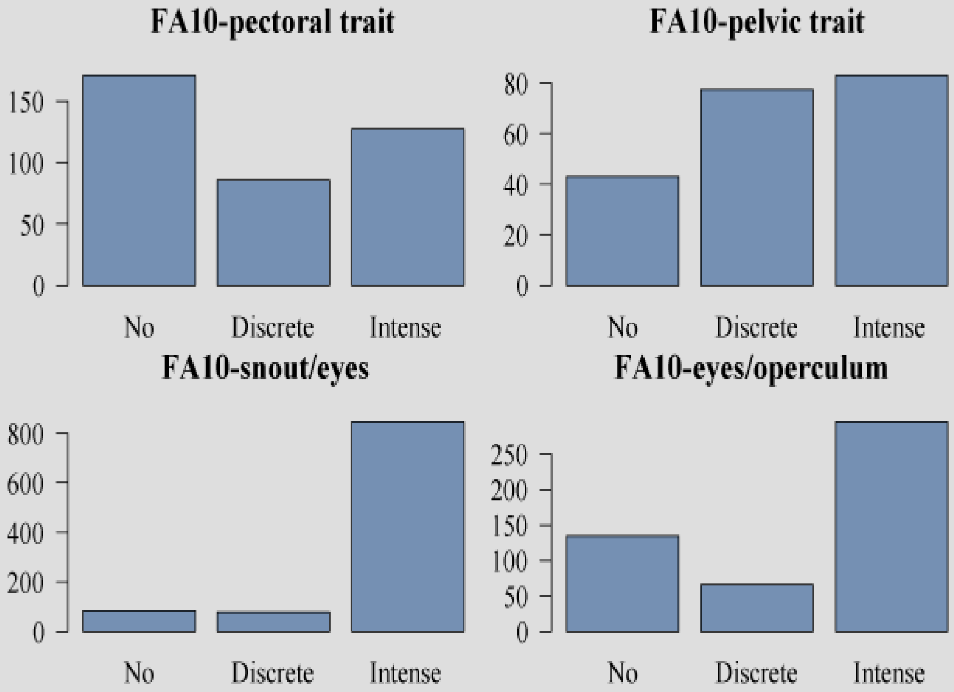
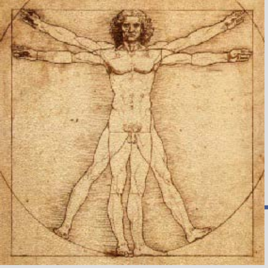
- Population approach
  - No significant fluctuating asymmetry for any trait between sites

Example for the fish:





Fluctuating asymmetry (FA): results

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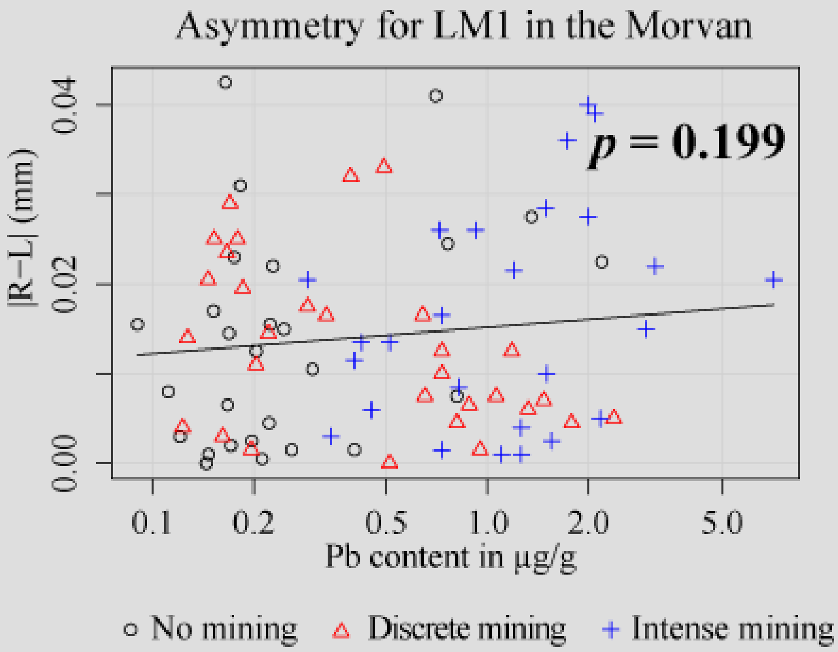
  - Data compatible with the fluctuating asymmetry study
- Population approach
  - No significant fluctuating asymmetry for any trait between sites
- Individual approach
  - No significant relationship between |R-L| variations and metal content

Example for the rodent:



Discussion/Conclusion

- Soil
  - Long after the industrial activities have ceased, trace metals can still be found in soils
    - ⇨ **For all study metals (Pb, Cd, Zn, Cu)**

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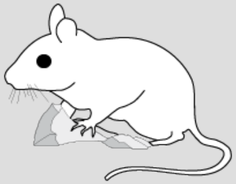
- WOOD MICE AND BROWN TROUT



  - For the wood mouse
    - ⇨ **Homeostatic regulation for Cu and Zn (Rogival et al., 2007)**
    - ⇨ **Pb and Cd in kidneys are correlated with the presumed contamination degree**
    - ⇨ **Individual Pb content reflects the Pb concentration in soils**

  - For the brown trout
    - ⇨ **No effect of Pb in sediment**
    - ⇨ **Individual Cd content reflects the Cd concentration in sediments**

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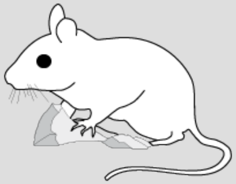

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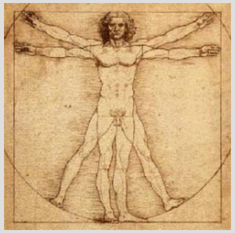
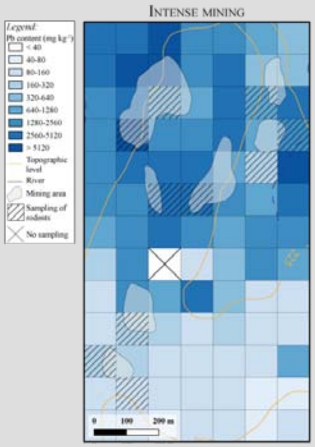
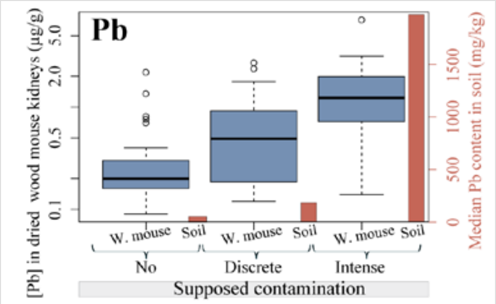


- NO SIGNAL FOR FLUCTUATING ASYMMETRY
  - Contamination levels not high enough?

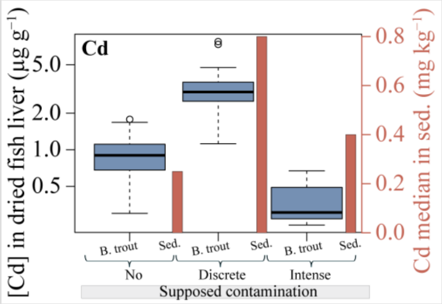
Take home messages

- Spatial distribution of trace metal in soil mirrors the archaeological mining and metallurgical activities





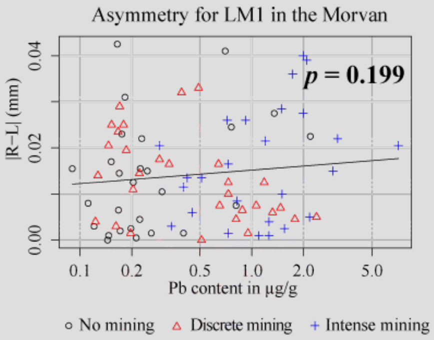
Rodent



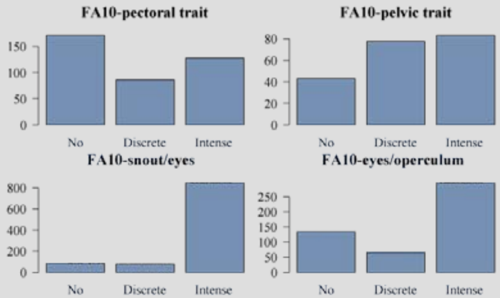
Fish

- Metal contents in wild animals can be correlated to the metal contents in their living environment

Rodent



- No fluctuating asymmetry differences for this study



Fish

Thank you for your attention

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Archéologie Terre Histoire Sociétés

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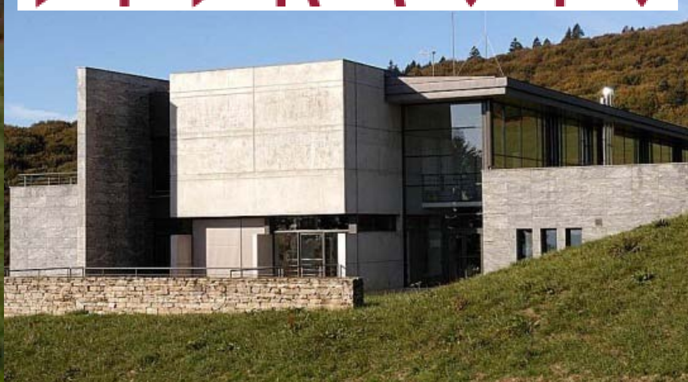
Parc naturel régional du Morvan

BIBRACTE



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Conseil régional

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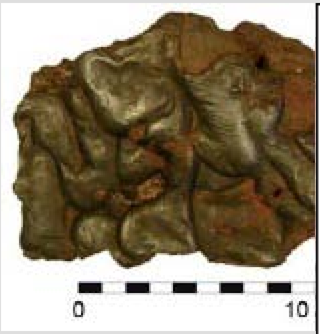
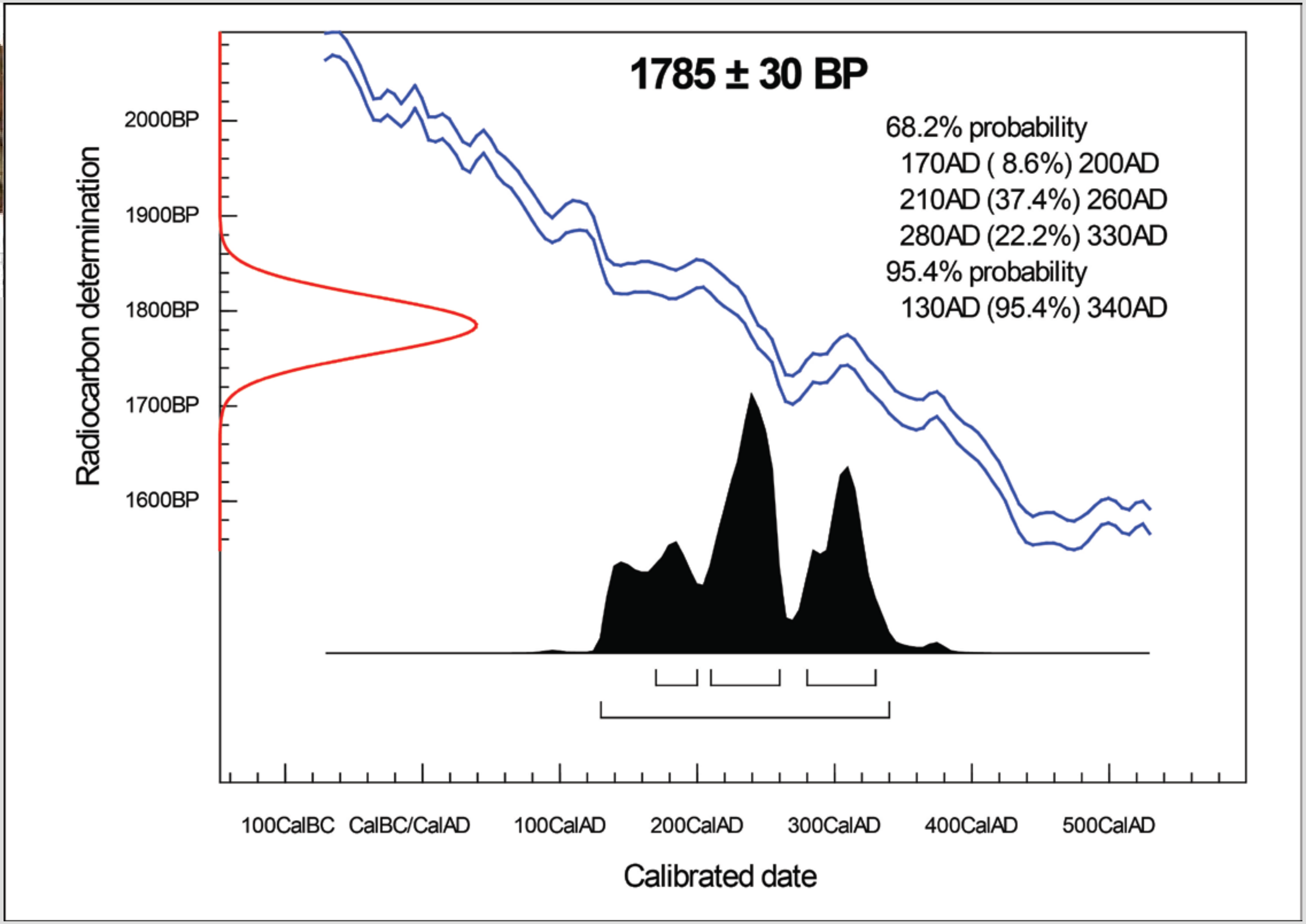
FEDER

DREAL BOURGOGNE
Direction régionale de l'Environnement, de l'Aménagement et du Logement

Présent pour l'avenir

Slag from the discrete mining area





Data from Poznan Radiocarbon Laboratory