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WILL RUSSIA PASS OVER THE GREAT PLUME DEBATE?

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From 28th August to 1st September of 2005, in Fort William, Scotland, the American Geophysical Union carried out the polemical conference "The Great Plume Debate. The Origin and Impact of LIPs and Hot Spots." More than 80 scientists from the USA, Great Britain, Germany, Netherlands, Australia, France, India, Japan, and other countries took part in this conference. The polemical style of the conference dictated its agenda. Equal time was given to proponents and opponents of the plume hypothesis of the formation of large igneous provinces and hot spots. Much time was dedicated to discussion. The agenda responsibility was shared by the conference conveners: plumists J. Morgan and I. Campbell and controversionalists G. Foulger, J. Natland, and D. Presnall.

The debatable subjects were theoretical questions of plume and alternative hypotheses, estimation of temperature of the mantle in the regions of hot spots and mid-ocean ridges, critical analysis of geochronological, geochemical, seismological, and petrological data, numerical and analogous modeling, as well as volcanism of Venus and Mars.

The conference proceedings are exposed on the site www.mantleplumes.org. As the Russian geologists largely keep aloof from this discussion, a short history of the "Great Plume Debate" will be given below. Though Russian geologists contributed much to the plume hypothesis [e.g., 1–5], only English publications will deliberately be reviewed in this essay.

In 1965, Wilson [6] proposed a hypothesis that aseismic oceanic ridges, e.g., the Hawaiian Ridge, are underlain by anomalously heated mantle—hot spots. Somewhat later, in 1971, Morgan [7] supposed that these hot spots were situated at tops of localized ascending mantle flows—mantle plumes. The apparent spatial stability of the mantle plumes as compared with drifting lithospheric plates suggested that the plumes rise from the lower mantle, from a region that lies below the intensely mixing layer of the upper mantle. Initially, this idea was based on the concepts of fluid dynamics, according to which plumes can originate exclusively on thermal boundary layers. The only appropriate thermal boundary layer was known to be layer D″ between the outer core and lower mantle. Morgan [7] supposed that about twenty active zones of volcanism (Hawaii, Iceland, Tristan da Cunha, Yellowstone, etc.) are related to plumes of this kind. Initially, plumes were considered a mechanism of whole-mantle convection and the casual force of plate tectonics. Recent paradigm includes ideas of plume tectonics, probably, independent of plate tectonics.

The plume ideas began to actively develop in the middle 1980s [8] (Fig. 1). Important support for them came from the 1980–90 works on analog modeling using syrups of various viscosity in transparent tanks [9] and from high ratios $^3He/^4He$ found in volcanics of hot spots as compared with expressions of upper mantle volcanism—rocks of mid-ocean ridges [10].

Analog modeling shows that plumes have a large head and narrow conduit. The plume's head should lead to large within-plate uplifts such as the East African Plateau and to large catastrophic effusions like the Siberian traps. After the head had struck the lithosphere sole to become mushroom-shaped and the hot material had been exhausted by volcanism, the conduit of the plume began to burn through the lithosphere to form linear chains of volcanoes on the moving lithospheric plates such as the Hawaii-Emperor chain in the Pacific. The high ratios $^3He/^4He$ seem to be a convincing proof for the existence of non-degassed lower mantle with the initial solar ^3He. The plume hypothesis explains the volcanism far from the boundaries of lithospheric plates and seems to be an elegant addition to plate tectonics. Since the late 1980s-early 1990s, the number of publications with the word "plume" in the title (chiefly, in the English literature) increasingly grew (see Fig. 1) [8]. The number of volcanic regions (hot spots) associated with mantle plumes grew as well. In 1977, in their paper (humorous in style but serious in essence), Holden and Vogt [11] estimated that, given the rate of addition of new plumes kept the same, instead of 20 plumes proposed initially in 1971 [7] they will number 1,000,000 by the year 2000. Of course, this "forecast" turned out to be overestimated. Nevertheless, in 1999, it was supposed that 5200 plumes of various

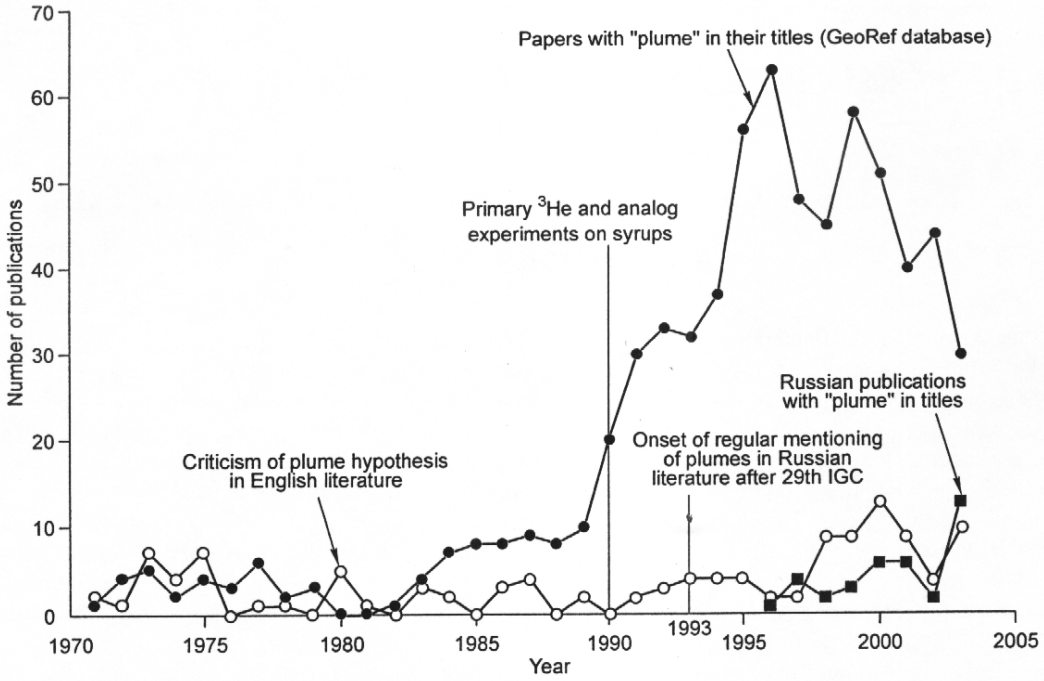

Fig. 1. Frequency of the term "plume" in the titles of the GeoRef-indexed papers [8] and in the Russian scientific literature as well as number of the English publications that criticize the plume hypothesis as a whole or some aspects of it. The information is given for the period from 1971 to 2003. Since the middle 1990s, the GeoRef database has contained translated Russian journals. IGC — International Geological Congress. The data on Russian and English journals are borrowed from the site www.mantleplumes.org and have also been obtained by looking through files of Russian geological journals [30].

ranks might be acting on the Earth simultaneously [12]. Even this number was too large, so that in subsequent years the number of contemporaneous plumes was reduced by two orders of magnitude. As to the lower-mantle plumes, most researchers believe that they number about ten [13–15]. However, there is no consensus on which hot spots are associated with these ten plumes [16]. The authors of three publications [13–15] share the opinion only on two hot spots from the given list. They all agree that a lower mantle plume exists beneath the island of Easter (Pacific) and there is no lower-mantle plume beneath Yellowstone (North America) (Table 1).

As the plume hypothesis became more popular, controversies and discrepancies between the initial idea and snowballing facts increased. For instance, the Siberian trap volcanism was preceded by downwarping, not uplift [17]. The "immobile" Hawaii-Emperor chain of volcanoes migrated southward in its infancy at a velocity commensurate with that of fast plates [18]. The plume volcanoes of the "non-degassed" lower mantle with high ratios ^{3}He/^{4}He are poor in He (degassed) and the volcanoes fed from the "degassed" upper mantle, on the contrary, are characterized by high concentrations of He (non-degassed) [19]. Some authors [20] doubted that the mantle below many "hot" spots, including Hawaii, is hotter than the "normal" mantle below mid-ocean ridges. As a result, since the second half of the 1990s critical publications have become more frequent (see Fig. 1). In 2002, 2004, and 2005, the American Geological Society and American Geophysical Union carried out successively three conferences in Iceland, California, and Scotland on the same subject "Do plumes exist and, if do, what are they?" In 2003, the Geological Society of London carried out on-line debates in the Internet [21]. In the same year the leading scientific journal *Science* published simultaneously two papers, 'pro' and 'contra' plumes [22, 23]. In 2005, the Royal Astronomical Society (UK) awarded G. Foulger the Price Medal for the leadership and critical approach to the traditional paradigm of mantle-derived hot spots. At last, in the same year China joined in the discussion. Its leading scientific journal *Chinese Science Bulletin* published opinions of G. Foulger and plume proponent G. Davies, a 2005 laureat of the European Union of Geosciences [24–26]. At the same time, the growth of plume-related publications in Russian journals implies that the critical discussion and even hot debates are ignored

Table 1

Comparison of Hot Spots Below which Mantle Structure was Analyzed for Revealing Lower Mantle Plumes [13–15]

Hot spot	[13] (48)	[14] (23)	[15] (59)
Afar	Plume	Plume	No plume
Bouvet	No plume	»	»
Macdonald	»	»	»
Hawaii	Plume	»	»
Iceland	»	»	»
Reunion	»	No plume	»
Tristan	»	»	»
Louisville	»	Plume	»
Samoa	No plume	»	Plume
Taiti	»	No plume	»
Ascension	»	»	»
Azores	»	»	»
Canary	»	»	»
Easter	**Plume**	**Plume**	**Plume**
Yellowstone	**No plume**	**No plume**	**No plume**

Note. Parenthesized is the number of references to these papers since the time of their publication to September of 2005 (from the database Web of Science http://portal01.isiknowledge.com). Coincidences are bold-faced.

by Russian geologists. The frequency of the word "plume" in the titles of the reports published in Russian journals remarkably follows the curve of English critical publications, though actually these two curves should be opposite (see Fig. 1).

To conclude this essay, it seems reasonable to ask following the plume hypothesis proponents, D. DePaolo and M. Manga: "Is there evidence that deep mantle plumes exist? And do all volcanoes not associated with plate boundaries require a deep mantle plume? The answers seem most likely to be "yes" and "no", respectively" [22]. An additional question arises: What leads to the formation of within-plate volcanoes not associated with mantle plumes? Obviously, to answer this question, we must pay close attention to alternative models discussed in recent scientific literature. Worthy of note are models for propagating crack [27], for penetrating mantle convection [16], for lithospheric delamination [28], for impact [29], etc.

Nearly 30 years ago, Holden and Vogt wrote [11]: "Since plumes are better hidden from observation than plates it may take years to prove or disprove their existence". Some time later the plume hypothesis deeply rooted in the minds of geologists and is often considered scientific paradigm. But the time necessary for accumulating factual material has lapsed, and there is a point for plumes to pass serious exams. Critical analysis of the paradigm will either give solid support to it or lead to a new paradigm. In any case, there is a unique possibility to find principally new explanations of the known facts and to reveal new natural phenomena. I hope that this essay will awaken interest of Russian geologists in the "Great Plume Debates".

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