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Combining high resolution time-marker stratigraphy and dating methods for a refined age of the 4 kyr B.P. impact-ejecta across the two hemispheres

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The research effort devoted to the impact record through Earth history has for long demonstrated the importance to combine high-resolution biostratigraphy, geochemical-stratigraphy and high-precision geochronology for sequencing impact events. This is illustrated by the ongoing controversies on the exact role of the Chixculub impact on the Cretaceous/Tertiary crisis.

We present here the novel approach we have developed to construct an age model of the 4 kyr B.P. impact. The challenge for an impact recorded in the recent past of the Earth was to achieve an understanding of geological processes down to time and spatial scales that are significant in terms of human history. In the absence of a well-attested impact crater, our approach is at first based on the identification of the 4 kyr BP impact-signal using high resolution micro-facies analysis of marine and continental records across the two hemispheres. We define the close association of various exotic components ranging from impact-ejecta micro-debris to large impact-breccia blocks and facies anomalies of the host materials produced by the explosive pulverisation of

rocks yielding a metal-rich carbonaceous melt. We consolidate the genetic filiation of the signal-component at all spatial scales by using a unique suite of similar organic, mineral and metallic tracers that are characterised by XRD, Raman microspectrometry, SEM-EDS, SEM-WDS, HRTEM, EELS, GC-IR-MS, isotopes (C, O, S, Pb, Fe, Cr) and noble gas measurement. We use the intact components of the 4 kyr BP signal that comprise various rock clasts and a micro-faunal assemblage (foraminifera, diatoms and radiolaria) from subtropical, subpolar and austral seawaters to recognise a common origin of the impact-ejecta from multiple target sources in the Southern hemisphere. This set of robust criteria allows to adjust the choice of dating strategies to the quality of the 4 kyr BP impact-signal. Charred plant materials associated with the well-preserved 4 kyr BP impact-signals, when not contaminated by the exotic carbonaceous sources, give the most coherent C^{14} radiometric ages : 4050-3950 $\pm$ 50 yr BP (i.e. 2600-2300 BC, $2\sigma^{14}$C Cal.). This association allows to correlate the multiple expression of the instantaneous fall that ranges from a cm-thick strata to a few metre thick accumulation of the impact-ejecta across distances not exceding a few hundred metres. It also allows to establish the strict synchronism of the ejecta-pulverisation with a thermal blast firing the host soil at the surface and the formation of micro-crater fields due to the disintegration of impactite blocks. The close cluster of ^{14}C ages from a high quality sequence shows that the duration of the 4 kyr BP impact-event lies within the precision range of the ^{14}C radiometric technique. The integration of archaeological markers and historical data provides a maximized estimation of a few years for the direct impact processes, i.e. the instantaneous ejecta deposition and the short-term fall of the fine dust launched into the upper atmosphere. The duration of the indirect environmental effects, i.e. heavy rain, cooling and acidification, does not seem to have exceeded a few decades as estimated from the sequence of micro-facies formed subsequently to the impact event. In contrast, we illustrate how the uncontrolled use of the radiometric technique on poor-quality 4 kyr BP impact-signals give either too early dates due to contamination by allochtonous fossil carbon, or scattered clusters of ^{14}C ages. These incoherent time series can be confused with an event lasting a few hundred years, or with a periodical event.

The integration of impact-marker stratigraphy and accurate dating techniques allows to securely establish the synchronism of the short-term 4 kyr BP impact-processes from the micro-regional to the inter-hemispheric level. The older ages previously obtained by the ^{40}Ar/^{39}Ar dating technique on scattered impact glasses from the southern hemisphere that are similar to the 4 kyr BP components may reflect the presence of xenocrysts incorporated during the incomplete melting of precursors.

In the absence of recent analogues and of real-scale experiments, the 4 kyr B.P. impact offers a unique database useful for all stratigraphers, paleontologists and geochronol-

ogists interested in the chronology of impact events through Earth history.