Cours 2023-2024:
La perception des objets mathématiques élémentaires:
Formes géométriques, motifs et graphiques
Perception of elementary mathematical objects:
Geometric shapes, patterns, and graphics

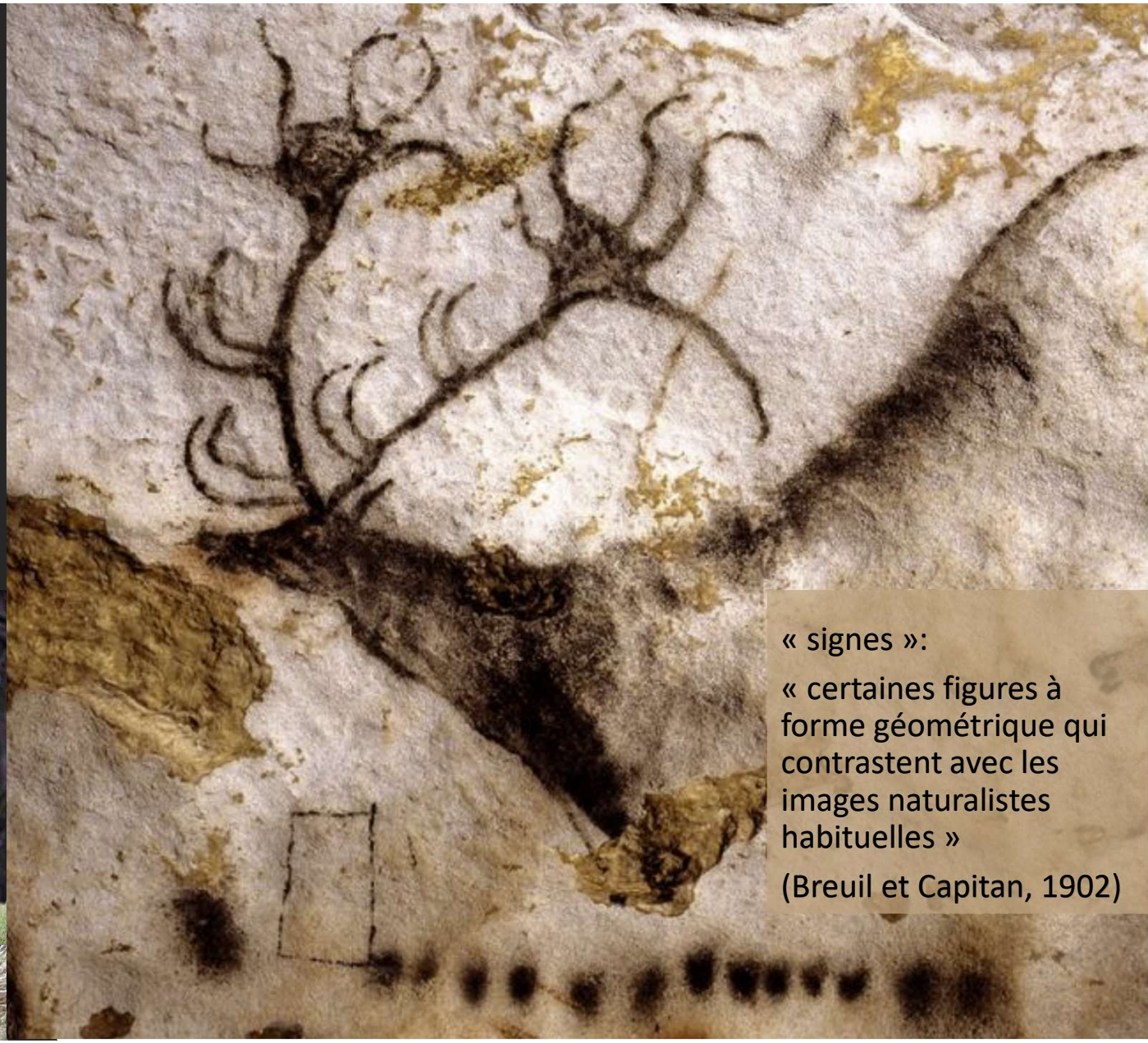
Stanislas Dehaene
Chaire de Psychologie Cognitive Expérimentale

Cours n°1

L'origine des symboles géométriques depuis la préhistoire: un langage de la pensée ?

The origins of geometric symbols since prehistory: A language of thought?

Iconic and symbolic drawings in the Lascaux cave



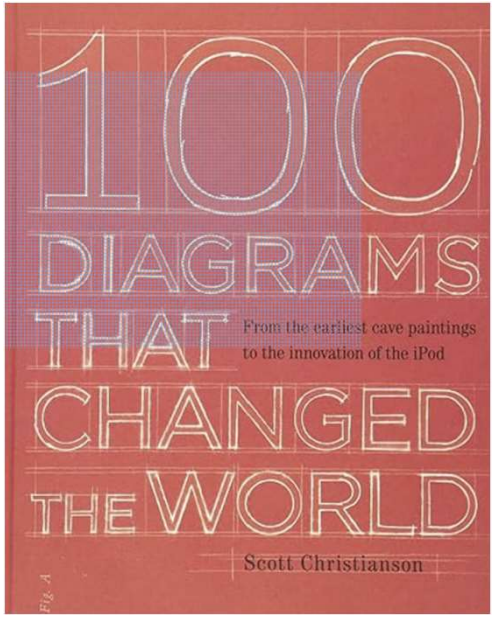
« signes »:

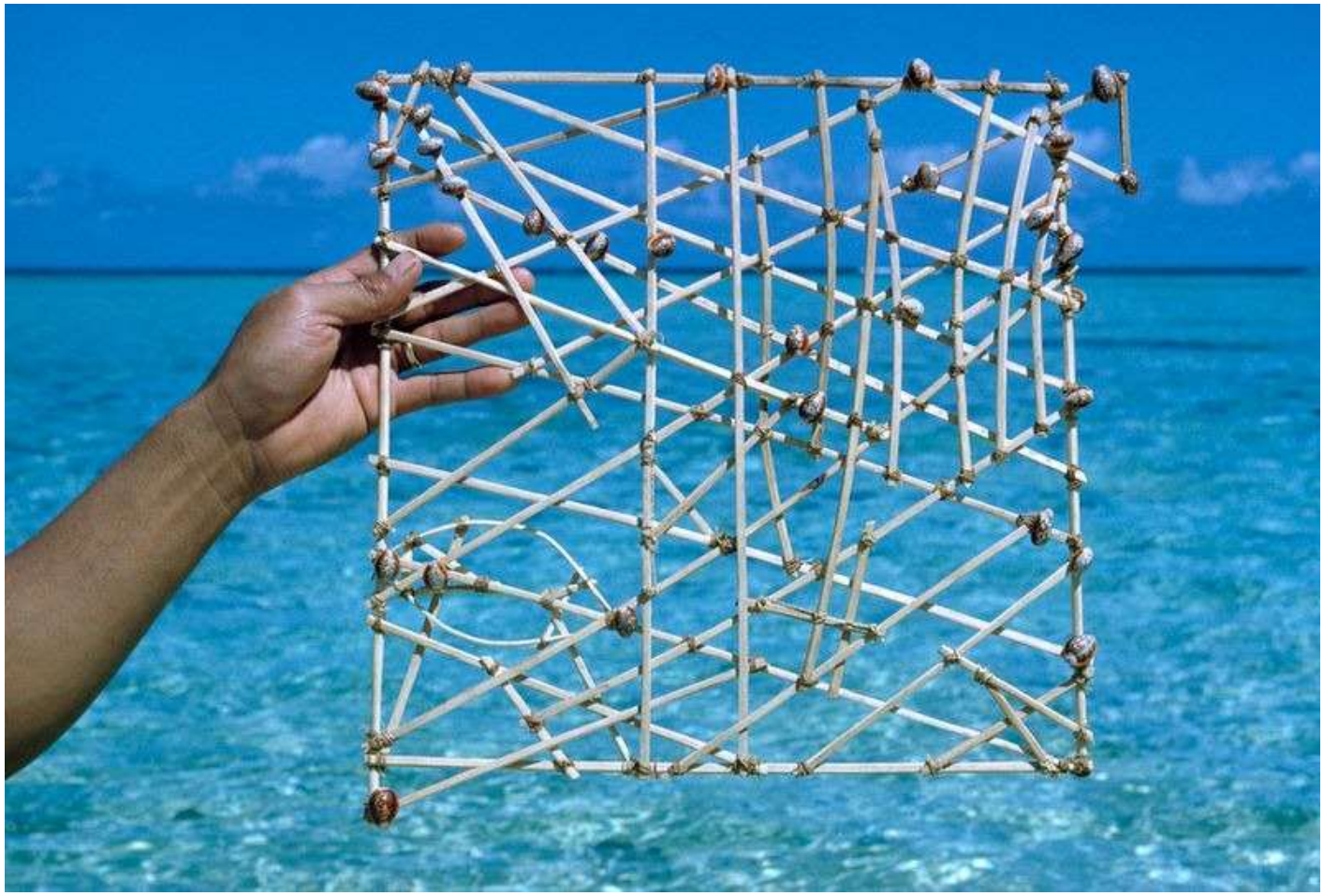
« certaines figures à forme géométrique qui contrastent avec les images naturalistes habituelles »

(Breuil et Capitan, 1902)

Theme of the course: The universal human propension for geometrical shapes, patterns, and diagrams

Diagram = a figure made of lines and shapes, which serves as a plan, a sketch, an outline, a graphic representation of relationships between parts or between variables.



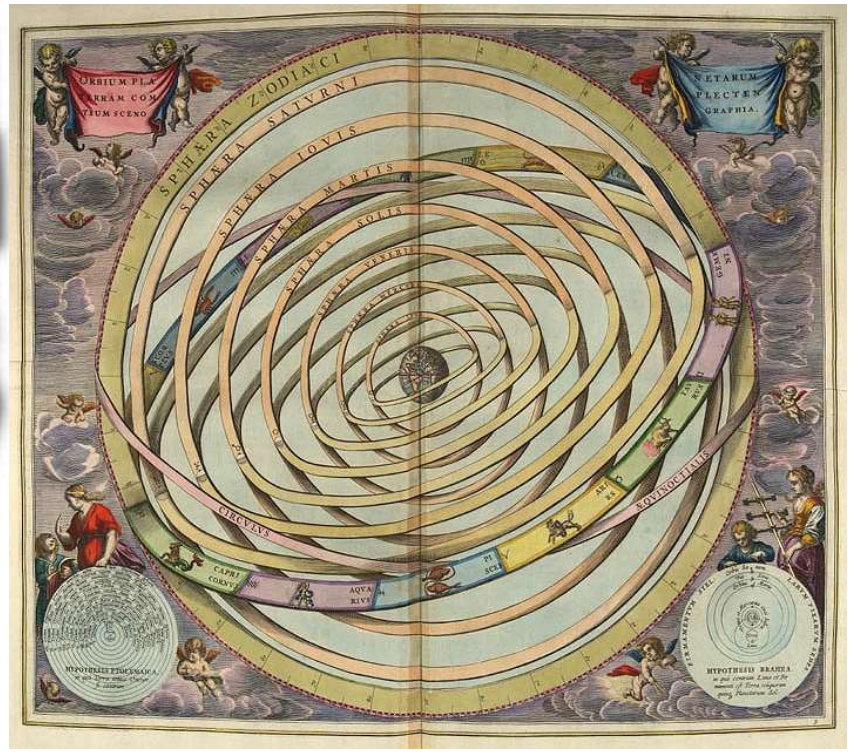


Marshall Islands navigation chart

We seem to use a small array of « platonic » shapes to construct mental models of the world

… even when these models are false !
We may speak of an **idealization by a geometric model.**

Babylonian map of the world (600 BC)



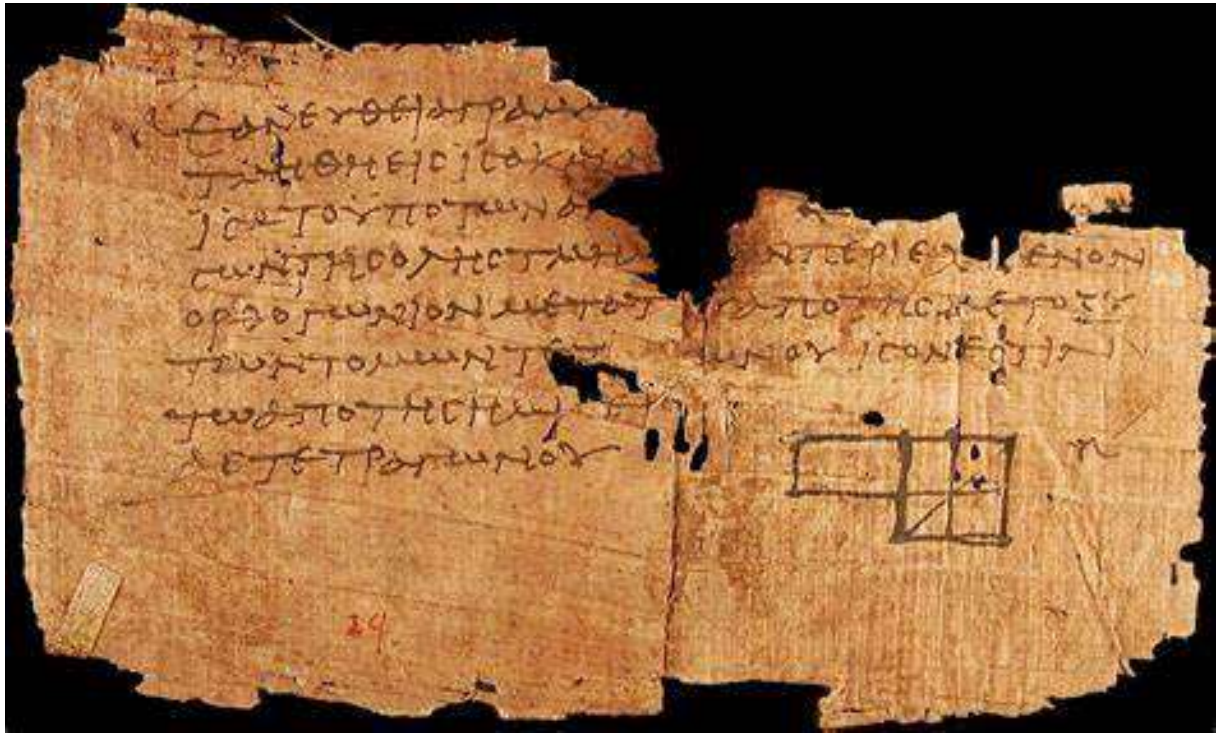
Ptolemaic model of the universe
(Alexandria, AD 85-165)

Aztec calendar (1427-1479 AD)

Nebra sky disc (1600 BC)

These universal shapes and diagrams lie at the foundations of the language of mathematics

Babylonian tablet (1900-1700 BC) suggesting knowledge of the square root of 2 and the "Pythagorean" theorem

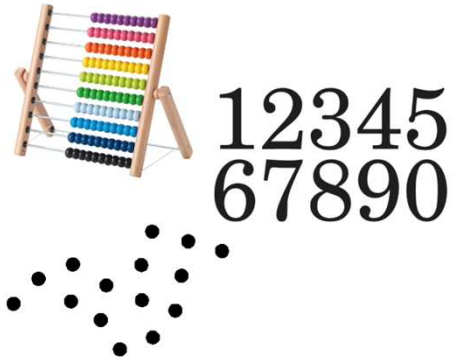


Papyrus (AD 75-125) with the oldest example of a diagram from Euclid's Elements

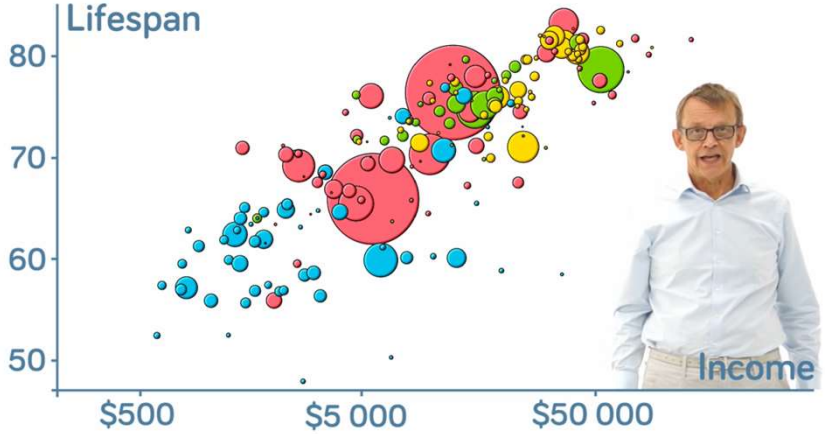
« Graphicacy » is a dramatically understudied cultural acquisition

LITERACY

NUMERACY



GRAPHICACY



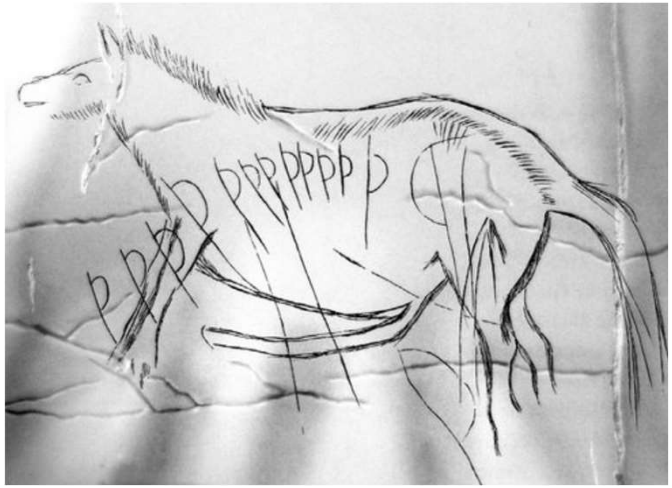
Graphics share many characteristics with words and numbers:

1) They are human **cultural inventions**
2) They are **symbolic** representations forming a graphic language
3) They are based on shared **conventions** (both in terms of semantics and syntax)
4) They recycle the **visual channel** for efficient information transmission
5) They require considerable **learning**
6) They are taught at **school** (to a variable degree)

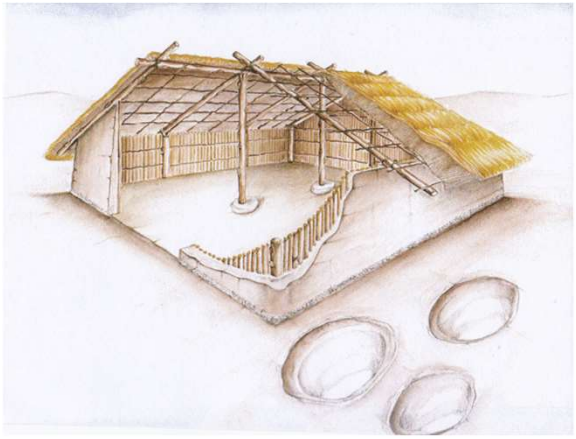
Markers of humanity : drawing and geometry as very ancient species-specific behavior

Drawings

signs



Circular and square shapes abound at all spatial scales in cave paintings, engravings, architecture…



Houses and communal space at Jerf el Ahmar (Syrie) 10,000-9000 BP

The same geometrical patterns recur, based on

- Circles or spirals
- Straight lines, parallel or perpendicular
- Forming squares or rectangles

Guilaine, J. (2016). Maisons néolithiques : Exemples méditerranéens. *Palethnologie. Archéologie et sciences humaines*, *8*, Article 8. https://doi.org/10.4000/palethnologie.468

Complex compositions of shapes:

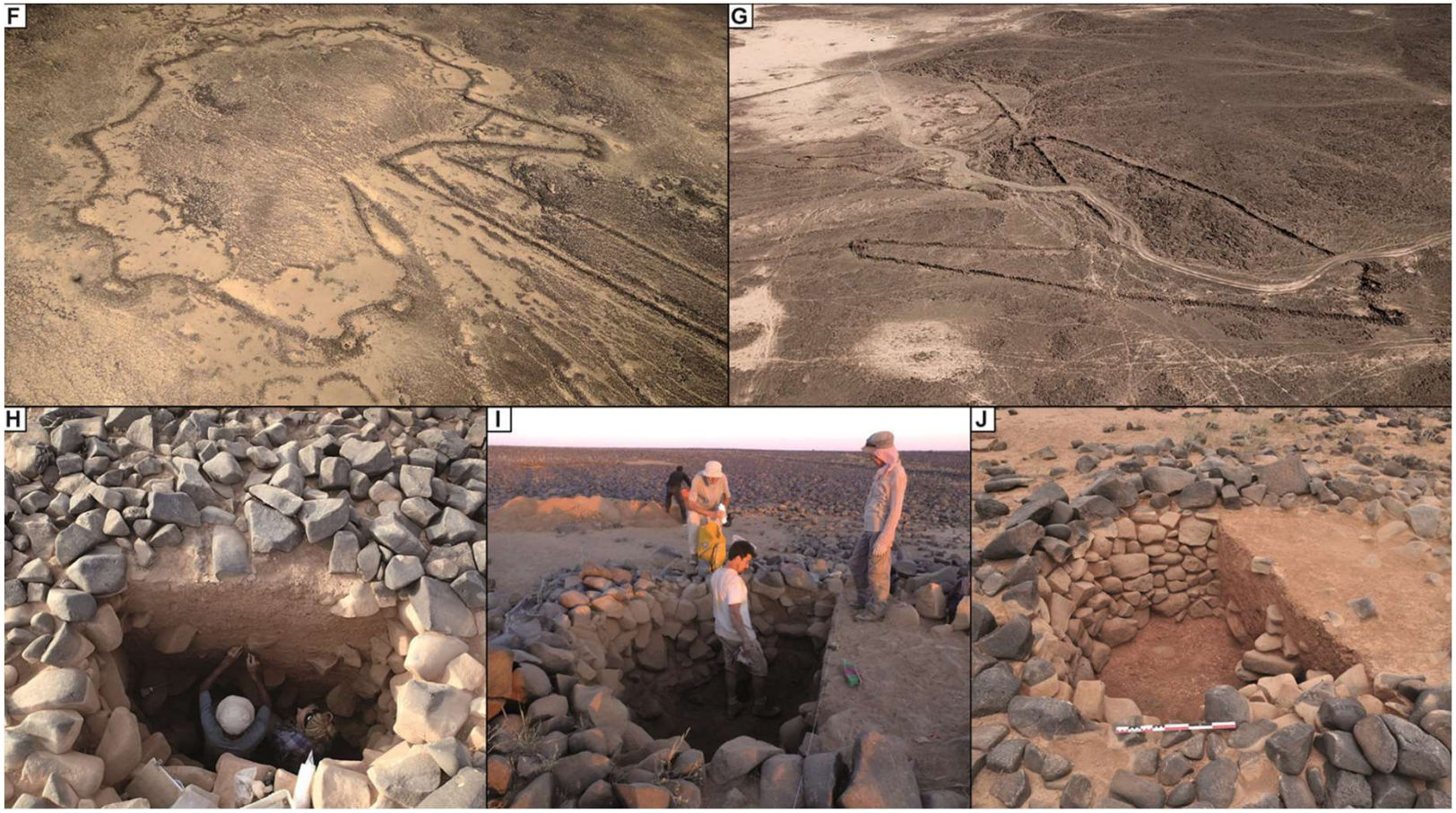
Bedolina map, Val Camonica

A clearer example of a stone-age map: the case of desert kites

Crassard, R., Abu-Azizeh, W., Barge, O., Brochier, J. É., Preusser, F., Seba, H., Kiouche, A. E., Régagnon, E., Sánchez Priego, J. A., Almalki, T., & Tarawneh, M. (2023). The oldest plans to scale of humanmade mega-structures. *PLOS ONE*, *18*(5), e0277927. https://doi.org/10.1371/journal.pone.0277927

"Desert kites are gigantic archaeological structures made of stone alignments and walls. Kites are composed of driving lines (from hundreds of meters to 5km long) converging towards an enclosure (median size: 1ha), which is surrounded by up to 4-meter-deep pits (called 'pit-traps', from 1 to more than 20 in number per enclosure) where animals were trapped by hunters."

They are found in Jordan and Saudi Arabia, and some are thought to be 9000 years old.



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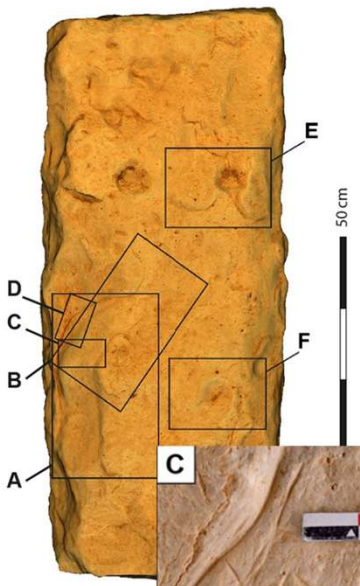
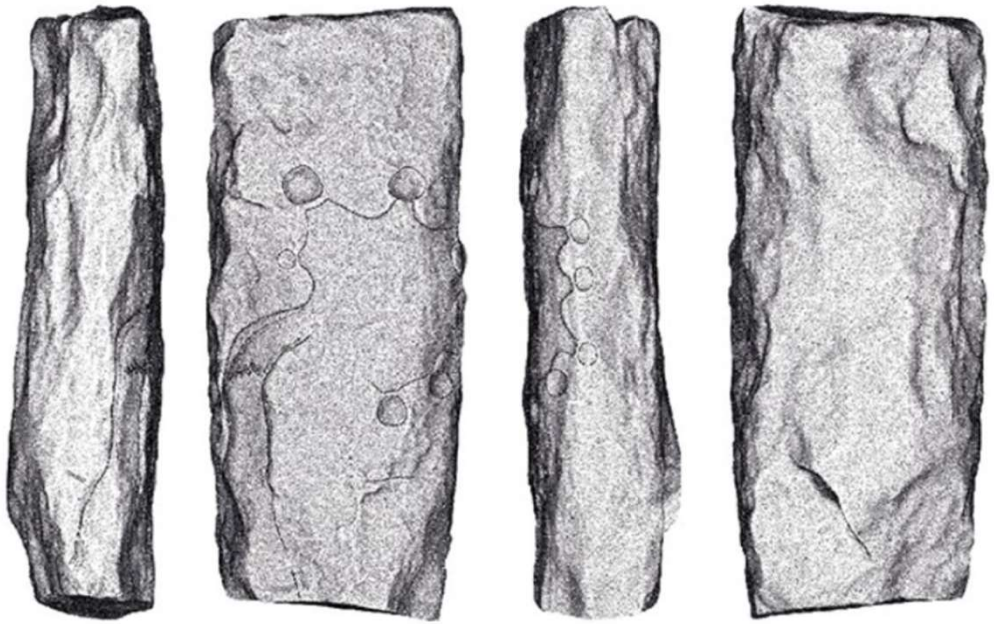
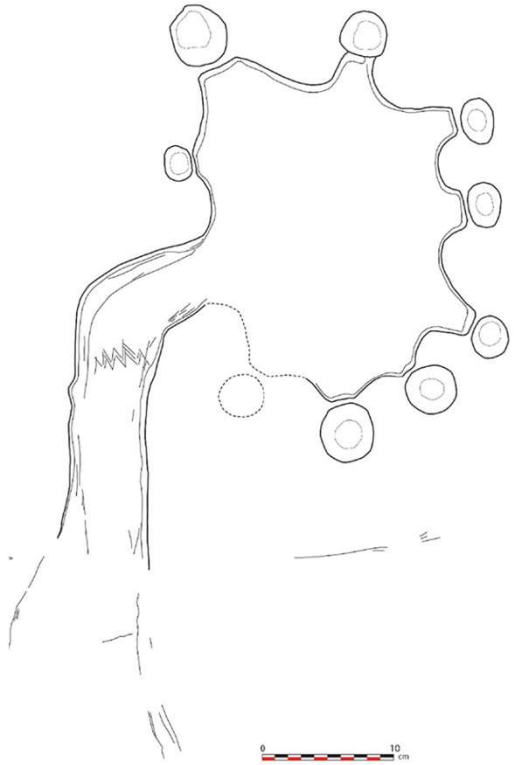
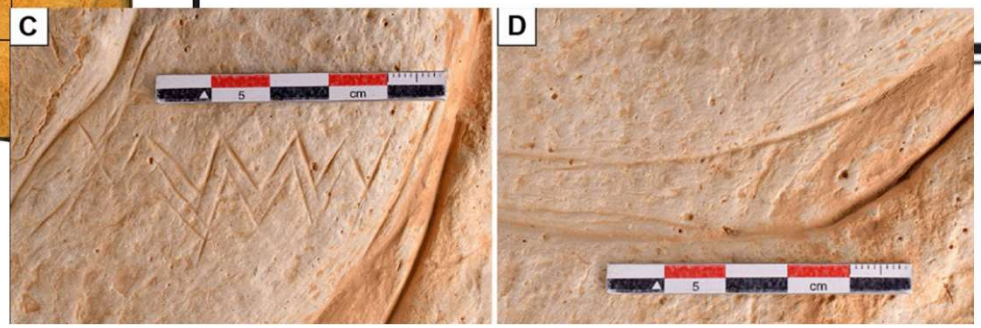
The archaelogists recently discovered a large monolithic stone with engravings clearly depicting a desert kite (as well as a zigzag and other curves, which may also depict local geographic features).





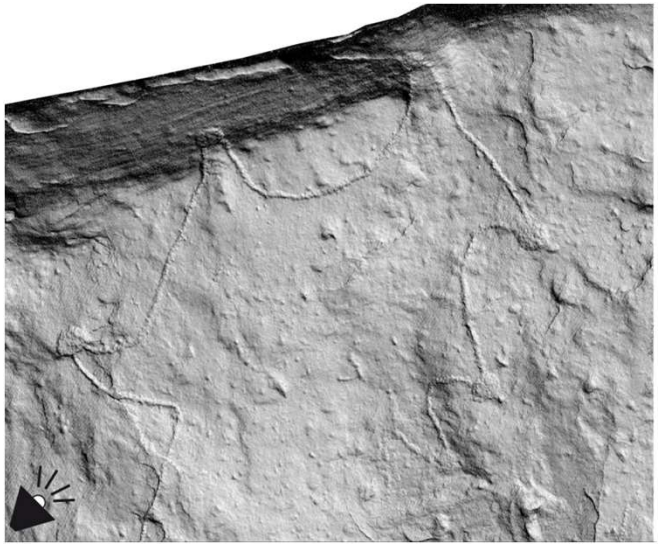


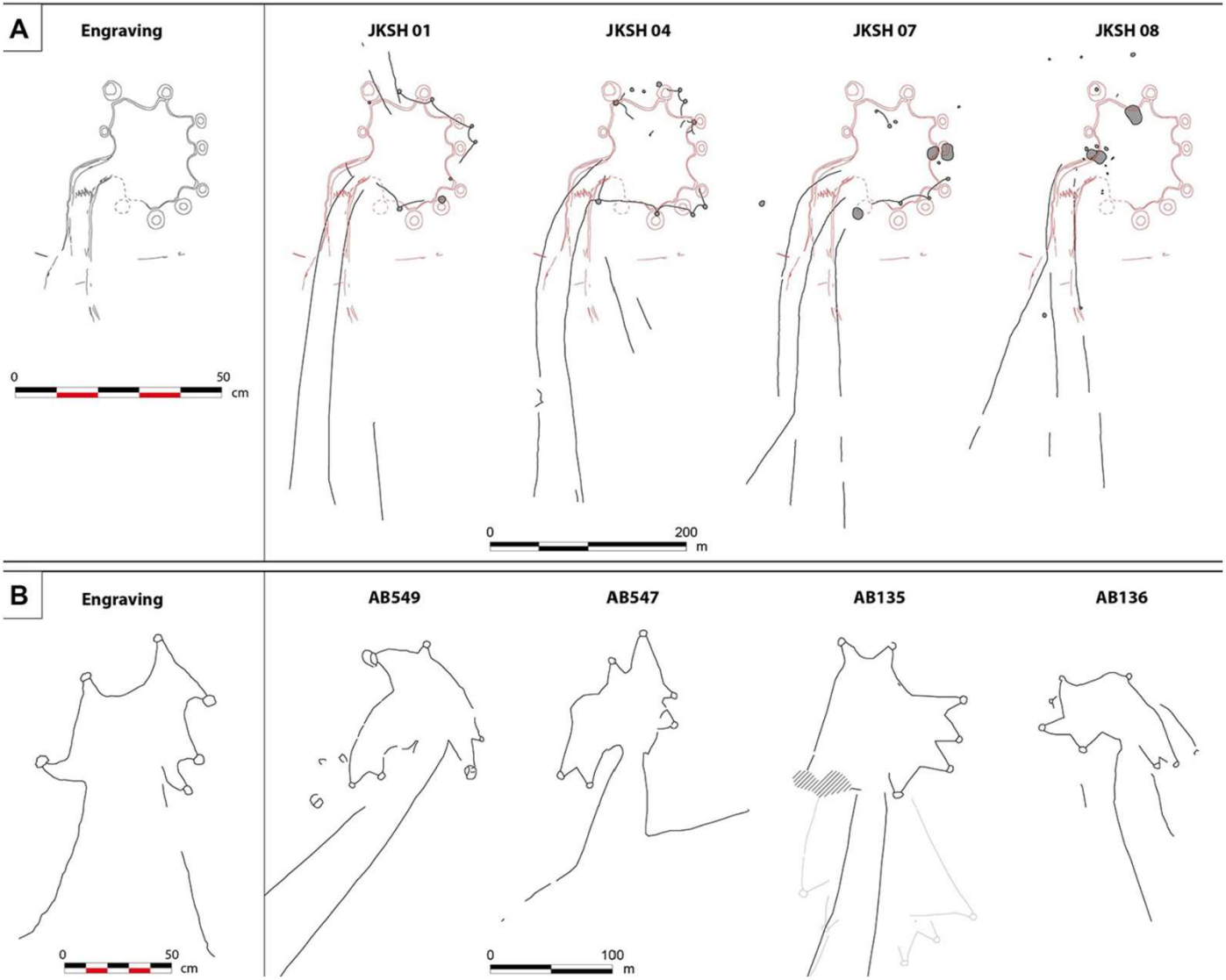


A clearer example of a stone-age map: the case of desert kites

A second engraved stone with a kite shape was found.

And amazingly, in both cases, a computerized graph analysis suggests a tight match of this “map” with a nearby kite, located only a few kilometers away.





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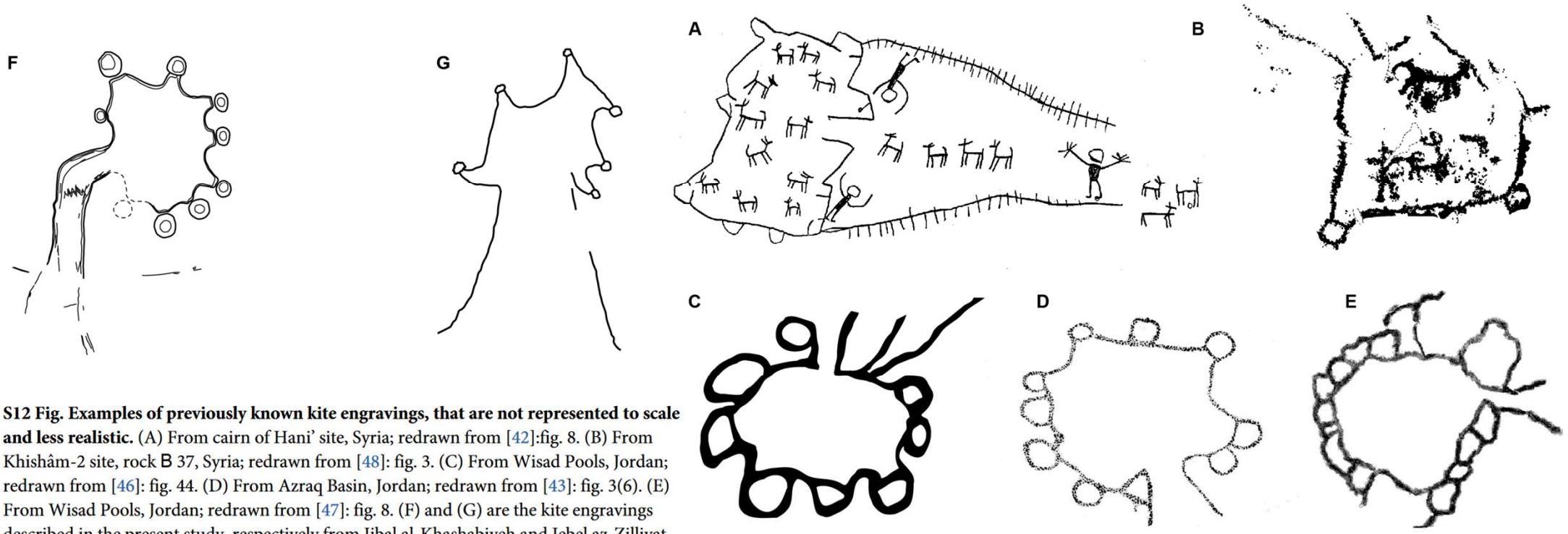
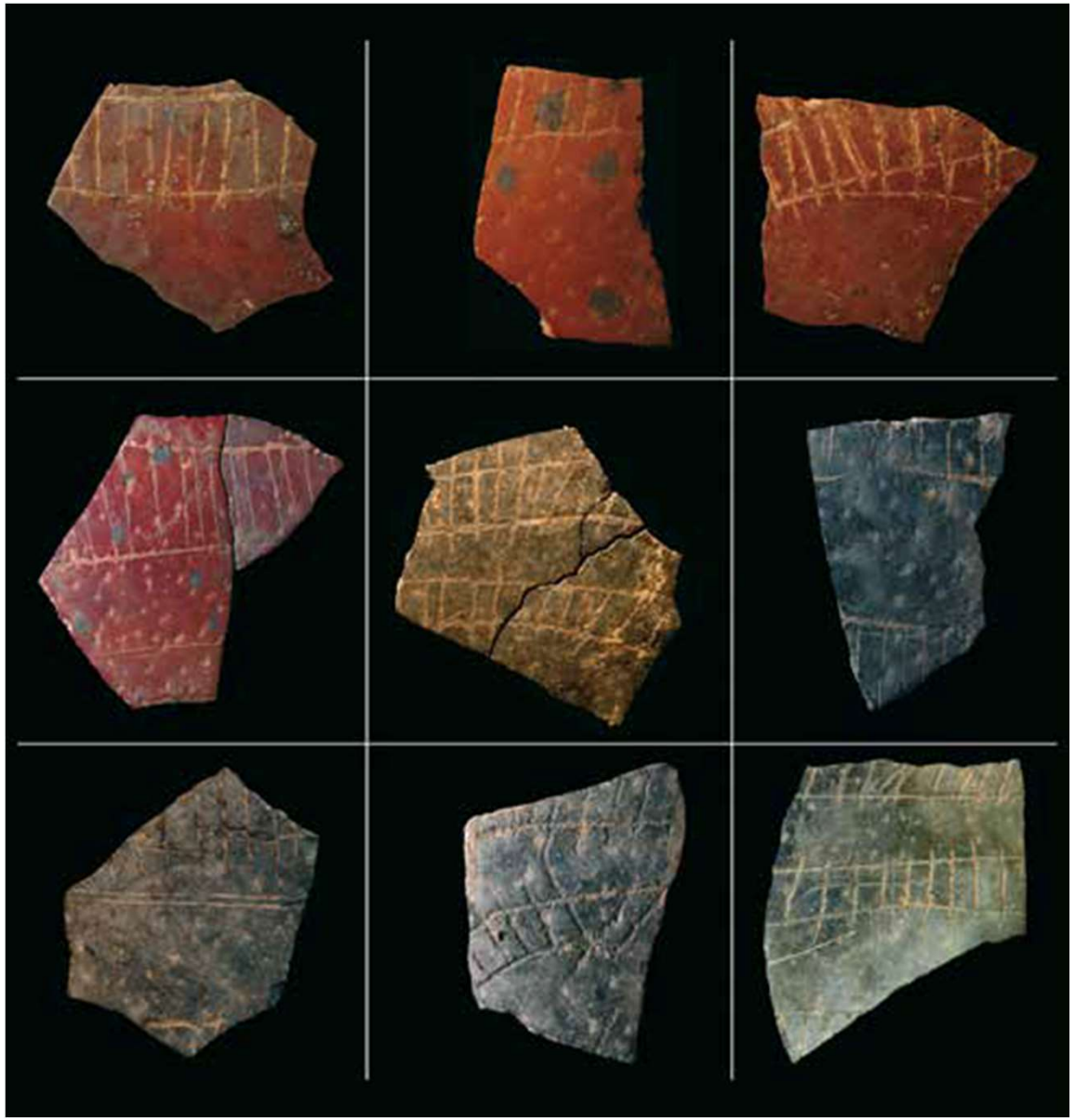
Similar maps of kites exist at other sites.
The evidence suggest that humans were already able to conceive of an **idealized bird's eye view** of the landscape – an abstract mental image of something that they could never see.



S12 Fig. Examples of previously known kite engravings, that are not represented to scale and less realistic. (A) From cairn of Hani' site, Syria; redrawn from [42]:fig. 8. (B) From Khishâm-2 site, rock B 37, Syria; redrawn from [48]: fig. 3. (C) From Wisad Pools, Jordan; redrawn from [46]: fig. 44. (D) From Azraq Basin, Jordan; redrawn from [43]: fig. 3(6). (E) From Wisad Pools, Jordan; redrawn from [47]: fig. 8. (F) and (G) are the kite engravings described in the present study, respectively from Jibal al-Khashabiyeh and Jebel az-Zilliyat, represented in this figure to be directly compared with the previously known ones.

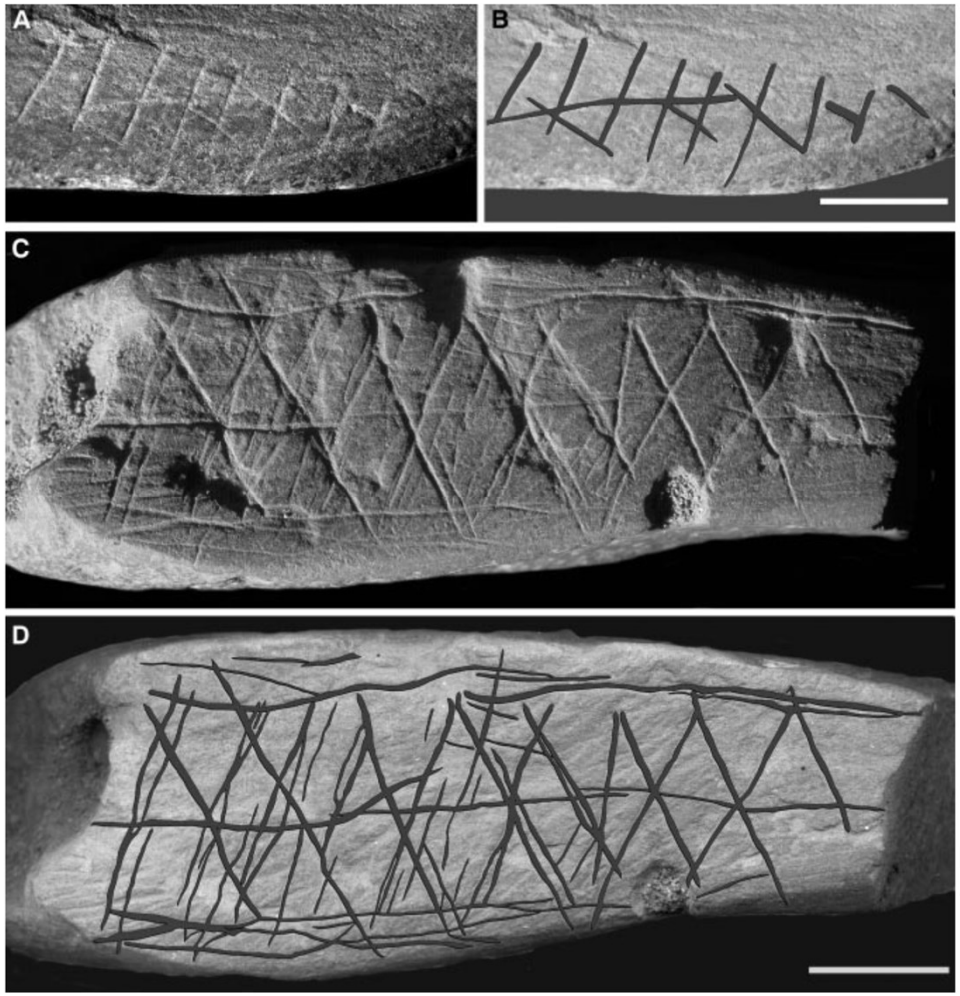


Geometrical decorations are attested prior to realistic depictions

Fragments of engraved ostrich eggshells.
Howieson's Poort, Eastern Cape, South Africa
Middle Stone Age
- 60,000 years old

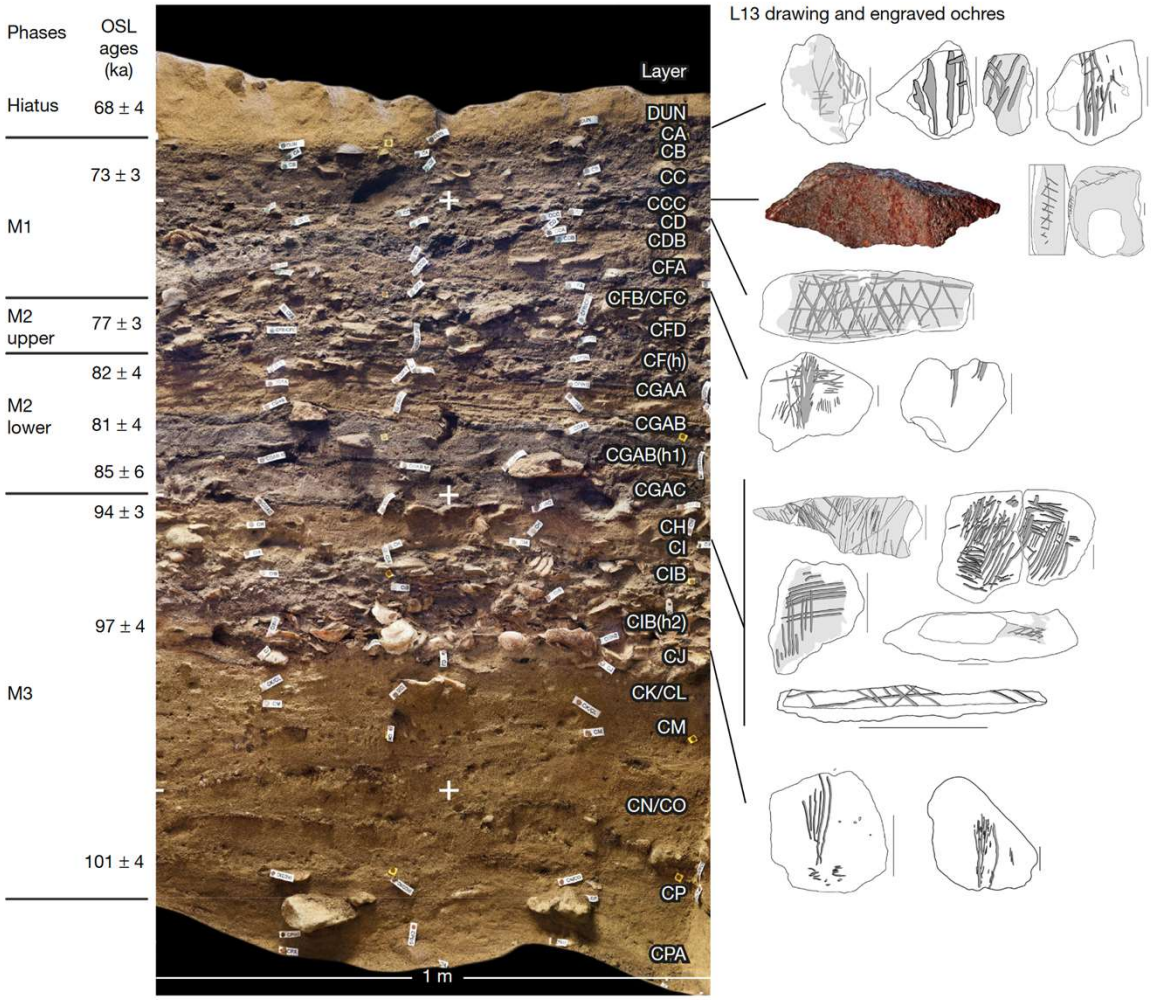
Geometrical patterns from Blombos, South Africa

Pieces of ochre bear parallel lines forming triangles, diamonds, and hexagons (Afrique du Sud, 100,000-70,000 BP)



- Henshilwood, C. S., d' Errico, F., Yates, R., Jacobs, Z., Tribolo, C., Duller, G. A. T., … Wintle, A. G. (2002). Emergence of modern human behavior: Middle Stone Age engravings from South Africa. *Science (New York, N.Y.)*, *295*(5558), 1278–1280. doi:10.1126/science.1067575
- Henshilwood, C. S., d' Errico, F., van Niekerk, K. L., Coquinot, Y., Jacobs, Z., Lauritzen, S.-E., … García-Moreno, R. (2011). A 100,000-year-old ochre-processing workshop at Blombos Cave, South Africa. *Science (New York, N.Y.)*, *334*(6053), 219–222. doi:10.1126/science.1211535
- Henshilwood, C. S., d' Errico, F., & Watts, I. (2009). Engraved ochres from the Middle Stone Age levels at Blombos Cave, South Africa. *Journal of Human Evolution*, *57*(1), 27–47. doi:10.1016/j.jhevol.2009.01.005

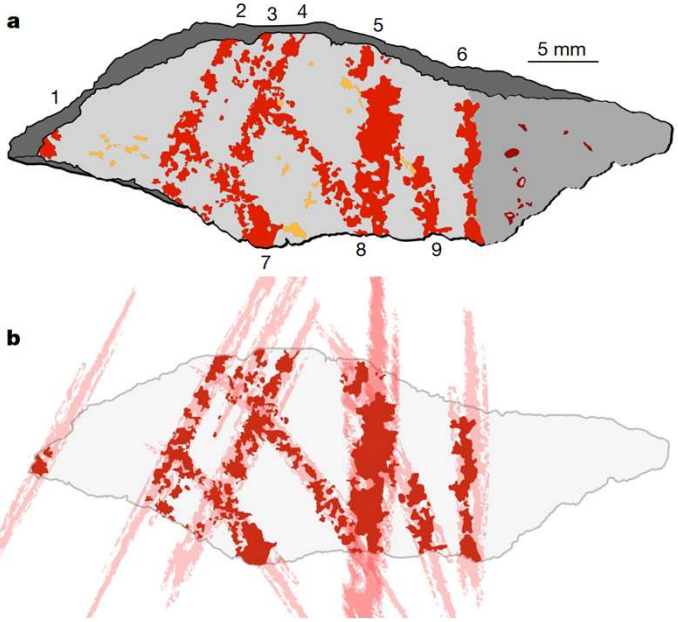
Geometrical patterns from Blombos, South Africa



Henshilwood, C. S., d'Errico, F., van Niekerk, K. L., Dayet, L., Queffelec, A., & Pollarolo, L. (2018). An abstract drawing from the 73,000-year-old levels at Blombos Cave, South Africa. Nature, 562(7725), Article 7725. https://doi.org/10.1038/s41586-018-0514-3

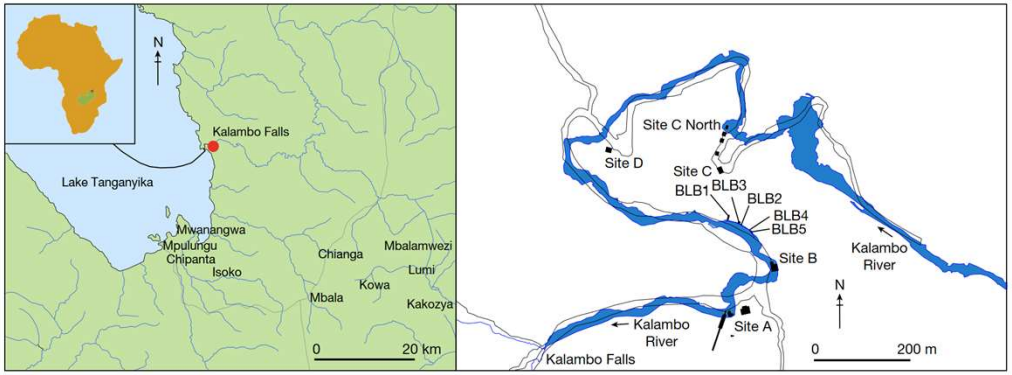
The same sort of geometrical design was deliberately drawn using red ochre on a stone flake found within the same archeological layers,

Fig. 2 | Image of the Blombos Cave silcrete flake L13 displaying the drawn lines that form a cross-hatched pattern. Image credit, C. Foster.

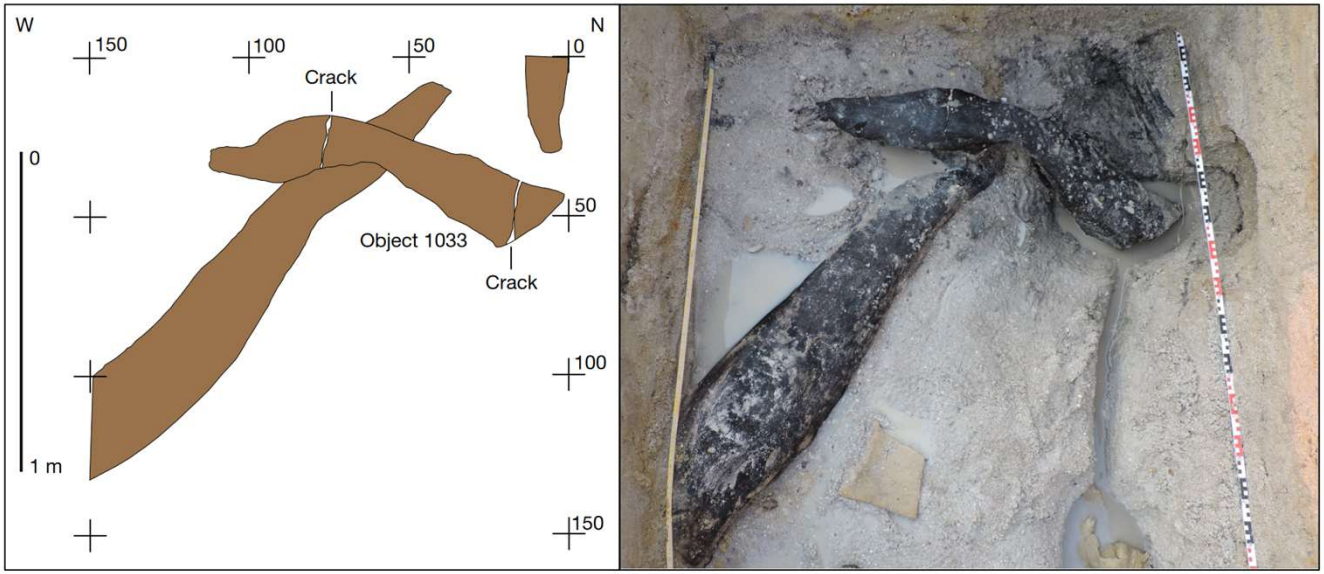


A walk back in time… a wooden construction prior to Homo Sapiens

Barham, L., Duller, G. a. T., Candy, I., Scott, C., Cartwright, C. R., Peterson, J. R., Kabukcu, C., Chapot, M. S., Melia, F., Rots, V., George, N., Taipale, N., Gethin, P., & Nkombwe, P. (2023). Evidence for the earliest structural use of wood at least 476,000 years ago. *Nature*, 1-5. https://doi.org/10.1038/s41586-023-06557-9

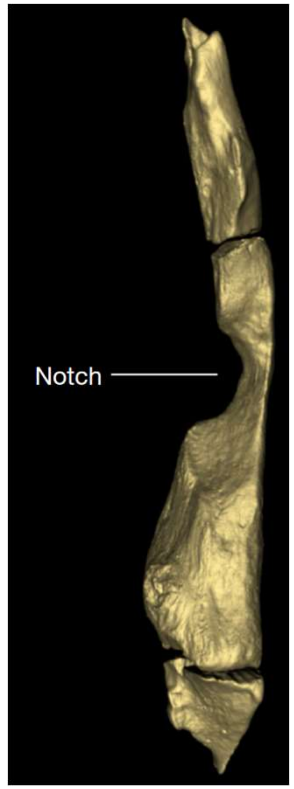


In Kalambo falls, Zambia, humidity is so constantly high that wood was preserved in the sand. The researchers discovered several wooden tools and an exceptional "cross" construction made of two overlapping logs.
The shorter log shows evidence of a dug-out notch, which would have facilitated assembly.
Both logs show evidence of scrapping and shaping of the ends.
This is interpreted as part of a platform over the water.



The sediments around the wood are dated ~476,000 years ago (±27,000), i.e. prior to Homo sapiens (~300,000 years ago in North Africa).

From a purely geometric standpoint, this construction is exceptionally interesting:
- the notch cuts the shorter log roughly in its middle
- the two logs were probably perpendicular to each other



A geometrical pattern attributed to Homo erectus

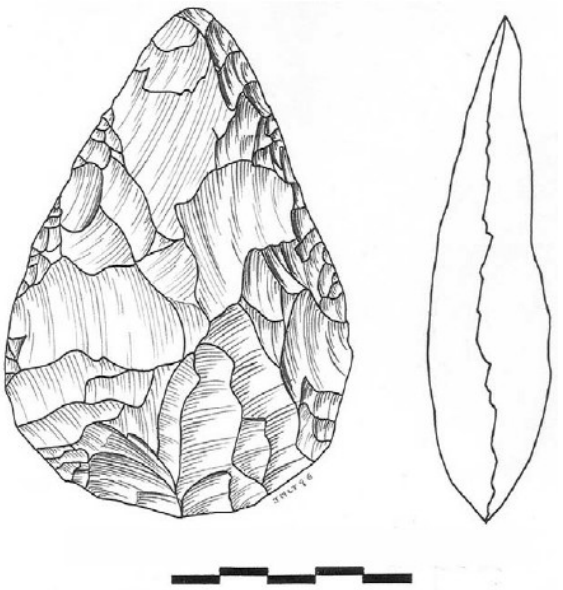
Zigzag shape
Dated approximately 540,000 before present
Attributed to Homo erectus, not Homo sapiens

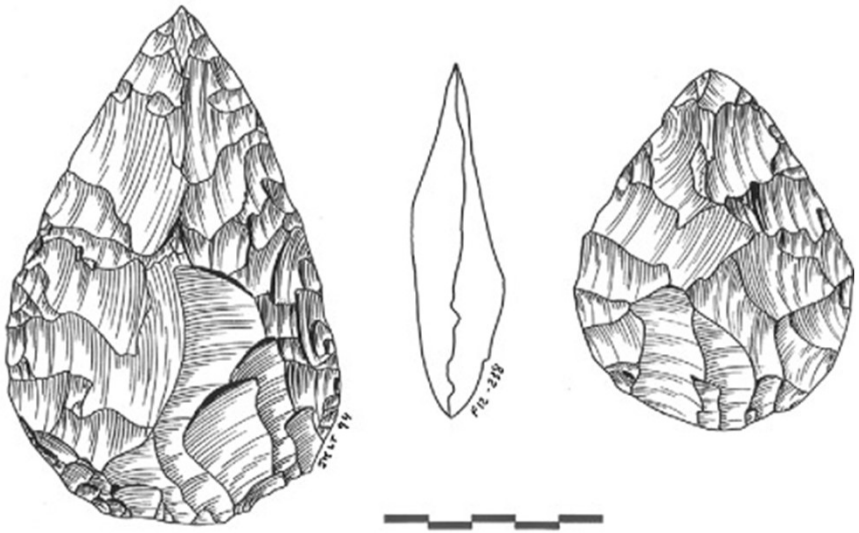
Joordens, J. C. A., d' Errico, F., Wesselingh, F. P., Munro, S., de Vos, J., Wallinga, J., … Roebroeks, W. (2014). Homo erectus at Trinil on Java used shells for tool production and engraving. *Nature*. doi:10.1038/nature13962

Symmetry in Acheulean bifaces

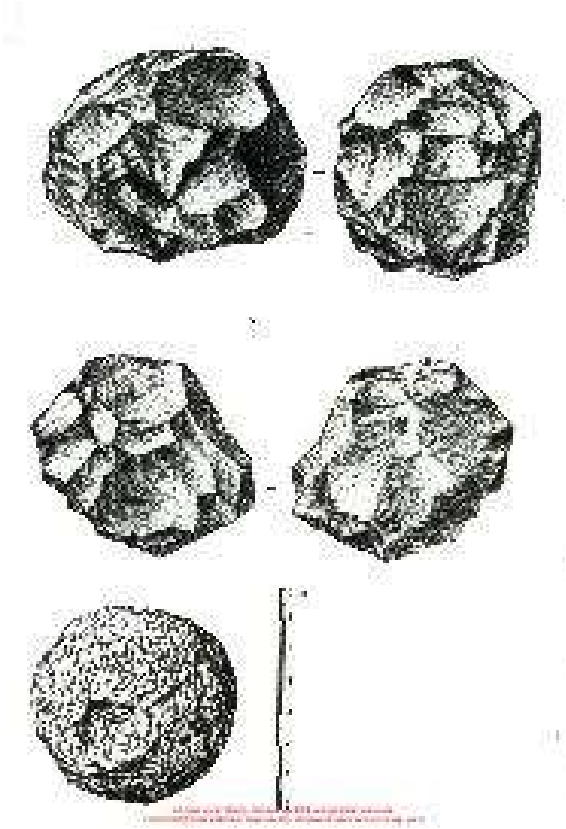
Le Tensorer, J.-M. (2006). C R *Palevol*, *5*(1–2), 127–135. https://doi.org/10.1016/j.crpv.2005.12.003

- "Biface" ➔ two planes of symmetry -- without any direct utility
- « The biface probably appears in Eastern Africa, about 1.8 million years ago, with the first Homo ergaster or archaic erectus »





Polyedras, spheroids and bolas



- Near-spherical stone « balls » or polyedric shapes tending towards the sphere.
- Sometimes with an exquisite degree of perfection, reflecting hundreds of hours of work
- They weigh up to one kilogram, and therefore could not have been used as « bolas » (although this is debated)
- They appear up to 2 million years ago in Africa, *before* the first bifaces

A 3D computerized analysis of spheroids

Muller, A., Barsky, D., Sala-Ramos, R., Sharon, G., Titton, S., Vergès, J.-M., & Grosman, L. (2023). The limestone spheroids of 'Ubeidiya : Intentional imposition of symmetric geometry by early hominins? *Royal Society Open Science*, *10*(9), 230671. https://doi.org/10.1098/rsos.230671

150 spheroids dated ~1.4 million years ago, at a Homo erectus site in Northern Israel. Were they conceived intentionally? Or just a by-product of other activities?

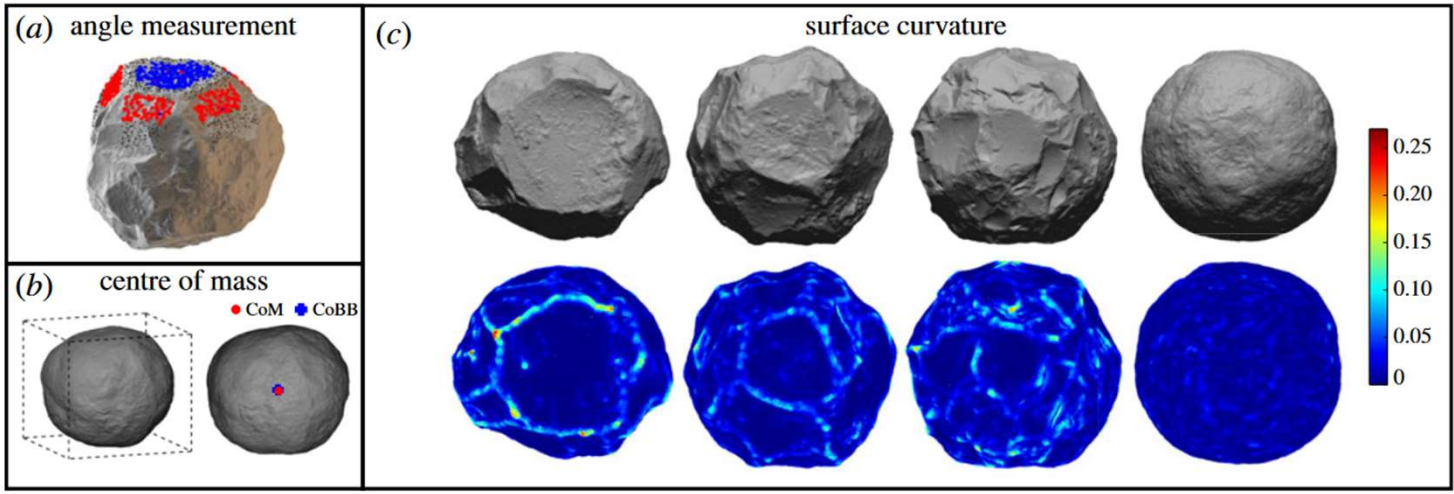
"We reconstruct the spheroid reduction sequence based on trends in their scar facets and geometry, finding that the spheroid makers at 'Ubeidiya followed a **premeditated reduction strategy**."

Many sides have a primary surface followed by the chipping away of smaller sides. The end result is not smooth, unlike what would happen e.g. in the bed of a river, but closely approaches a sphere.

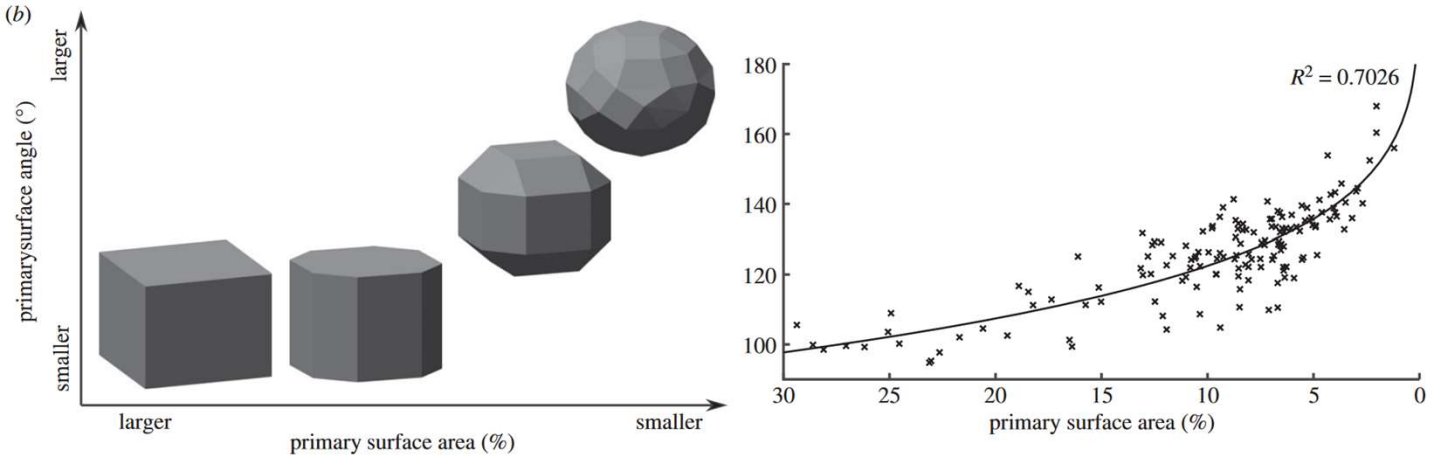
"During their manufacture, the spheroids do not become smoother, but they become markedly more spherical."

"They approach an ideal sphere, a feat that likely required skillful knapping and **a preconceived goal**."

→ symmetry, beauty? But at least geometry!



Scenario for the design of spheroids: surfaces get smaller and increasingly parallel to nearby ones (flat angle).



Hypothesis: geometrical symbols and artefacts reflect a uniquely human capacity for abstract thought, a precursor of mathematics

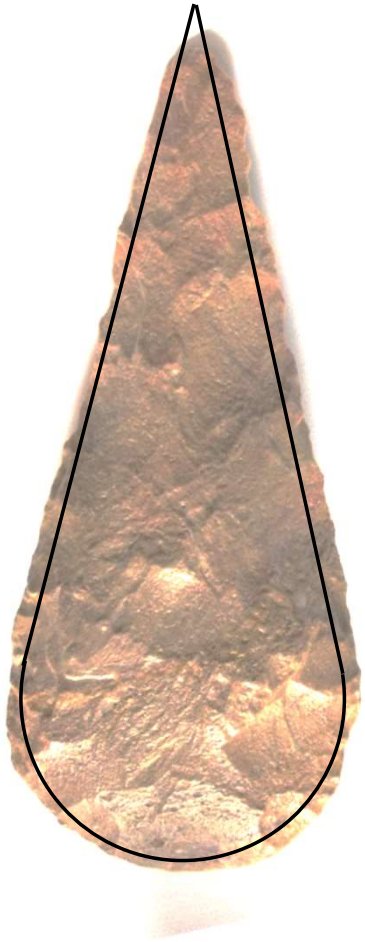
In this course, we will try to characterize the mental representations that underlie the perception and production of geometric shapes

And, in this manner, we will attempt to narrow down the search for the cognitive singularity of the human brain.

Proposal:

- all humans are endowed with a **language of geometry** with a small set of primitives and a simple syntax

- the geometric shapes that are attested across many cultures correspond to **miminal descriptions in this language**



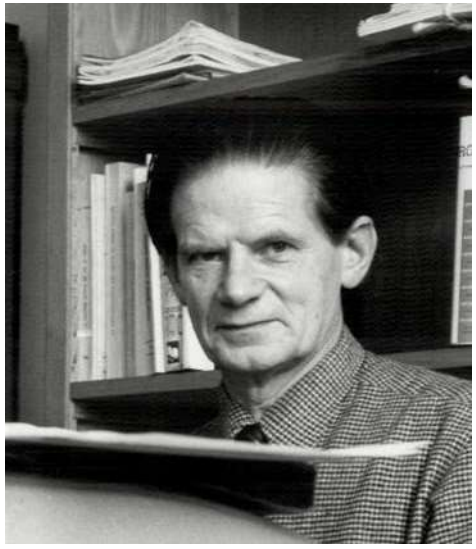
« 2 lines of equal length touching a circle »

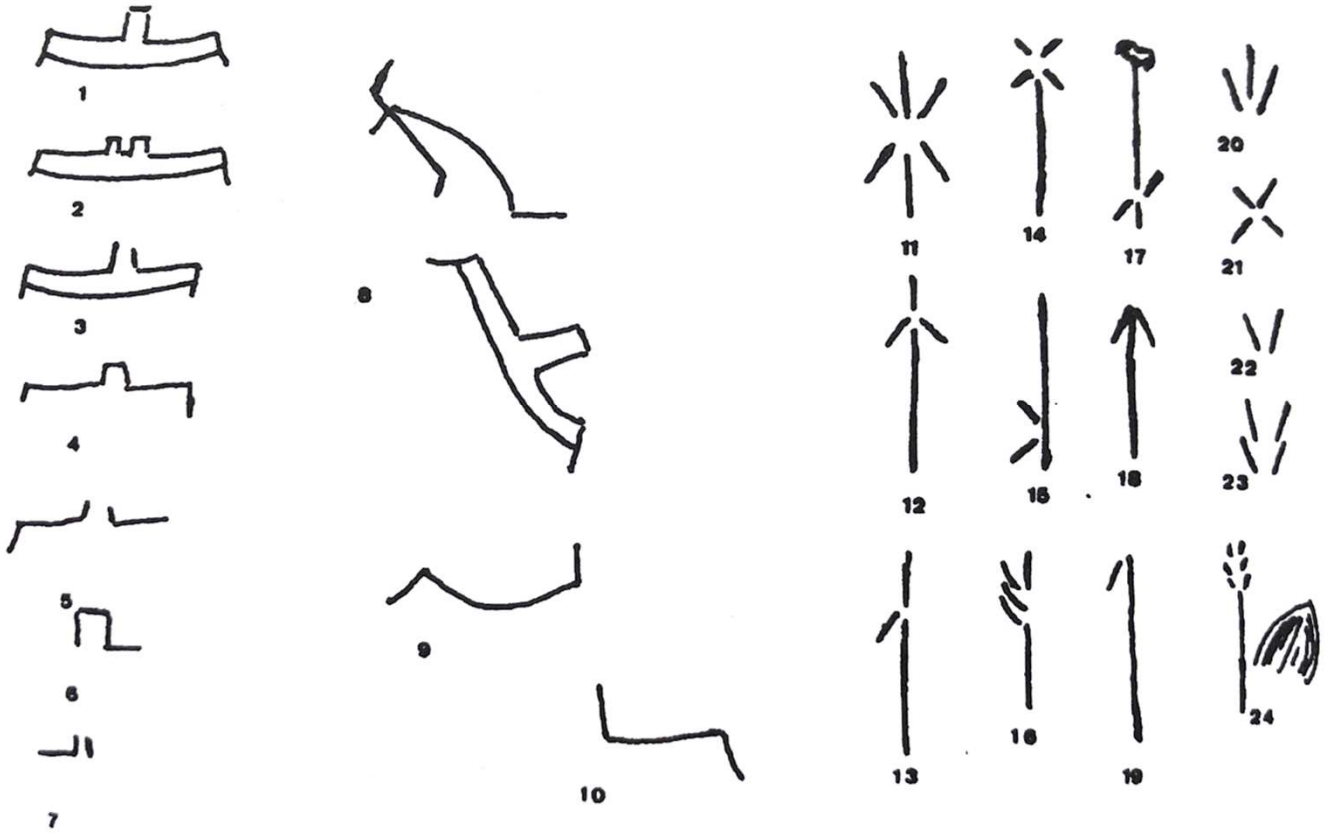
André Leroi-Gourhan: a methodic analysis of prehistoric art

In his course at Collège de France, André Leroi-Gourhan proposed a “methodic analysis of prehistoric art”.
In research of amazing breadth, he embraced all available discoveries of his time (cave paintings, engravings, sculpture…) and examined them in all their dimensions: archeological, stylistic, geographical, symbolic…
In particular he focused on geometric “signs” that did not have an obvious iconic resemblance to existing animals or objects, and observed

- that many signs were reproduced on cave walls as well as on objects
- that the signs could be decomposed into a series of disjoint elements, which could occur in partial form (a process he called “disjunction”).

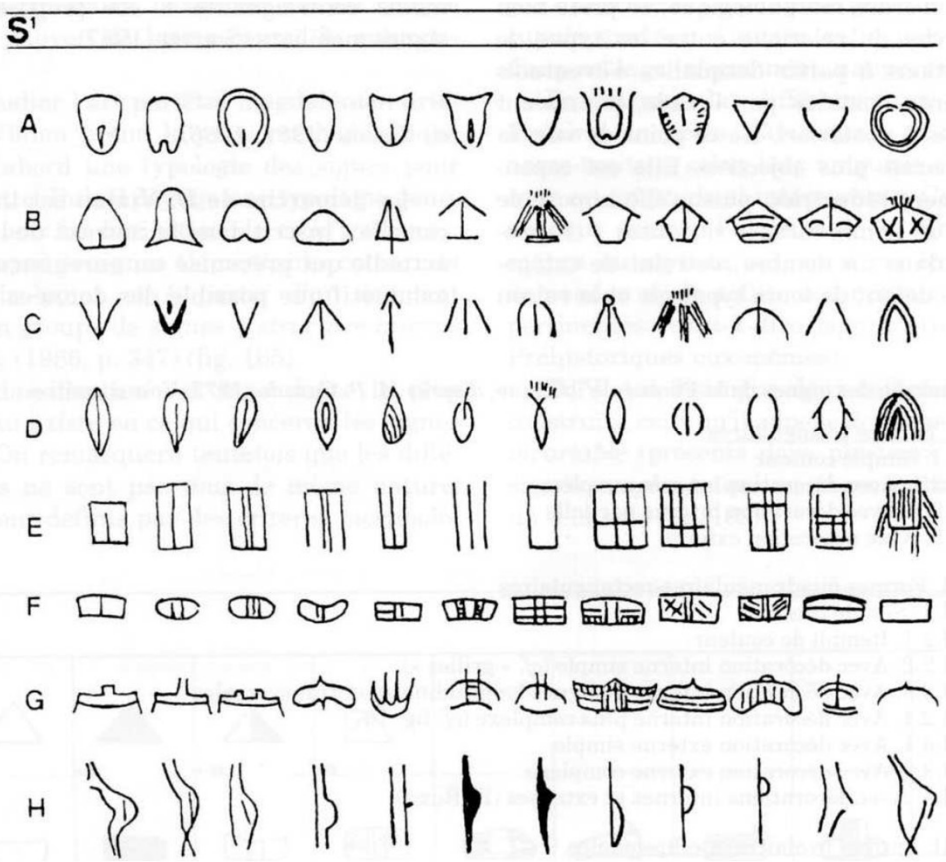
Leroi-Gourhan also attempted to provide a systematic classification and interpretation of those signs – in fact several such systems.

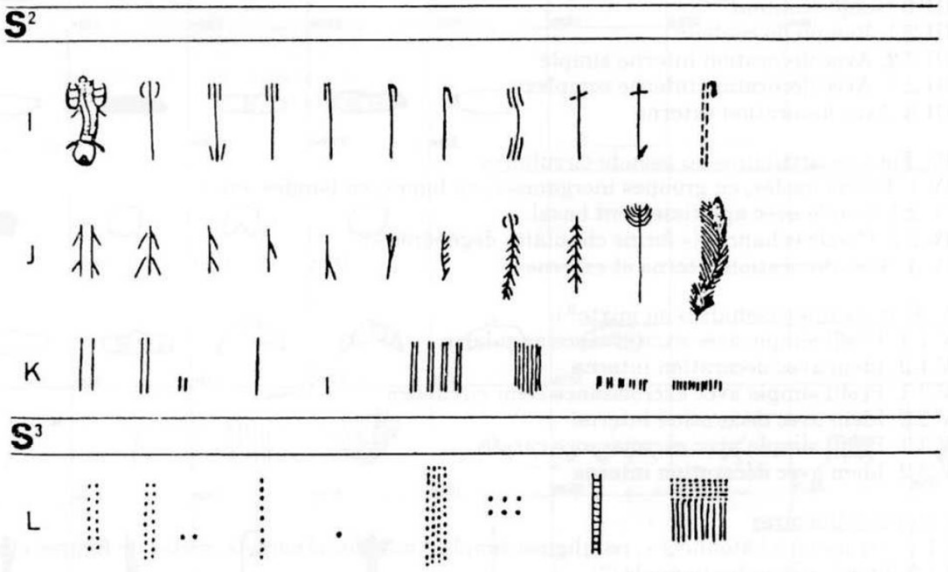




André Leroi-Gourhan's classification of paleolithic signs : objective shape and subjective interpretation

Leroi-Gourhan's classifications were based on both an objective geometric description (e.g. round versus straight line) and a subjective interpretation (notably his famous dichotomy of male/female signs).





Typologie des signes pariétaux franco-cantabriques, *d'après A. Leroi-Gourhan, 1972*.

Le groupe S^1 (8 catégories morphologiques) est constitué par « des symboles génitaux féminins qui vont de la représentation complète de la femme, au torse avec représentation du sexe, à la vulve réaliste, à des figures de plus en plus stylisées en ovale, en triangle, en cercle, en rectangle ».

Les groupes S^2 (3 catégories morphologiques) et S^3 (groupe dit « complémentaire ») « correspondent à des variantes sur le symbole génital masculin figuré par l'homme complet, par le phallus, par des représentations d'un schématisme croissant qui se résolvent en bâtonnets crochus ou barbelés, en traits simples, doubles ou multiples, en lignes ou en nappes de points, voire en un point unique ».

(André Leroi-Gourhan proposed many such tables over the years – this one, after Leroi-Gourhan 1972, is a summary by Georges Sauvet in a chapter called « Les signes pariétaux »).

Semantics versus syntax:
The example of the “tectiform” signs typical of Bernifal cave and its surroundings

It is tempting to interpret such signs as a construction, a roof, an animal trap.
Yet those **semantic** interpretations must remain tentative and cannot be proven.
While the **meaning** of those figures is unclear, their **structure** is evident.
It comprises, at the very least, the following geometrical concepts:
Lines, parallelism, equal distance, equal length, symmetry, repetition, numbers 2, 3, 4, 5…, circles and half-circles…
This list is short – but we shall see that it suffices to generate all such geometrical figures.

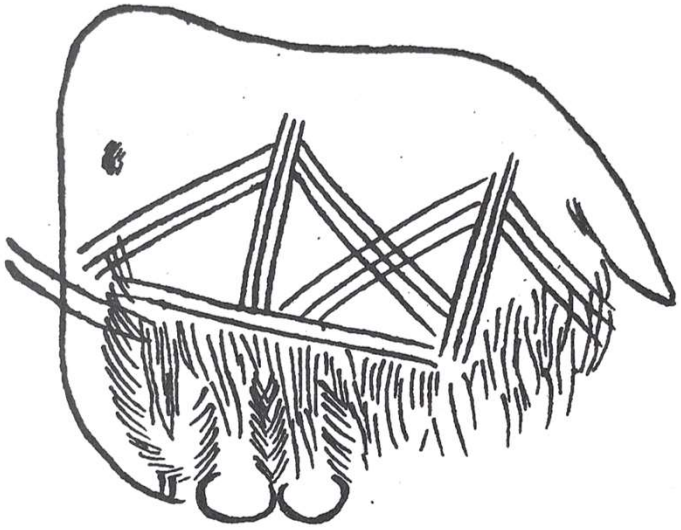


Fig. 12

Bernifal : mammouth et tectiforme interprété comme piège

Bernifal, From André Leroi-Gourhan,
L’art pariétal, Langage de la préhistoire
(présentation de Marc Groenen, p.85)

Bernifal

Bernifal

Font-de-Gaume

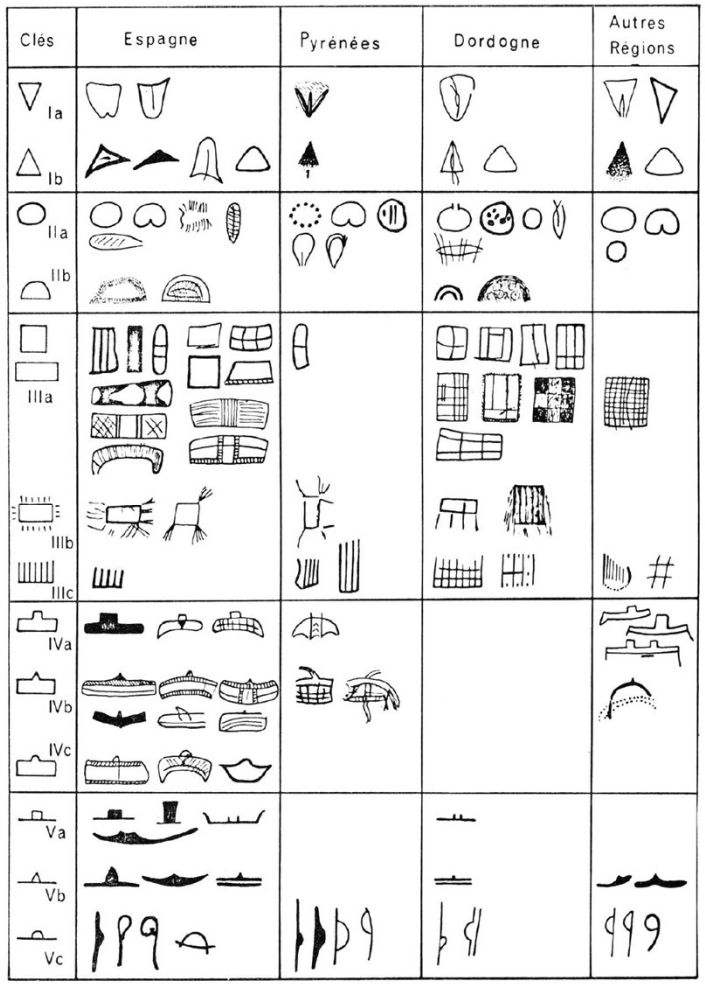
Towards a semiology of prehistory

Sauvet, G., Sauvet, S., & Wlodarczyk, A. (1977). Essai de sémiologie préhistorique (Pour une théorie des premiers signes graphiques de l'homme). *Bulletin de la Société préhistorique française*, *74*(2), 545-558. https://doi.org/10.3406/bspf.1977.8467

While it is probably impossible to decipher the **meaning** of prehistoric signs, it is still possible to collect a systematic list of them and to study how they are composed and combined with each other (graphic content and syntax).

Georges and Suzanne Sauvet, together with André Wlodarczyk, reject Leroi-Gourhan's hypothesis of a binary sexual opposition (male/female signs), but they attempt to create a typology of signs according to their geometry, and to characterize their syntax.

They propose a system of 12 "keys": based on shape alone, they distinguish triangles; circles and ovals; "typical" quadrilaterals; quadrilaterals with "outgrowths" ; claviforms; pentagons; arrows; barbed-wire and twig signs; chevron signs; crosses; sticks; and dots or punctuated signs.



bleau I. — Analyse typologique des signes pariétaux. — I. Triangles pointe en bas (a) et pointe en haut (b). — II. Cercles ovales (a) ; demi-cercles (b). — III. Quadrilatères typiques (a), à appendices (b) et ouverts (c) (« grilles » ou « peignes »). IV. Quadrilatères à excroissance carrée (a), triangulaire (b) et hémicirculaire (c). — V. Claviformes à excroissance carrée (

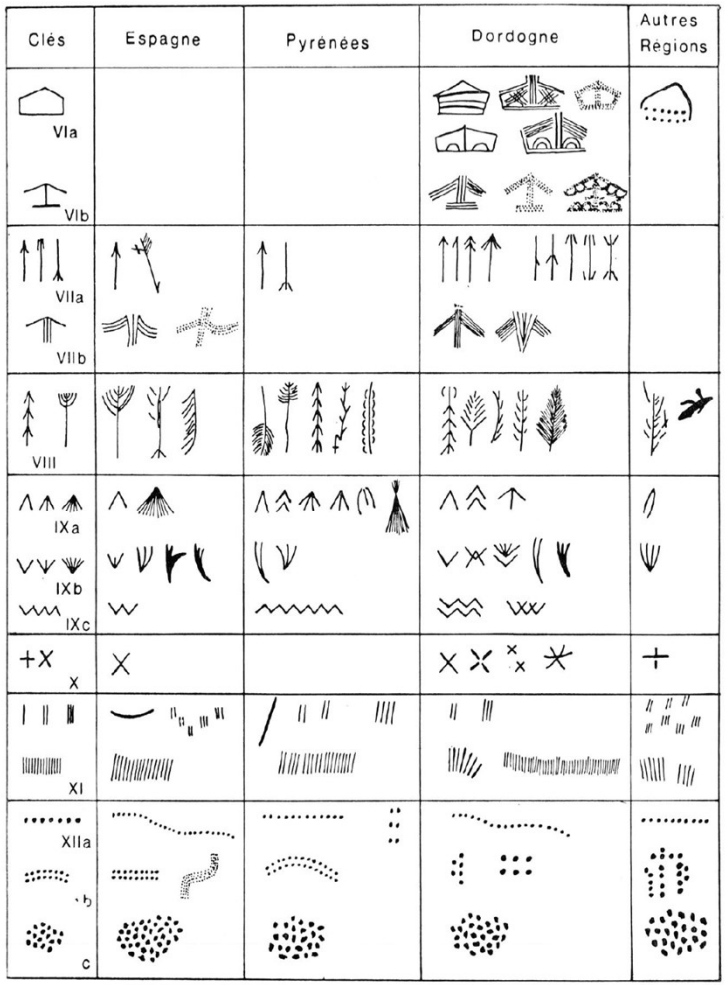


Tableau I (suite) — ... VI. Pentagones tectiformes vrais (a) et pseudotectiformes ouverts (b). — VII. Flèches à axe simple (a) et à axe multiple (b). — VIII. Signes barbelés et signes en « rameau ». — IX. Chevrons pointe en haut (a) et pointe en bas (b) ; zigzags (c). — X. Croix. — XI. Bâtonnets. — XII. Ponctuations en ligne simple (a) et en lignes multiples (b) ; nuages

Towards a semiology of prehistory

Sauvet, G., Sauvet, S., & Wlodarczyk, A. (1977). Essai de sémiologie préhistorique (Pour une théorie des premiers signes graphiques de l'homme). *Bulletin de la Société préhistorique française*, *74*(2), 545-558.

The Sauvets briefly mention the problem of **meaning.**

They note that some light could be shed on the problem by comparing paleolithic signs with ideographic writings whose meaning is known.

However, they immediately disqualify this idea by showing how the very same sign could have a wide variety of meanings. While perhaps not fully arbitrary, the relation is certainly not devoid of ambiguity.

"Cette voie n'est donc qu'une impasse".

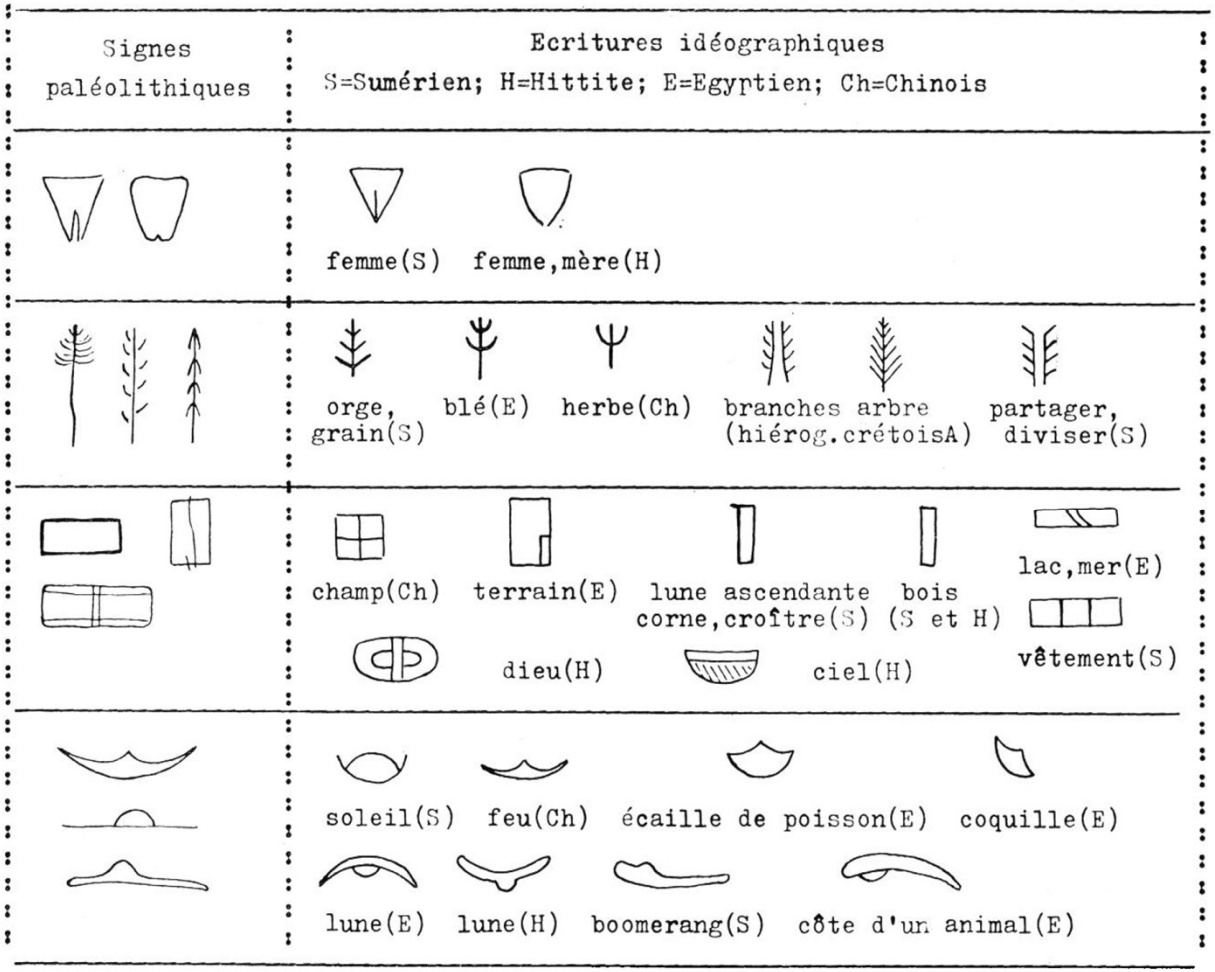


Tableau VII. -- Comparaison morphologique entre signes paléolithiques et idéogrammes.

Towards a semiology of prehistory

Sauvet, G., Sauvet, S., & Wlodarczyk, A. (1977). Essai de sémiologie préhistorique (Pour une théorie des premiers signes graphiques de l'homme). *Bulletin de la Société préhistorique française*, *74*(2), 545-558.

On the other hand, they suggest that **the syntax of signs** can be analyzed.

Complex signs can be analyzed into simpler components.

Many signs are composed of multiple parts using operations such as
- hatching (filling with one or two systems of parallel lines)
- adding a "scaliform band"
- cutting into two or three, in various directions
- or adding an outgrowth.

Sometimes several such operations are combined.

Most importantly, they suggest three basic operations of **shape syntax**:

- Integration-- which we will call **nesting** or **recursive composition**, e.g. an oval of dots, a circle of lines)
- Superposition and Juxtaposition-- which both correspond to **concatenation** of two shapes, either disjoint or superimposed.
- They forget to mention **repetition,** although (or perhaps because!) it is all too obvious from their drawings that this operation is extremely frequent.

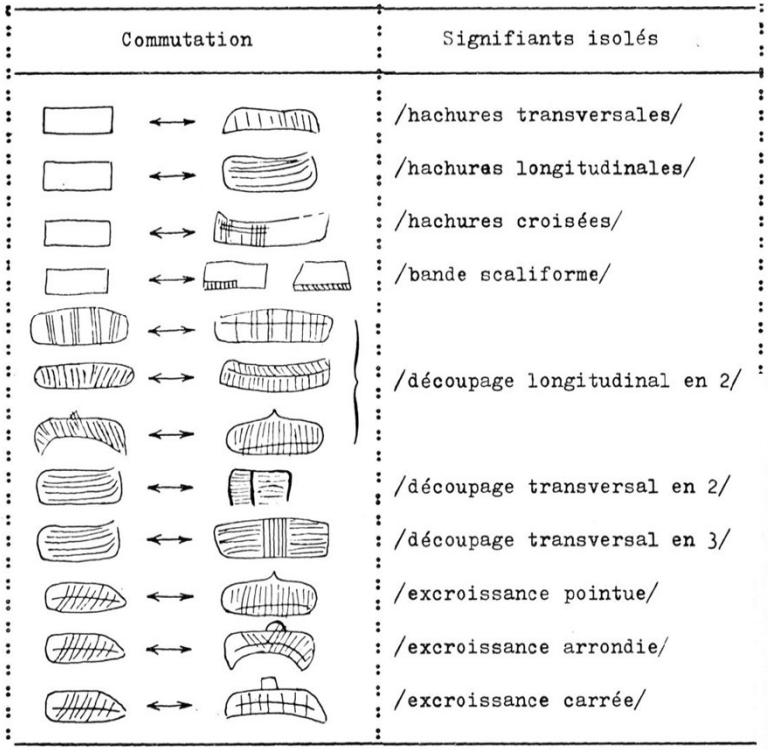


Tableau II. — Mise en évidence d'unités signifiantes minimales par commutation.

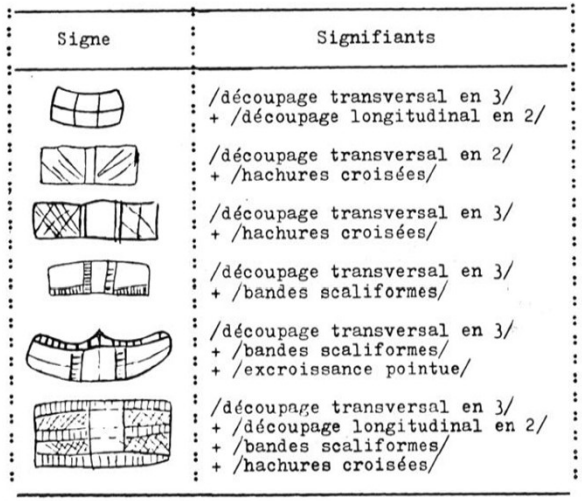


Tableau III. — Analyse de signes complexes en signifiants élémentaires.

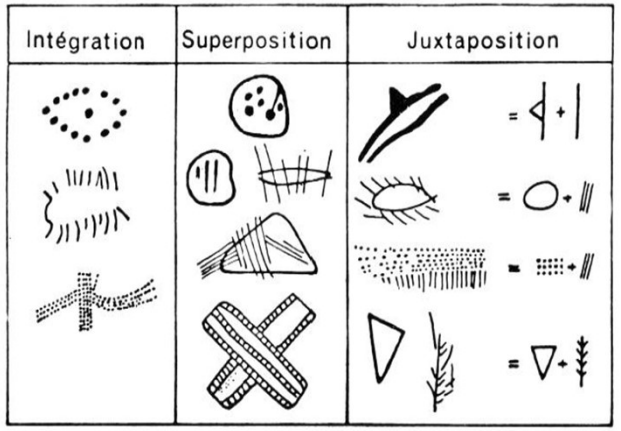
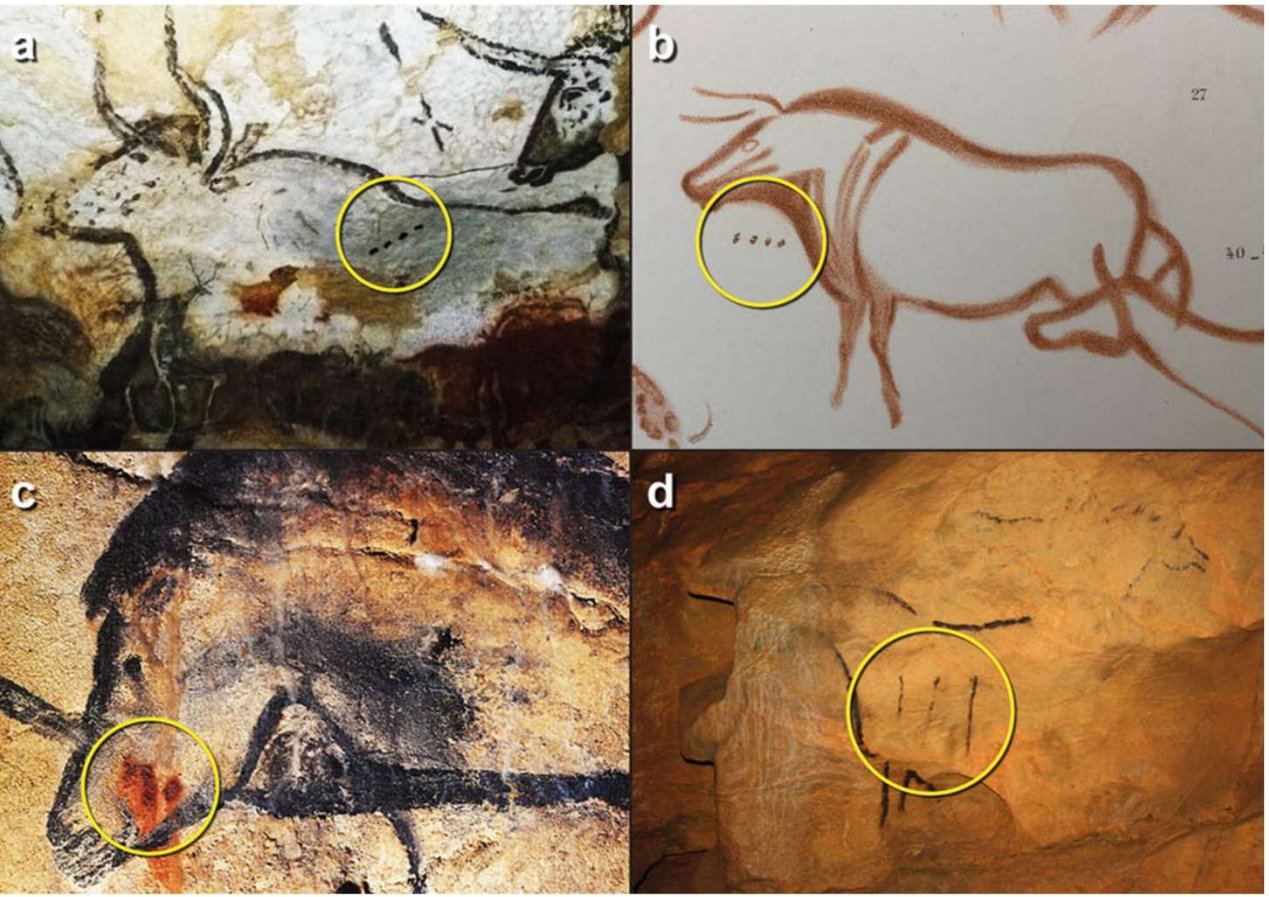


Tableau IV. — Procédés d'obtention de signes complexes.

→ Convergence with cognitive science: **Repetition**, **concatenation** and **nesting** are the only 3 syntactic operations in our language of geometry

On the opposite end of the semantic-syntax spectrum: An attempt to interpret the meaning of numbers of strokes in prehistoric signs

Bacon, B., Khatiri, A., Palmer, J., Freeth, T., Pettitt, P., & Kentridge, R. (2023). An Upper Palaeolithic Proto-writing System and Phenological Calendar. *Cambridge Archaeological Journal*, 1-19. https://doi.org/10.1017/S0959774322000415



"We demonstrate that when found in close association with images of animals the line <|> and dot <•> constitute numbers denoting months, and form constituent parts of a local phenological /meteorological calendar beginning in spring and recording time from this point in lunar months.

We also demonstrate that the <Y> sign, one of the most frequently occurring signs in Palaeolithic non-figurative art, has the meaning <To Give Birth>.

The position of the <Y> within a sequence of marks denotes month of parturition, an ordinal representation of number in contrast to the cardinal representation used in tallies.

Method: compilation of a database of sequences, mostly from textbooks and internet.

Table 1. *Number of sequences with and without <Y> in our analysis, by group.*

Analytical group	Number of sequences of dots/ lines without <Y>	Number of sequences with <Y>	Total
Aurochs	30	15	*45*
Bison	89	41	*130*
Caprid	41	17	*58*
Cervid	102	50	*152*
Fish	132	8	*140*
Horse	199	104	*303*
Mammoth	13	/	*13*
Bird	/	21	*21*
Total	*606*	*256*	*862*

On the opposite end of the semantic-syntax spectrum: An attempt to interpret the meaning of numbers of strokes in prehistoric signs

Here are the distributions of the numbers of dots or lines (fitted with a mixture of Gaussians) relative to lunar months since spring (an arbitrary decision)
The data do not validate the hypothesis very precisely. For caprids, in particular, the distribution is essentially flat.
There does seem to be some displacement in the distribution as a function of species, but this is not tested statistically.
Instead the authors perform a very strange logistic regression, with the DV = 0 or 1 depending on whether this is a mating month, and IV = number of observations. In this statistic (1) the degrees of freedom are wrong [months, not observations] (2) significance could just be due to missing large numbers.

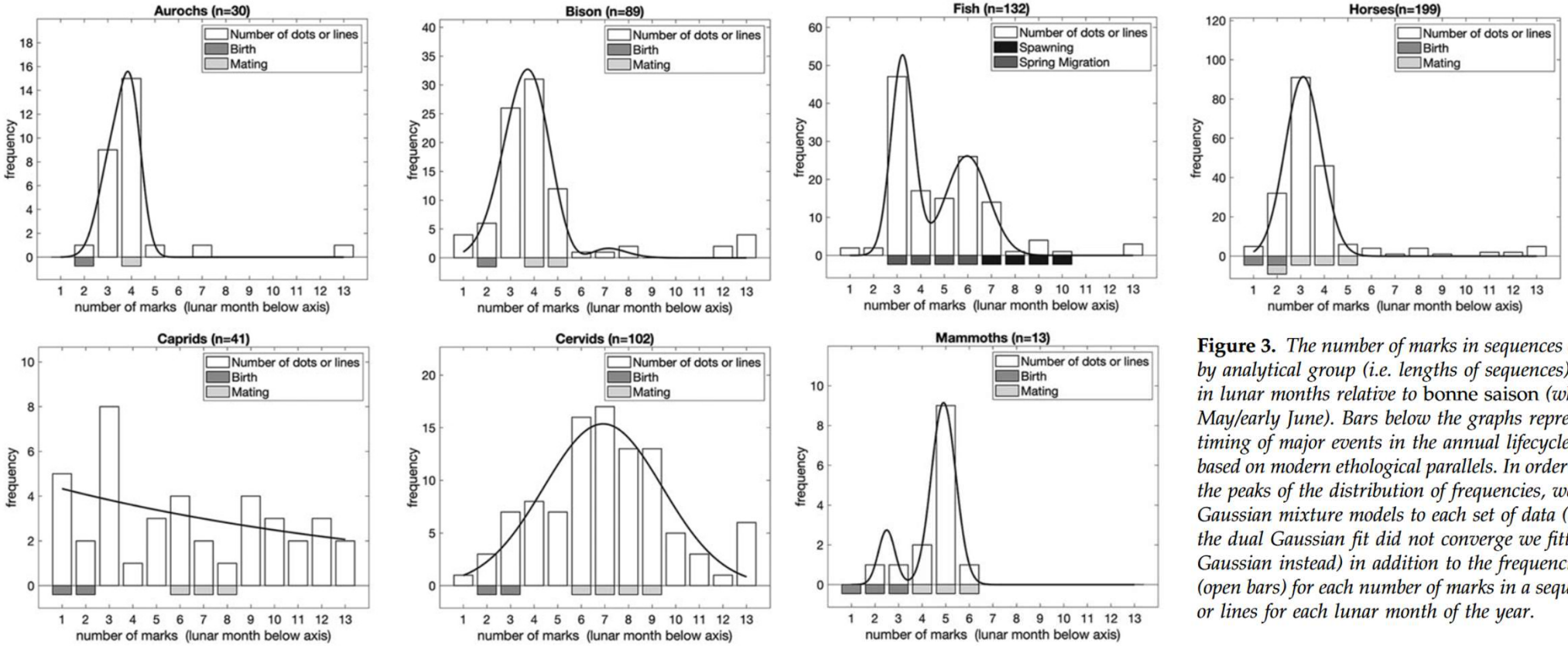
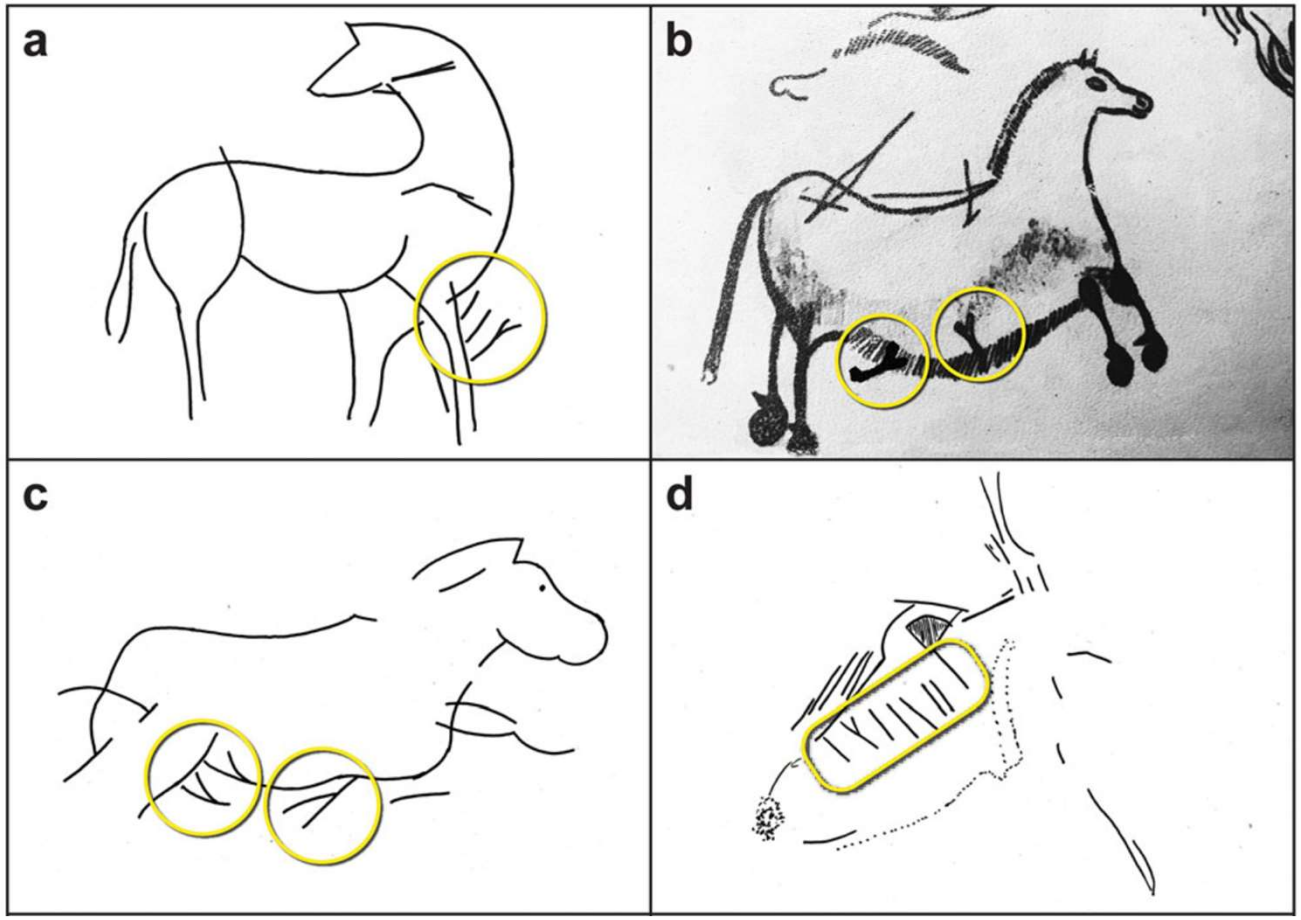


Figure 3. *The number of marks in sequences of lines/dots by analytical group (i.e. lengths of sequences), expressed in lunar months relative to* bonne saison *(where 1 = late May/early June). Bars below the graphs represent the timing of major events in the annual lifecycle of the taxa based on modern ethological parallels. In order to illustrate the peaks of the distribution of frequencies, we fitted dual Gaussian mixture models to each set of data (solid line; if the dual Gaussian fit did not converge we fitted a single Gaussian instead) in addition to the frequencies observed (open bars) for each number of marks in a sequence of dots or lines for each lunar month of the year.*

On the opposite end of the semantic-syntax spectrum: An attempt to interpret the meaning of numbers of strokes in prehistoric signs



The authors also count the position of the Y sign in sequences.

Here again there is an arbitrary decision : which direction should be considered as the tally decision?

The authors arbitrarily label the direction of the sequence as the direction of the animal movement.

Here are four examples:

(a) Horse: Pair-non-Pair, early, <Y> sign in position 3 in sequence of 3;
(b) Horse: Lascaux, late, <Y> sign in position 1 of sequence of 1;
(c) Horse: Sotarizza, late, <Y> sign in position 1 of sequence of 1;
(d) Chamois: Labastide, late, <Y> sign in position 2 in sequence of 7;

On the opposite end of the semantic-syntax spectrum: An attempt to interpret the meaning of numbers of strokes in prehistoric signs

There are problems with those graphs (for instance, given the previous figure, there should be at least two horses with a Y at position 1).
But even we neglect this issue, the histograms suggest that the Y is almost always in position 2 (?), **regardless** of the species – except for horses (?), but why? They do not have a later parturition month.
In summary, the analysis is statistically flawed and suggestive at best, but overall totally unconvincing.
Deciphering geometrical syntax is much easier than deciphering meaning!

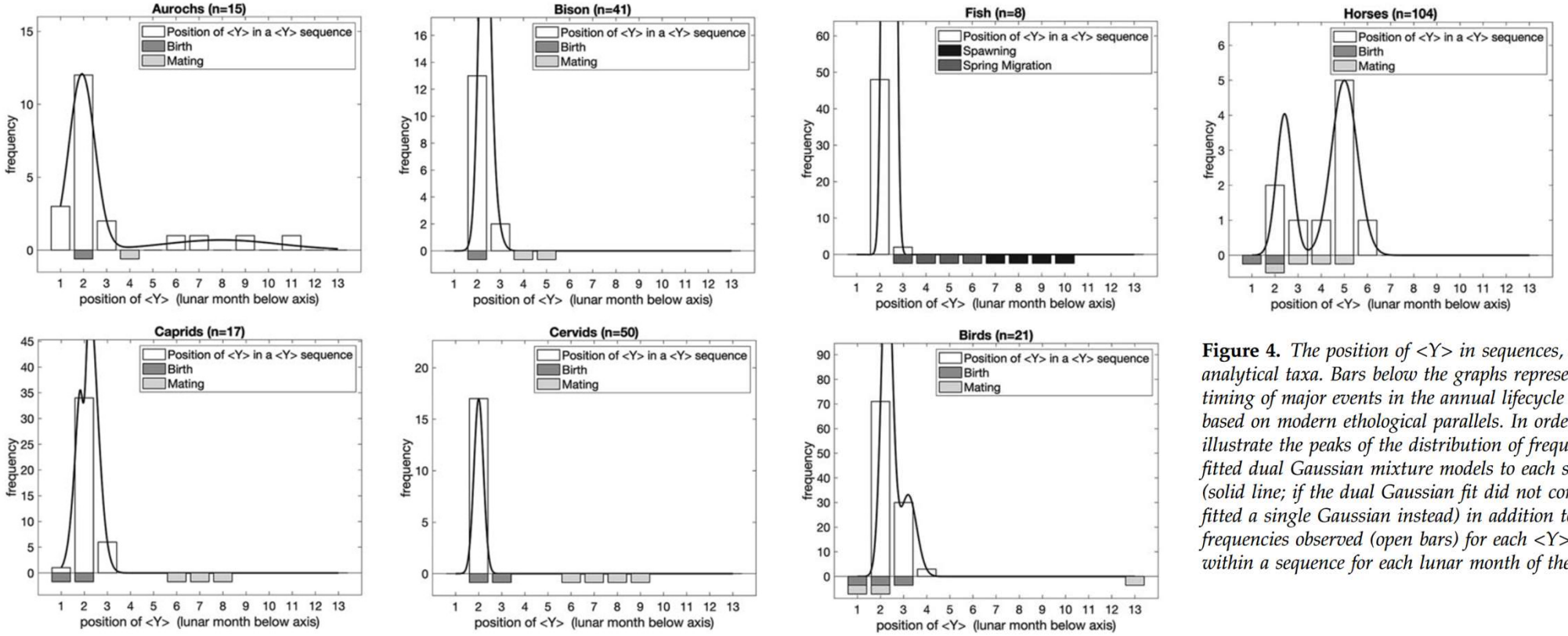


Figure 4. *The position of <Y> in sequences, by analytical taxa. Bars below the graphs represent the timing of major events in the annual lifecycle of the taxa based on modern ethological parallels. In order to illustrate the peaks of the distribution of frequencies, we fitted dual Gaussian mixture models to each set of data (solid line; if the dual Gaussian fit did not converge we fitted a single Gaussian instead) in addition to the frequencies observed (open bars) for each <Y> position within a sequence for each lunar month of the year.*

A modern database of geometric signs

Dutkiewicz, E., Russo, G., Lee, S., & Bentz, C. (2020). SignBase, a collection of geometric signs on mobile objects in the Paleolithic. *Scientific Data*, *7*(1), https://doi.org/10.1038/s41597-020-00704-x

Dutkiewicz et al. collected a large number of prehistoric signs from more than 500 objects from various sites of the European Upper Paleolithic, African Middle Stone age, Near East and Southeast Asia.

The signs are classified into:

(1) Line, (2) Oblique line, (3) Concentric lines, (4) Dashed line, (5) Radial line, (6) Circumferential line, (7) Circumferential spiral, (8) Notch, (9) Oblique notch, (10) Radial notch, (11) Circumferential notch, (12) Dot, (13) Cupule, (14) Cross, (15) Rhombus, (16) Hashtag, (17) Grid, (18) Hatching, (19) Zigzag, (20) Zigzag row, (21) Rectangle, (22) Macaroni, (23) V, (24, 25) Pin to the left or to the right, (26) Star, (27) Vulva, (28) Paw; and also anthropomorph, zoomorph, other.

The database allows to compute frequencies (notch=48% of objects; line=33%, cross=10%; Dots=7%; cupules=2%)

and to examine the geographical distribution of signs, similarity across sites, etc.

Several critiques :

- Signs on cave walls are missing.
- The relationships among signs are often missing (e.g. the indication “dot” does not explain if it is a line of dots, a circle of dots, etc)
- It might have been more interesting to encode which geometrical properties are present, e.g. alignment, parallelism, concentricity, fixed curvature, equal length, equal angles, etc.

Proposal : **do not classify** geometric signs ; in fact, **do not treat them as “signs”** at all, which implies that they have a signifier and a signified (the latter escapes us). But (1) focus only on their **shape**, and the cognitive faculties it implies; (2) characterize their **geometrical language**, their **syntax**; (3) use modern cognitive science tools to probe the existence of such a language in all humans.

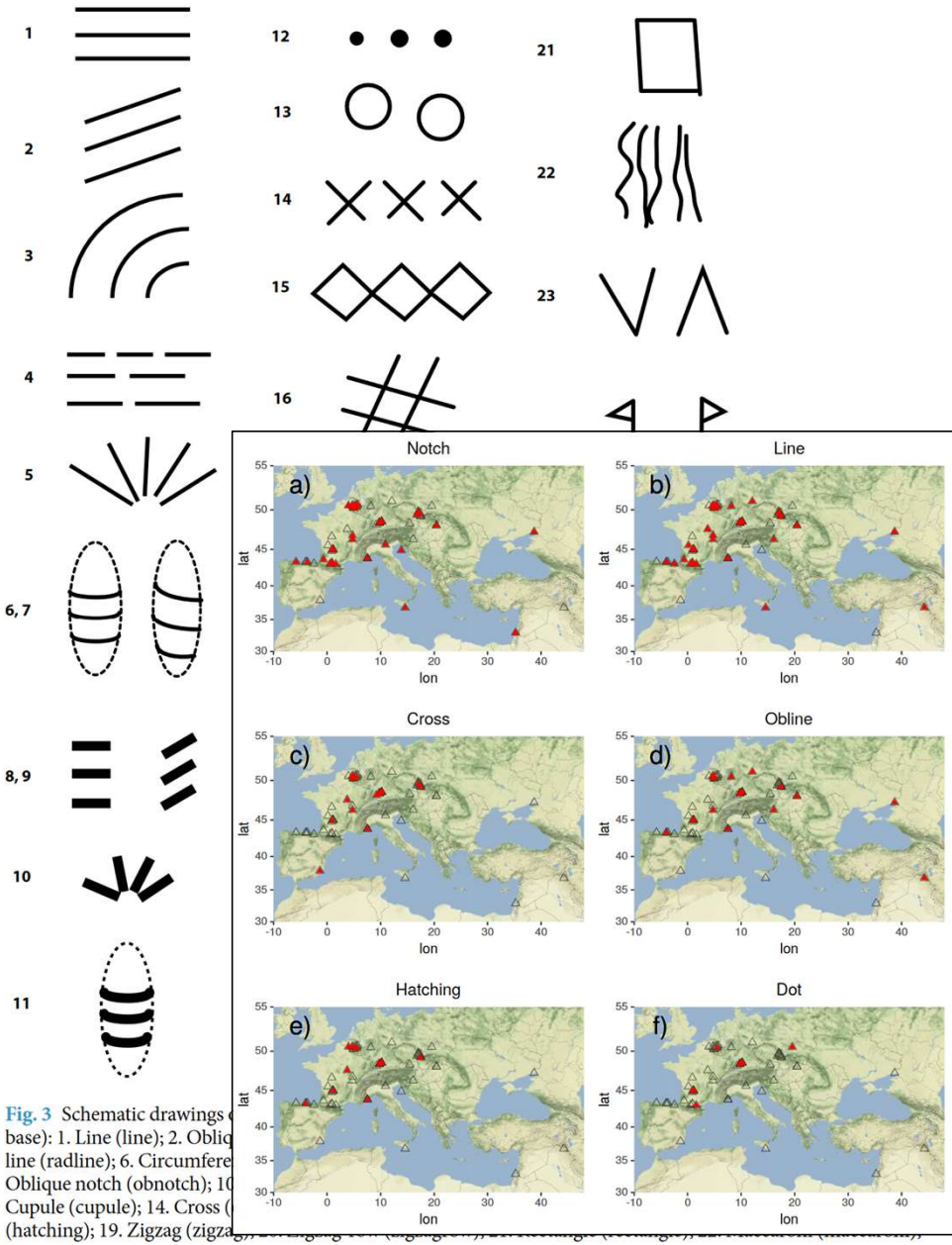


Fig. 3 Schematic drawings (base): 1. Line (line); 2. Oblic line (radline); 6. Circumfere Oblique notch (obnotch); 1(Cupule (cupule); 14. Cross ((hatching); 19. Zigzag (zigza

Prochains cours:

- Dessins d'enfants et universaux géométriques : comment les expliquer?
- Motifs géométriques et musicaux et leurs mécanismes cérébraux
- Perception des quadrilatères et singularité de l'espèce humaine en géométrie
- Rôle de l'éducation et de l'expérience visuelle dans l'intuition géométrique
- Modèles de la perception de la géométrie