

# Morphométrie des haches à talon de l'âge du Bronze.

- Etude de la variation spatiale des formes. Implications sur la production et l'exportation-

Monna, F.; Jébrane, A.; Gabillot, M.; Laffont, R.; Specht, M.; Bohard, B.; Camizuli, E.; Petit, C.; Chateau, C.; Alibert, P.



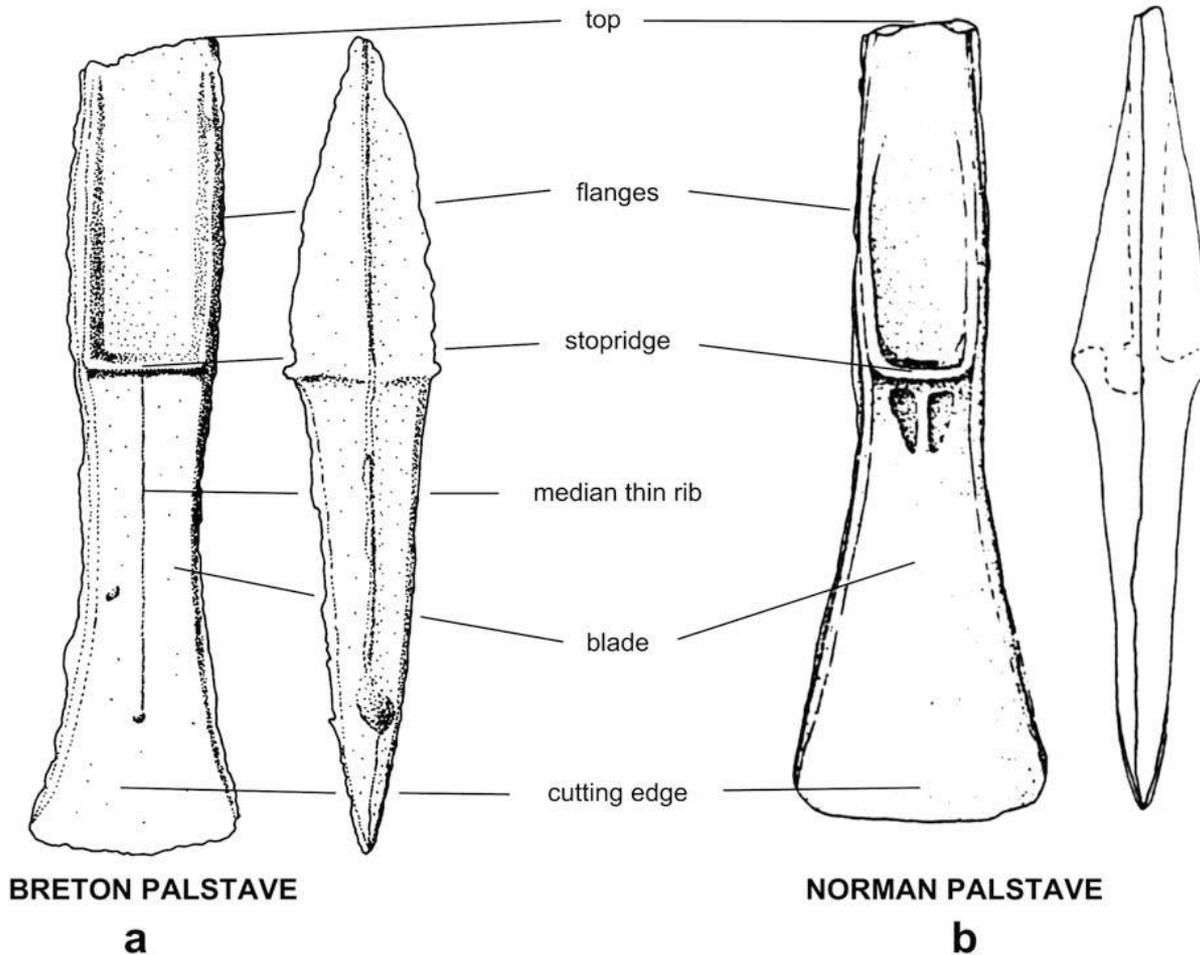
# Introduction

Production de  
masse



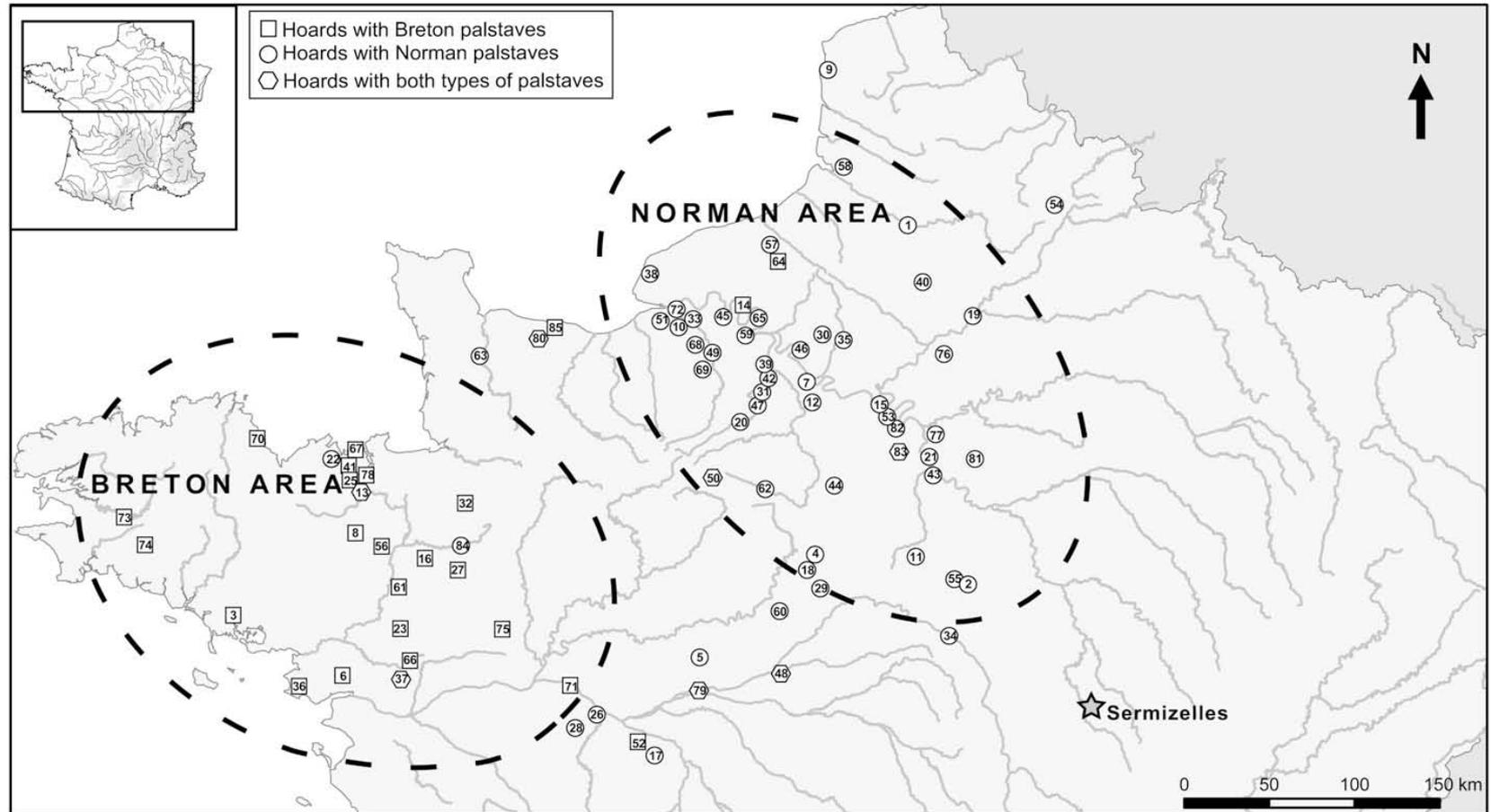
# Introduction

Une première étude...



Forel, B., Gabillot, M., Monna, F., Forel, S., Dommergues, C.H., Gerber, S., Petit, C. Mordant, C., Château, C. (2009) Morphometry of Middle Bronze Age palstaves by Discrete Cosine Transform. *Journal of Archaeological Science*. 36, 721-729.

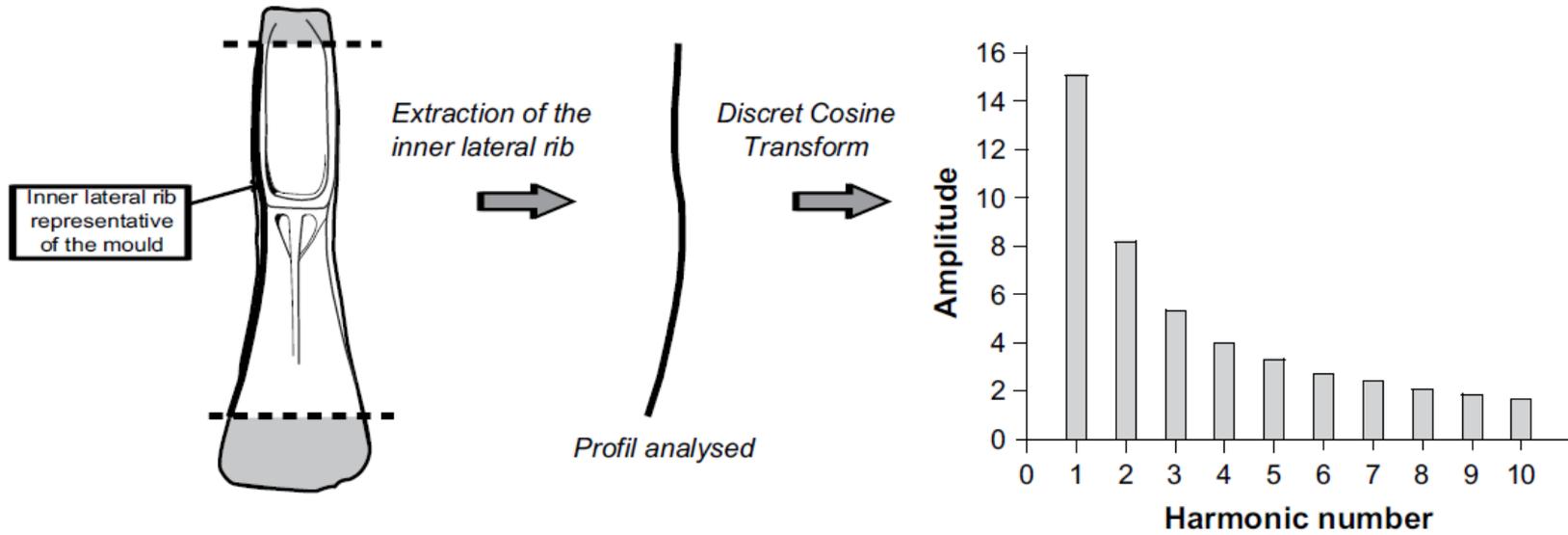
# Introduction



**Fig. 2.** Location of the sites where the Norman and Breton palstaves were excavated. On the map, the sites with a circle correspond to hoards with only Norman palstaves, those with a square have only Breton palstaves. The hexagon symbol indicates the presence of both types in the hoards. The grey star indicates the town of Sermizelles. The number between parentheses in the following list corresponds to the number of palstaves used in the study. All references concerning the Norman and Breton palstaves studied here are presented in Gabillot (2003). 1 Amiens (1); 2 Amilly (1); 3 Auray (1); 4 Bazoches-en-Dunois (1); 5 Beaumont-la-Ronce (1); 6 Besné (2); 7 Blaru (2); 8 Boisgervilly (6); 9 Boulogne-sur-Mer (2); 10 Bourneville (2); 11 Boynes (1); 12 Beval (4); 13 Calorguen (2); 14 Canteleu (1); 15 Chambourcy (2); 16 Chaumeré (1); 17 Chaveignes (1); 18 Civry (1); 19 Compiègne (2); 20 Conde-sur-Iton (1); 21 Corbeil-Essonnes (2); 22 Créhen (1); 23 Derval (1); 24 Dierre (1); 25 Dinan (4); 26 Distré (1); 27 Domalain (6); 28 Doué-la-Fontaine (1); 29 Epieds-en-Beauce (1); 30 Etrépagny (1); 31 Evreux (16); 32 Fougères (1); 33 Fourmetot (3); 34 Gien (1); 35 Gisors (2); 36 Guérande (1); 37 Héric (4); 38 Heuqueville (30); 39 La Chapelle-du-Bois-des-Faulx (24); 40 La Herrelle (1); 41 Languenan (4); 42 Le-Boulay-Morin (4); 43 Le Coudray-Montceaux (1); 44 Le Gué-de-Longroi (6); 45 Le Landin (1); 46 Les Andelys (1); 47 Les Baux-Sainte-Croix (4); 48 Les Montils (2); 49 Livet-sur-Authou (6); 50 Longny-au-Perche (8); 51 Manneville-la-Raoult (1); 52 Marçay (1); 53 Mareil-Marly (1); 54 Molain (1); 55 Montargis (1); 56 Mordelles (2); 57 Muchdent (2); 58 Nouvion (1); 59 Orival (2); 60 Oucques (1); 61 Poligné (2); 62 Pontgouin (1); 63 Rampan (1); 64 Rosay (1); 65 Rouen (6); 66 Saffré (2); 67 Saint-Briac-sur-Mer (1); 68 Saint-Georges-du-Vivère (1); 69 Saint-Léger-de-Rotes (1); 70 Saint-Quay-Portieux (2); 71 Saint-Rémy-la-Varenne (2); 72 Saint-Samson-de-la-Roque (3); 73 Saint-Thois (141); 74 Scaer (1); 75 Segré (1); 76 Senlis (1); 77 Sucy-en-Brie (4); 78 Taden (1); 79 Tours (4); 80 Vaux-sur-Aure (8); 81 Ver-sur-Mer (1); 82 Verneuil-l'Étang (1); 83 Ville-d'Avray (3); 84 Villejust (1); 85 Vitry (2).

# Introduction

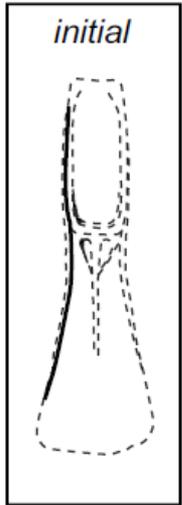
## Treatment of the axe



a

# Introduction

## Norman axe



A1



A1 + A2



A1 + A2 + A3

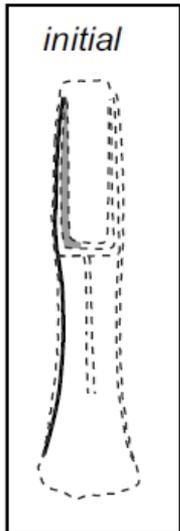


A1 + A2 + A3 + A4



A1 + A2 + A3 + A4 + A5

## Breton axe



A1



A1 + A2



A1 + A2 + A3

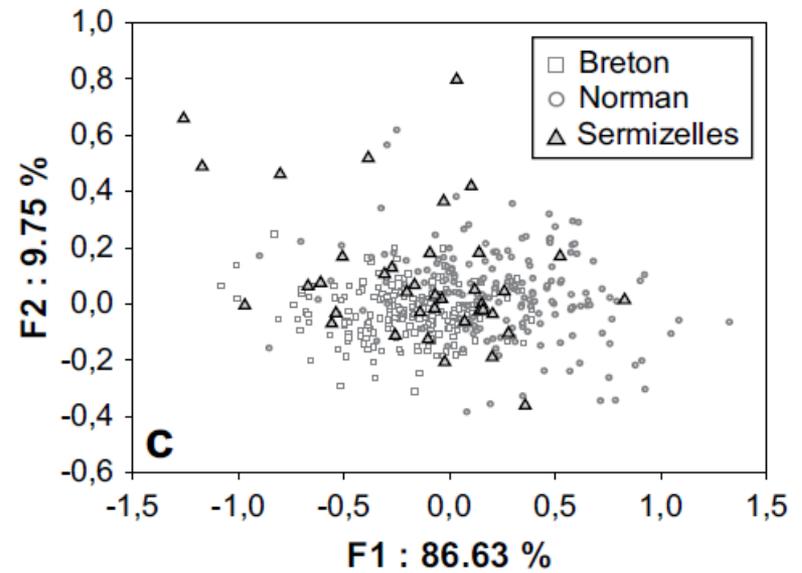
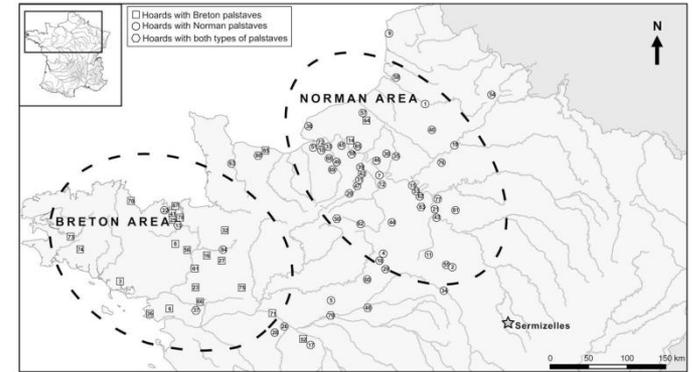
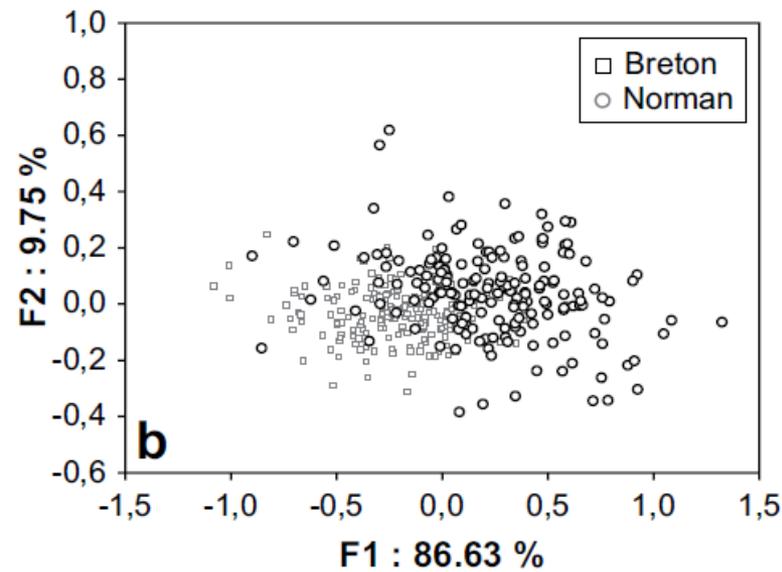
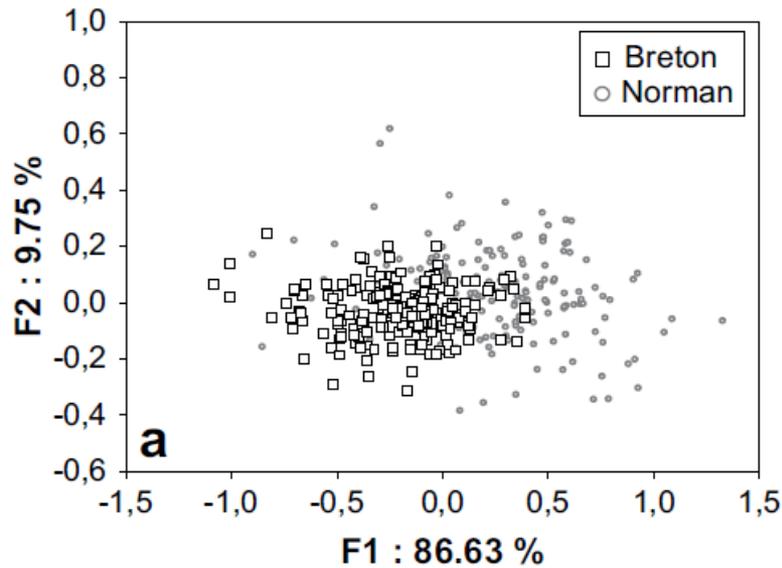


A1 + A2 + A3 + A4

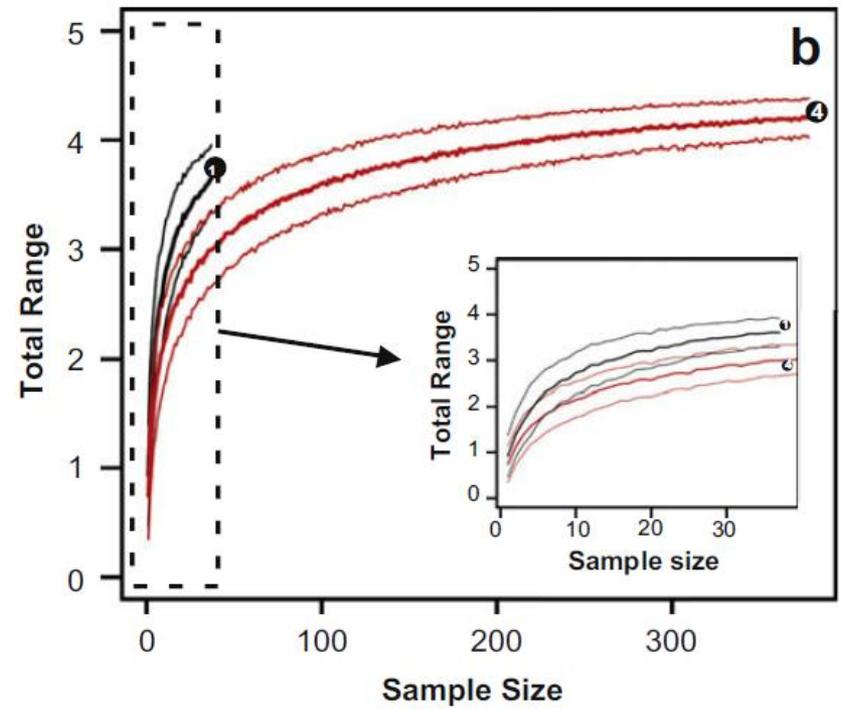
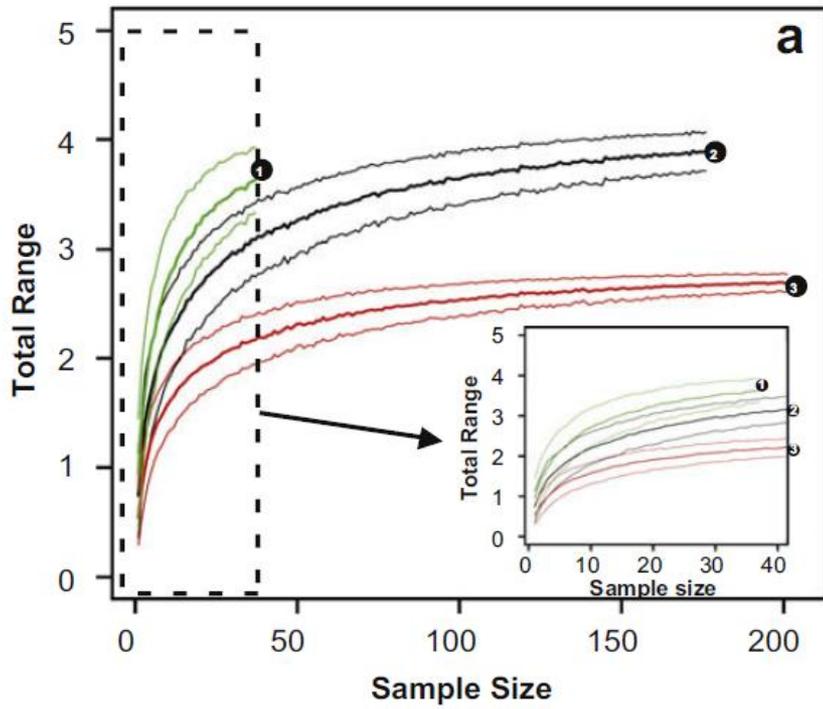


A1 + A2 + A3 + A4 + A5

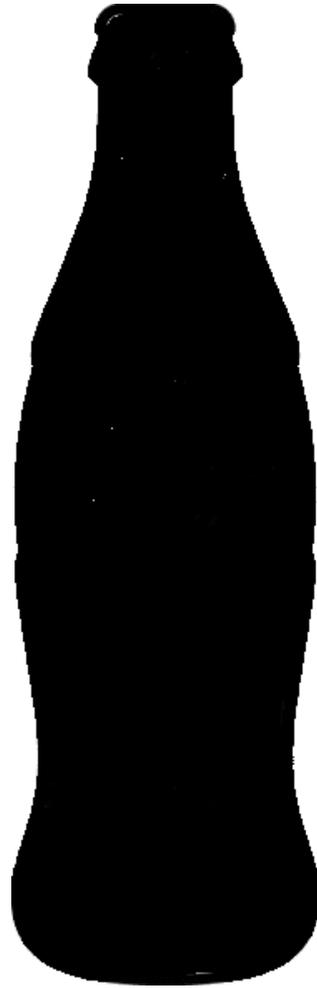
# Introduction



# Introduction



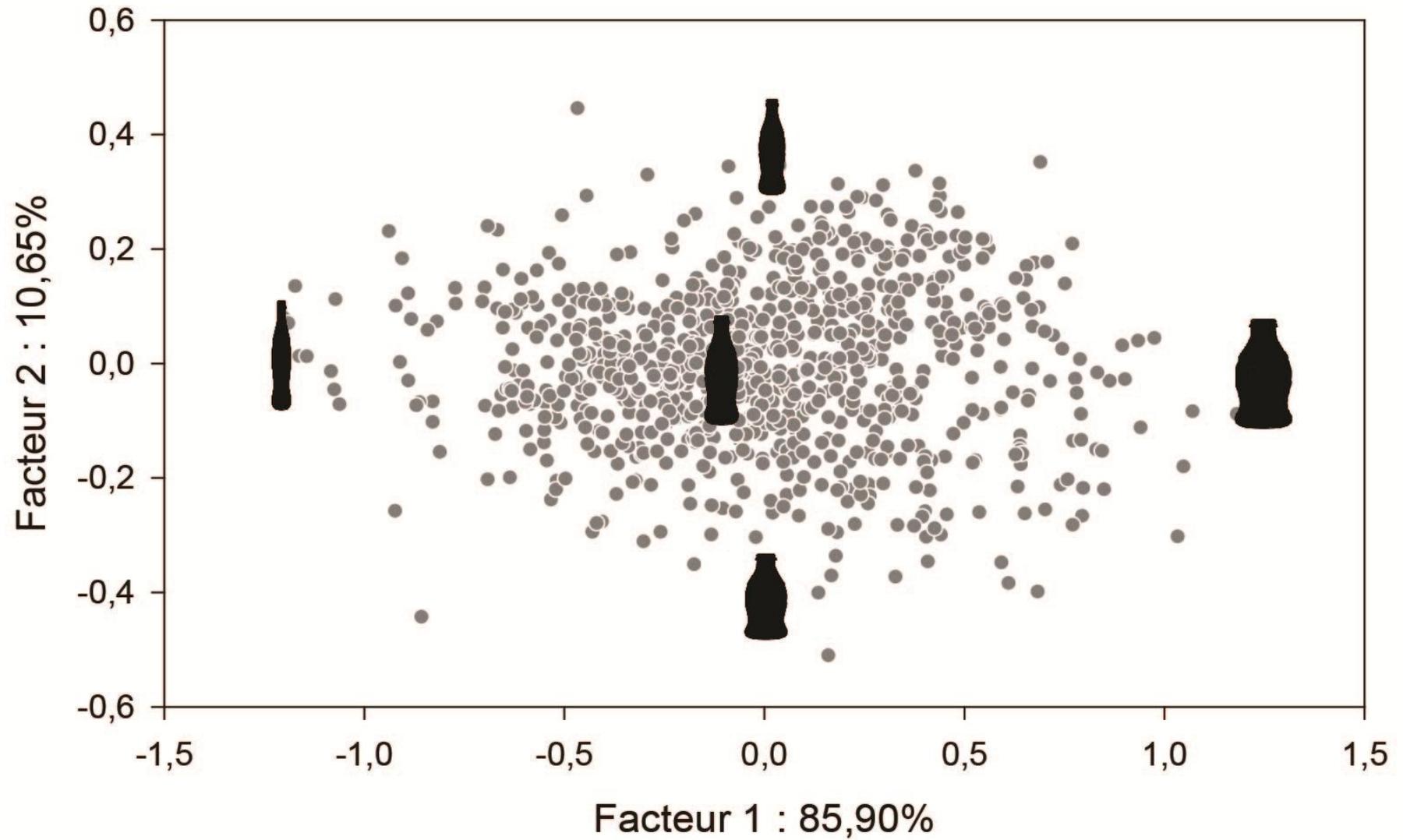
# Vers une approche spatiale de la donnée morphométrique...



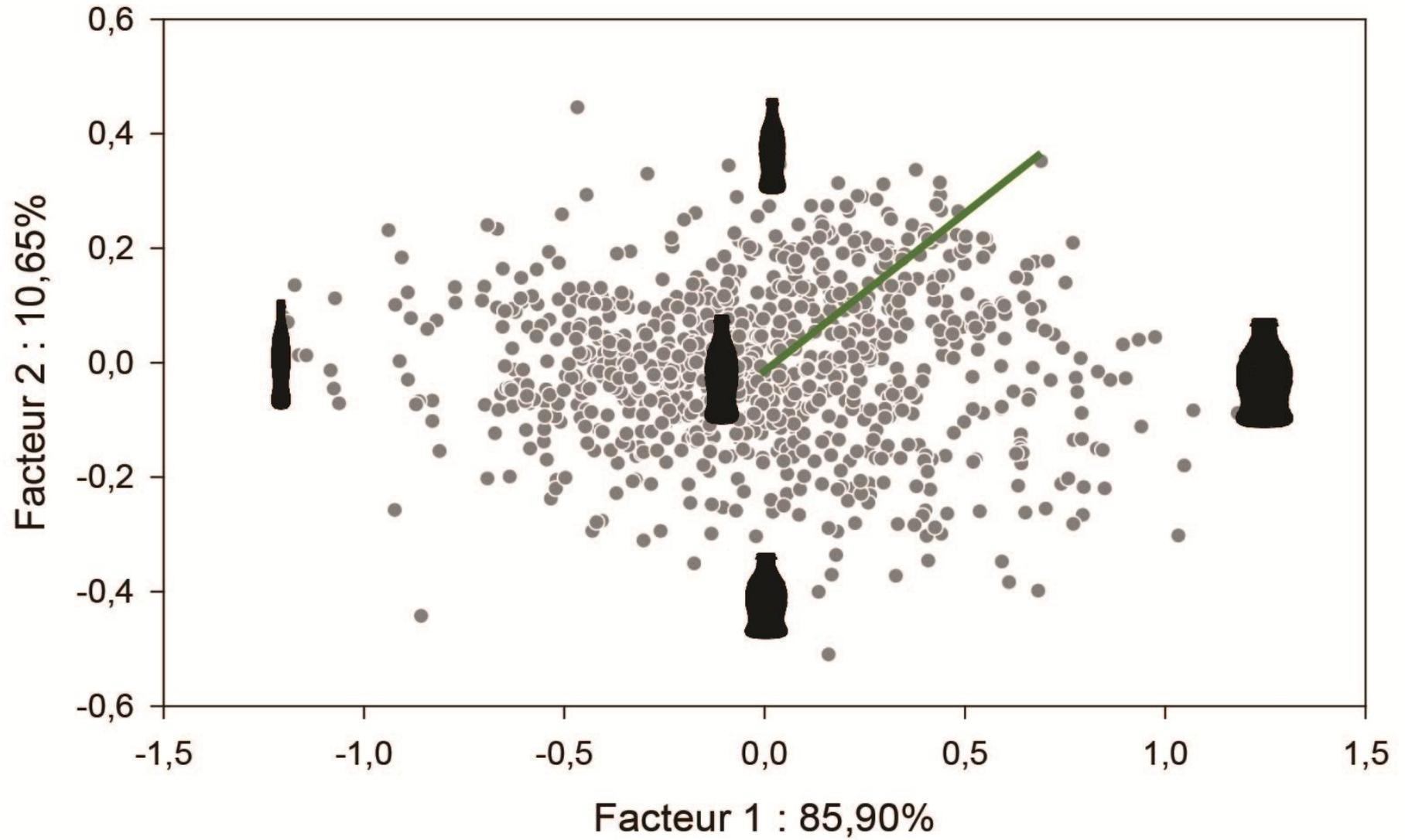
# La présente étude



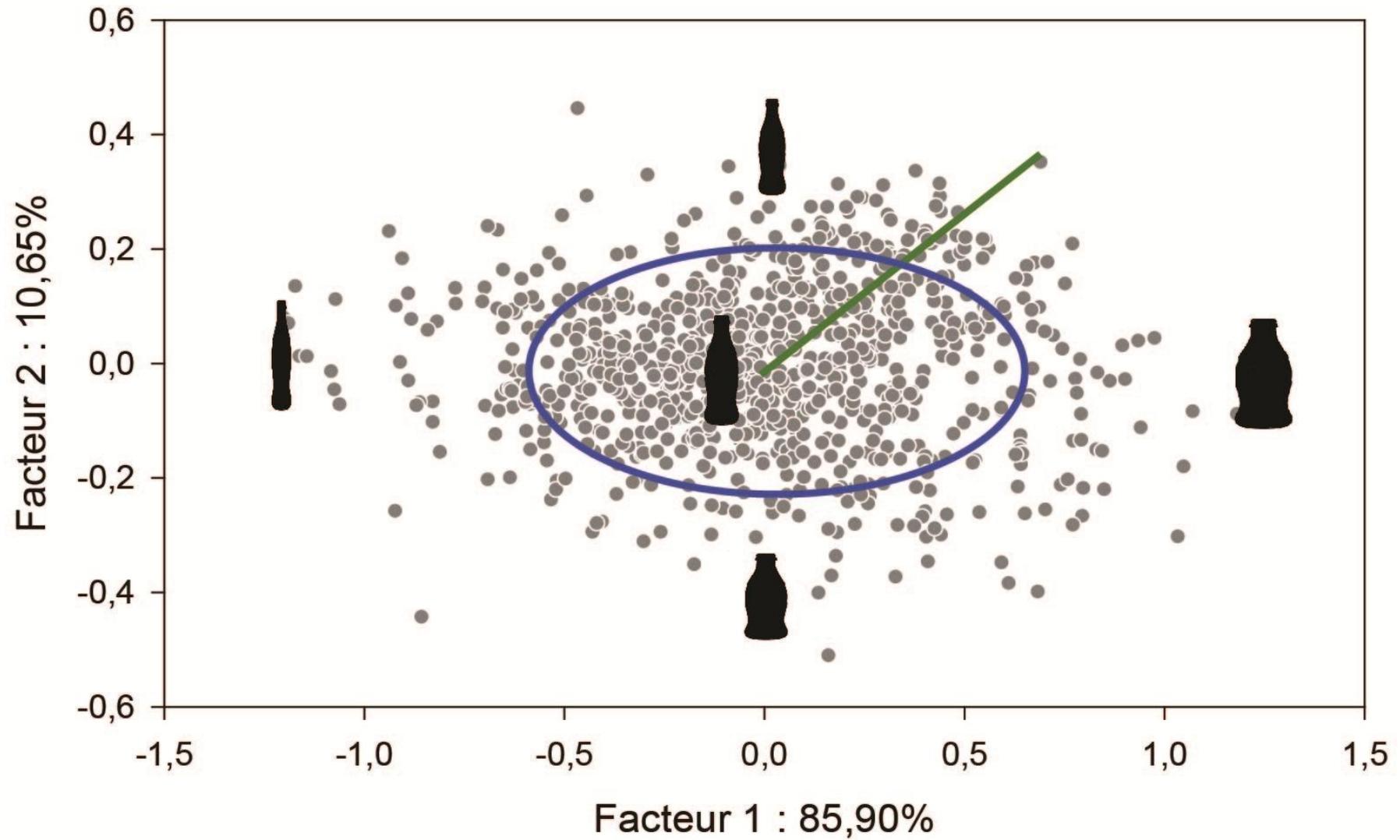
# La présente étude



# La présente étude



# La présente étude

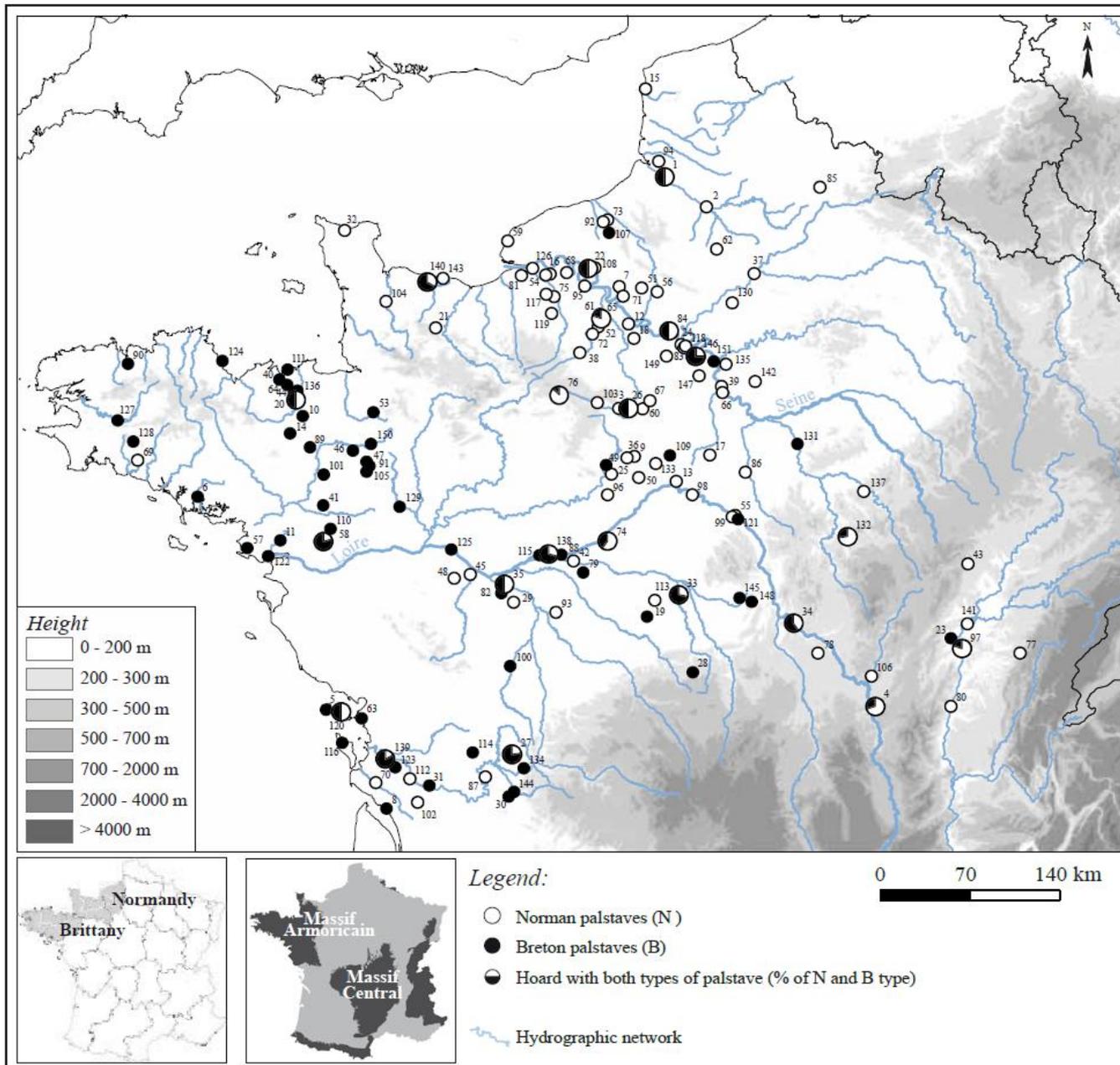


# La présente étude

Spatialisons!

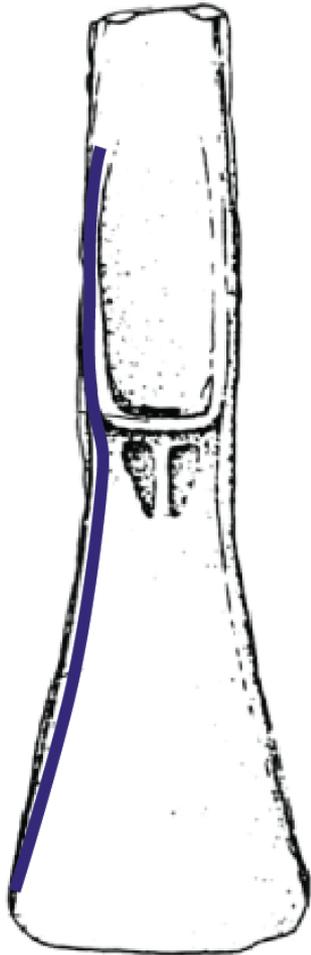


# Un corpus étendu

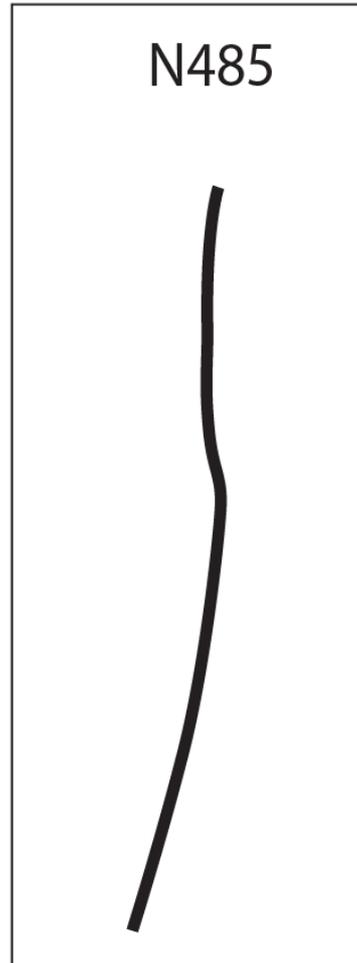


629 haches: 310 B,  
319 N, au lieu de  
203 et 177,  
respectivement.

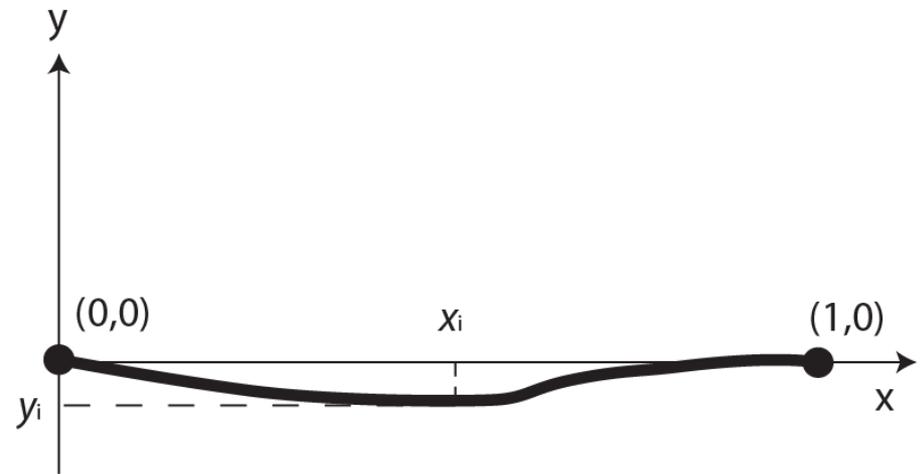
# Sampling



Dessin à partir de la documentation



Scan 300 dpi (TIFF)



*N485*  
*X1, Y1*  
*X2, Y2*  
*X3, Y3*  
...  
...  
*X200, Y200*

Sampling

# Une Procédure légèrement modifiée

Approche polynomiale classique

$$Y = \sum_{i=0}^p \beta_i X^i + \epsilon$$

Polynômes orthogonaux

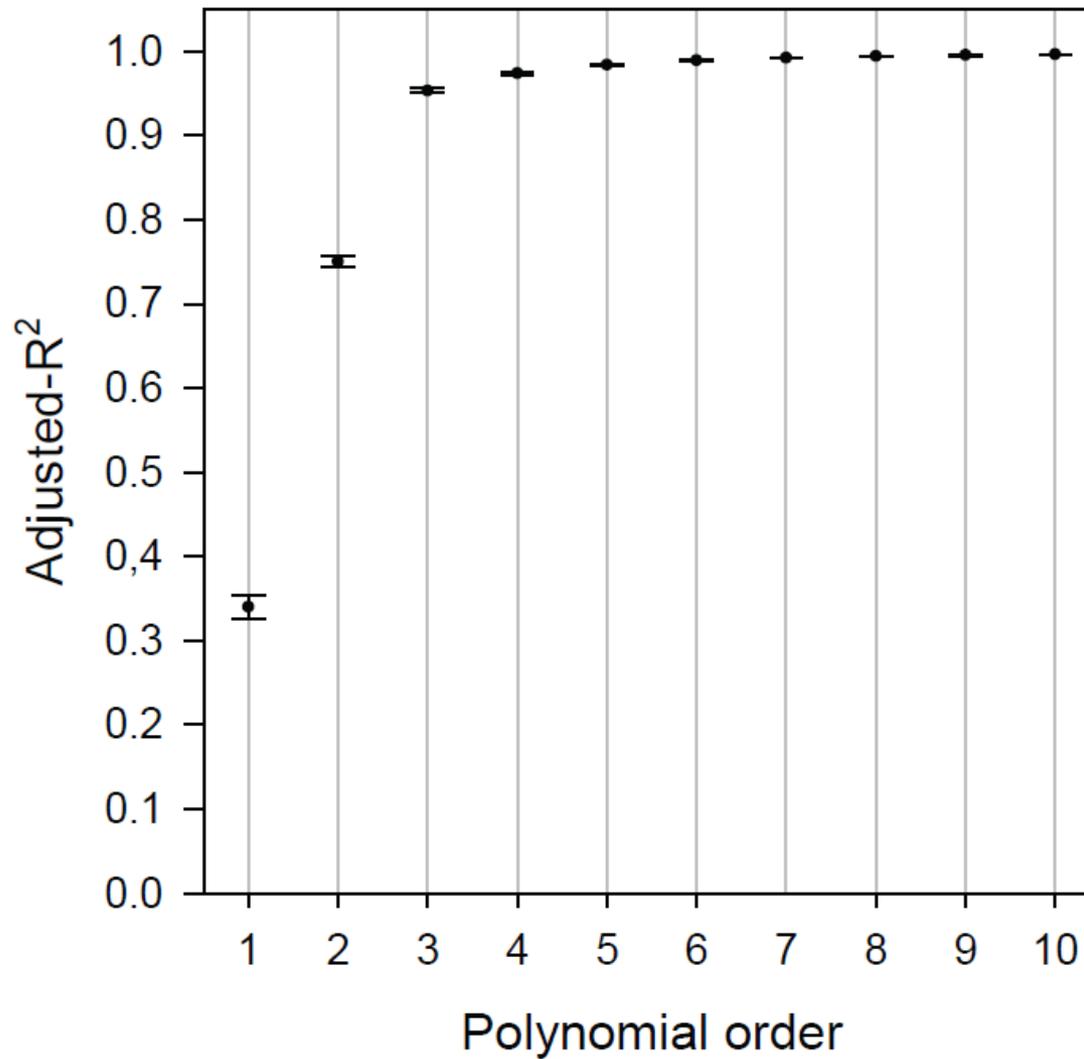
$$Y = \sum_{i=0}^p \alpha_i \varphi_i(X) + \epsilon$$
$$\langle \varphi_i(x) | \varphi_j(x) \rangle = \int_{-1}^1 \varphi_i(x) \varphi_j(x) dx = 0$$

La séquence de Legendre peut être obtenue par récurrence,  $\varphi_0(x) = 1$ ,  $\varphi_1(x) = x$ , en utilisant la

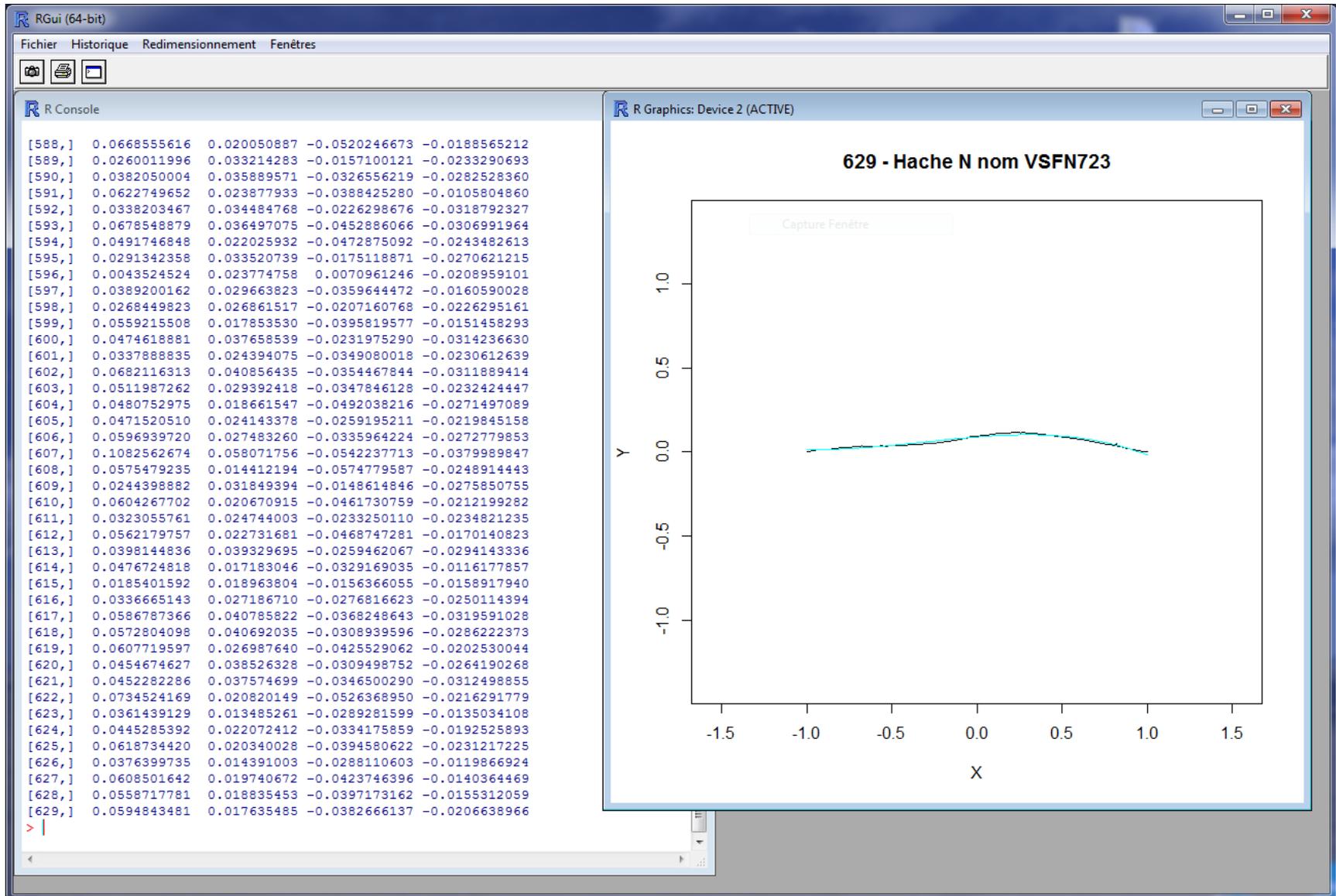
formule de Bonnet:

$$(n+1)\varphi_{n+1}(x) = (2n+1)x\varphi_n(x) - n\varphi_{n-1}(x)$$

# Une Procédure légèrement modifiée



# Une Procédure légèrement modifiée



R: package orthopolynom

$$\alpha_i = (\hat{\alpha}_{i,0}, \hat{\alpha}_{i,1}, \hat{\alpha}_{i,2}, \dots, \hat{\alpha}_{i,p})^T$$

# Detection des haches « bizarres » (outliers)

**Moyenne des groupes:**

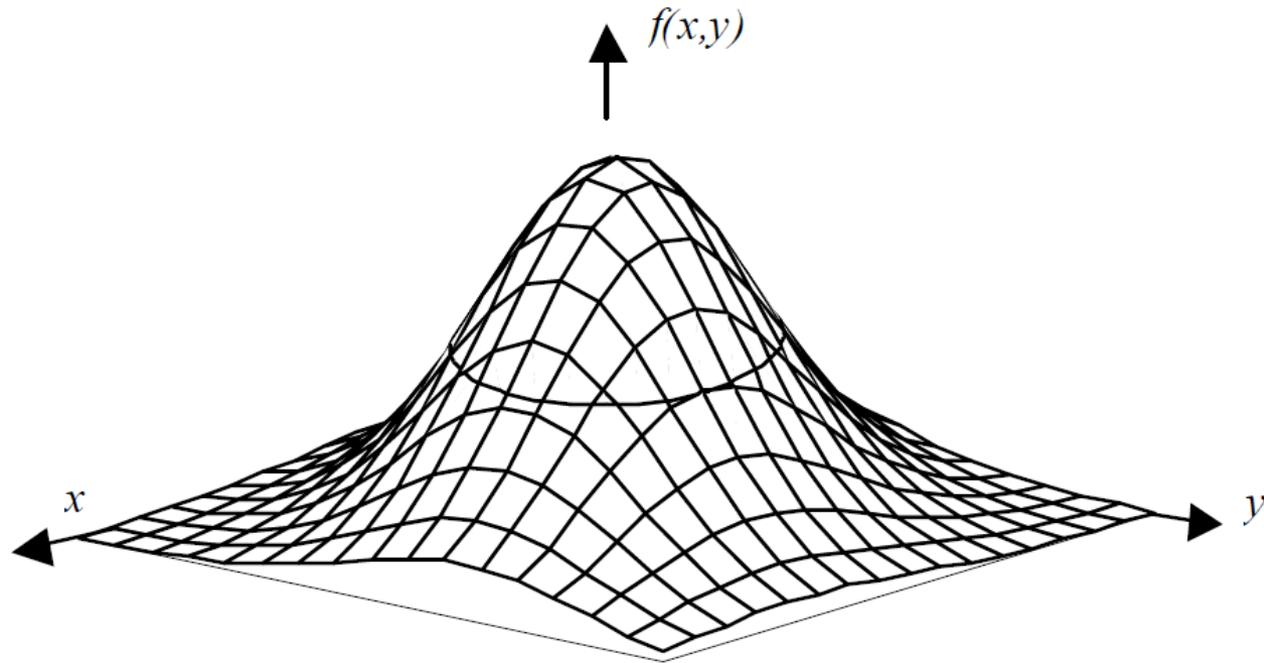
$\boldsymbol{\mu} = (\hat{\mu}_0, \hat{\mu}_1, \hat{\mu}_2, \dots, \hat{\mu}_p)^T$ , où  $\hat{\mu}_k$  est la moyenne de tous les  $\hat{\alpha}_{i,k}$  d'un groupe.

La **distance de chaque specimen au centroïde du groupe** peut être évaluée en utilisant le carré de la

distance de Mahalanobis,  $D_i^2$ :

$$D_i^2 = (\boldsymbol{\alpha}_i - \boldsymbol{\mu})^T \boldsymbol{\Sigma}^{-1} (\boldsymbol{\alpha}_i - \boldsymbol{\mu})$$

# Detection des haches « bizarres » (outliers)



Si  $\alpha$  suit une distribution multinormale ,  $Di^2 \sim \chi^2$  à  $p$  degrés de liberté (ici 4).

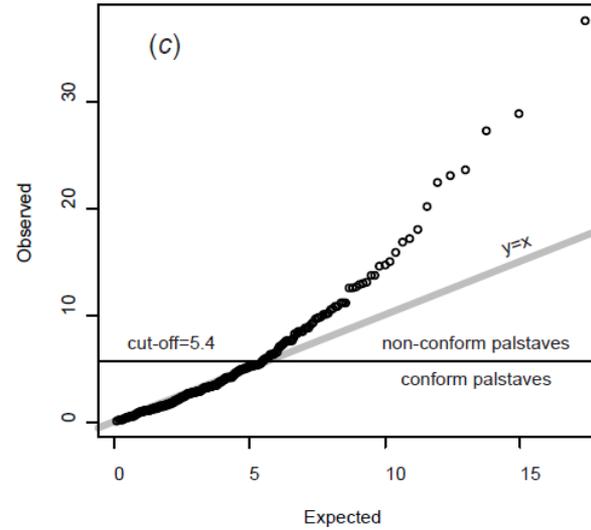
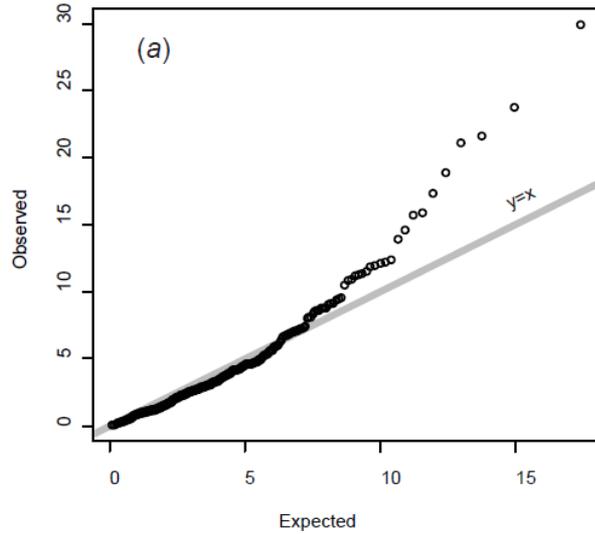
**Problème:** La présence d'outliers modifie  $\boldsymbol{\mu}$  et  $\boldsymbol{\Sigma}$ !

**Solution possible:** l'approche robuste

$$RD_i^2 = (\boldsymbol{\alpha}_i - \mathbf{t})^T \mathbf{S}^{-1} (\boldsymbol{\alpha}_i - \mathbf{t})$$

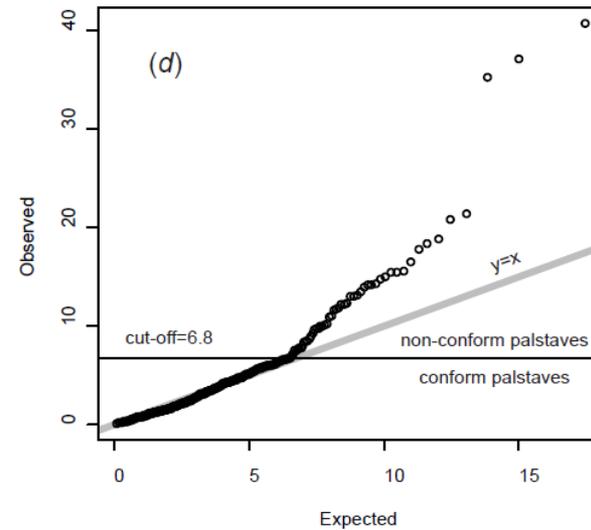
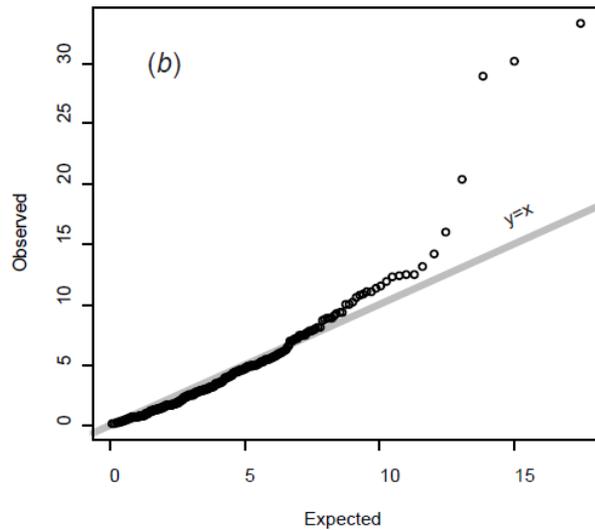
# Detection des haches « bizarres » (outliers)

NORMAN



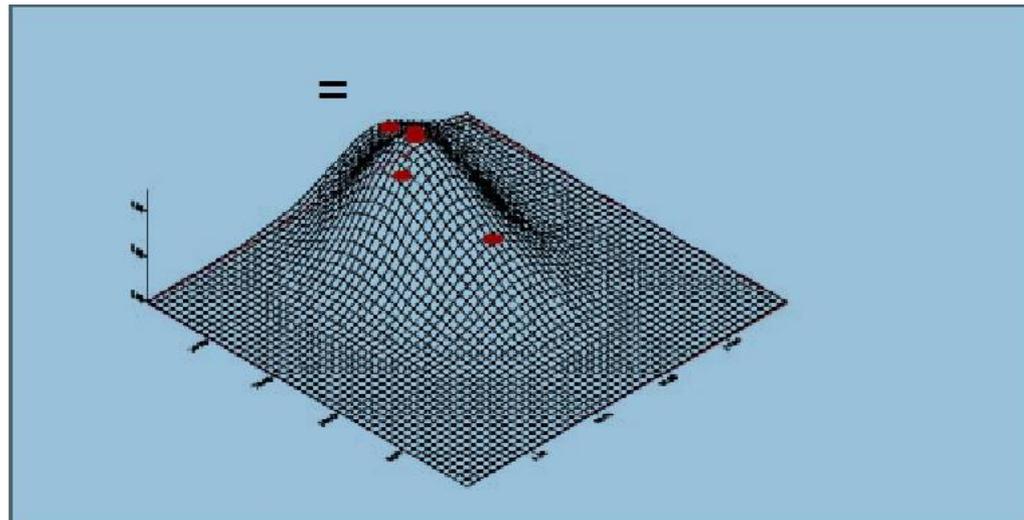
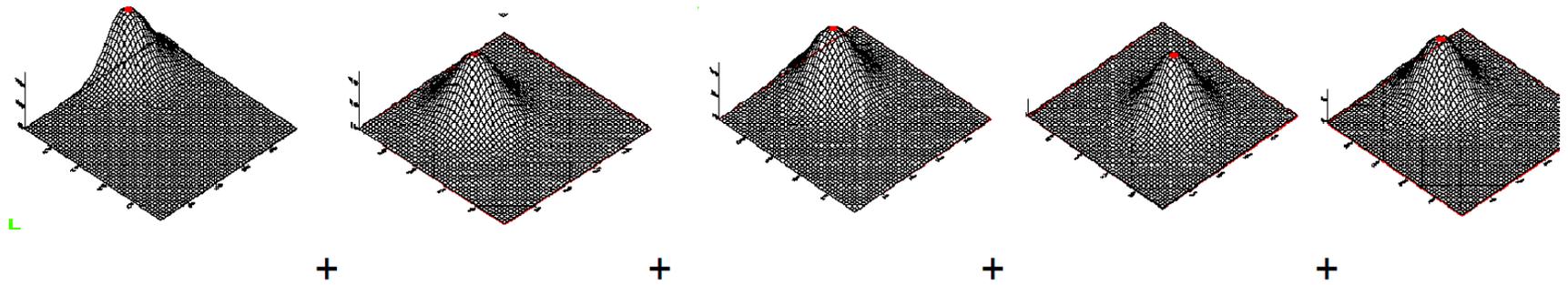
233 specimens conformes /  
77 specimens non-conformes  
= 3.03

BRETON



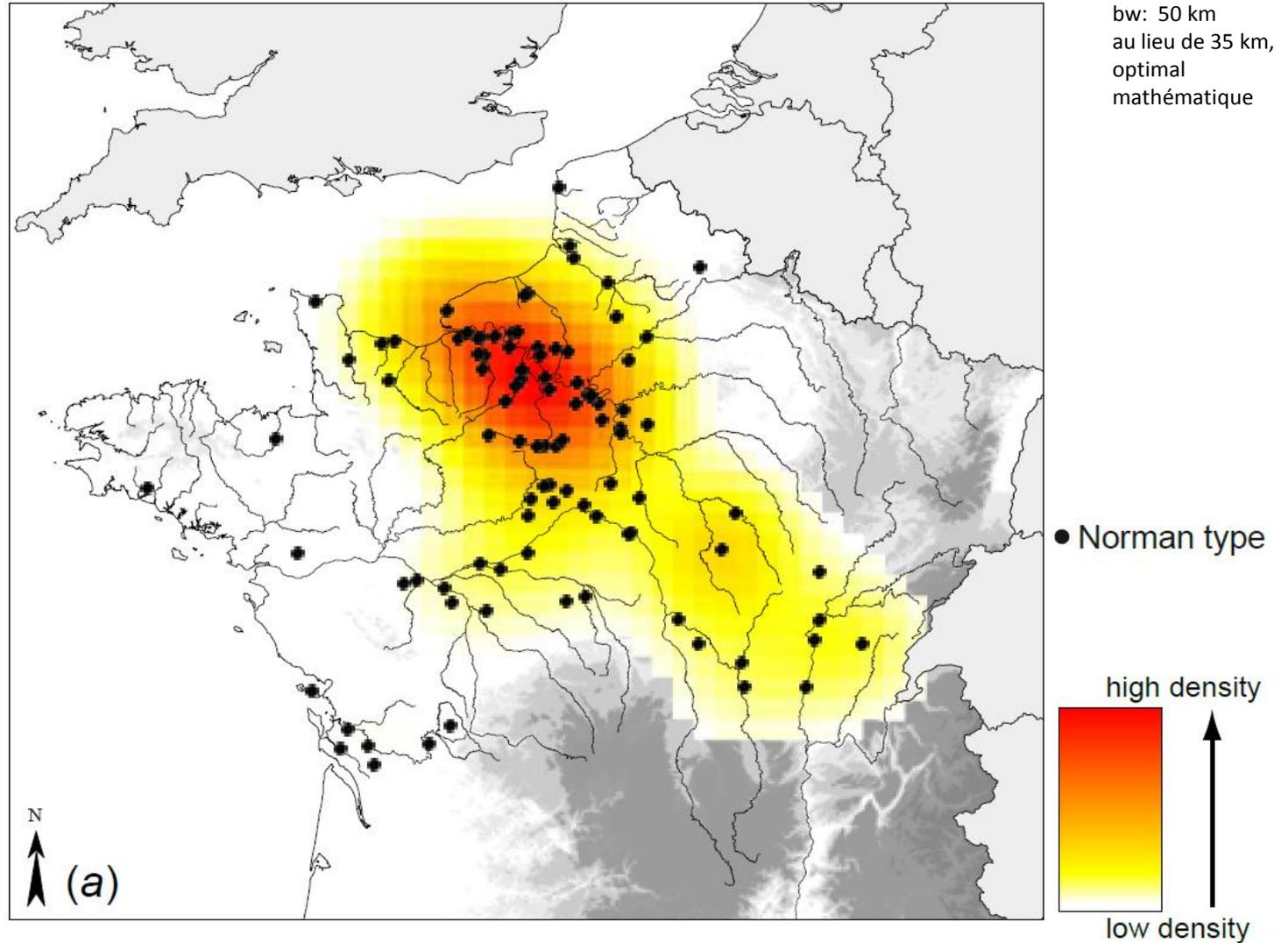
266 conformes /  
53 non-conformes = 5.02

## Représentation Kernel

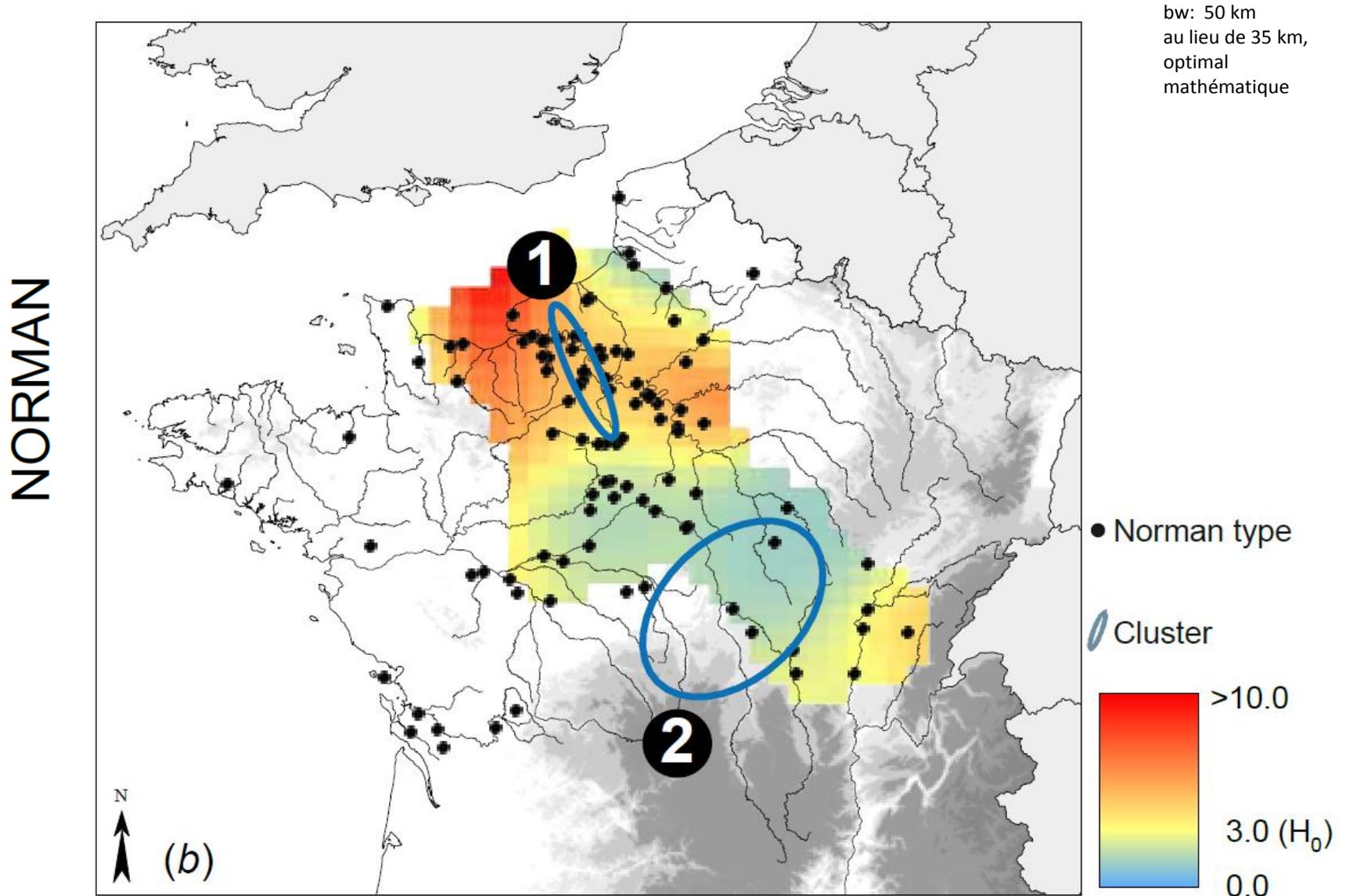


## Kernel density

NORMAN

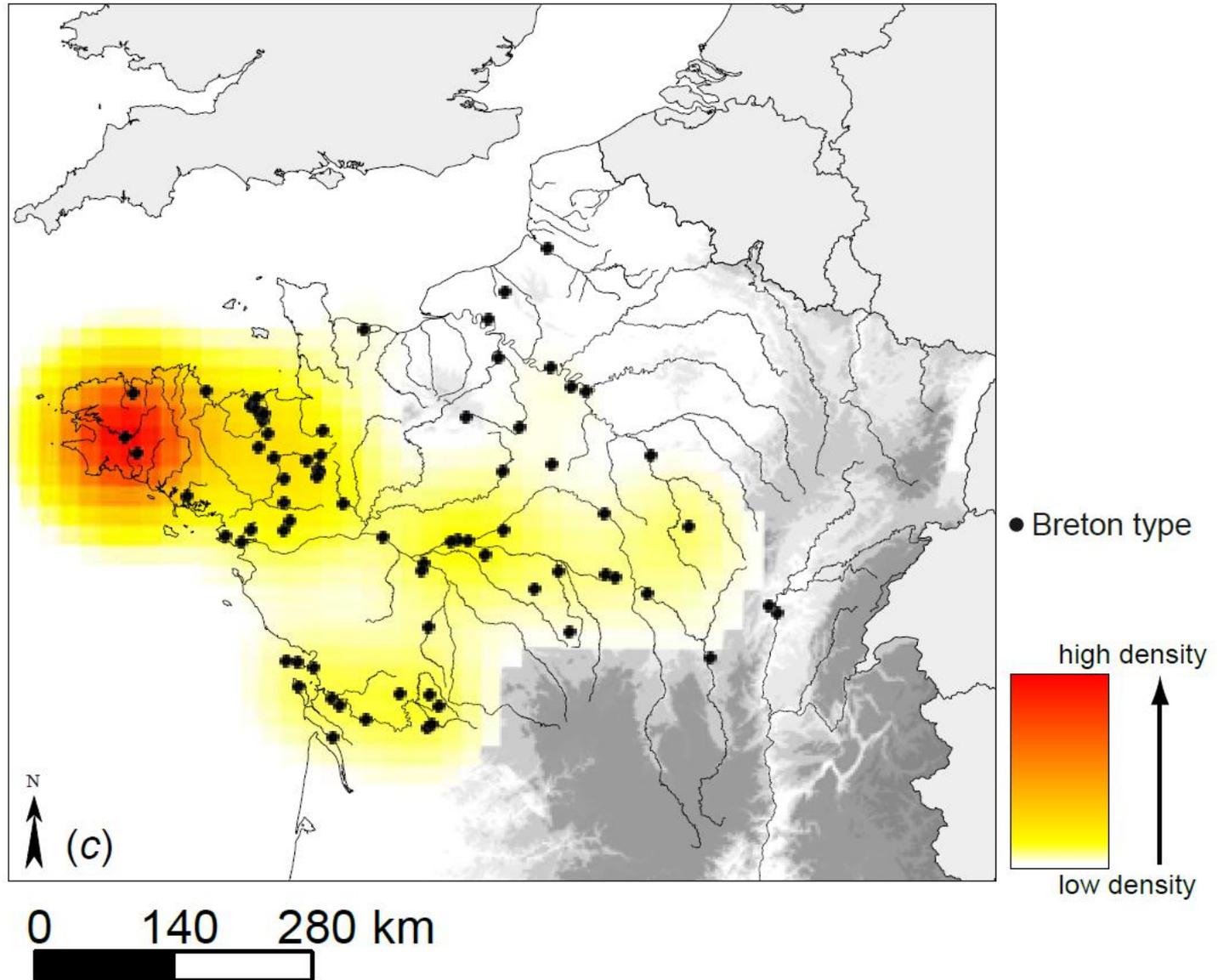


## Dual kernel



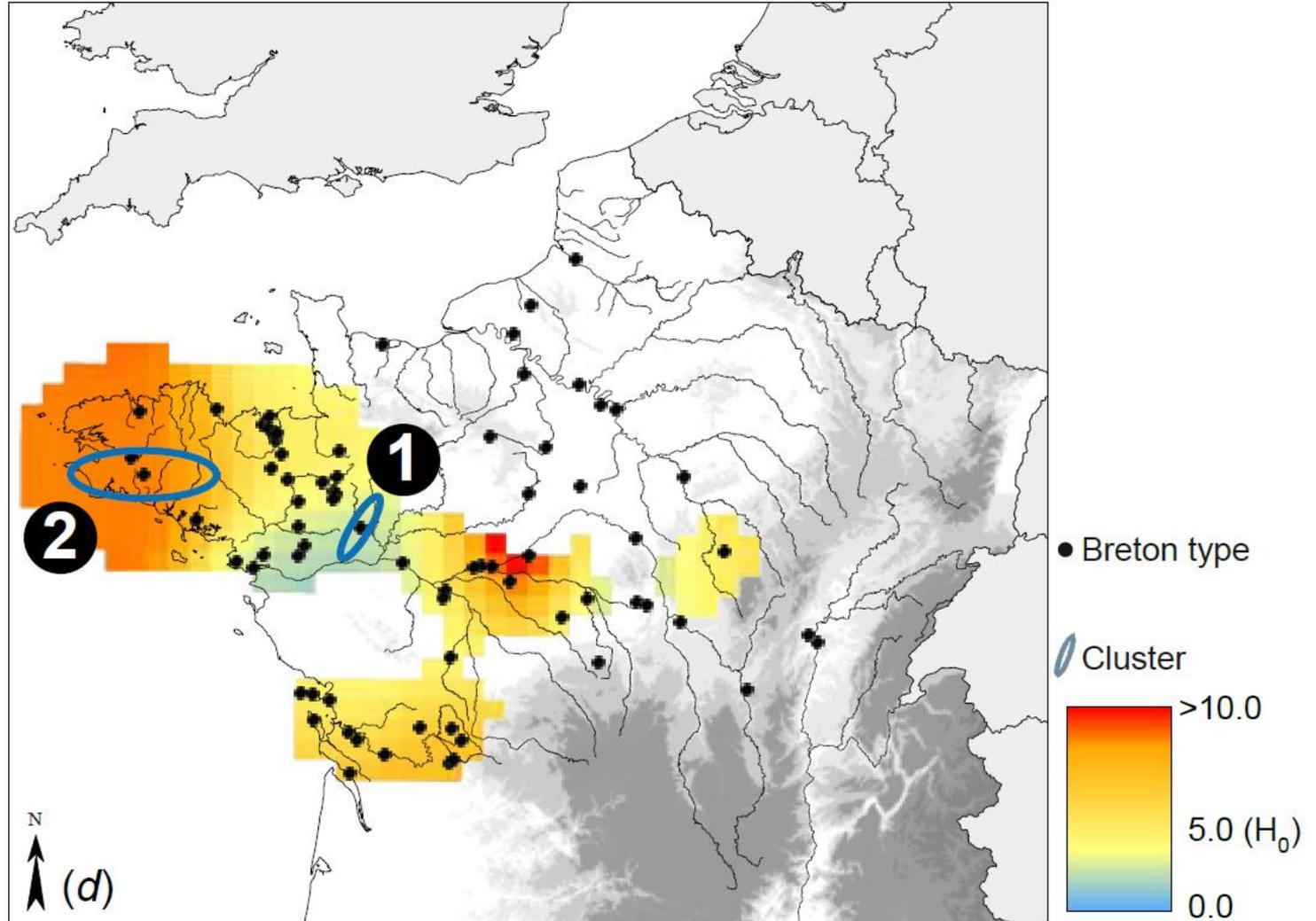
# Kernel density

BRETON



# Dual kernel

BRETON

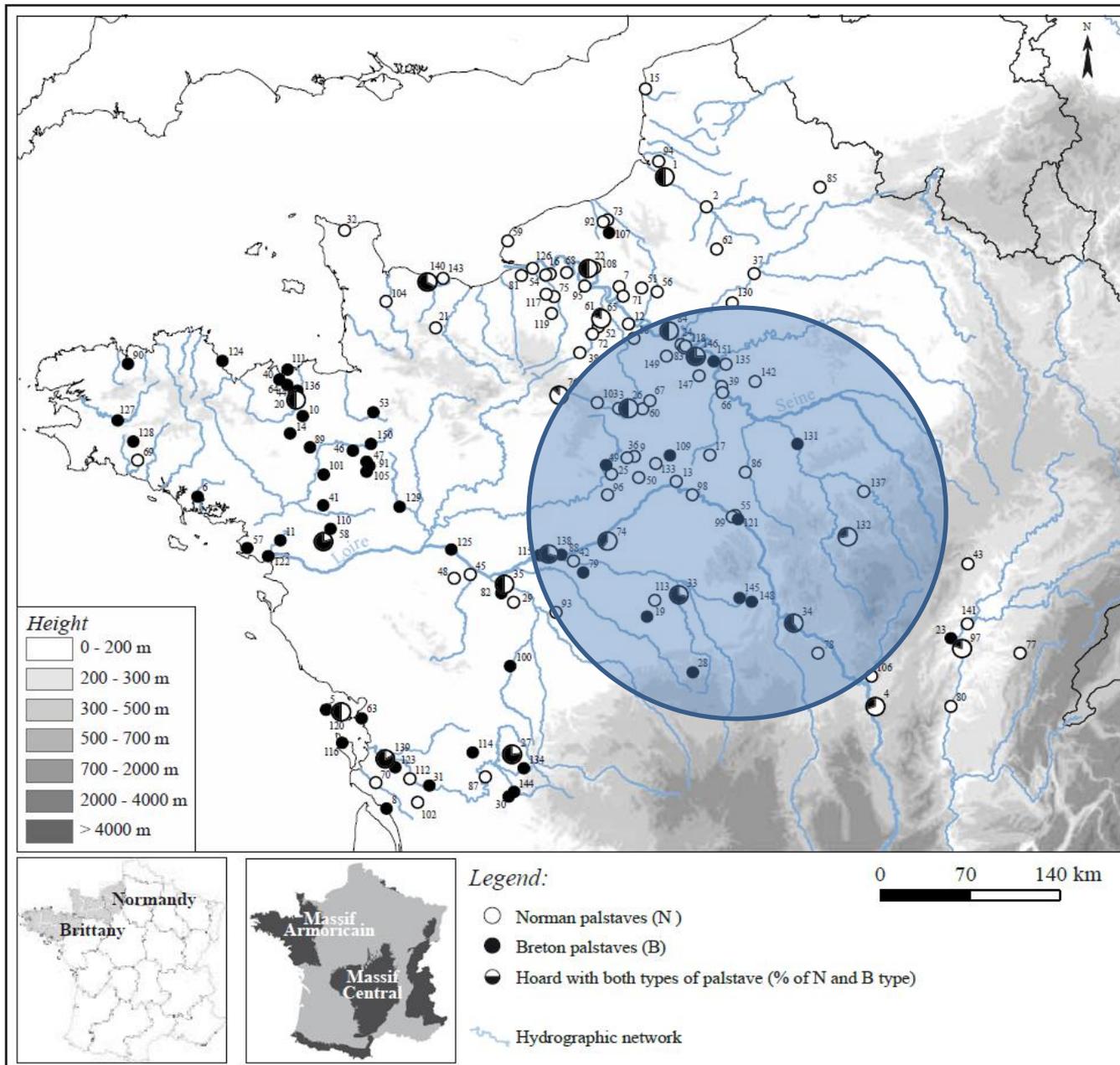


**Problème:** Le census n'est pas pris en compte

**Solution possible:** l'approche SatScan

**Test sur la loi binomiale – calcul des rapports de vraisemblance –  
calcul des  $p$ -values.**

# Approche spatiale

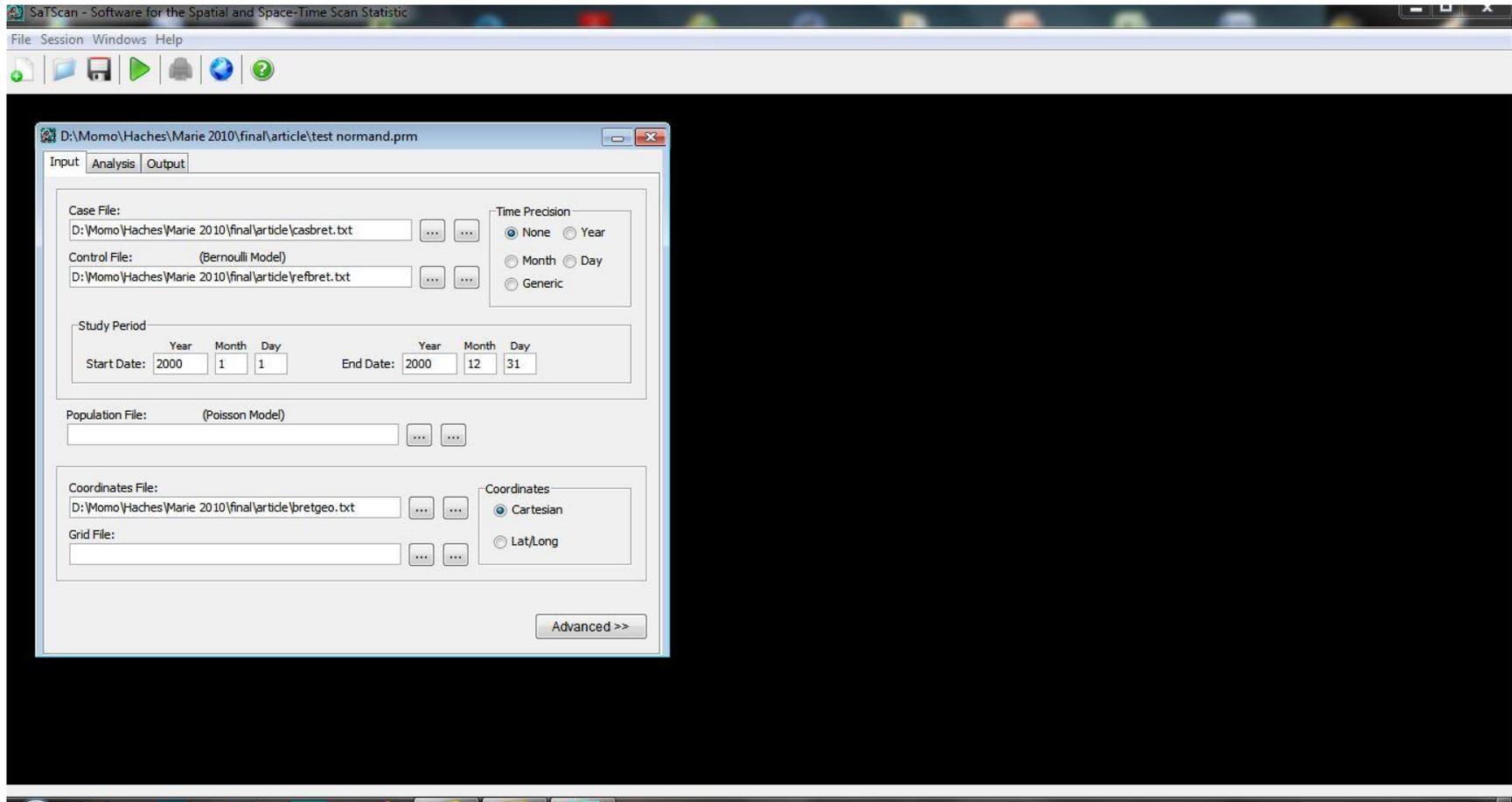


Ellipses ou cercles  
de tailles  
croissantes

Test sur la base  
de la loi de  
Bernouilli  
(distribution  
**binomiale**)

$H_0$ : le taux de  
« bizarres » est le  
même partout

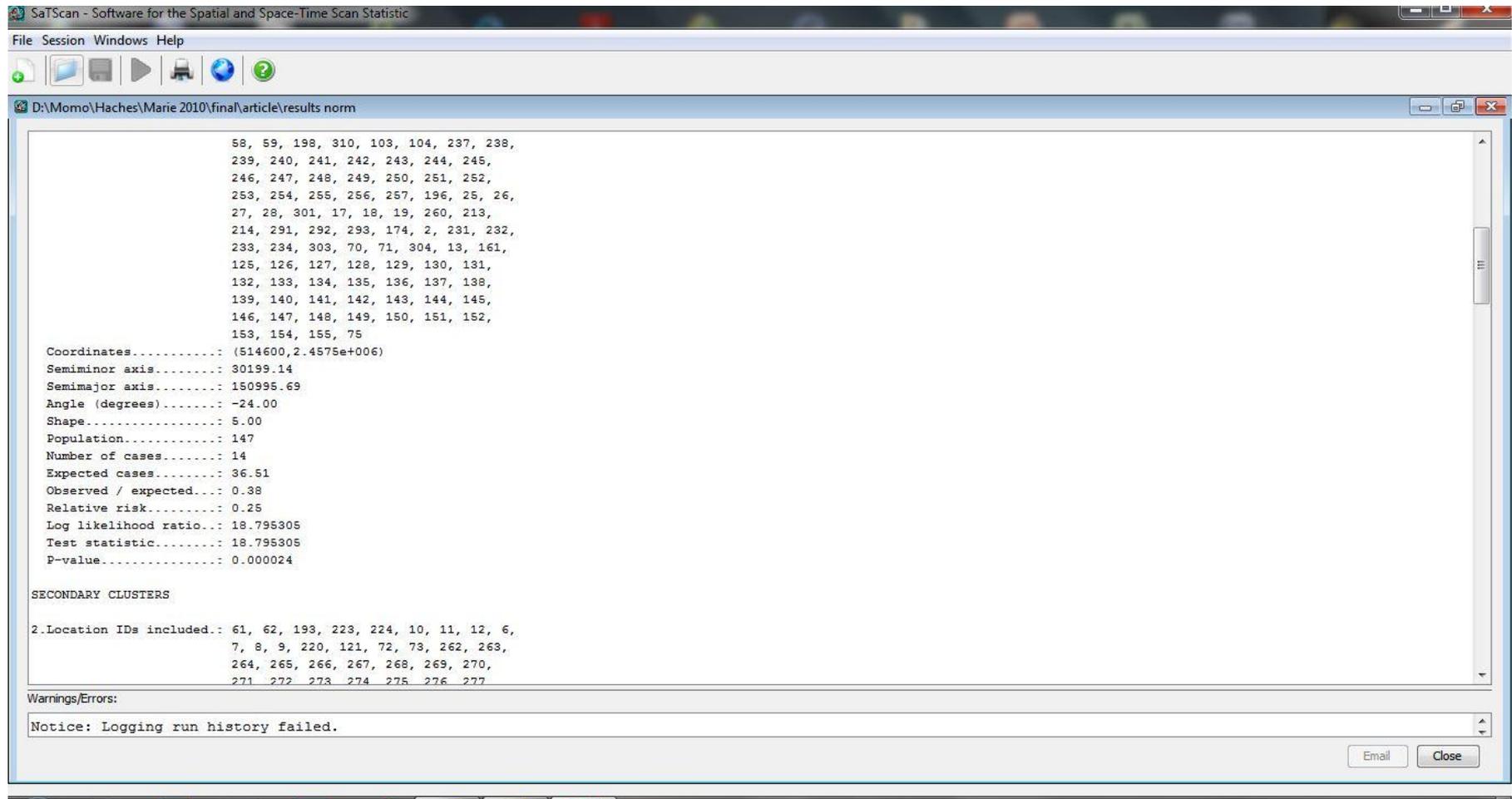
# Analyse spatiale



Un logiciel simple et gratuit:

<http://www.satscan.org>, Kulldorff et al. (1998, etc....)

# Analyse spatiale



SaTScan - Software for the Spatial and Space-Time Scan Statistic

File Session Windows Help

D:\Momo\Haches\Marie 2010\final\article\results norm

```
58, 59, 198, 310, 103, 104, 237, 238,  
239, 240, 241, 242, 243, 244, 245,  
246, 247, 248, 249, 250, 251, 252,  
253, 254, 255, 256, 257, 196, 25, 26,  
27, 28, 301, 17, 18, 19, 260, 213,  
214, 291, 292, 293, 174, 2, 231, 232,  
233, 234, 303, 70, 71, 304, 13, 161,  
125, 126, 127, 128, 129, 130, 131,  
132, 133, 134, 135, 136, 137, 138,  
139, 140, 141, 142, 143, 144, 145,  
146, 147, 148, 149, 150, 151, 152,  
153, 154, 155, 75  
Coordinates.....: (514600,2.4575e+006)  
Semiminor axis.....: 30199.14  
Semimajor axis.....: 150995.69  
Angle (degrees).....: -24.00  
Shape.....: 5.00  
Population.....: 147  
Number of cases.....: 14  
Expected cases.....: 36.51  
Observed / expected...: 0.38  
Relative risk.....: 0.25  
Log likelihood ratio..: 18.795305  
Test statistic.....: 18.795305  
P-value.....: 0.000024  
  
SECONDARY CLUSTERS  
  
2.Location IDs included.: 61, 62, 193, 223, 224, 10, 11, 12, 6,  
7, 8, 9, 220, 121, 72, 73, 262, 263,  
264, 265, 266, 267, 268, 269, 270,  
271, 272, 273, 274, 275, 276, 277
```

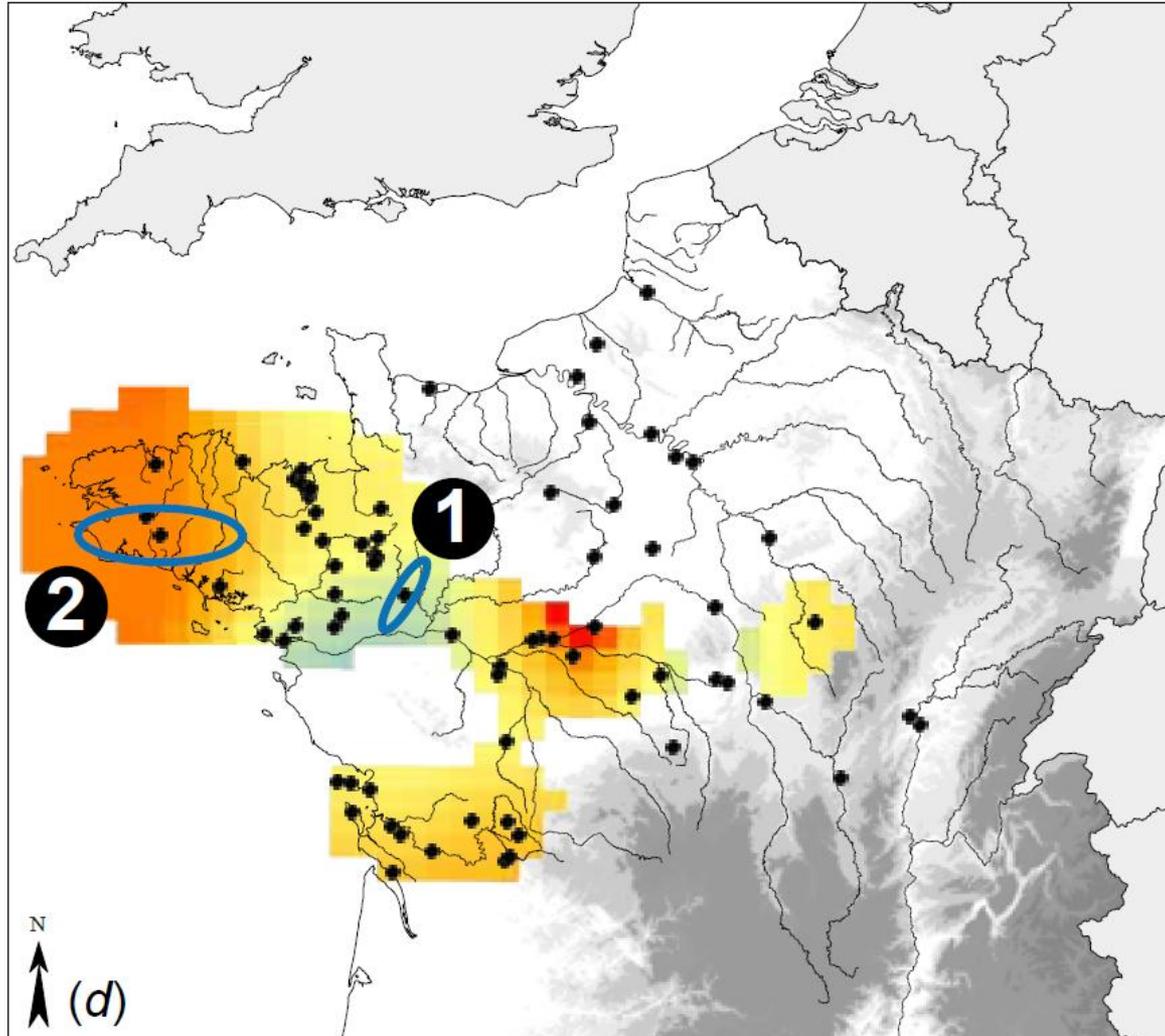
Warnings/Errors:  
Notice: Logging run history failed.

Email Close

<http://www.satscan.org>, Kulldorff et al. (1998, etc....)  
 $p$ -values obtenues par randomization (Monte-Carlo)

## Dual kernel

BRETON

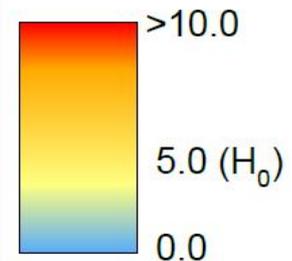


① : 5 haches  
5 non-conformes  
0.8 attendues  
 $p=0.048$

② : 159 haches  
16 non-conformes  
26 attendues  
 $p=0.702$

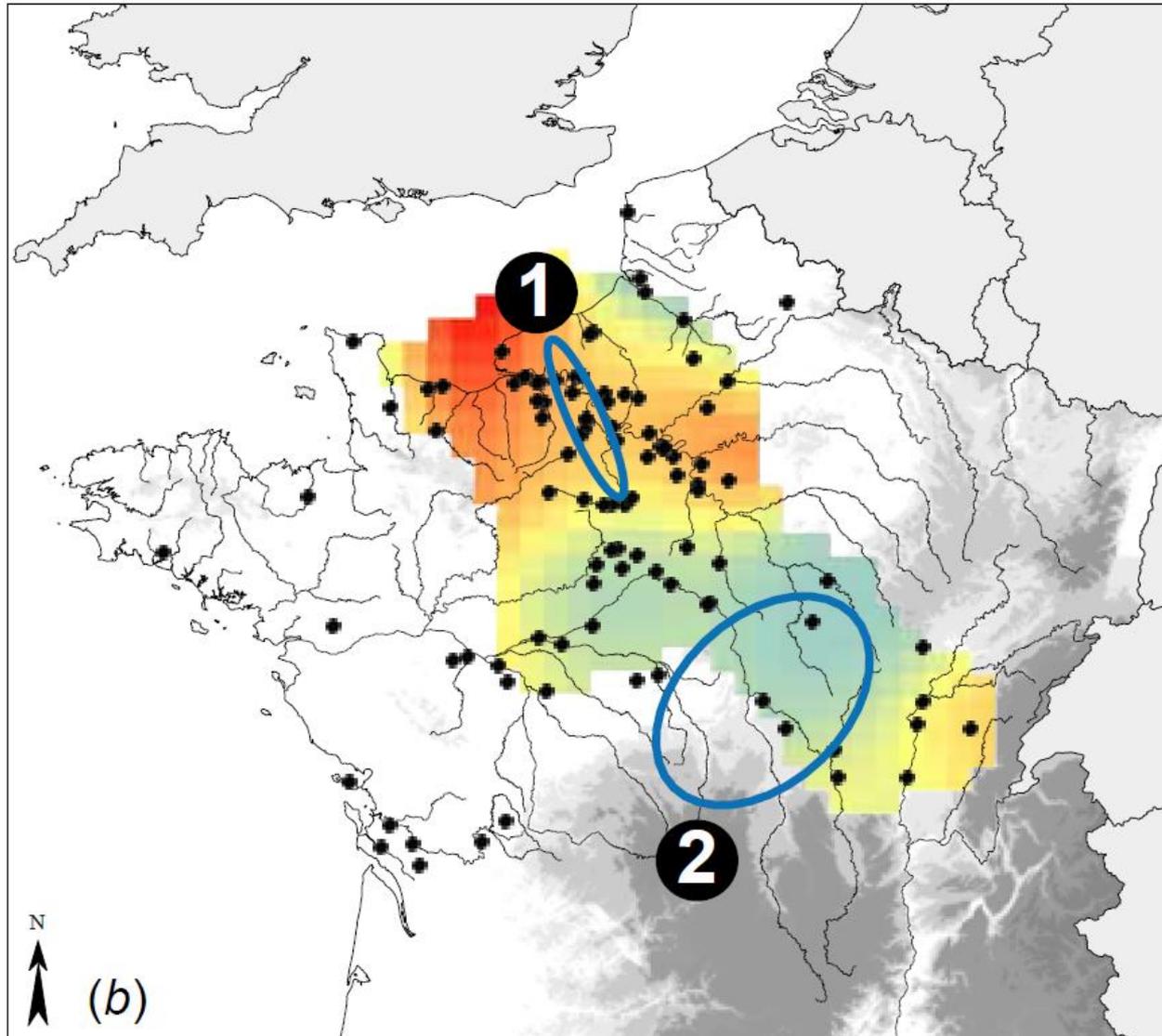
● Breton type

○ Cluster



## Dual kernel

NORMAN

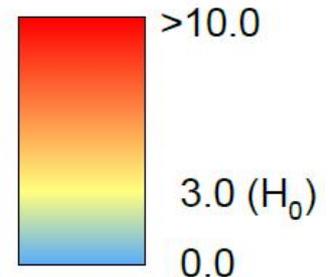


① : 148 haches  
14 non-conformes  
37 attendues  
 $p = 10^{-5}$

② : 89 haches  
38 non-conformes  
22 attendues  
 $p = 0.027$

● Norman type

○ Cluster



# Une histoire cohérente...

Des travaux discrets...

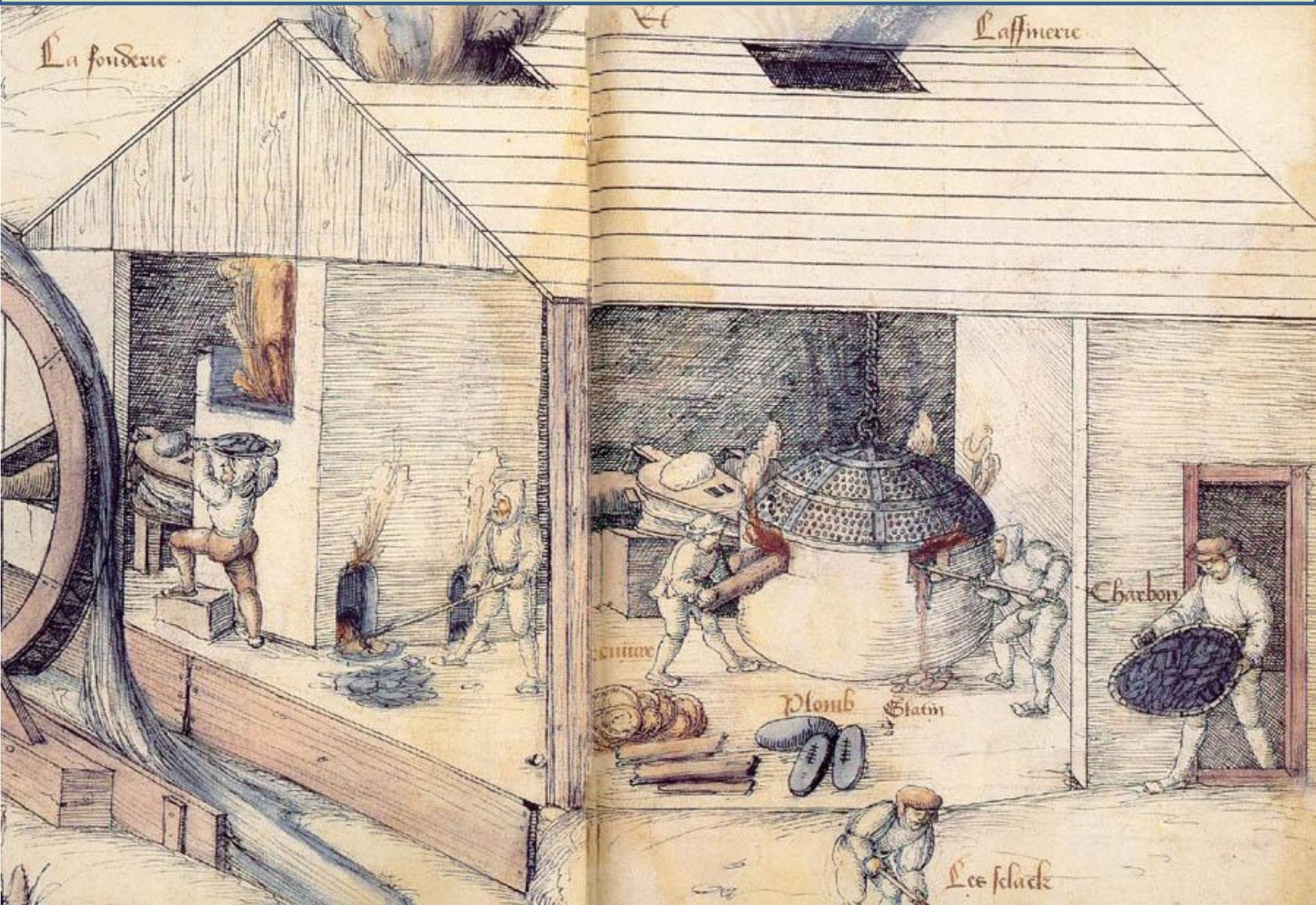


# Une histoire cohérente...

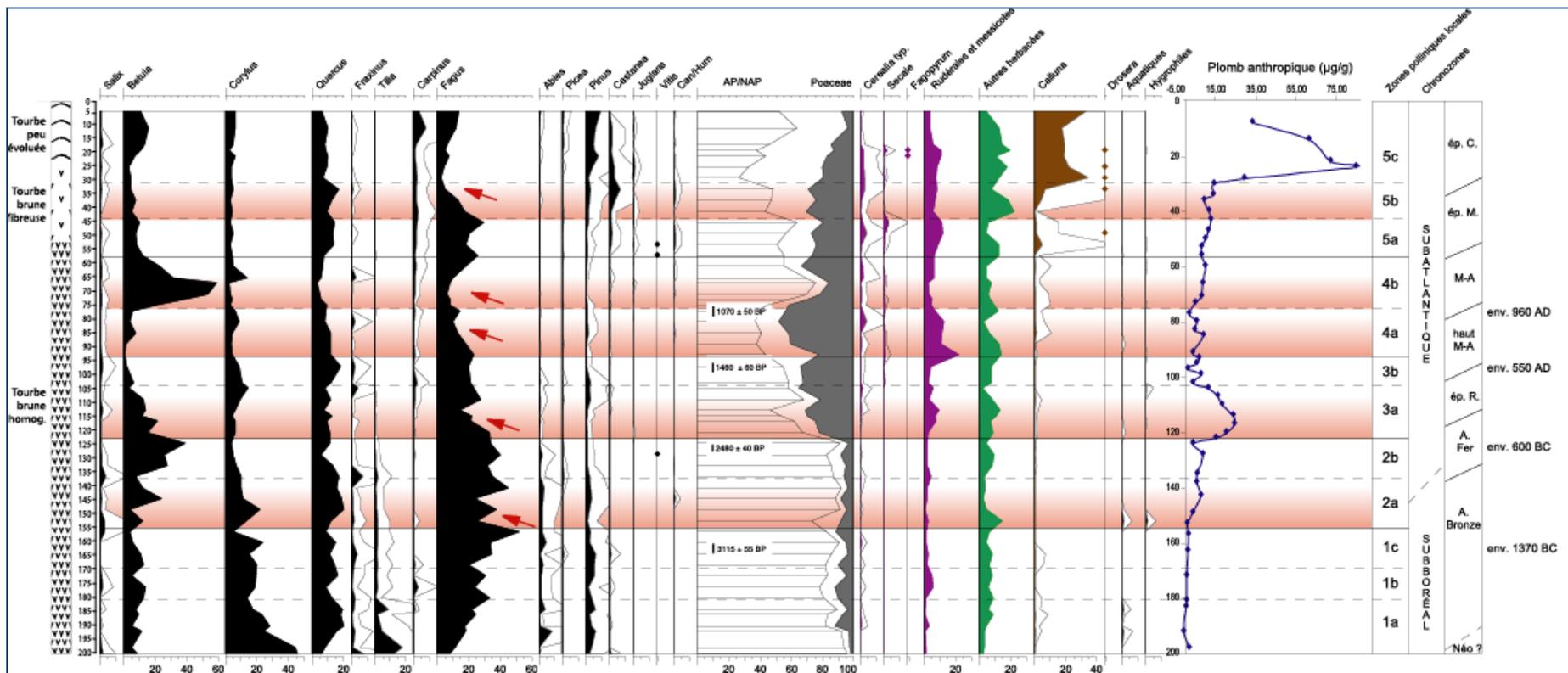


Mine de plomb/ zinc dans le Yukon

# Une histoire cohérente...



# Une histoire cohérente...

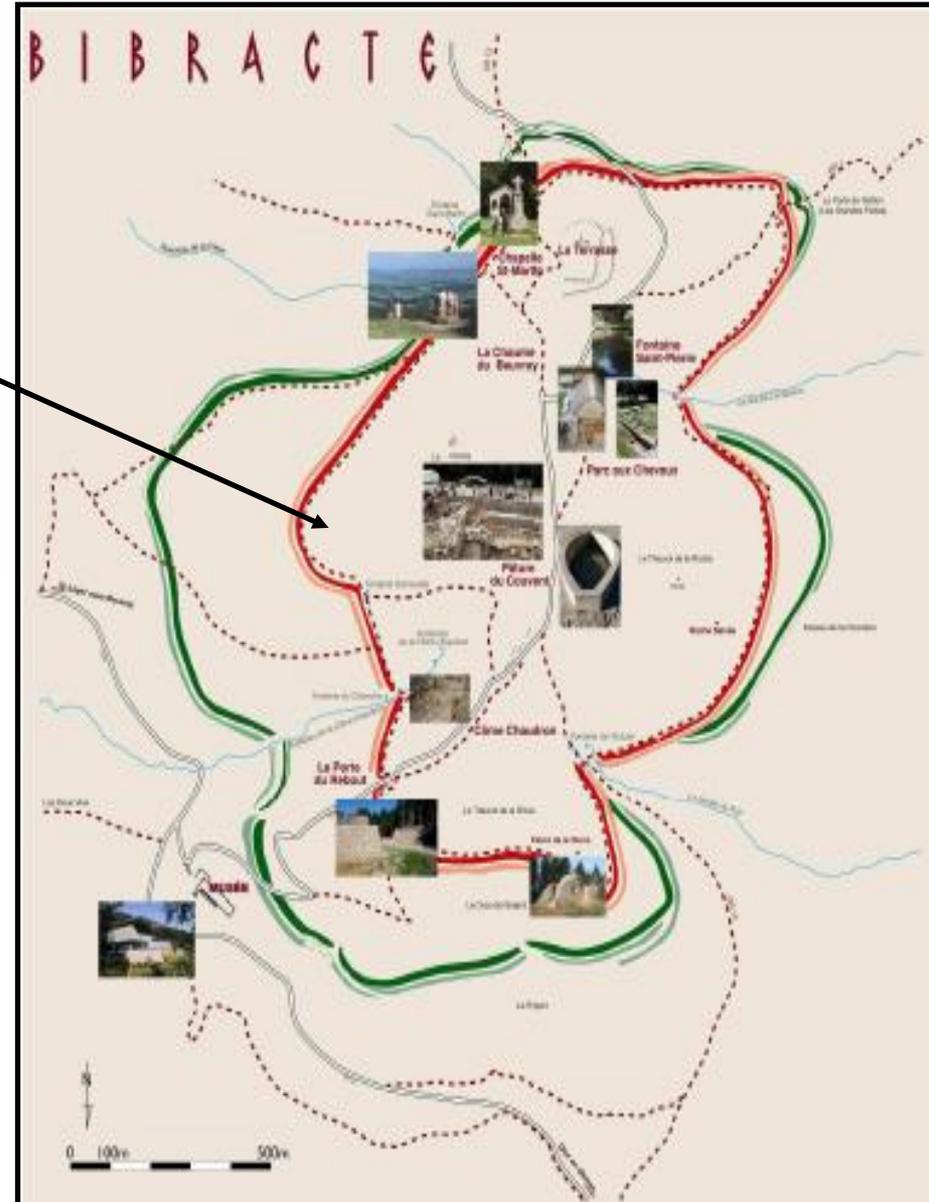
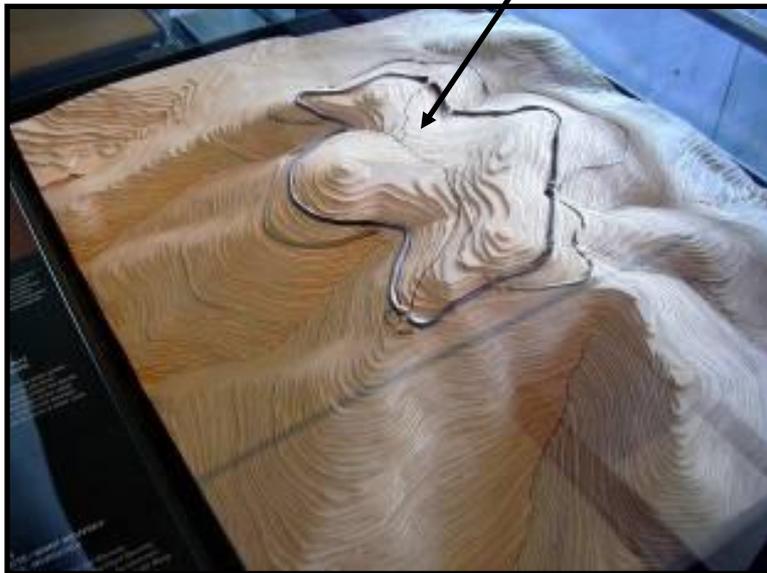


Monna, F., Petit, C., Guillaumet, J.-P., Jouffroy-Bapicot, I., Blanchot, C., Dominik, J., Losno, R., Richard, H., Lévêque, J., Chateau, C. History and environmental impact of mining activity in Celtic Aeduan territory recorded in a peat-bog (Morvan – France). *Environ. Sci. Technol.*, 38, 3, 657-673, 2004

Une histoire cohérente...



# Une histoire cohérente...



# Une histoire cohérente...

mais complexe....

