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WERE THE FALKLAND ISLANDS HIT BY A GIANT ASTEROID 250 MILLION YEARS AGO?

by

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A rather startling claim, widely reported in May 2017, located one of the largest asteroid impact craters yet discovered on planet Earth just to the west of the Falkland Islands. Even *Penguin News*, the Falklands' very own local newspaper, ran the story under the headline 'Falkland Basin may be largest impact crater' (Vol. 28, No. 43 for 12 May 2017, p. 7). In these days of fake news, our first inclination was to suspect that the report might be a hoax, but even though it's almost certainly not true there is rather more to the story than its improbability might suggest, and its background is worth exploring.

The flurry of media attention in 2017 was stimulated by the publication of a scientific paper in the well-known international journal *Terra Nova* (Rocca *et al*. 2017), but the proposal originated back in 1992, when Michael Rampino (now based at New York University and a co-author of the *Terra Nova* paper) introduced the impact crater hypothesis in a presentation to a meeting of the American Geophysical Union (AGU). Since then he has achieved an impressive record of 'astrogeology' research and publication, culminating in his provocative 2017 book *Cataclysms*. In the published, very short abstract to his AGU presentation, Rampino (1992) claimed that two geophysical features on the Falkland Plateau had, potentially, the characteristics of impact craters, but neither was specifically located. However, in *Cataclysms*, he confirms (on page 113) that one of the two features he had originally identified was that subsequently described by Rocca *et al*. (2017) immediately to the west of West Falkland (Figure 1). In his 1992 abstract Rampino described the supposed impact as of "probable Late Permian age" (that's about 250 million years ago), coincident with "the most severe mass extinction of life in the geological record" but gave no details of the evidence justifying that conclusion. However, a major and radical reinterpretation of the regional geological structure was implied.

When Michael Rampino gave his talk at the 1992 AGU meeting, the association of mass extinction with asteroid impacts was a particularly hot topic. In 1991, after a decade of controversy and world-wide investigations, an area in the Gulf of Mexico had been identified as the impact crater of the massive asteroid strike (now well documented as occurring 66 million years ago) that precipitated the demise of the dinosaurs (and much else): this was the famous Chicxulub crater (Hildebrand *et al*. 1991).

To be clear, both the Chicxulub crater and its putative Falklands equivalent are ancient features now deeply buried beneath thick successions of younger sedimentary rocks, so their initial detection was based on the interpretation of geophysical data. Variations in the strengths of gravity (caused by changes in bulk rock density within the crust) and geomagnetism (influenced by the quantity of iron-rich minerals in the underlying rock) are most helpful, supplemented by seismic results. But none of these are definitive, and confirmation of the Chicxulub structure was only made possible by the examination of rock cores derived from deep boreholes. For the Falklands example, there is no borehole evidence and even the available geophysical information is still sparse, so it is necessary to build up the regional picture through a lot of lateral extrapolation between widely spaced data points. That leaves plenty of scope for differences of opinion, but Rocca *et al*. (2017) based their proposal on what they took to be a large, circular, negative (i.e. weaker than background) gravity anomaly with a rim of smaller positive anomalies, all coinciding more-or-less, with an apparently circular, positive (i.e. stronger than background) magnetic anomaly; the perceived similarities to Chicxulub were stressed. The circular area is shown in Figure 1.

The Chicxulub crater is about 180 km in diameter, so was created by an impacting asteroid about 9 or 10 km wide (there's a 20:1 rule-of-thumb ratio for these things). The entertaining story of its eventual discovery is told by one of the principal protagonists, Walter Alvarez, in his excellent 1997 book with the splendid title *T. rex and the Crater of Doom*. The asteroid struck 66 million years ago and its effects are well-established from the geological record. The dinosaurs were just one casualty of the mass extinction that saw 75% of species and 50% of genera wiped out. The impact and its aftermath were truly apocalyptic, with massive tsunamis, a global firestorm, poisoned atmosphere and oceans, and years of 'nuclear winter' followed by longer-term global warming. All this is worth bearing in mind because the proposed Falklands impact, if it occurred, was equally large and possibly even bigger. In their *Terra Nova* paper, Rocca *et al*. (2017) gave a diameter of about 250 km; in an earlier account, Rocca & Báez Presser (2015) had claimed 250-300 km. A more realistic diameter for the area that they actually defined in those papers is probably a little less than 200 km (as shown in Figure 1) but even so, that's big. It suggests that any impacting asteroid would have been almost 10 km across, and its effects would have been commensurately devastating.

Unsurprisingly, once the Chicxulub story had been established and the realisation dawned that an event of that magnitude may not be unique, the hunt began for other potential impact sites, hence Rampino's (1992) flagging of the Falkland Plateau examples, albeit based only on the very limited geophysical information available at that time. Another 'crater hunter' was Max Rocca, based in Buenos Aires. He scoured the South American datasets and between 2001 and 2007 published about eight descriptions of possible impact craters and contributed to several other joint accounts.

These were then consolidated in a review paper (Acevedo *et al*. 2011) summarising the potential impact crater sites of South America, and listing amongst them "Argentina, No. 11 - South Atlantic Geophysical Anomaly: Islas Malvinas". This was the feature to the west of West Falkland but, at that stage, the interpretation was still described as "very speculative".

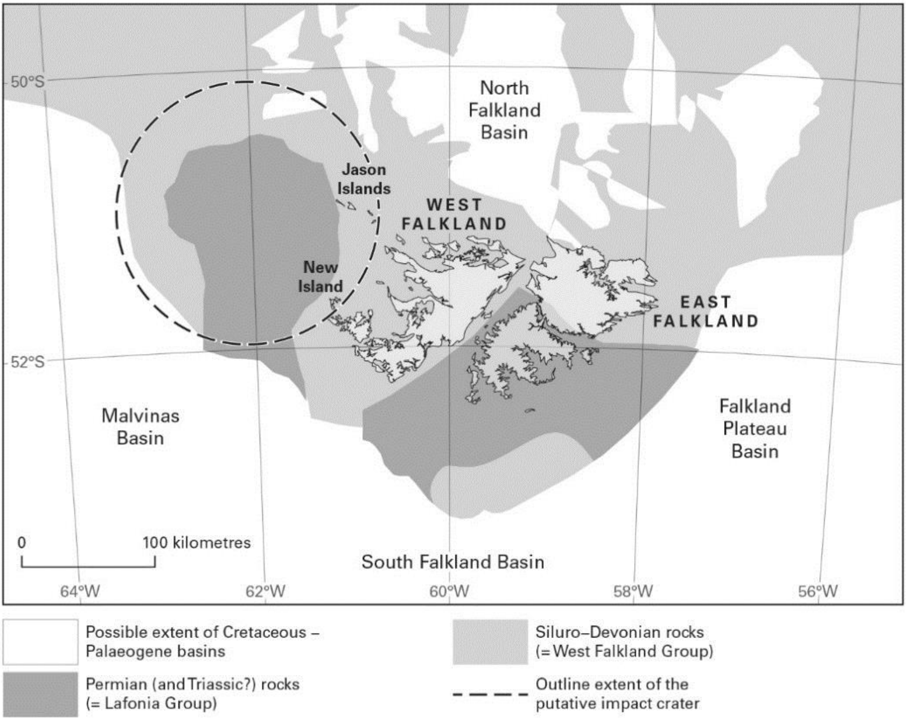

Figure 1. The Falkland Islands with a summary representation of the regional geology after Richards et al. (1996). The circular area shown is that defined by Rocca & Báez Presser (2015) and Rocca et al. (2017), from their geophysical interpretations, as an asteroid impact crater.

Whilst most of the early, world-wide crater hunting was based on the examination of geophysical datasets, there was an increasing focus on the more definitive evidence – the sheets of smashed-up debris ejected and redeposited around the impact sites. Some of these had been previously ascribed a different origin as glacial deposits, the jumbled rock and sediment deposits left behind by ice sheets and known as diamictites or tillites. So how widespread was the confusion? Rampino (1992, 1994) was an early and influential contributor to this discussion, but of more significance for the Falkland

Islands was the review by Oberbeck *et al*. (1993) that speculated on an alternative genesis as impact breccias for the extensive glacial diamictites of Late Carboniferous to Early Permian age (about 300 million years ago) found across the Earth's southern continents. At that time, they were united into the giant 'supercontinent' of Gondwana (Figure 2) and prior to its break-up the glacial deposits now represented by, for example, the tillites of the Dwyka Group in the Karoo Basin of southern Africa, and the Fitzroy Tillite Formation of the Falkland Islands, were once continuous.

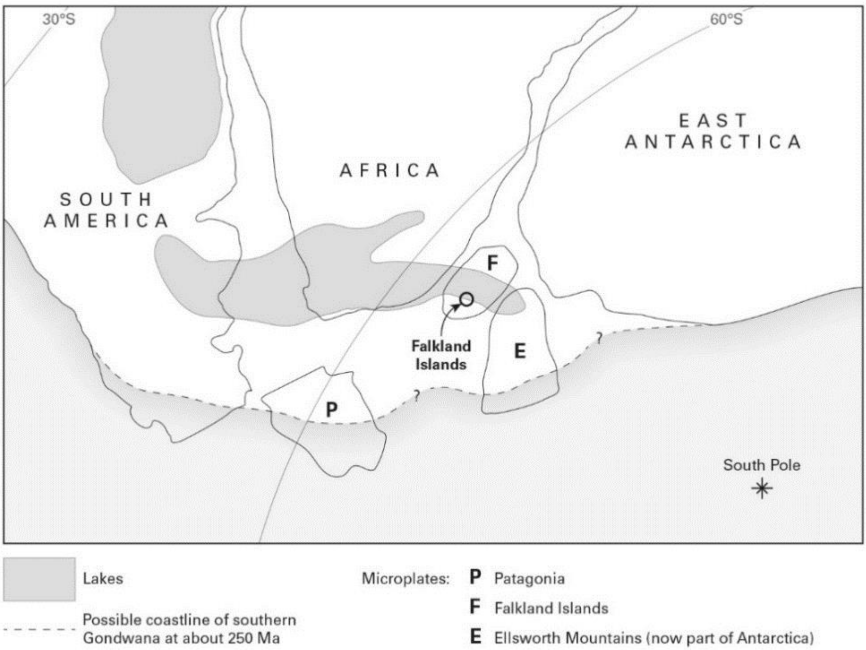

Figure 2. A palaeogeographical reconstruction of southern Gondwana at about 250 million years ago, after Torsvik and Cocks (2017, figure 10.8). The global climate was warm at that time and there was no polar ice-cap.

Despite the good evidence for the glacial interpretation (e.g. the work of Frakes & Crowell (1967) in the Falkland Islands), Oberbeck *et al*. proposed a dramatic alternative: a massive asteroid bombardment had created a vast blanket of ejecta breccia and by weakening the Earth's crust had initiated the break-up of Gondwana. Admittedly, Oberbeck *et al*. (1993, p.17) did note that "all of the existing field work implies a glacial origin for the tillites."

Clearly, if the Falkland Islands feature was to be tied into the wider debate, the timing of the putative asteroid strike was of critical importance. The more mundane explanation for the offshore geophysical anomalies, devoid of extra-terrestrial influence, related them to the presence of a deep sedimentary basin, either of Permian to Triassic age (c. 290-200 million years ago: Richards *et al*. 1996) or of Carboniferous to Permian age (c. 360-250 million years ago: Aldiss & Edwards 1998), broadly correlated with the onshore Lafonia Group. The controlling factors were the known presence (from limited offshore seismic data) of an overlying Jurassic and younger, mostly sedimentary succession (with the Jurassic part including volcanic rocks), and an underlying Devonian and older succession as seen onshore in the West Falkland Group. The detail of the onshore geology has been described in detail by Aldiss & Edwards (1999) and reviewed by Stone (2016 a & b) and will not be rehearsed here, but a time-line for the relevant features and events is shown in Figure 3.

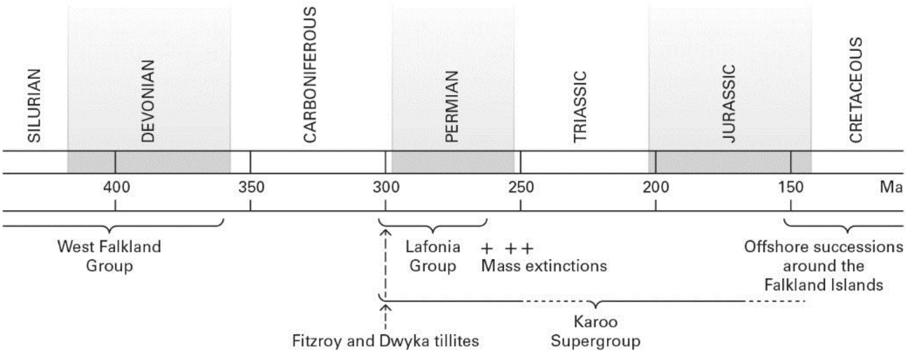

Figure 3. A time line setting out the principal geological features of the Falkland Islands in a regional context.

The same overall controls on timing applied to the impact crater hypothesis. So, in its next published iteration by Rocca & Báez Presser (2015) the impact could be described as “at least 300 million years old”, which placed it at some time in the Carboniferous Period. Then, picking-up on the suggestion by Rampino (1992) and Oberbeck *et al*. (1993) that the Gondwana tillites might be impact breccias, Rocca & Báez Presser linked the impact with the Fitzroy Tillite Formation, which was reinterpreted accordingly as an impact breccia. The depositional age of the Fitzroy Tillite is well established as being about 300 Ma, but Rocca & Báez Presser’s proposal defied abundant and well-documented evidence for its entirely glacigenic origin (Figure 4) (Frakes & Crowell 1967; Aldiss & Edwards 1999; Stone & Horan 2016). There is little chance that any part of it might be an impact breccia, but Rocca and Báez Presser soon moved on. Joining forces with Rampino and abandoning the tillite correlation, they produced the more fundamental paper published in *Terra Nova* (Rocca, Rampino & Báez Presser 2017), but supplemented it with a press release that ensured the media coverage noted at the beginning of this article.

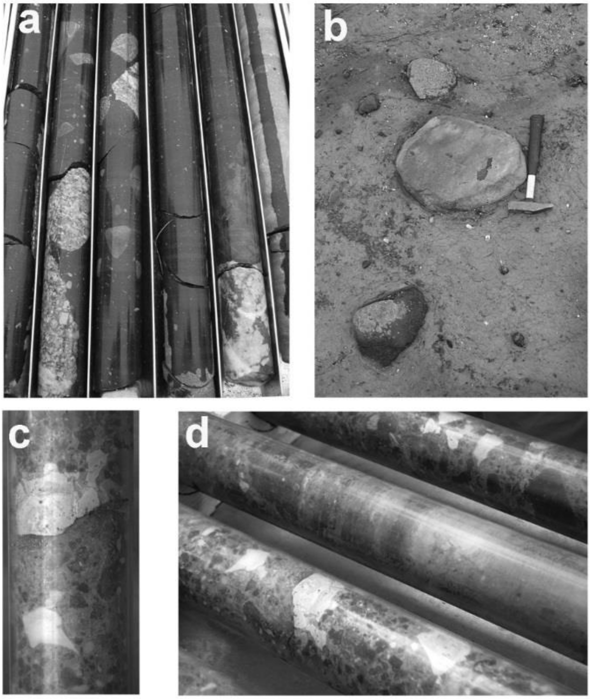

Figure 4. The Fitzroy Tillite Formation contrasted with impact breccias from the Chicxulub crater: a – borehole core (diameter 63 mm) through the Fitzroy Tillite from the Black Rock area of East Falkland; b – the Fitzroy Tillite as exposed near Hill Cove in West Falkland, note the large cobble of limestone adjacent to the hammer; c & d – borehole core (diameter 106 mm) through the impact breccia beneath the Chicxulub crater (images – Tulloch@ECORD_IODP). The impact breccia clasts are ragged and angular whereas the tillite clasts may be rounded and are supported in a fine-grained matrix. The tillite clasts have been brought together by glaciers feeding into a large ice sheet and some, like the limestone clast illustrated (b), may have a very distant origin.

Discovery of one of the World's largest asteroid impact craters might, in itself, have generated some media interest, but in their press release and subsequent interviews Rocca *et al*. spiced-up the story by mention of mass extinction. As reported in *Penguin News*:

"The scientists estimate the age of the basin to be from the late Paleozoic Era; approximately 270 to 250 million years ago. "If the proposed crater turns out to be 250 million years old, it could correlate with the largest mass extinction ever, the Permian extinctions, which wiped out more than 90 percent of all species," observes Rampino."

This wasn't the first time that a media maelstrom had been created by a claim that the end-Permian mass extinction was caused by an asteroid impact. Several attempts were made to link subtle geochemical and mineralogical evidence from the appropriate geological level, but it wasn't until 2001 that one such claim, based on data mainly from China, caught attention – Michael Rampino was involved (Becker *et al*. 2001) – and was followed-up by the identification of a possible candidate crater off the north-west coast of Australia. However, none of these suggestions proved sustainable so, next on the scene were the Falkland Islands.

In fairness to Rocca *et al*., speculative correlation with mass extinction did not make it into the *Terra Nova* (2017) scientific paper, and therein the impact's timing was only claimed to be "perhaps of Permian age". Nevertheless, if it happened, the Falkland Islands asteroid strike would most probably have been felt globally. Remember, its effects could have exceeded in magnitude those of the dinosaur-exterminating Chicxulub impact, and Rampino was quite correct when he told *Penguin News* that the mass extinction late in the Permian Period came close to causing the end of life on Earth. But the problems in the Late Permian were a bit more complicated than can be explained by a single massive cataclysm, and already have a credible alternative explanation anyway.

There has been a lot of investigation of the late Permian mass extinction, which is all admirably summarised in two excellent books: Michael Benton (2015) *When Life Nearly Died* (3rd edition), and Paul Wignall (2015). *The Worst of Times*. There were three major pulses of extinction: one about 262 million years ago, and then a double blow with two extinction events around 252 million years ago, one on either side of the Permian – Triassic boundary, that were only two or three hundred thousand years apart (Figure 3). The cause in each case was probably linked to vast eruptions of volcanic lava and associated gas emissions, first in south China and then on an even bigger scale in Siberia. It's easy to see the attraction of adding a giant asteroid strike to this mix: indeed, some see impacts and volcanism as cause and effect and simply add the effects of a major eruption episode in the Deccan area of India to the calamity that befell the dinosaurs. But in the end, for their *Terra Nova* paper, Rocca *et al*. (2017) played safe and stuck to geophysics, interpreting gravity, magnetic and seismic data in support of their impact crater proposition.

Unsurprisingly, the Rocca *et al*. interpretation of the Falklands data was met with some scepticism, and provoked two critical formal responses, both of which were subsequently published in *Terra Nova*: Reimold *et al*. (2017) and McCarthy *et al*. (2017). Reimold led a team that had considerable experience in applying geophysical criteria to the recognition of ancient impact craters, and they were not impressed by the putative Falklands example. They challenged the fundamental premises of the Rocca *et al*. interpretation and dismissed it completely, concluding that "[t]here is simply no evidence to support the presence of a large impact structure [to the west of the Falkland Islands]".

McCarthy *et al*. (2017) focussed more on the site-specific aspects of the interpretation but were equally dismissive of the claim that geophysical data supported the impact crater proposal. Their analysis of the gravity data supported an elongate anomaly extending north-west to south-east, parallel to the regional geological trends, as previously illustrated by Aldiss & Edwards (1998), rather than the circular pattern picked-out by Rocca *et al*. (2017): the two contrasting interpretations are summarised in Figures 5 and 6. The difference is fundamental because impact craters tend to be circular irrespective of the angle of impact, so great is the energy involved. To explain the geomagnetic anomalies, McCarthy *et al*. noted the widespread presence of igneous rocks, seen as high-amplitude reflectors in seismic sections. These could be either volcanic lavas or intrusive sheets parallel to the sedimentary bedding; a good example of the latter forms South Fur Island (Aldiss & Edwards 1999, p. 58), the most south-easterly of the Jason Islands (Figure 1).

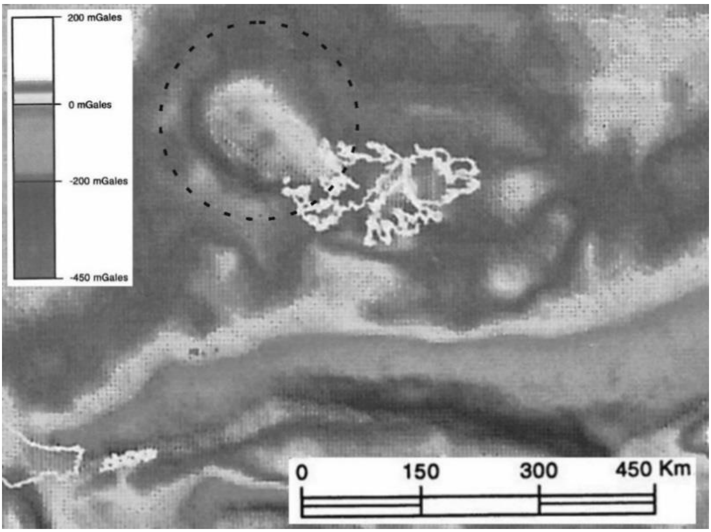

Figure 5. An extract of the gravity map presented by Rocca & Báez Presser (2015, fig. 3). A near-circular feature can be seen to the west of the Falkland Islands within the dotted line. Unfortunately, this map is based on relatively sparse data, and many features have been smoothed or contoured. For explanation of units see note 1.

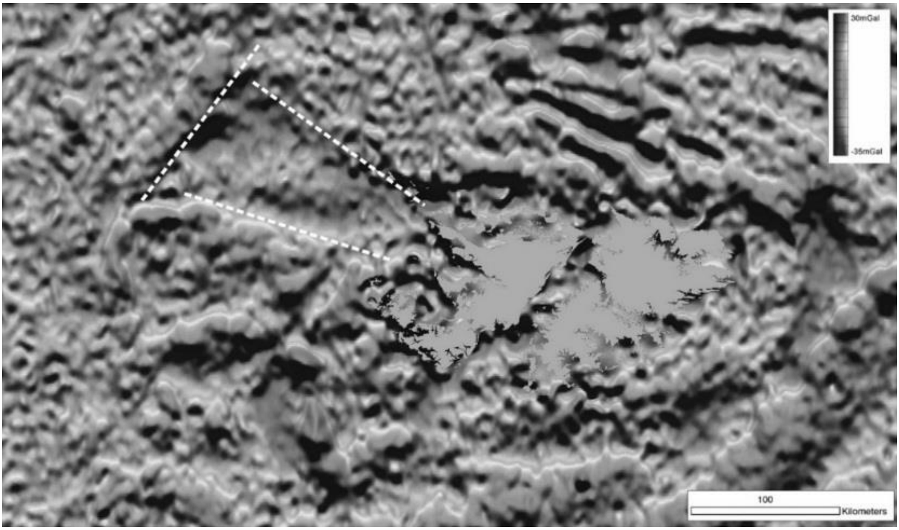

Figure 6. An extract of the gravity map presented by McCarthy et al. (2017, fig. 1). This map has been produced using all of the available satellite-derived gravity data and has been filtered to remove effects of topography and bathymetry. There is a marked feature (or anomaly) to the west of the Falkland Islands, but it is clear from this data that the feature is not circular. In fact, the margins are linear and are best interpreted as faults, located approximately by the white broken lines. For explanation of units see note 1.

Additionally, McCarthy *et al*. (2017) noted errors in the presentation of the seismic data by Rocca *et al*., and gave corrected alternatives that showed a Jurassic and younger sedimentary succession (but with volcanic rocks at the base) unconformably overlying a folded succession directly equivalent to the onshore, Silurian to Devonian West Falklands Group. There was no trace of the confused zone that might have been expected had the area been pulverised by a massive asteroid strike. McCarthy *et al*. also noted the proximity of the supposed impact crater to the westernmost islands of the Falklands archipelago: New Island and the Jason Islands. The geology of these localities is well established, and their strata show none of the disruption that must surely have been caused had their rocks originally lain close to the site of an enormous asteroid impact (Figures 7 and 8).

And what of the huge volume of impact breccia that would have been produced? Onshore in East Falkland the Lafonia Group extends from the Late Carboniferous up through much of the Permian and is devoid of any lithologies that might conceivably be related to a nearby massive asteroid impact. For the younger part of the Permian succession, missing in the Falkland Islands, we can turn to southern Africa and the

Permo-Triassic part of the Karoo Supergroup. Remember that for the time interval under discussion the Falkland Islands and South Africa were close together as parts of Gondwana (Figure 2).

Figure 7. The cliffs of New Island, West Falkland, showing the lateral continuity of the near-horizontal, Port Stephens Formation strata. Image kindly provided by Brian and Judy Summers.

Given the likely palaeogeography, the putative asteroid would have crashed to Earth close to the margin of a huge, relatively shallow inland sea or fresh-water lake wherein were deposited the Lafonia and Karoo successions. The immense force of the impact would certainly have left its mark throughout the lake, and in South Africa its Karoo Supergroup sediments are preserved in an unbroken succession through the Permian and up into the Triassic. Well-preserved across the boundary is evidence for a substantial diminution of the terrestrial flora and fauna coupled with major environmental changes, all commensurate with the global mass extinction, but there are no impact breccias, or any other indications of an extraterrestrial influence.

Figure 8. A close-up view of the New Island cliffs. Although the sandstone beds are cut by vertical joints they remain in continuity and show no effects of having been subjected to unusually high temperature or pressure. Image kindly provided by Brian and Judy Summers.

Naturally, Rocca, Rampino and Báez Presser vigorously defended their impact crater hypothesis against their critics, with Rampino, the scientifically most-established of the three, taking the lead in their *Terra Nova* response (Rampino *et al*. 2017). They emphasised areas of uncertainty in all the opposing proposals, leaving room for their radical model (reiterated by Rampino (2017) in *Cataclysms*) to survive as an alternative to the more conventional, 'sedimentary basin with igneous rocks' interpretations. And there the debate rests. However, asteroid impacts are such fun, and the story of the maverick team, identifying a global catastrophe in the face of opposition from the scientific establishment has such 'Hollywood-sci-fi' appeal, that the story is not going to fade away, irrespective of its dubious geological merits. Additional geophysical data might help resolve the issues raised, but things will probably only be settled to everyone's satisfaction when deep drilling at the site recovers – or more probably fails to recover – pulverised and fused rock packed with shock-fractured quartz crystals. That seems unlikely to happen anytime soon, so expect to hear more about the giant asteroid impact crater to the west of the Falkland Islands – just don't believe it all.

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Note 1

Gravity units used in figures 5 and 6. Gals or mGals are used to measure the variations in the Earth's gravitational field. A mGal is a thousandth of a Gal (the unit of acceleration named after Galileo), which itself is defined as 1 centimetre per second squared (1 cm/s^2). Variations in gravitational acceleration are caused by variations in the density of the lithosphere.

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