The Younger Dryas interval at Wonderkrater (South Africa) in the context of a platinum anomaly

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Wonderkrater in the Limpopo Province in South Africa is a late Quaternary archaeological site with peat deposits extending back more than 30 000 years before the present. Palaeoclimatic indices based on multivariate analysis of pollen spectra reflect a decline in temperature identifiable with the Younger Dryas (YD). A prominent spike in platinum is documented in a Wonderkrater sample (5614) with a mean date of 12 744 cal yr BP using a Bayesian model, preceding the onset of the YD cooling event. The YD platinum spike at Wonderkrater is the first to be observed in Africa in the southern hemisphere, supplementing new discoveries from Patagonia in South America, in addition to more than 25 sites with such platinum anomalies in the northern hemisphere. The observations from South Africa serve to strengthen ongoing assessments of the controversial YD Impact Hypothesis, whereby it is proposed that a meteorite or cometary impact contributed to a decline in temperature, associated *inter alia* with dispersion of atmospheric dust, mammalian extinctions and cultural changes.

Key words: cosmic impact, Terminal Pleistocene.

INTRODUCTION

The Younger Dryas (YD) event is recognized especially well in the northern hemisphere as an episode of cooling, the inception of which is *circa* 12 800 years BP (calibrated date), lasting until 11 500 cal yr BP. It can be identified for example from high resolution oxygen isotope data from ice cores such as those in Greenland (Petaev *et al*. 2013). In the southern hemisphere, the YD cooling event has been recognized *inter alia* from pollen spectra representing cool upland fynbos in Late Quaternary deposits at Wonderkrater (Scott *et al*. 2003; Thackeray & Scott 2006; Thackeray 2018), an archaeological site in the Limpopo Province of South Africa (Fig. 1), associated with a spring mound which consists primarily of peat more than 5 m thick (Scott 1982; McCarthy *et al*. 2010; Backwell *et al*. 2014). The Wonderkrater pollen samples identified initially by Scott (1982) and assessed by Scott *et al*. (2003, 2012) and Scott (2016) have facilitated the opportunity to identify relative changes in palaeotemperature (Scott & Thackeray 1987), calibrated on a Celsius scale (Thackeray 1999).

Thackeray (1993) compared temperature indices for zones W4–W10 in Core 3 at Wonderkrater with an oxygen isotope record at Sumxi Co in Tibet (14 000 cal yr BP to present day). The correlation indicated that the method of multivariate analysis of pollen spectra had merit, and that the temperature index reflected global changes in temperature, especially since it correlated also with deuterium isotope (palaeotemperature) records from Vostok in Antarctica for the period postdating 14 000 BP (Thackeray 1990).

Thackeray (2018) has raised the possibility that the YD at Wonderkrater may be associated with a cosmic impact such as that which has been invoked by the YD Impact Hypothesis (Firestone *et al*. 2007; Wolbach *et al*. 2018a,b; Israde-Alcantara 2012; Kennett *et al*. 2009, 2015; Petaev 2013; Moore *et al*. 2017; Pino *et al*. 2019). In terms of this hypothesis, an impact of the kind associated with a large meteorite crater beneath the Hiawatha glacier in northern Greenland (Kjær *et al*. 2018) would have affected plants, animals and humans over a wide geographical area. An expectation is that if a meteor, asteroid or comet was sufficiently large and vaporized or disintegrated on impact or in the atmosphere, leading to biomass burning, dust associated with this event would have been dispersed on a global scale, sufficiently to attenuate solar radiation in the earth's atmosphere, thereby contributing to a temporary decline in atmospheric and oceanic temperatures.

Meteorites are commonly known to be rich in platinum (Pt), and concentrations of this element in sedimentary sequences have been cited as evidence in support of the YD Impact Hypothesis, although volcanic sources of platinum may also be invoked (Tankersley *et al*. 2018). In this study we aim primarily to determine whether a Pt spike can be detected in YD deposits at Wonderkrater.

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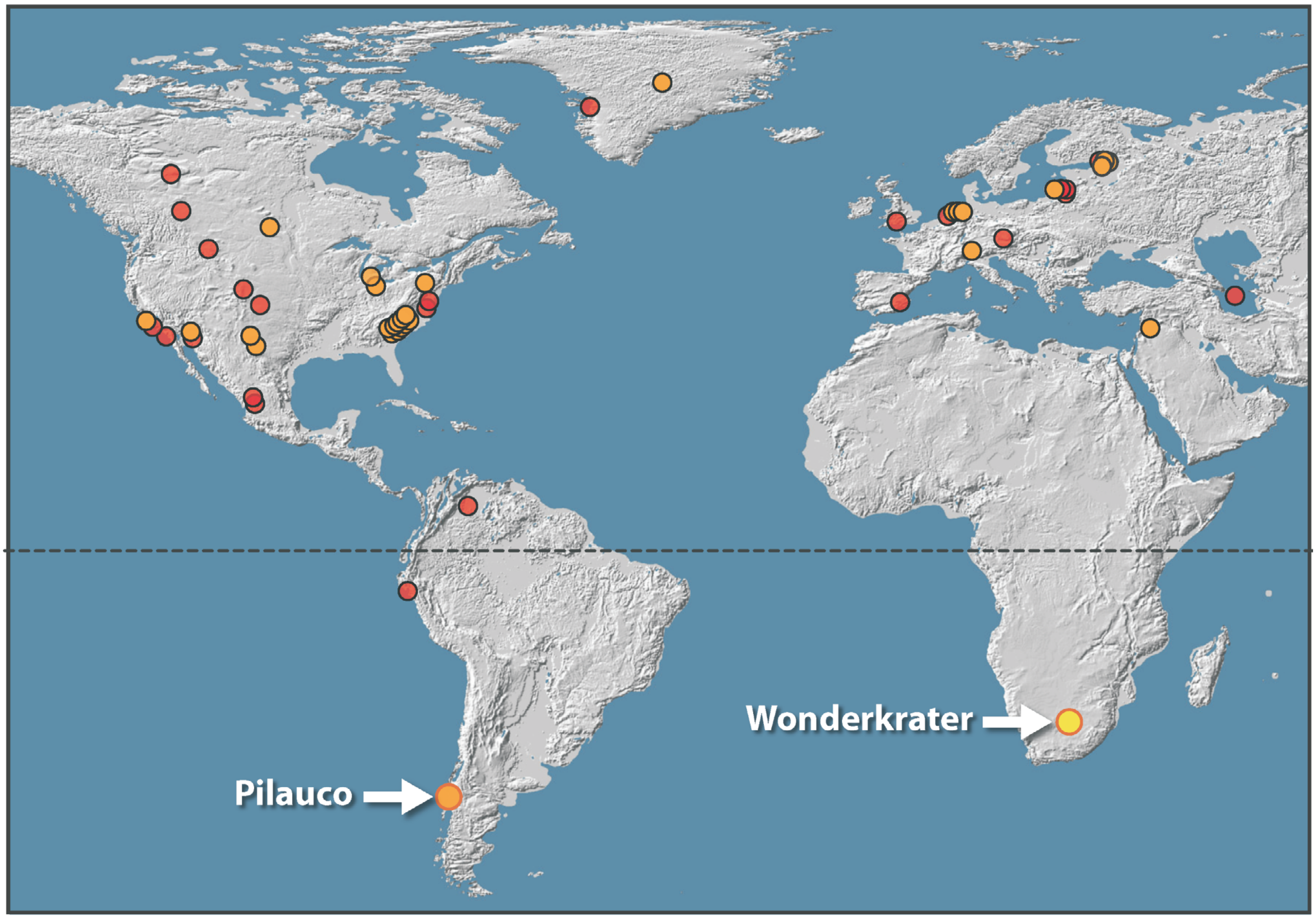

Figure 1. Map showing the location of Wonderkrater in South Africa, in relation to more than 25 other Younger Dryas (YD) sites which also have anomalies in platinum concentrations (orange dots) in deposits dated at *circa* 12 800 cal yr BP. Red dots represent sites with other YD impact proxies including spherules, as well as nanodiamonds as reported for example by Kurbatov *et al*. (2010). The Pilauco site in Patagonia (southern Chile) and Wonderkrater are as yet the only known sites in the southern hemisphere where YD platinum spikes have been reported. Map drawn after Pino *et al*. (2019). North and Central America map source: USGS, Sioux Falls; Japan ASTER Program (2003), ASTER Global Digital Elevation Map, GDEM-10 km-BW, from https://asterweb.jpl.nasa.gov/gdem.asp, 10.5067/ASTER/ASTGTM.002. Modified with Adobe Photoshop CC2014 (adobe.com/products/photoshop.html), and reproduced by permission of Pino (2019).

MATERIALS AND METHODS

Peat samples from Wonderkrater Core 3 were typically taken at intervals of 5 cm in a sequence that spanned more than 5 metres in depth (Scott 1982).

Changes in temperature indices were quantified by Scott & Thackeray (1987) on the basis of multivariate analysis of pollen samples (400 grains per sample) for ten pollen zones (W1–10). In the case of the first factor (F1) which accounted for most of the variance in an exploratory factor analysis, there was a clear dichotomy between taxa with high loadings (species known to occur primarily in relatively warm subtropical environments) and those with low loadings (species known to be found in more southerly cooler environments). It could thereby be inferred that F1 related primarily to temperature. For each pollen sample, a temperature index (SSF1) was calculated as a summary statistic based on the sum of the products of F1 loadings for each species and the relative abundance of the corresponding taxa, as in the case of a multivariate analysis of late Quaternary rodents from South Africa (Thackeray 1987). In the case of Wonderkrater, SSF1 was expressed on an arbitrary scale between 0 (coldest) to 100 (warmest).

The SSF1 temperature indices for Wonderkrater Core 3 (Fig. 2a) facilitated the identification of samples 5599 to 5616 within or adjacent the YD cool-temperature interval, at depths ranging between 300 and 370 cm below datum, respectively. These samples were selected for chemical analysis, focusing on platinum in an exploratory study.

The radio-carbon dating of the peat deposits at Wonderkrater is problematic in the context of contamination by roots. However, in the study undertaken by Scott *et al*. (2003), certain samples were recognized as being distinctly anomalous in an age-depth relationship and these were interpreted as being root-contaminated; hence they were discarded from further analysis. Scott (2016, Appendix A, Supplementary Data) reports the most recent age-estimates for peat samples using a Bayesian model including a technique described by Blaauw & Christen (2011). Those ranging between 1000 and 16 000 cal yr BP for Core 3 (at depths between 65 and 420 cm) are listed in Table 1. The age depth relationship is remarkably linear, associated with a r^2 value of 0.989. Earlier dates (at depths lower than 420 cm) do not show as strong a correlation on account of variable rates of deposition, but are of no consequence in this study which focuses primarily on the Younger Dryas between 11 500 and 12 800 cal years BP (calibrated date), corresponding to

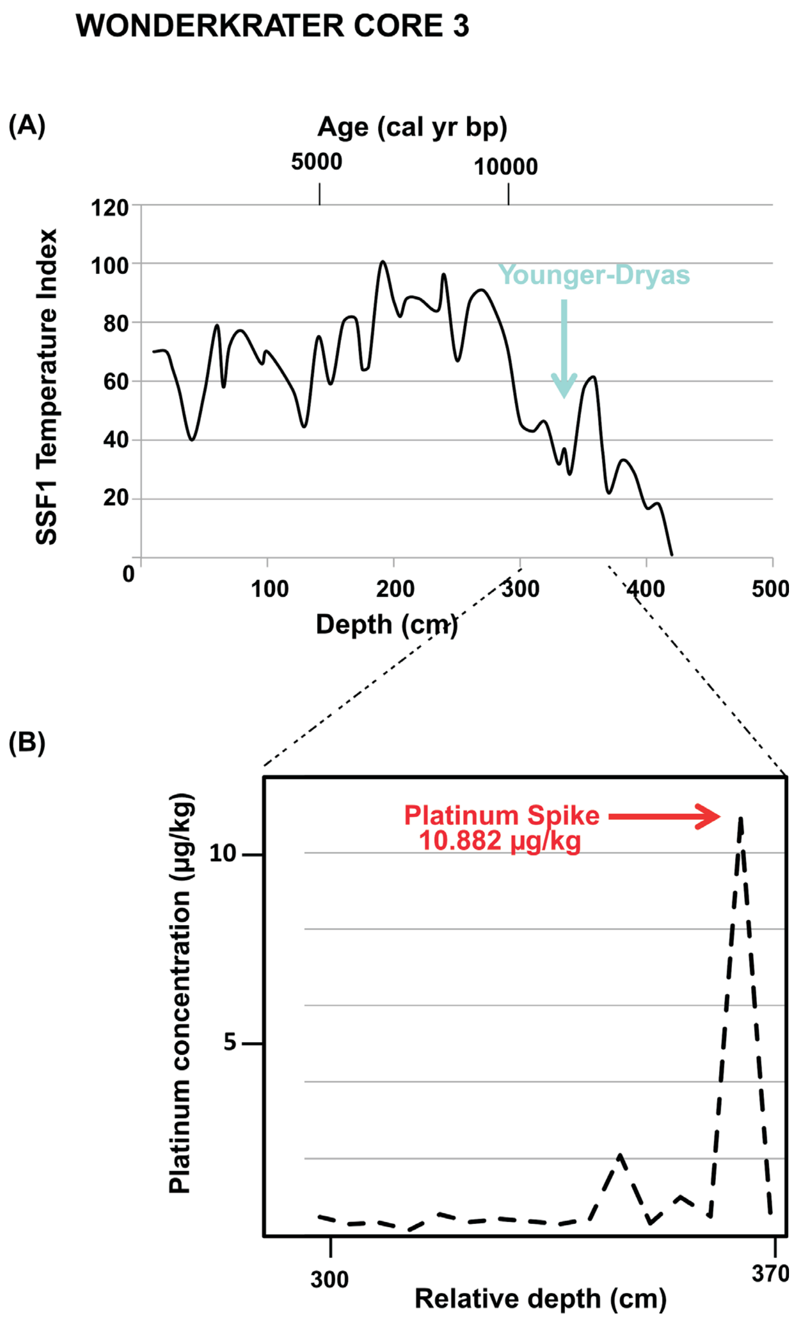

Figure 2. A, Temperature index (SSF1) based on multivariate analysis of pollen spectra in Core 3 from Wonderkrater, South Africa (Scott & Thackeray 1987; Thackeray 2018). An unambiguous platinum spike (**B**) is documented in sample 5614 at a depth of 360 cm (Table 1). A subsequent drop in temperature at the time of the Younger Dryas interrupts global postglacial warming.

depths between 340 and 380 cm, within the range of depths for which there is a strong linear relationship between age and depth, reflecting an almost constant rate of deposition.

Approximately 1 g of each sediment sample was treated in $HF:HNO_3$ and heated to 90°C for 24 hours, followed by treatment in $HCl:HNO_3$ to break down fluoride precipitates formed during the first step. ICP-MS analysis was undertaken on a Perkin Elmer NexION 300X quadrupole ICP-MS in Kinetic Energy Discrimination mode. ^{195}Pt was measured using ^{205}TL as the internal standard. The instrument was calibrated using calibration standards ranging from 10 to 100 ng/l for Pt (R^2 = 0.9999).

RESULTS

A prominent spike in platinum is documented in sample 5614 at a depth of 360 cm (Table 2, Fig. 2b). A spike in this sample is confirmed when a platinum–aluminium (Pt/Al) ratio is quantified (Table 2).

On the basis of Scott's (2016) Bayesian model, the mean age for sample 5614 is 12 744 cal yr BP. The lower and upper 95% confidence limits are 11 834 and 13 866 cal yr BP, respectively.

DISCUSSION AND CONCLUSIONS

The platinum spike in sample 5614 at Wonderkrater precedes the onset of the Younger Dryas cooling event (Fig. 2a,b). Since strong evidence for spikes in platinum has been obtained for the YD interval from more than 25 sites in Europe, Asia and North America (e.g. Kennett *et al.* 2009, 2015; Petaev 2013; Moore *et al.* 2017) as well as Mexico (Israde-Alcantara 2012) and Patagonia (Pino *et al.* 2019),

Table 1. Wonderkrater Core 3, depths and calibrated ages using Bayesian model.

Depth (cm)	Calibrated age (years) Min	Max	Median	Mean
10	12.8	359.6	144.5	157.2
20	148.8	552.6	349.3	349.4
25	239	616.6	448.3	444.2
30	356.6	672.7	542.7	538.3
40	585.8	809.4	687.3	688.1
50	678	946	801.4	804.8
60	815.9	1079.2	931.1	934.5
65	875.2	1226.3	1022.7	1032.9
70	954.8	1370.3	1125.2	1133.5
80	1250.2	1824.6	1503.1	1518.2
95	2188.8	3271.2	2814.6	2799.1
100	2862.9	3438	3226.4	3203.7
110	3131.1	3860	3503.7	3508.5
120	3405	4150.4	3795.6	3795.8
130	3745.4	4399.1	4081.4	4084.2
140	4134.2	4855.8	4420.2	4439.7
150	4432.7	5398.8	4888.1	4899.6
160	4831	5832.8	5383.9	5374.7
170	5496.3	6118.9	5847.1	5852.9
175	5617.8	6244.9	5978.8	5970.9
180	5730.1	6345.1	6069.4	6063.5
190	5929.6	6532.9	6256.7	6252.5
200	6138.9	6699.9	6435.4	6434.6
205	6270	6778.2	6530.3	6530.8
210	6411.6	6860.4	6621	6624.4
220	6624.5	7137.6	6857.2	6865.8
230	6849	7377.7	7121.9	7122.4
240	7150.4	7676.6	7399.5	7408.8
250	7405.3	8326.3	7785	7812.3
260	7707.4	8775.8	8213.9	8223.4
270	8072.4	9149.1	8634.3	8635.1
280	8538.1	9437.1	9058.2	9044.4
290	9150.9	9690.2	9470.8	9458.1
300	9415.4	10338.8	9836.1	9852.9
305	9583.5	10545.6	10041	10055.3
310	9755.5	10760	10241.3	10252.9
315	9922.2	10925.8	10440	10443.1
320	10144.7	11078.1	10644.3	10642.4
325	10400.5	11215.5	10843.9	10843.6
330	10708.5	11321.2	11044.3	11042.9
335	10890.1	11883.1	11282.6	11307.7
335	10890.1	11883.1	11282.6	11307.7
340	11051.8	12340.5	11543.7	11592.9
345	11218.8	12768.5	11826.3	11878.4
350	11407.6	13155.7	12107.8	12164.8
355	11622.4	13514.6	12398.5	12450.3
359	11800.7	13771	12635	12685.8
360	11834.3	13866.2	12693.1	12744.5
365	12041.7	14204.5	12979.5	13027.7
370	12257.4	14521.1	13265.2	13314.1
380	12731.2	15158.3	13849.5	13886.7
390	13228.4	15772.8	14429.6	14457.2
400	13737.2	16331.5	15006.9	15029.9
410	14288.2	16848	15594.2	15600.3
420	14880.2	17401.2	16168.8	16170.6
430	15477	17883.4	16764.4	16750.6
440	16103.2	18369.4	17335.5	17325.3

and now also at Wonderkrater in the southern hemisphere (Fig. 1), the Younger Dryas Impact Hypothesis is in part supported, recognizing criticisms expressed by Pinter *et al*. (2011), Holliday *et al*. (2014) and others. One criticism (Tankersley *et al*. 2018) is that volcanic activity

Table 2. Wonderkrater sample numbers, depth (cm), estimated dates (cal yr BP) based on a Bayesian model (Scott 2016), platinum concentrations (μg/kg) and platinum/aluminium ratios (Pt/Al). Prominent platinum and platinum/aluminium spikes occur in sample 5614. Using Scott's (2016) Bayesian model, the mean age for sample 5614 is 12 744 cal yr BP.

Sample no.	Depth (cm)	Date (Scott)	Lower 95 %	Upper 95%	Platinum μg/kg	Pt/Al ratio
5599	300	9 852	9 415	10 338	0.474	0.043
5600	305	10 055	9 583	10 545	0.275	0.045
5601	310	10 252	9 755	10 760	0.317	0.046
5602	315	10 443	9 922	10 925	0.123	0.018
5603	320	10 642	10 144	11 078	0.526	0.070
5604	325	10 843	10 400	11 215	0.324	0.069
5605	330	11 042	10 708	11 321	0.411	0.162
5606	335	11 307	10 890	11 883	0.341	0.069
5608	335	11 307	10 890	11 883	0.282	0.062
5609	340	11 592	11 051	12 340	0.410	0.065
5610	345	11 878	11 218	12 768	2.076	0.372
5611	350	12 164	11 407	13 155	0.297	0.066
5612	355	12 450	11 622	13 514	0.980	0.238
5613	359	12 685	11 800	13 771	0.478	0.136
5614	360	**12 744**	**11 834**	**13 866**	**10.882**	**3.366**
5616	370	13 027	12 041	14 204	0.481	0.262

can be a source of platinum (apart from cosmic impacts), but no volcanic activity has been documented in southern Africa within the late Quaternary.

The YD Impact Hypothesis expresses the view that Terminal Pleistocene extinctions can be attributed to a cosmic impact. Without invoking any one particular causal factor, we note the occurrence of terminal Pleistocene extinctions of fauna such as *Equus capensis*, *Syncerus antiquus*, *Megalotragus priscus* and *Antidorcas bondi* in South Africa (Klein 1972 1978; Faith 2011, 2012, 2013a,b, 2014; Thackeray 1980). However, a YD impact cannot account as an instantaneous causal factor since *Megalotragus* (for example) persists in the interior of the country at Wonderwerk (probably at low population densities) until about 7500 BP (Thackeray 2015).

Megafaunal extinctions in South Africa may be attributed to both environmental change and human predation within a period of time before and after 12 800 cal yr BP. However, on the basis of data presented in this study, it may be cautiously considered that the consequences of a hypothesized YD cosmic impact (and the dispersion of atmospheric dust) may have contributed to some extent to the process of extinctions not only in southern Africa, but also to that which occurred in North and South America as well as Europe, recognizing synchroneity of Pt anomalies (Kennett *et al*. 2015) that has been cited in support the Younger Dryas Impact Hypothesis.

We note that in terms of culture, the apparently abrupt change from Robberg to Oakhurst technocomplexes in South Africa as documented, for example, at Boomplaas Cave in the southern Cape (H.J. Deacon 1979 1995; J. Deacon 1982 1984), penecontemporary with the Younger Dryas, is closely co-incident with the cultural change from Clovis to Folsom technologies in North America. The question as to whether this relates indirectly if not directly to a common causal YD cosmic impact is beyond the scope of this article which serves primarily to report a YD platinum anomaly in the Wonderkrater sequence.

Apart from Wonderkrater, the Younger Dryas cooling interval has been detected from the analysis of pollen in hyrax middens (Chase *et al*. 2011, 2013, 2015, 2018) and also from oxygen isotope records from terrestrial *Achatina* snails at Bushman Rock Shelter (Abell & Plug 2000) and marine mollusc shells from Elands Bay (Cohen *et al*. 1992). Notably, the cultural change between Robberg and the Oakhurst techno-complexes at the former site occurs at about the time of the YD (Mitchell 1988; Lombard *et al*. 2012 ; Porraz *et al*. 2015).

The suggestion that the hypothesized YD impact is related in particular to the Hiawatha crater in northern Greenland remains to be conclusively determined on the basis of absolute dates. However, it can already be noted that the large crater rim (31 km in diameter) has not been subject to substantial erosion, and glacial ice older than 12 800 BP is missing (Kjær *et al*. 2018). Irrespective of where an impact might have occurred, the YD Impact Hypothesis is supported in part by this study of the Wonderkrater Core 3 sequence in South Africa in which a platinum spike is reported for sample #5614, with a mean date of 12 744 cal yr BP using Scott's (2016) Bayesian model, preceding the onset of the YD cooling event. This is the first evidence in Africa to partially support the YD Impact Hypothesis on the basis of a platinum anomaly in a late Quaternary sedimentary sequence. The Pilauco site in Patagonia in southern Chile (Pino *et al*. 2019) and Wonderkrater are as yet the only known sites in the southern hemisphere where YD platinum spikes have been reported, supplementing the corresponding evidence from more than 25 sites in the northern hemisphere, dated *circa* 12 800 cal yr BP.

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