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Response to: Comment on "A global environmental crisis 42,000 years ago" by A. Picin *et al.*

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Abstract

Our study on the exact timing, and potential climatic, environmental and evolutionary consequences of the Laschamps Geomagnetic Excursion has generated a novel hypothesis that geomagnetism represents an unrecognised driver in environmental and evolutionary change (*1*). It is important that this is tested with new data, and encouragingly, none of the studies presented by Picin *et al.* (*2*) undermine our model.

Main Text

Numerous geomagnetic excursions have occurred throughout geological time, but currently we know very little about their potential impacts (*1*). During the late Quaternary, ancient DNA records have demonstrated that major population (and even species) extinction and replacement events have occurred relatively frequently, but often remain invisible within the fossil record (*3*). As a result, it is unclear what impact many earlier geomagnetic excursions, such as the Blake (~114ka) and post-Blake (~109ka), may have had on Neanderthal populations as mentioned by Picin *et al (2).* However, recent studies on European Neanderthal populations around this time (*4*) suggest that environmental changes caused population fragmentation around 115-100ka, while Spanish Neanderthal populations underwent a major population replacement around ~112-107ka, similar to the Laschamps observations.

As we noted (*1*), the environmental changes at 42ka are more obvious in sediment and glacial records in the Pacific region, whereas the pronounced Dansgaard-Oeschger cycles in the North Atlantic potentially obscure similar impacts. In this regard, it is important to recognise that the Greenland ice records do not represent global climate, but preserve northern Atlantic regional environmental changes. Nevertheless, the refined timing created via the kauri record reveals that the periods of collapsed magnetic field strength and implied cooling impacts during the Laschamps align very closely to Greenland Stadial-11 and the climatically anomalous GS-10 (*1,5*) (Fig. 1).

The staggered spatiotemporal pattern of European Neanderthal extinctions during the repeated (cold) stadials GS-12 to GS-10 has been explained as competitive exclusion from invading Anatomically Modern Human (AMH) populations re-expanding more rapidly after each cycle (*6*). Neanderthal population sizes and genetic diversity were decreasing throughout the Late Pleistocene but their survival through multiple glacial-interglacial cycles makes it seem unlikely that a standard Greenland Stadial (*i.e.* GS-10) alone could have caused their extinction. However, we know very little about the nature or rate of change of geomagnetic-caused environmental changes during GS-10, which arguably could have been much faster or had more severe impacts (Fig. 1). We used the most comprehensive available compilation of high-quality radiocarbon dates (*7*) to show that the final ages of western European Neanderthal populations were coincident with the Laschamps excursion. This conclusion has been further reaffirmed by studies re-dating anomalously young dates such as from the site Spy (*8*), the impacts of the latest radiocarbon calibration curve (IntCal20) for this period (*9*), and seemingly by the additional data and figure presented by Picin *et al. (2)* (Fig. 1).

Picin *et al.* point out that in Europe '*Homo sapiens* clearly survived the climatic consequences of the Laschamps' (*2*), however a recent study (led by one of the co-authors) demonstrated that the AMH populations before and after the Laschamps represent two genetically different populations (*10*), separated by a complete replacement around the Laschamps (Fig. 1). Specifically, Initial Upper Paleolithic AMH populations were replaced sometime after 45.3-42.6ka, immediately before Laschamps, while the subsequent Aurignacian populations appear during or shortly after the Laschamps. Indeed, both the (alternative) short and long Early Upper Paleolithic chronologies presented by Picin *et al.* (*2*) indicate a major transition associated with the Laschamps (Fig. 1), while the start of the Early Aurignacian is contemporaneous when calibrated with IntCal20 (*9*) or kauri-Hulu (*1*). More remarkably, the Aurignacian itself appears to end during the next major geomagnetic excursion, Mono Lake at 35ka (*11*) (Fig. 1), after which it is genetically replaced by Gravettian populations which first appear in eastern Europe at that time (*12*). The AMH record is important as there are few other detailed European megafaunal genetic records around Laschamps, making it challenging to detect local extinction events. However, a cluster of megafaunal genetic extinction events is apparent around Mono Lake, where records are more detailed (*1,3*).

We specifically stated that high UV levels during the Laschamps seem unlikely to have caused major negative impacts on early AMH populations such as extinctions or altered migration patterns (*1*). However, our climatic and solar physics models suggested the intense UV light radiation and other associated phenomena during short (1-2 day) Solar Energetic Particle (SEP) events during the Laschamps would be consistent with a sudden increase in global cave use, including a clear intensification in the appearance and diversification of early figurative cave art, and red ochre utilisation including hand stencils (*1*). As we suggested, the sudden increase in figurative art in disparate locations across Europe and southeast Asia probably represented a preservation bias associated with the increased use of caves (potentially as short-term shelter during SEP events). We also clearly stated that the quality and diversity of cave art at ~42ka implied figurative art was already well established, likely in the external environment such as rockshelter and cliff walls.

In the Southern Hemisphere, the peak of megafaunal extinction events in Australia has previously been estimated at 42ka (*13*), while recent work in northeast Australia (*14*) referred to by Picin *et al.* (*2*) reveals that the youngest megafaunal layers (dated between 41.8-38.4ka, 1sd) appear to be associated with environmental deterioration starting around this period (Fig. 1). Similarly, the youngest radiocarbon-dated megafaunal remains in Tasmania are 41.9-40.9ka (*1*) when calibrated using the new kauri-Hulu curve. Within southern Africa, spatiotemporally-staggered patterns of cultural transitions complicate interpretation, although we noted that the fully developed expression of Late Stone Age technologies ~42ka (Fig. 1) recorded at Border Cave matched parallel megafaunal changes at Boomplaas Cave. Importantly, we had overlooked equatorial African palynological records which also detail major changes in vegetation patterns and moisture levels 43-40ka (*16*), parallel to those we report in the Pacific (*1*).

Our hypothesis that the Adams Transitional Geomagnetic Event and Laschamps excursion caused major global environmental (and climatic) impacts is based on precisely-aligned records and global chemistry-climate modelling. We do not claim to have resolved the full details of the mechanisms that drove global change or contemporaneous evolutionary events, as this will require further testing and analysis. However, Picin *et al.* (or Hawks) do not present any data that challenges our hypothesis, such that geomagnetic excursions remain a potentially important new environmental and evolutionary driver that has been previously overlooked.

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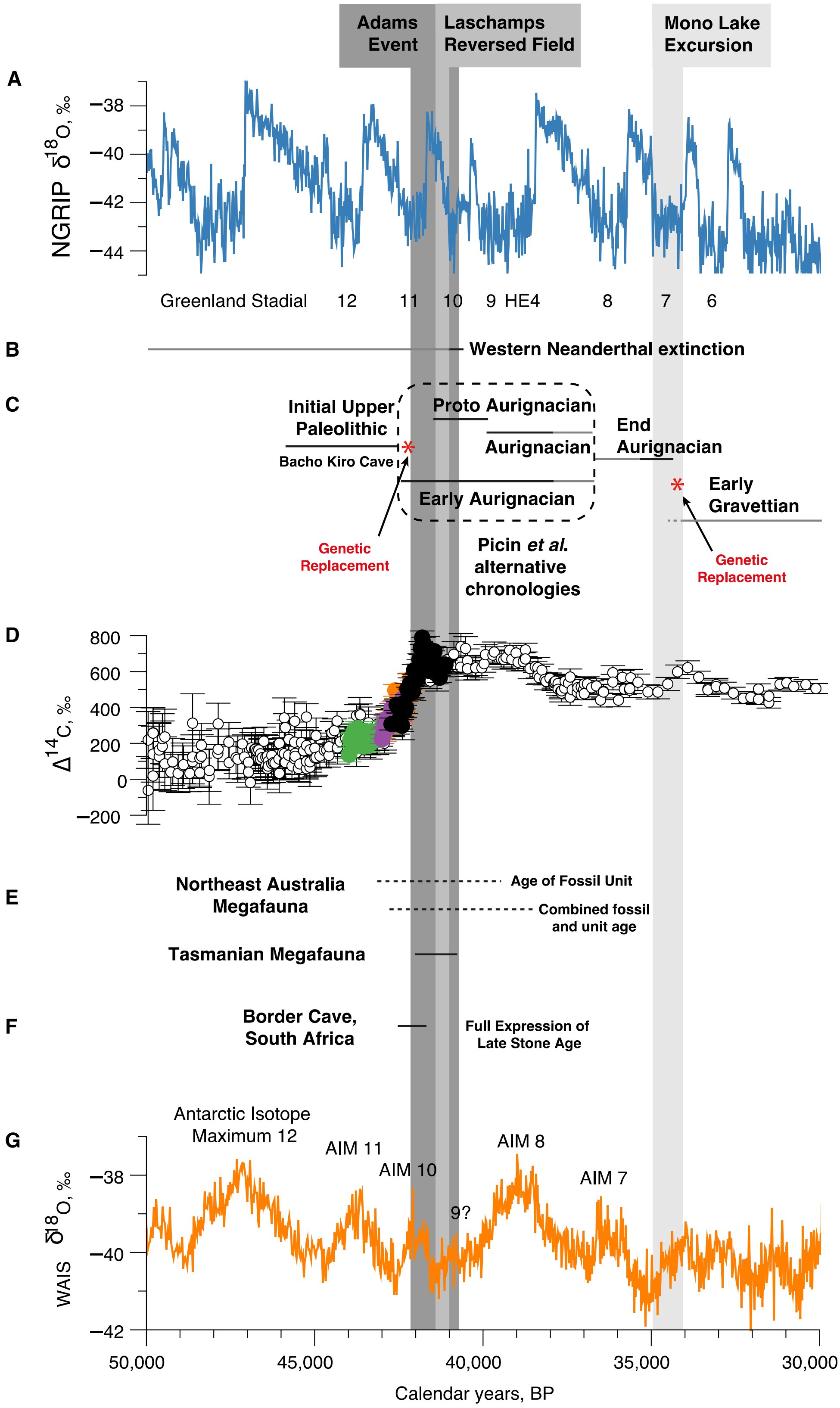
Adams Event
Laschamps Reversed Field
Mono Lake Excursion
A
NGRIP δ18O, ‰
−38
−40
−42
−44
Greenland Stadial 12 11 10 9 HE4 8 7 6
B
Western Neanderthal extinction
C
Initial Upper Paleolithic
Bacho Kiro Cave
Proto Aurignacian
Aurignacian
End Aurignacian
Early Aurignacian
Early Gravettian
Genetic Replacement
Genetic Replacement
Picin et al. alternative chronologies
D
Δ14C, ‰
800
600
400
200
0
−200
E
Northeast Australia Megafauna
Age of Fossil Unit
Combined fossil and unit age
Tasmanian Megafauna
F
Border Cave, South Africa
Full Expression of Late Stone Age
G
Antarctic Isotope Maximum 12
AIM 11
AIM 10
9?
AIM 8
AIM 7
WAIS δ18O, ‰
−38
−40
−42
50,000
45,000
40,000
35,000
30,000
Calendar years, BP