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Discussion

Asteroid/comet impact clusters, flood basalts and mass extinctions: Significance of isotopic age overlaps[☆]

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Abstract

Morgan et al. [J. Phipps Morgan, T.J. Reston, C.R. Ranero. *Earth Planet. Sci. Lett.* 217 (2004) 263–284.], referring to an overlap between the isotopic ages of volcanic events and four epoch/stage extinction boundaries, suggest a dominant role of Continental Flood Basalts (CFB) and of explosive CO₂-rich volcanic pipes (“Verneshots”) as mass extinction triggers. Here I point out that Morgan et al. overlook 3 overlaps between the ages of extraterrestrial impacts, volcanic and mass extinction events, and 3 overlaps between the ages of extraterrestrial impact and volcanic events. These overlaps suggest that both extraterrestrial impacts and volcanism served as extinction triggers separately or in combination. A protracted impact cluster overlaps extinctions at the end-Devonian (~374–359 Ma) and impact-extinction age overlaps occur in the end-Jurassic (~145–142 Ma), Aptian (~125–112 Ma); Cenomanian–Turonian (~95–94 Ma); K–T boundary (~65.5 Ma) and mid-Miocene (~16 Ma) (Table 1). Morgan et al. appear to question the uniqueness of shock metamorphic and geochemical criteria used to identify asteroid/comet impacts. However, shock pressures at 8–35 GPa, indicated by intra-crystalline planar deformation features (PDF), exceed lithospheric and volcanic explosion pressures by an order of magnitude and are not known to be associated with explosive volcanic diatremes, kimberlites or lamproites. These authors make reference to apparent iridium anomalies of volcanic origin. However, platinum group element (PGE) abundance levels, volatile/refractory PGE ratios, and Cr and Os isotopes of meteoritic materials are clearly distinct from those of terrestrial volcanics. Given a Phanerozoic time-integrated oceanic/continent crustal ratio >2.5 and the difficulty in identifying oceanic impacts, I suggest the effects of large impacts on thin thermally active oceanic crust—capable of triggering regional to global mafic volcanic events and ensuing environmental effects—provide an essential clue for understanding the relationships between impacts and volcanic events which, separately or in combination, result in deleterious environmental effects, in some instances leading to mass extinctions.

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[☆] Comment on: “Contemporaneous mass extinctions, continental flood basalts, and ‘impact signals’: are mantle plume-induced lithospheric gas explosions the causal link?” by J. Phipps Morgan , T.J. Reston, C.R. Ranero, *Earth Planetary Science Letters* 217 (2004) 263–284.

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Morgan et al. [1] refer only to a part of the existing database of asteroid/comet impacts, which within analytical error, include several instances where the ages of extraterrestrial impact clusters overlap the ages of continental flood basalt (CFB), large igneous provinces (LIPs) and mass extinctions, as indicated in Table 1. Extraterrestrial impacts and extinction/radiation events coincide or overlap at the Ediacaran (~580 Ma), late Devonian (~374–359 Ma), end Jurassic (~145–142 Ma), and K–T boundary (65.5 ± 0.3 Ma). CFB and LIP events and mass extinctions overlap at the end lower Cambrian (513 ± 2 Ma), Permian–Triassic boundary (251 ± 0.4 Ma), late to end Devonian (~374–359 Ma), end-Triassic (199.6 ± 0.6 Ma), end Pliensbachian (190 ± 4 Ma) and K–T boundary (65.5 ± 0.3 Ma), therefore including:

- 3 impact/volcanic/extinction age overlaps (end-Devonian ~374–359 Ma; Jurassic–Cretaceous boundary ~145 Ma; K–T boundary ~65.5 Ma).
- 3 impact/volcanic overlaps (Aptian ~125–112 Ma; Cenomanian–Turonian ~95–94 Ma; late Eocene ~36 Ma).
- 3 volcanic/extinction age overlaps not known to be associated with contemporaneous major impacts (end lower Cambrian ~513–507 Ma; Triassic–Jurassic boundary ~199 Ma; Permian–Triassic boundary ~251 Ma).
- 1 impact–extinction/radiation coincidence not known to be associated with major volcanic activity (Acraman impact–Bunyeroo extinction/radiation ~580 Ma).

Morgan et al. [1] question the unique criteria used for recognition of extraterrestrial impact structures and the role of impacts as triggers of mass extinction, and make references to apparent existence of volcanic-related intracrystalline planar deformation features (PDFs) ([1] p.263) and terrestrial iridium anomalies ([1] p.270), thus revisiting earlier “cryptoexplosion” ideas [2–4]. However, a volcanic-related origin of high shock pressure features has long been discredited on both observational and experimental basis [5–7]. No shatter cones or PDF have ever been documented in volcanic feeders, kimberlites or lamproites. Shatter cones (2–30 GPa), PDFs (8–35 GPa) and diaplectic glass (25–40 GPa) represent shock pressures with an order of magnitude higher than lithospheric pressures

and volcanic explosive pressures (<4 GPa). Pressures at the deepest magma source of ~240 km portrayed by Morgan et al. ([1] Fig. 3) would not exceed ~8 GPa, even if volatile pressures of this magnitude can be translated to the surface.

Morgan et al. [1] neglect the geochemical and isotopic distinctions between the meteoritic signatures of impactites and volcanic suites. Platinum Group Element (PGE) abundance patterns of impact melt breccia and ejecta are distinguished by both high absolute PGE levels (commonly >5 ppb Ir) (Fig. 1) as well as their chondritic or near-chondritic PGE ratios ($\text{Pd/Ir} \leq 1.0$), except where altered or contaminated by terrestrial components [8–10]. These relations contrast with terrestrial ultramafics and komatiites ($\text{Ir} < 2$ ppb) characterized by high to very high volatile/refractory PGE ratios ($\text{Pd/Ir} \gg 1.0$) [8,10] (Fig. 1). Mineralogical indicators of meteoritic contribution include Ir nanonuggets [9], Ni nanonuggets [10] and Ni-rich spinels ($\text{NiO} < 23\%$) [11]. Cr isotopic ratios of K–T boundary and Archaean fallout ejecta ($\varepsilon_{\text{M}} \sim -3$ to -5) are akin to those of carbonaceous chondrites and distinct from those of terrestrial and mantle compositions ($\varepsilon_{\text{M}} \sim 0$ [12,13]).

Morgan et al. [1] appear to question criteria used to distinguish impact craters from volcanic caldera, suggesting that “Verneshot” craters may contain PDFs and shatter cones, where they state “The first five of these characteristics are very similar to those of impact craters” ([1] p.277). However, whereas both impact structures and diatremes may contain a central uplift and raised rims—albeit of different nature and origin [14,15]—features such as the centripetal sense of shock-rebound deformation, elevated basement plugs, multiple ring synclines, petrologic shock metamorphic features and lack of related volcanic rocks (cf. Vredefort, Woodleigh, Puchezh-Katunki, Popigai, Chesapeake Bay, Ries) clearly discriminate impact structures from volcanic diatremes [7]. Secondary craters formed from the ejecta of primary impact structures or from putative “Verneshots” would be small due to the fragmented nature and relatively low velocity of such ejected blocks as compared to primary projectiles.

It should be emphasized that the mere age overlap of two or more events does not necessarily prove genetic connections. On the other hand such coincidences invite examination of cause and effect relationships. The age overlaps between impact clusters, CFB/LIPS and

Table 1

Comparison between ages of some epoch/stage boundaries, some asteroid/comet impacts and some Large Igneous Provinces (LIP) and Continental Flood Basalt (CFB) provinces

Epoch/stage boundaries and mass extinctions (EXT)	Asteroid/comet impacts (IMP)	Large Igneous Province (LIP, CFB)	Age overlaps
Mid-Miocene Langhian 15.97 Ma	Ries (24 km) 15.1 ± 1 Ma	Columbia Plateau Basalt 16.2 ± 1 Ma	
Eocene–Oligocene boundary 33.9 ± 0.1 Ma	Popigai (100 km) 35.7 ± 0.2 Ma; Chesapeake Bay (85 km) 35.5 ± 0.3 Ma	Ethiopean Basalts 36.9 ± 0.9 Ma	IMP–CFB Near age overlap
KT boundary 65.5 ± 0.3 Ma	Chicxulub (170 km) 64.98 ± 0.05 Ma; Boltysh (25 km) 65.17 ± 0.64 Ma	Deccan Pleateau Basalts. 65.5 ± 0.7 Ma (pooled Ar ages — 65.5 ± 2.5 Ma) Madagascar Basalts 94.5 ± 1.2 Ma	IMP–CFB–EXT age overlap
Cenomanian–Turonian 93.5 ± 0.8 Ma	Steen River (25 km) 95 ± 7 Ma	Ontong-Java LIP 120 Ma; Kerguelen LIP 120–112.7– 108.6 Ma; Ramjalal Basalts 117 ± 1 Ma	IMP–CFB Age overlap
Aptian (Lower Cretaceous) 125–112 Ma	Carlswell (39 km) 115 ± 10 Ma; Tookoonooka (55 km), Tallundilli (30 km) both 128 ± 5 Ma; Mien (9 km) 121 ± 2.3 Ma; Rotmistrovka (2.7 km) 120 ± 10 Ma	Dykes SW India 144 ± 6 Ma	Possible IMP (Carswell) – LIP age overlap
Jurassic–Cretaceous boundary 145.5 ± 4 Ma	Morokweng (70 km) 145 ± 0.8 Gosses Bluff (24 km) 142.5 ± 0.8 Ma; Mjolnir (40 km) 143 ± 2.6 Ma	Peak Karoo volcanism Start 190 ± 5 Ma; Peaks $193,178$ Ma; Lesotho 182 ± 2 Ma	CFB–EXT age overlap
End-Pliensbachian 183 ± 1.5 Ma		Central Atlantic Igneous Province — 203 ± 0.7 to 199 ± 2 Ma; Newark Basalts 201 ± 1 Ma	CFB–EXT age overlap
Triassic–Jurassic 199.6 ± 0.3 Ma	Manicouagan (100 km) 214 ± 1 Ma; Rochechouart (23 km) 213 ± 8 Ma; Saint Martin (40 km) 220 ± 32 Ma	Siberian Norilsk 251.7 ± 0.4 to 251.1 ± 0.3 Ma	CFB–EXT age overlap
Permian–Triassic 251 ± 0.4 Ma 251.4 ± 0.3 to 250.7 ± 0.3 Ma	Minor impact effects (possible pdf in detrital quartz grains, metal particles)		
Late to end Devonian ~ 374 – 359 Ma	Woodleigh (120 km) 359 ± 4 Ma; Siljan (52 km) 361 ± 1.1 Ma; Alamo breccia (~100 km) ~ 360 Ma; Charlevoix (54 km) 342 ± 15 Ma Several small poorly dated impact craters	Rifting and 364 Ma Pirpyat–Dneiper–Donets volcanism	IMP–CFB–EXT age overlap over ~ 15 m.y.
End-Ordovician 443.7 ± 1.5 Ma			EXT
End-lower Cambrian 513 ± 2 Ma ~ 580 Ma	Acraman/Bunyeroo	Kalkarindji volcanic Province, northern Australia 507 ± 4 Ma	CFB–EXT age overlap
IMP–EXT/ RADIATION age overlap			

Sources of age data [1,17–19,22].

extinctions (Table 1) are consistent with the deleterious environmental effects expected from *both* impact and volcanism. A key observation bearing on the significance of impact–volcanic age overlaps is provided by the clustered nature of some of the largest extraterrestrial impacts (Table 1). With a Phanerozoic time-integrated oceanic/continent crustal ratio of >2.5 , impact of unrecorded members of impact clusters in oceanic

basins is inevitable, including impacts impinging on thin thermally active crustal regions. Penetration of a ~ 10 km-diameter projectile into near-midridge oceanic domain, triggering adiabatic melting in the underlying asthenosphere, is capable of producing regional to global mafic volcanic provinces and ensuing environmental effects [16], consistent with the role of both mafic and felsic volcanism in mass extinctions [17,18].

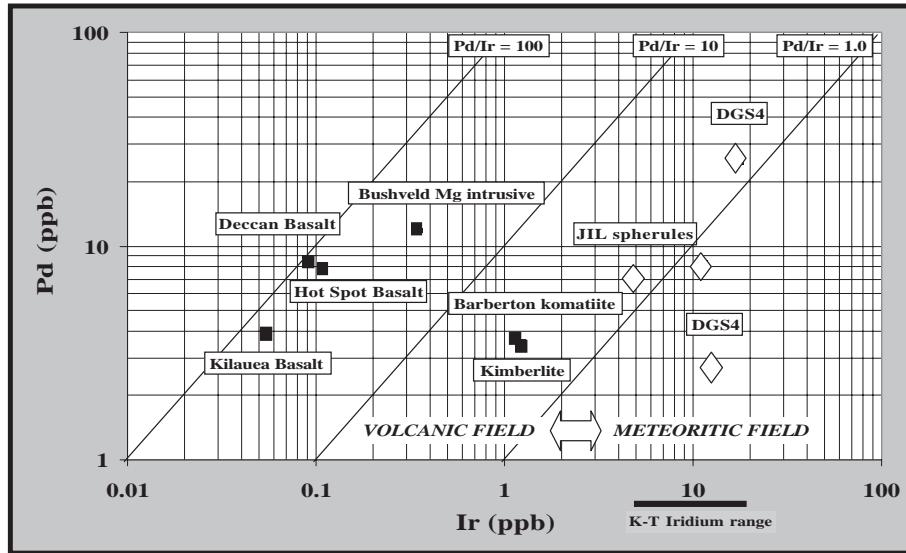


Fig. 1. Pd–Ir relations in impactites and volcanic rocks. Data for impactites after [9,10]; data for volcanic rocks after [8]. Kimberlite (Pd 3.57 ± 2.2 ppb; Ir 1.23 ± 0.5 ppb), Hot Spot Basalt (Pd 8.1 ± 5.4 ppb; Ir 0.11 ± 0.08 ppb), Kilauea Basalt (Pd 3.2 ppb; Ir $0.055, 0.38$ ppb), Deccan trap basalt (Pd 8.3 ppb; Ir 0.092 ppb, Bushveld magnesian intrusives (Pd 12 ± 5.84 ppb; Ir 0.35 ± 0.32 ppb) and other mafic rocks ([8] Table 1).

Nearly 200 structures showing diagnostic shock metamorphic and geochemical signatures of extraterrestrial impact are documented to date [19]. By contrast not a single “Verneshot” pipe containing shock metamorphic indicators is reported in the literature (cf. [20]) — leaving the hypothesis of Morgan et al. [1] *uncontrolled* as well as inconsistent with the large body of evidence for extraterrestrial impacts and possibly related volcanic and extinction events. Questions regarding genetic relations between impact, volcanism and mass extinction need to be examined *in each particular case in its own right* — it is unlikely that a single cause will be found [21].

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