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CONCEPTS, METHODS AND TOOLS

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A simple way to formalize the dating of stratigraphic units

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Abstract
Building the stratigraphic relative chronology from field observations is at present a quite clear intellectual task, thanks to Edward Harris (Harris 1979). However, the following step – placing stratigraphic units in the absolute time by means of dated materials, historical indications, and stratigraphic observations – is far from being always totally explicit. The frequently used notions of terminus post quem (TPQ) and terminus ante quem (TAQ) do not define all the aspects of this dating reasoning. In particular, the formation durations of the stratigraphic units are rarely taken into account in a quantified way. So, even the basic notion of ‘dating a layer’ may be ambiguous.

This paper briefly presents some developments (from previous works about formalized stratigraphic data process and tool - Desachy 2010, 2012) in order to formalize and to computerize this basic but no so clear process of absolute dating of the stratigraphic units.

Keywords: stratigraphy, chronology, absolute time.

1. From stratigraphic time to quantified time: intervals of inaccuracy

A stratigraphic unit is defined at first in a relative time. It necessarily exists also in the absolute time: it has a beginning of formation, an end of formation, and a duration between these two endpoints. The formation duration may be seen as a segment on the absolute time line; the beginning and the end are just moments, i.e. points on this line. Another duration must be taken into account: the duration ‘masked’ by a stratigraphic relationship when there is a discontinuity of absolute time between two successive stratigraphic units; more exactly, between the end of the formation of the previous unit and the beginning of the formation of the next unit.

These two moments (beginning and end of the formation of a unit) and these two durations (formation duration of a unit, and duration between two successive units) are the absolute dating framework of a stratigraphic sequence. Most frequently, the archaeologists do not have direct indication about those moments and durations. However, it is always possible to define an interval of inaccuracy for each of these moments and durations.

The [TPQ, TAQ] interval is traditionally used by the archaeologists to date the deposits. According to the most common definition of the TPQ (as the date provided by the later dated find in the deposit), this time slot is actually an inaccuracy interval for the end of the formation of the considered unit (so that this end time cannot be older than the TPQ nor more recent than the TAQ), but not for the duration of this formation. Indeed, it is worth emphasizing that a TPQ provides an earliest limit for the end, and not for the beginning of the formation duration.

The same principle of interval of inaccuracy may be applied to the whole dating framework of a stratigraphic sequence. So, besides the [TPQ, TAQ] interval, we can consider 3 others intervals of inaccuracy: one interval [earliest date, latest date] including the beginning of the unit formation; and two intervals [shortest duration, longest duration] to include the unit formation duration, and to include the duration between two successive units. Those four intervals involve height limits in the absolute (quantified) time (figure 1):

- Be(x): earliest date for the formation beginning of a unit x;
- Bl(x): latest date for the formation beginning of a unit x;
- Ee(x): earliest date for the formation end of a unit x (corresponding to the common notion of terminus post quem);
- El(x): latest date for the formation end of a unit x (corresponding to the common notion of terminus ante quem);
- Ds(x): shortest possible duration for the formation of a unit x;
- Dl(x): longest possible duration for the formation of a unit x;
- Ds(x, y): shortest possible duration assignable to the order relation between units x and y;
- Dl(x, y): longest possible duration assignable to the order relation between units x and y;

Of course, all these quantified values must use the same time measuring unit (usually, this unit is the year).

2. Taking into account the diversity of the dating clues

As every archaeologist knows, different kinds of dating elements may be available to localize the stratigraphic units
in the absolute time. These diverse dating elements do not inform the same intervals and limits, according to their nature and to their position related to the considered unit (typological or analytical dating of finds contained in this unit, absolute time data about the unit formation provided by geophysical or geoarchaeological studies, extrinsic historical sources...).

Concerning specifically the artifacts found in archaeological context, there is an abundant literature about their chronological characteristics and their use to dating. Let us only remind that the moment when an artifact goes into the archaeological context (where the archaeologist will find it later) is the end time of a whole previous chronological path including production, use, sometimes reuse, discard or deposit, and sometimes (very often in the urban contexts for instance) transfers from a stratigraphic unit to a new unit disrupting the previous one. This trajectory must be taken in account if an artifact is used as absolute dating element (what is possible also by the means of inaccuracy intervals applied to the artifact chronological path). Of course, in all cases, it is necessary to eliminate the intrusive elements, which actually belong to later stratigraphic events.

More generally, archaeologists record carefully a lot of chronological evidences from the contexts they study, but these evidences are not always fully used in the absolute dating reasoning. The set of intervals exposed above allows to value all the dating clues available in order to date an archaeological context, whatever their nature; then, the question is ‘what interval and what limit(s) does this clue inform?’ For instance, field observations, possibly resorting to geoarchaeology or taphonomy, may provide evidences about the formation duration of a unit. Then, it may be necessary to translate a qualitative assessment (e.g. ‘not very long’) into a quantified order-of-magnitude (e.g. ‘from one to ten years’) usable as an interval [shortest possible duration, longest possible duration].

Sometimes the beginning, or the end, or the duration of the formation of a unit is directly known and dated (for instance if this unit is related to a known historical event). In this case the inaccuracy interval has a nil length and its two limits receive this same known chronological value.

3. Processing the inequations system

The intervals and the stratigraphic relations are the components of a system of inequations which can be automatically processed by the means of simple – but boring to execute manually – logical and algebra calculation. The system has the following form:

for each unit x,

\[ Ee(x) - Dl(x) \leq Be(x) \leq Ee(x) - Ds(x) \]
\[ El(x) - Dl(x) \leq Bl(x) \leq El(x) - Ds(x) \]
\[ Be(x) + Ds(x) \leq Ee(x) \leq Be(x) + Dl(x) \]
\[ Bl(x) + Ds(x) \leq El(x) \leq Bl(x) + Dl(x) \]
\[ Ee(x) - Bl(x) \leq Ds(x) \leq Dl(x) \leq Ee(x) - Be(x) \]

for each relation x before y,

\[ Be(y) - Dl(x, y) \leq Ee(x) \leq Be(y) - Ds(x, y) \]
\[ Bl(y) - Dl(x, y) \leq El(x) \leq Bl(y) - Ds(x, y) \]
\[ Ee(x) + Ds(x, y) \leq Be(y) \leq Ee(x) + Dl(x, y) \]
\[ El(x) + Ds(x, y) \leq Bl(y) \leq El(x) + Dl(x, y) \]
\[ Be(y) - El(x) \leq Ds(x, y) \leq Dl(x, y) \leq Bl(y) - Ee(x) \]

For each unit and relation, the unknown values (limits not informed by dating elements) may be completed: an ‘absolute beginning’ and an ‘absolute end’, chosen by the archaeologist so as to include the whole studied occupation, are the default values for the unknown limits at the earliest and at the latest; the difference between them gives the total maximal duration, default value for the unknown longest possible durations; as for the unknown shortest possible durations, the logical default value is zero.

Let us take an example: archaeologists found remains of wall, with a coin dated from 1600 BC lost in the masonry. The analysis of this masonry leads to conclude that its
building was quite fast, certainly less than one year. This masonry was set in a foundation trench, itself excavated and filled in a short time (deduced, for instance, from vertical edges in a loose ground), certainly also less than one year. Furthermore, an old photo and later documents indicate that in 1860 BC, this wall was no more visible, thus it was already destroyed. If we consider the two stratigraphic units: ‘x’ for the foundation trench, ‘y’ for the masonry of the wall, and the relation x before (filled by) y, we can write these limits (with year as time unit):

\[ D_l(x) = 1 \]
\[ D_l(x, y) = 1 \]
\[ E_e(y) = 1600 \]
\[ E_l(y) = 1860 \]
\[ D_l(y) = 1 \]

The aim of the process is to reduce the initial intervals by deducing increased earliest limits and shortest duration, and reduced latest limits and longest durations. So we can use only the corresponding parts of the inequations exposed above to deduce, as far as possible, the new more accurate limits:

\[ E_e(y) - D_l(y) = B_l(y) \] thus \[ B_l(y) = 1600 - 1 = 1599 \] (beginning at the earliest for the formation of y)
\[ B_l(y) = E_l(y) - D_s(y) \] thus \[ B_l(y) = 1860 - 0 = 1860 \] (beginning at the latest for the formation of y)
\[ E_l(x) = B_l(y) - D_s(x, y) \] thus \[ E_l(x) = 1860 - 0 = 1860 \] (end at the earliest for the formation of x)
\[ B_e(y) - D_l(x, y) = E_e(x) \] thus \[ E_e(x) = 1599 - 1 = 1598 \] (end at the earliest for the formation of x)
\[ B_l(x) = E_l(x) - D_s(x) \] thus \[ B_l(x) = 1860 - 0 = 1860 \] (beginning at the latest for the formation of x)
\[ E_e(x) - D_l(x) = B_e(x) \] thus \[ B_e(x) = 1598 - 1 = 1597 \] (beginning at the earlier for the formation of x)

The new deduced values provide absolute time intervals for each unit with the best (or the least bad) accuracy according to the whole available dating elements and stratigraphic relations. This deducing process uses the whole stratigraphic partial order, including transitively deductible relations, so that the deduced duration interval of each relation gives the critical path duration between the two units. Logical faults due to contradictory dating elements are detectable by the deduction of negative intervals of time.

4. Results: the times of a stratigraphic sequence and their display

The deduced intervals provide the units with two kinds of localization in the absolute time: a possible time zone, and/or a certain time zone (figure 2).

If a unit has inaccuracy intervals (with a length more than zero), this inaccuracy involves logically a time zone of possibility (and not certainty) of formation of this unit, between its oldest possible beginning date (Be) and its latest possible end date (El).

The earliest date for the formation beginning of a unit is necessary prior to the latest date for this beginning, but the latest for the beginning (Bl) may be later than the earliest date for the end (Ee). In this case, the inaccuracy is so strong that the unit has no certain time into its possible time of formation. Indeed, at each moment of its possible time, its formation may be not yet begun, or may be already ended. It is the case of the example above, and it is generally the case when only dated finds giving TPQ are available as dating elements.

If Bl(x) is earlier than Ee(x), the unit x has a partial time zone of certainty between these two limits. If its inaccuracy intervals have a nil length, the unit has a totally certain time of formation.

Displaying these intervals and time zones in the absolute time needs a specific graph. The Harris Matrix (and its variants) is the best and well-known way to display synthetically a stratigraphic sequence. However, it is actually a graph of the partially ordered set composed of the stratigraphic units of this sequence, what involves that the units are displayed as nodes, by only one point in the time. It is possible to show on such a graph either the TPQ or the TAQ (as horizontal thresholds, and assuming that the displayed point in time for each unit is the end of its formation – Desachy 2010), but this kind of graph can’t practically show absolute durations. So, a complementary kind of graph, on a quantified time scale, is necessary to display the absolute time (figure 3). This sort of quantified time scale graph may be more or less detailed: showing all the inaccuracy intervals and dating elements for a single unit graph, or only the certain/possible time zones of each unit for a more synthetic view of the whole sequence.

If a shortest and/or a longest possible duration of formation (smaller than the possible time zone of the unit) is known, it may be displayed at the earliest or at the latest, showing...
5. Uncertainty and estimate time

Inaccuracy is not the only kind of imperfection which affects the data: some stratigraphic relations may be uncertain, or less certain than others, when field observations provide significant clues but not totally decisive evidence. It was proposed (Desachy 2010) to take into account this difference of status through a modality of uncertainty assignable to the stratigraphic relations, so that a relation may be recorded as ‘estimated’ (not certain). This ‘two-speeds’ system of statements is only a very simple form of modal logic, but it allows to deal more flexibly with the qualitative heterogeneousness of the data.

Transforming this modal stratigraphic time into quantified time involves a double set of intervals and limits in the absolute time: the set of certain limits exposed above, and, possibly, a second set of ‘estimated’ limits and intervals, more accurate but less certain than the first one. These estimated intervals of inaccuracy may be used for less certain dating elements, or for chronological hypothesis testing.

If this double set of limits is used, it may be an estimated earliest date for the formation beginning of a unit \( x \) – \( EBe(x) \) – and an estimated latest date for the formation end of \( x \) – \( EEI(x) \), defining a third kind of time zone: an estimated formation time zone, contained into the possible time zone and including the certain time zone (if it exists) (figure 2).

6. Towards a more explicit chronological reasoning: limits and prospects

The formalization discussed above in terms of inaccuracy intervals and inequations system relates only to the basic – but fundamental – chronological reasoning from stratigraphic data and dating elements, that archaeologists practice every day to produce statements such as ‘this feature dates from the second half of the 1st century BC’. Our formalization is an attempt to find the simplest way to make sounder and more explicit the production of this sort of statements. Indeed, a more explicit view of the contexts in the absolute time (in terms of certain, possible or estimate time) is useful, in particular to typochronological researches using the archaeological contexts to date artifacts. The aim is also, of course, a computerizable process, in order to save time and to get easily a chronological synthesis of available data as an archaeological excavation progresses.
Practically, the immediate prospects include the integration of this process into the next version of the computerized stratigraphic data processing tool *Le Stratifiant* (Desachy 2010).

This simplicity involves conceptual limits: into the ‘possible time’ defined by the inaccuracy intervals, even if chronological hypotheses may be displayed (by the way of ‘estimated’ time zones), there is no way to decide if a hypothesis is better than another one. The answer to this problem is a further step, of real chronological modelling, using more advanced mathematical tools (probability theory, fuzzy logic...).

Another limit, which is also a way to development, is that the process exposed above is applied only to the stratigraphic chronology, i.e. the succession of the archaeological ground formation steps. The same simple way of inaccuracy intervals process is applicable to the more synthetic and elaborate scale of the historic entities (who can, or not, arise from archaeological observations and in this case from one or several stratigraphic units) whose chronology is imperfectly known; but then, it will be necessary to move from the stratigraphic notion of formation duration of a unit, to a wider historical and functional notion of cultural existence duration (for instance, in this wider notion, an archaeological feature may have times of use and reuse after its time of formation); and to move from the strict notion of stratigraphic relationship to a wider notion of constraint of succession.

**Figure 4**: Chronological hypotheses for a stratigraphical unit, with the shortest and the longest formation durations.

**References**

