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HISTORY OF EARTH SCIENCES

In search of historical roots of the extraterrestrial impact theory, II: two unknown German pioneers from the 1850s, Ludwig Pfeil and Karl Reichenbach

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Abstract

The mid-nineteenth century is not regarded as the time when the theory of extraterrestrial catastrophism developed. However, two German scholars independently introduced original concepts of terrestrial impacts of large celestial bodies at that time. Ludwig Pfeil (1803–1896), a self-educated wealthy landowner, and Karl Reichenbach (1788–1869), an eminent scientist and industrialist, independently proposed in the 1850s that the Earth is an aggregate of meteoritic masses and has experienced many impact-induced cataclysms throughout its geological history. Until 1891, Pfeil analyzed the effects of the collision of a comet's gaseous body with Earth. He tried to simulate the effects of tsunami waves generated by impacts into the ocean and inferred the route of "cometary currents" from the morphology and orientation of coastlines and associated mountain ranges. Reichenbach speculated about fertilization of the terrestrial surface by extraterrestrial dust in the context of an accretionary origin for Earth that also manifested in meteoritic sources of volcanic extrusions. He linked the Mesozoic succession of "buried living worlds" to geological catastrophes, caused by successive meteorite impacts. These cosmic bombardment concepts were comprehensively criticized by contemporary researchers, but soon found many conceptual successors in the German-speaking science community. Therefore, Pfeil and Reichenbach should be regarded as pioneers of the impact theory.

Keywords Extraterrestrial impact · Meteoritics · Mass extinctions · Geosciences history · German science

Introduction

In the modern paradigm, asteroid and comet impacts are widely accepted in the scientific community to constitute the most extreme natural hazards (Marriner et al. 2010). This research field began as early as 1694 by Edmond Halley, who was among the first to suggest the probability of a comet collision with Earth (Schechner 1997: 166). Subsequent research on this theme over almost three centuries has followed two essentially independent pathways. The first involved an explanation of mysterious circular structures observed on the surface of the Moon (Hoyt 1987). At the time the structures were first observed, the activity of giant volcanoes was commonly acknowledged as the origin of the craters, but a competitive hypothesis, the meteorite impact model, was proposed following Ernst Chladni's (1794) discovery that "stones falling from the sky" were of celestial origin (Sheehan and Dobbins 2001; Cummings 2019). This produced a long-standing controversy between lunar "volcanists" and "impactists" that persisted with a generally vague connection to terrestrial aspects. One leading impact proponent was Franz von Paula Gruithuisen, a German selenographer whose concepts included the nascent impact theory of lunar craters in the 1820s (Hoyt 1987; Sheehan and Dobbins 2001; Cummings 2019; Racki and Koeberl 2019). His concept of cosmic body accretion due to meteorite bombardment was continuously developed over decades as an "aggregation theory." Gruithuisen was indeed a thought-provoking scientist, but his reputation was constantly undermined because of his observational overinterpretations, culminating in the sighting of a "moon city" (Sheehan and Dobbins 2001).

The second pathway, publicized in the eighteenth century as the cometary threat, fell out of favor temporarily by

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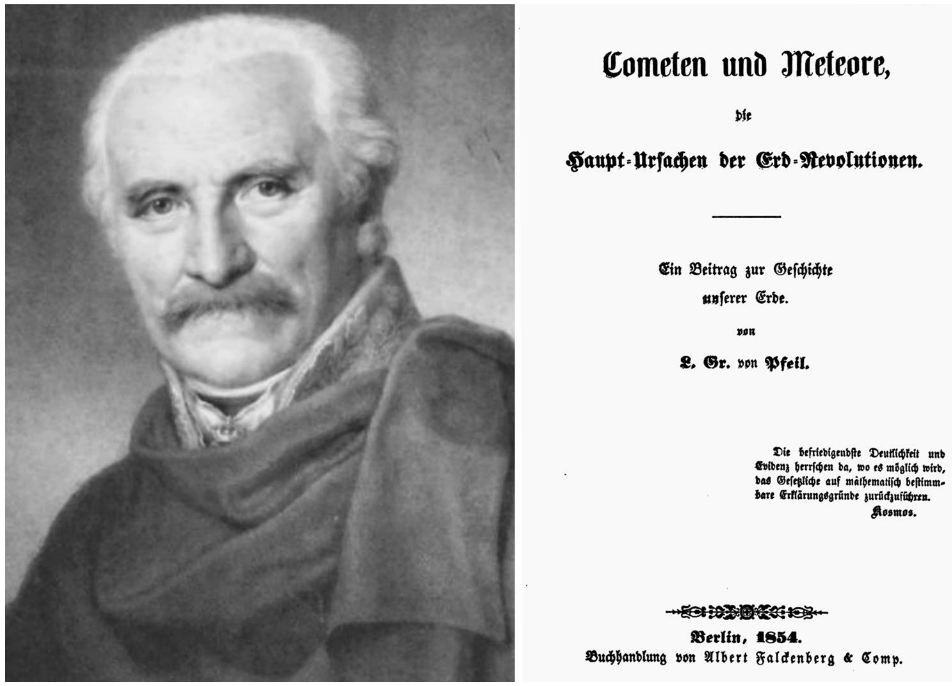


Fig. 1 Ludwig Pfeil [born in Pilgramsdorf (Pielgrzymka, Złotoryja district, modern Poland), March 19, 1803; died in Hirschberg (Jelenia Góra, modern Poland), January 1, 1896]. His full name and titles were Carl Friedrich Ludwig Fabian von Pfeil-Burghauss or von Pfeil und Klein-Ellguth, the count and laird of the land estate Lasaan (=Łażany) in Lower Silesia, hereditary member of the Prussian manor house and of the House of Representatives of the Prussian State Parliament. He was a conservative politician, publicist and naturalist (portrait from "Illustrirte Zeitung," 26, 1856, p. 412). Shown is the title page of his provocative essay from 1854 (note a motto from Alexander Humboldt's "Kosmos")

observations that the passage of approaching comets posed minimal or no danger (Schechner 1997). However, the eminent Pierre Simone Laplace drew attention to the inevitable occurrence of apocalyptic cataclysms in Earth's geological history that could be caused by comet strikes; this was later assigned by him—after establishing the icy nature of comet nuclei—to "local revolutions" (Laplace 1808: 213–214). In fact, this probabilistic rationale corresponds to the recent theory of rare geological events (Racki 2015). At the time, however, this intriguing scenario for geology was ignored by the contemporaneous catastrophic school.

The rapid initial proliferation of pro-impact ideas toward the end of the German Enlightenment (see review in Racki and Koeberl 2019) was later definitively blocked by the domination of orthodox uniformitarianism following Charles Lyell's (1830) seminal treatise, eventually strengthened by Darwin's gradualistic doctrine. Thus, the mid-nineteenth century can be described as a time of intellectual inertia in the English-speaking scientific community for the evolution of extraterrestrial concepts. However, this was not true for the German-speaking scientific world, and catastrophic notions fascinated well-educated enthusiasts of natural science outside of the main professional academic centers. Thus, we discuss two little-known German scholars who, in the 1850s, independently introduced the original concepts of extraterrestrial impacts on Earth. This note is a continuation of our earlier work on the same theme, which focused on the first half of the nineteenth century (Racki and Koeberl 2019).

Ludwig Pfeil, a self-educated land owner

A good example of an amateur scientist is Ludwig Pfeil (Fig. 1), about whom little is known. His publications and scarce biographic information (Bettelheim 1897; von Oettinuen 1904; https://www.deutsche-biographie.de/pnd14383200X.html) reveals that he was highly erudite and active in various scientific branches, but was predominantly a political and social activist (e.g., he participated in the Revolution of 1848). This self-educated nobleman from Lower Silesia was especially prolific in mathematical sciences and various aspects of natural sciences, which were popularized by him in many books, brochures, articles and notes, including well-known popular science magazines (see list of publications in Online Appendix 1.1), and at lectures.

Between 1853 and 1857, Pfeil published three very similar essay books, but we have focused on his publication from 1854 because of its highly provocative and still relevant title: *Comets and meteors, the main causes of the Earth revolutions. A contribution to the history of our Earth* (Fig. 1; Online Appendix 2). An anonymous reviewer in 1855 quoted *in extenso* the most perplexing introductory excerpt: "From time to time larger and smaller bodies, mainly consisting of iron, fall from space onto the Earth and increase their weight, albeit by a very small amount … we are compelled to regard the aerolites as primordial universe bodies … it is to be shown that in earlier times and during certain revolutions of the Earth's surface a stronger fall of meteor stones is to be suspected … and we can therefore assume that at least

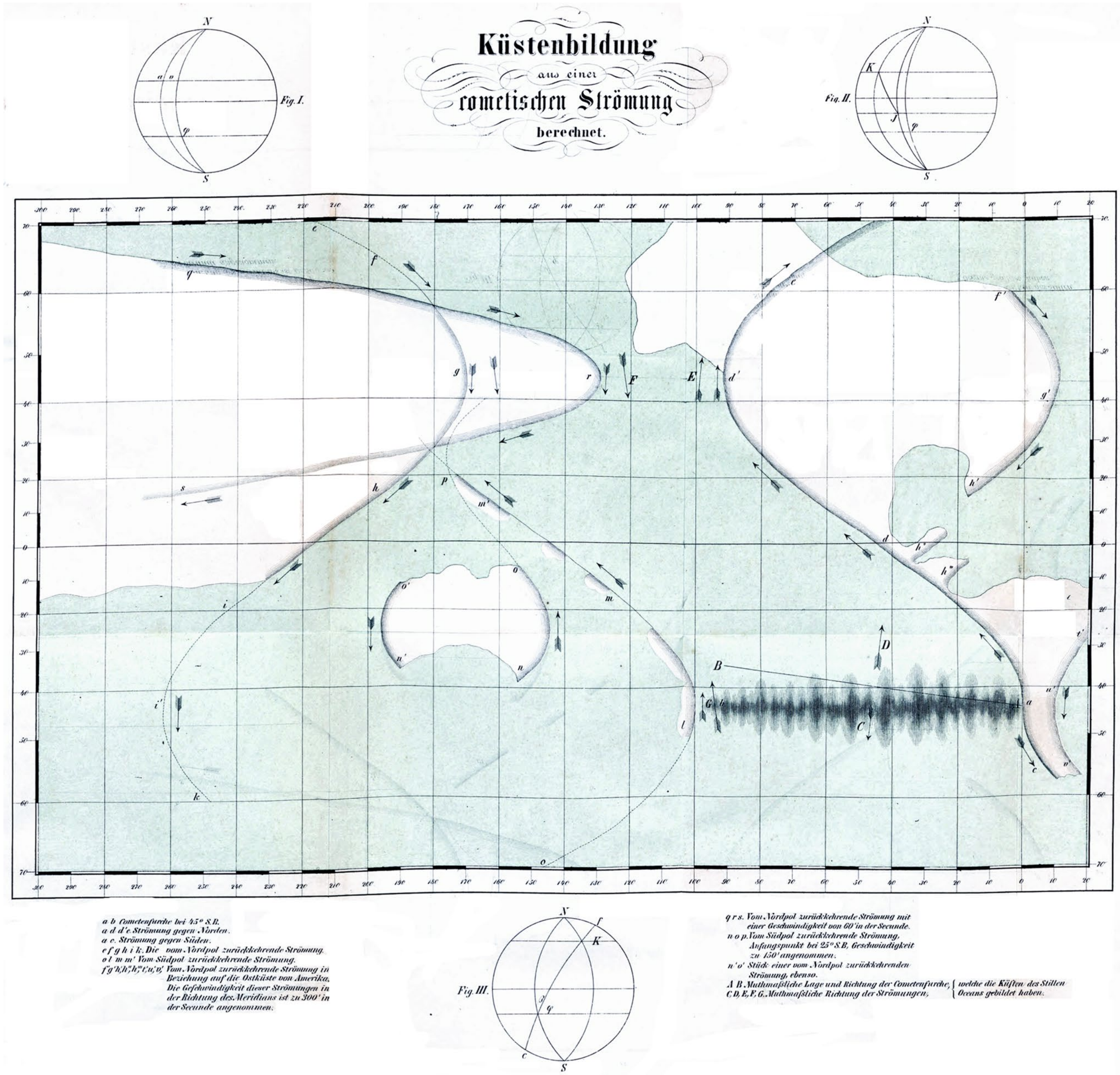
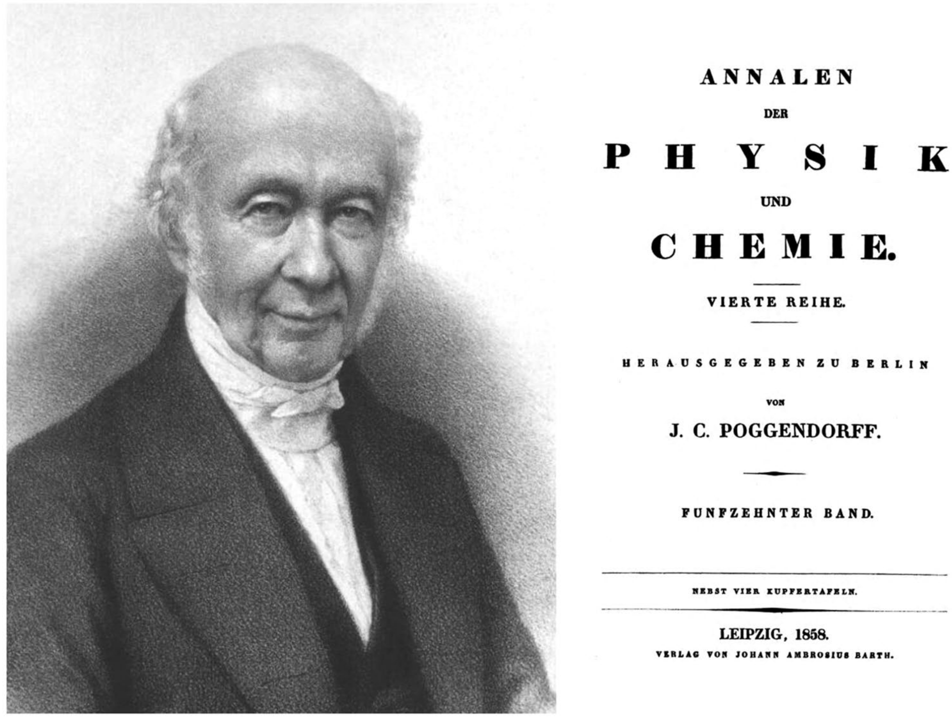


Fig. 2 A depiction of Pfeil's model of collisional interactions between comets (route marked with arrows) and the Earth, recorded in the transformation of oceanic coasts by tsunami waves (Pfeil 1854, plate; for explanation see Online Appendix 2)

a partial composition of our planet from meteoric iron has been proven." (Pfeil 1854: 3–4).

This reviewer stated: "A very sublime logic! After the Earth has arisen from meteor stones in the author's sense, the comets arrive, and by their tremendous impact shape the surface of the Earth and bring air and water to the whole cosmic body, since plants grow on it, and animals and people can live on it." (Anon., 1855: 882; Online Appendix 3). In fact, recurring unavoidable comet-driven Earth revolutions were the main theme of the brochure (92 p., 1 plate; Fig. 2) and developed further in the book *Cometary currents on the Earth's surface*, published as four editions between 1879 (198 p., 5 plates) and 1891 (315 p., 6 plates).

Pfeil analyzed, in detail, the effects of a collision between a comet's gaseous body and Earth, which he postulated would have occurred "with great speed" at ~ 0.1 km/s; in fact, this is at least one order of magnitude slower than in reality. The sudden compression, and consequently heated and exploding mass "would throw the less solid parts of the Earth's surface to one side, but if it hit an oceanic basin, it



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FUNFZEHNTER BAND.
NEBST VIER KUPFERTAFELN.
LEIPZIG, 1858.
VERLAG VON JOHANN AMBROSIUS BARTH.

Fig. 3 Karl Reichenbach, (Karl (or Carl) Ludwig Freiherr [Baron] von Reichenbach; born in Stuttgart, February 12, 1788; died in Leipzig, January 19, 1869) was a notable chemist, geologist, metallurgist, industrialist and philosopher (https://upload.wikimedia.org/wikipedia/commons/7/7d/Karl_Reichenbach.jpg). Shown is the title page of *Annalen der Physik und Chemie*, where he published his contributions to meteoritics

would cause flooding of large parts of the Earth's surface, or even the whole Earth with great speed" (Pfeil 1854: 27–28). According to him, the trajectory of the rapidly induced "cometary currents" would be recorded in the morphology and orientation of the coastlines and related mountain ranges (Fig. 2; Online Appendix 2). In this theory, the origin of mountains is attributed to disturbances in Earth's surface mass caused partially by fluvial processes (Pfeil 1854: 45, 48).

Using modern terminology, we can interpret Pfeil's attempt as trying to simulate the effects of tsunami waves caused by an oceanic impact. Despite his use of mathematical calculations, the inferred cataclysmic coastal remodeling was greatly exaggerated due to insufficient geophysical knowledge at the time. Nevertheless, this first attempt to assess extraterrestrial shock processes on Earth's surface was a significant achievement. Pfeil's 1854 book was dedicated to Alexander Humboldt, expressed in the "Kosmos" motto on the title page, emphasizing the use of mathematical proofs in the natural sciences (Fig. 1). Stevens (1863: 556) reported that Humboldt had Pfeil's books in his library, and he even annotated that "Pfeil was the discoverer of the Law of Coast Formations."

Karl Reichenbach, a distinguished scholar and industrialist

Karl Reichenbach, who attained his PhD from the University of Tübingen, became famous for discovering commercially important chemicals in beech tar, including wax paraffin and phenol (Farrar 1981; Fig. 3). He published numerous articles on meteorites in 1841–1865 (see list in: http://wiki.meteoritica.pl/index.php5/Bibliografia/Reichenbach_Karl_Freiherr_von) because his fortune allowed him to devote himself to collecting and researching them (Burke 1986: 112, 148–152, 178–180). He was the first to observe meteorites under a microscope to investigate their structure and mineralogical composition. Meteorites, Reichenbach postulated, were originally formed by particle condensation in a nebula, while comets and asteroids originated from the aggregation of meteoritic swarms. In his "consolidation theory," planets and satellites in the solar system had an accretion origin.

Reichenbach rarely speculated about extraterrestrial impacts, even if he knew geology (Reichenbach 1834). Among others, he discussed a possible fertilizing effect on Earth from falling meteoritic matter (Reichenbach 1864). His most important geological interpretations were presented in the article "On the number of meteorites and considerations about their role in the Universe structure" (Reichenbach 1858, Online Appendix 5). The crucial statement was: "If we take a look at the succession of *mountain formations* [K.R. emphasis], which make up the crust of the Earth accessible to us, we find, particularly in the Floetz mountains [*Flötzgebirge*; = the Permian to the Cenozoic (Tertiary)], a repeated recurrence of rock types, of limestone, of sandstone, of clay deposits, of conglomerates and between them large coal sediments which are the remnants of preceding, once living, organized creatures…. So there were once living worlds that have been destroyed, and these destructions occurred repeatedly." In this context, Reichenbach emphasized the importance of meteorite impacts: "When great meteoritic masses combine with the Earth, they first, according to known laws, have to circle the Earth a few times, burst, and thereby cause disturbances on the Earth's surface which dislodge the oceans from their position of equilibrium. Immeasurable floods with all their devastation are then the inevitable consequences… After all, geological catastrophes exist and so do meteorites, and when one of sufficient size appears, such upheavals on the Earth's surface *must* be the inevitable consequence." (Reichenbach 1858: 559–560). Hence, Reichenbach linked the succession of "buried living worlds" (i.e., mass extinctions) to consequences of catastrophic meteorite impacts.

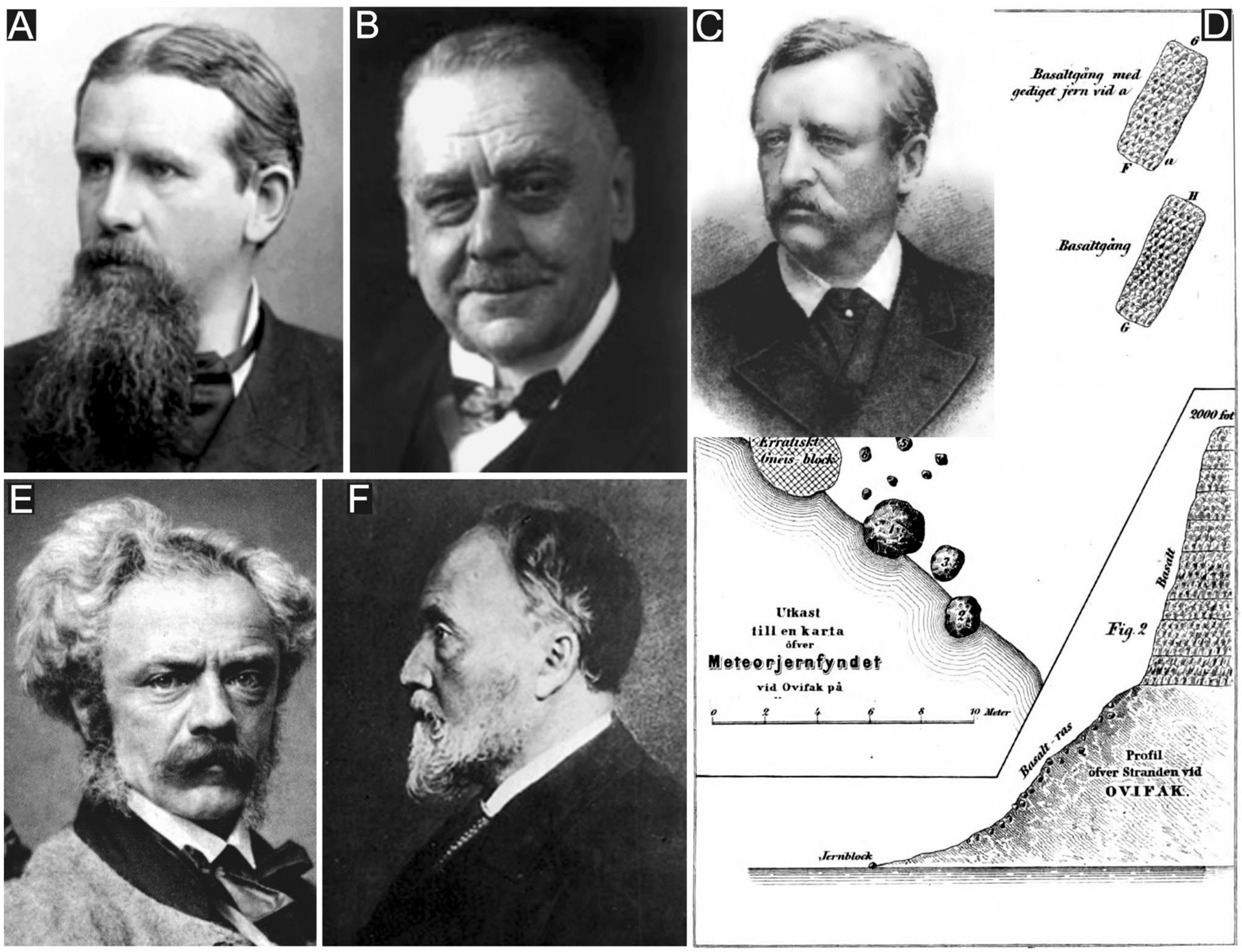

Fig. 4 Opponents (**a**, **b**, **e**, **f**) and supporter (**c**) of the meteoritic model, engaged in the discussion of the concepts of Pfeil and Reichenbach. **a** Friedrich Ratzel (1844–1904), a German geographer, ethnographer and anthropologist (https://www.google.pl/search?q=ratzel+friedrich&tbm=isch&source). **b** Heinrich Gravelius (1861–1938), a German mathematician and applied geoscientist (https://tu-dresden.de/ua/dokumentationen/dokumentationen/vorsteher-direktoren-und-rektoren-von-der). **c**, **d** Adolf Erik Nordenskiöld (1832–1901), a prominent Finnish-Swedish geoscientist and Arctic explorer (**c**; https://upload.wikimedia.org/wikipedia/commons/0/01/A_E_Nordenskiold.jpg), and geological sketch of Ovifak native iron occurrence in Disko Island, Greenland, thought by him to be the site of the meteorite hitting basalt (**d**; pl. 18 from Nordenskiöld 1870). **e** Franz von Kobell (1803–1882), a German mineralogist and writer (https://upload.wikimedia.org/wikipedia/commons/4/4f/Franz_von_Kobell.jpg). **f** Fredrik Johan Wiik (1839–1909), a Finnish geoscientist (https://upload.wikimedia.org/wikipedia/en/9/98/Fredrik_Johan_Wiik.jpg)

He hypothesized that "the interior of our Earth either itself has the mineralogical constitution of a meteorite, or as is not completely improbable, consists altogether of an aggregate of meteorites… We are thus in no manner foreign to each other, the meteorites and the Earth; we are obviously siblings and come from the same mother… From the largest planet to the smallest meteorite there is only one continuous series." (Reichenbach 1858: 559, 561, 563).

Debate on pro-impact works in the late nineteenth century

As a result of the two scientists' publication histories, reactions to their challenging hypotheses and novel publications were contrasting. Reichenbach, as a renowned scientist, published his essay in a recognized scientific journal; therefore, its reception was generally neutral, although its reach was limited to a narrow circle of academics. His articles (Reichenbach 1858, 1864) were recorded in various forms in at least 17 journals, series and books, including meteorite monographs. Nevertheless, he had some critics; for example, Enders (1866) was skeptical about the number of meteorites Reichenbach estimated fell to Earth. Kobell (1864; Fig. 4e) similarly criticized the concept of a "meteor shower," especially in the context of comet impacts, judging it mostly guided by imagination ["phantasie"; p. 70; Online Appendix 6.1].

Reichenbach's (1858) article was later quoted by Wiik (Fig. 4f) in his polemical article with Adolf Erik Nordenskiöld (Wiik 1883) that suggested a cosmic nature for basalts (Online Appendix 6.2). Nordenskiöld, an eminent polar explorer, was involved in several ways in the study of meteorites (Burke 1986: 191–192, 239), in particular as a primary participant on the losing side of the famous controversy over native Ovifak iron blocks from Greenland (Nordenskiöld 1883; Fig. 4c, d). This vigorous discussion, which is still under some debate (Jones et al. 2006), had a negative influence on the development of meteoritics, including an explanation of the origin of Meteor (Barringer) Crater (Racki et al. 2018: 554). However, Nordenskiöld propagated the concept of a meteoritic origin for Earth and other planets, quoting the discovery of dark micrometeorite-enriched dust on the surface of Greenland glaciers (cryoconite; Nordenskiöld 1883). This discovery was recently comprehensively confirmed (e.g., Kurat et al 1994).

It is therefore unsurprising that Pfeil referred to the authority of Nordenskiöld in his works and that garnered a much wider response. His three books from the 1850s have been reviewed twice and referenced in the literature at least 40 times. However, Pfeil's later book on cometary currents was reviewed at least 11 times (Online Appendix 1.2), cited 10 times (Online Appendix 1.3) and referenced > 40 times. Their wide dispersal is evidenced by the variety of sources, ranging from newspapers to bibliographic reviews, popular nature magazines and various scientific periodicals. However, references were rare in mainstream journals (*Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* and *Proceedings of the Royal Geographical Society*) and monographs (Nölke 1919: 175, 205, 247).

Pfeil's pro-impact hypotheses were comprehensively criticized in 1879–1991 by German and Austrian researchers and lecturers (Fig. 4a, b). He was treated as an uneducated intruder with academic ambitions, and criticism was based on the presumption of Pfeil's ignorance of earlier literature and scientific methodology—the frustrated tone of these reviews is exemplified by the chronologically first and last one, given in Online Appendices 3–4 (Anon., 1855; Gravelius 1891; Fig. 4b). It is worth noting that Pfeil himself was an ardent polemicist (Online Appendix 4.2) and he included uncompromising replies to seven negative reviews in the introduction of his 1881 book edition.

The last decades of the nineteenth century were the zenith of impactist/volcanist discussions in Germany, and Pfeil's popularization activities fit this trend well. Moreover, two early opponents of his ideas, Friedrich Ratzel (Fig. 4a) and Max W. Meyer, later became known advocates of the meteorite hypothesis and cosmic cataclysm (Racki et al. 2018). Pfeil believed in the strength of mathematical argument within the natural sciences, especially with the Laplacian probabilistic approach, and he is in fact the historic winner of this debate.

Final remarks

Pfeil and Reichenbach independently proposed the concept that the Earth may be a meteoritic mass aggregate and has been repeatedly and catastrophically affected by extraterrestrial impacts throughout geological history. The uniqueness of their work at a time of increasing domination of orthodox uniformitarianism is beyond doubt, and Pfeil directly criticized uniformitarian and evolutionary dogma (Pfeil 1854: 12; Pfeil 1891: 137–138; Online Appendix 4.2).

The ideas of Pfeil and Reichenbach were just some of a number of "embryonic planetesimic hypotheses" at that time that were separately proposed by prominent scholars, such as Nordenskiöld, Joly, Sorby, Mayer and Proctor (Burke 1986; Brush 2006; Racki and Koeberl 2019). However, the partially closed circulation of information curtailed advances in the model, as can be seen from the limited references in the works and subsequent debates. It is therefore unsurprising that these original and correct hypotheses originated and remained at the scientific periphery, while mainstream research was conceptually constrained by the informal principle of "paradigmatic correctness."

Despite the disapproval of Pfeil's concepts by his contemporaries, his "renegade" ideas of extraterrestrial bombardment opened the door to future broad interest in the subject and the development of a doctrine regarding catastrophic events as a result of the effective dissemination of his publications outside academic centers. The ideas of Pfeil and Reichenbach can, therefore, be seen as a continuation of the Chladni–Laplace conceptions and direct successors to Gruithuisen's ideas; however, these were omitted in their works. Pfeil and Richenbach were precursors of the renaissance of pro-impact theories in Germany in the late nineteenth and early twentieth centuries (Cummings 2019; Racki and Koeberl 2019), culminating in Wegener's well-known 1921 experimental study. Pfeil and Reichenbach should, therefore, have an appropriate place among the pioneers of extraterrestrial catastrophe theory.

Supplementary Information The online version contains supplementary material (Online Appendices 1-6) available at https://doi.org/10.1007/s00531-021-02004-0.

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