IRIDIUM AND THE CHICXULUB IMPACT DUST

Pavle I. Premović,
Laboratory for Geochemistry, Cosmochemistry&Astrochemistry,
University of Niš, 18000 Niš, Serbia

Summary. The prominent Cretaceous-Paleogene boundary clays of marine origin are characterized by their 0.2 - 0.4 cm thick basal layer so-called the ejecta layer anomalously enriched with mostly extraterrestrial iridium. It is now generally agreed that this iridium originated from the globally dispersed submicron impact dust originated from the carbonaceous chondritic impactor of the Chicxulub impact (Mexico). This note shows that the previous estimation of the mass (10^{13} - 10^{14}g) of this dust by Pope [1] is probably greatly underestimated. On the other hand, the far higher mass assessments (ca. 10^{17} g) by Alvarez et al. [2], Toon et al. [3], and Moore et al. [4] are far more satisfactory.

Key words: Cretaceous-Paleogene, asteroid, impact, boundary, clays, iridium.

Introduction. The CretaceousPaleogene boundary (KPB), about about 65 millions years ago, marks one of the most significant impact events in the Phanerozoic. This impact was probably largely responsible for one of the great extinctions in Earth's history. Alvarez et al. [2] have recorded the enhanced iridium (Ir) concentrations in the prominent KPB marine clays of Italy (Gubbio), Denmark (Stevns Klint) and New Zealand (Woodside Creek), Fig. 1. Around the same time Smit and Hertogen [5] reported anomalous Ir in the marine boundary clay at Caravaca (Spain), Fig. 1. Both research teams proposed that these Ir anomalies were originated from an asteroid impactor.

Discussion. In their initial proposal, Alvarez et al. [2] also hypothesized that the Ir-enriched boundary clays of marine origin are composed of a large quantity of fine dust which was globally distributed in the atmosphere following the impact. Using the Ir anomaly of these clays, the authors estimated that the mass of the impacting asteroid equals 3.4×10^{17} g, assuming the asteroid mass fraction injected and globally dispersed is 0.22 (Krakatau factor). It is now almost generally accepted that the Chicxulub crater (the Yucatan Peninsula, Mexico, Fig. 1) marks the KPB impact [6].

The chondrite identifications of this impactor is still open for debate and encompasses four types: CI [2], CI **(**Orgueil chondrite) or CV (Allende chondrite) [7], CM or CO type [8] and CM [9]. Alvarez et al. [2], based their identification on the fact that it appears CI chondrites are typical material within solar system. Shukolyukov and Lugmair [7], Trinquier et al. [9] and Quitte et al. [10], argue that chromium (Cr) isotopic signature of the ejecta layers at Stevns Klint and Caravaca (and elsewhere) is consistent with the carbonaceous chondrites but not with mantle derived rocks (and their phases) and terrestrial rocks. However, recent high precision mass spectrometric analysis of Cr by Qin et al. [11] shows that there is no systematic difference between these rocks. In addition, according to Wang et al. [12] oxidative weathering may effect Cr isotopic ratio of the sediments, implying that a similar process may occur in the ejecta layers. A more extensive discussion of these Cr isotope issues is beyond the scope of this paper and it will be presented elsewhere.

Kyte [8] based his identification on a 2.5 mm fossil meteorite found in the KPB sediments of the DSDP site 576 (Shatsky Rise), Fig. 1. As pointed out by Quitte et al. [10], this meteorite fragment may be a fragment of the impactor, although it is impossible to ascertain if it was originated as a part of the Chicxulub impactor. Moreover, the fragment contains about 2000 times of gold (Au) than the CM carbonaceous chondrite. A study by Goderis et al. [13] infers that the impactor was probably a carbonaceous chondrite of CM or CO type. Their proposal is based on an extensive set of data of marine and continental KPB sites related to their siderophile abundances and ratios.

Figure1. Geographic locations of the KPB sites referred in the text.

Most of the prominent boundary clays are of marine provenance and at the paleodistal sites world wide; a paleodistal site is at a distance of > 7000 km to the proposed Chicxulub impact site. They are characterized by their 0.2 – 0.4 cm thick basal layer so called the ejecta layer [1, 14, 15]. Early studies assumed that the primary source of this layer is created by the (stratospheric) submicron dust of the impact ejecta [1, 2, 3, 16]. It is now generally agreed that this dust originated mainly from condensation of impact vaporized substances. This vapor condensate was composed of the chondritic impactor and an insignificant volume of the target rocks (mainly derived from continental crust). The submicron dust was promptly dispersed after the impact on the Earth's surface [1, 2, 3, 16].

The average Ir contents in the carbonaceous chondrites vary between 472 ppb (CI) up to 758 ppb (CV) [17]. The Ir anomaly of the prominent marine and continental KPB clays is largely concentrated in the ejecta layers**.** The most recent estimation of global Ir fluences at marine and continental KPB sites vary by over two orders of magnitude from 8 ng cm^{-2} to 1087 ng cm^{-2} corresponding to a geometric mean of 53 ng cm^{-2} [4]. This value agreed with previous estimate the mean amount of Ir deposited globally of about 55 ng cm^{-2} [18] or ~ 2.75×10^{11} g (using the fact that the Earth's total surface area is about 5.1×10^{18} cm^2).

The host of the Ir in the ejecta layers is still not known. Schmitz [19] and Kyte et al. [20] hypothesized that Ir in these ejecta layers is associated with fine (submicron) dust fraction of ejecta fallout which has since diagenetically altered to clay. Indeed, most of the impact generated large particles would have a very short residence time in the atmosphere and only the stratospheric portion of fine (submicron) dust from the impact could be deposited globally [21]. Indeed, according to Morgan et al. [22] the total number, maximum and average size of shocked quartz grains in the impact ejecta fallout decrease gradually with paleodistance from Chicxulub; their average size is about 60 µm. In addition, Korchagin and Tsel'movich [23] described a numerous metallic microparticles (about 2 µm - 50 µm) composed of Fe, Ni, Co and Cr of extraterrestrial origin found in the KPB clay (the Fish Clay) at paleodistal Stevns Klint. The authors suggest that these microparticles are related to the asteroid fragments or micrometeorites. Premović et al. (24) reported the occurrence of micrometer-sized particles of pure silver in the ejecta layer of the Fish Clay. Most of these particles are spherical whose diameter ranges from approximately 20–200 µm.

Pope [1] argued that the most of ejecta fallout worldwide is derived from vapor condensation droplets ~200 µm in diameter. If this is correct, then all Ir would be associated the coarse (~200 µm) dust fraction in the global ejecta fallout. However, no submilimeter-size particles containing anomalous Ir was found any of the ejecta layers in the marine or continental KPB clays. A few large Ir-rich particles are only, however, found in two oceanic KPB clays at DSDP Site 577 (Shatsky Rise, Fig. 1) [8, 25]. Although these particles have Ir contents that range up to chondritic values, it appears they are not the principal carrier of Ir at these sites [26]. Moreover, these oceanic boundary clays have no distinctive Ir-rich ejecta layer. Thus, it seems highly likely that extraterrestrial Ir was initially associated with the submicron portion of the dust.

For a sake of simplicity, in the following calculations it is reasonable assumed that the global ejecta layer is ca. 0.3 cm thick and its density is about 2 g cm^{-3}; the submicron dust of this layer contains 0.22 [2] and 0.5 [27] of CI asteroid material containing the lowest Ir (472 ppb) of the all carbonaceous chondrites [17]; and, the Earth's total surface area is about 5.1×10^{18} cm^2.

Toon et al. [3] estimate that the Chicxulub impactor generated about 3×10^{17} g of stratospheric submicronmeter-particles globally dispersed which is sufficient to shut down photosynthesis for several months immediately after the Chicxulub event. If the entire mass of the global ejecta layer represented submicrometer-sized dust then it would weight about 0.06 g. This layer would contain 0.01 - 0.03 g of the impactor material with about 5 - 14 ng of extraterrestrial Ir. In this case the Ir fluency of global ejecta layer with the volume of 0.6 g would be about 5 - 14 ng cm^{-2}. This Ir abundance is about 4 - 10 times lower than that, 55 ng cm^{-2}, reported by Donaldson and Hildebrand [18].

The above calculations may infer that the mass of submicron dust of the impact vapor plume was higher than the volume of this dust (~ 3×10^{17} g) proposed by Toon et al. [3]. Another possible explanation is that the global abundance of Ir (55 ng cm^{-2}) at the KPB is lower than previously estimated. It is worthy of note that Moore et al. [4] calculated that the global Ir fluency is 28 ng cm^{-2} and that the mass of the Chicxulub impactor was about 2.4×10^{17} g. Their assessment is based on the incongruity between the Ir and osmium (Os) fluence estimates at the marine and continental KPB sites.

It is worth of note that simulations of impacts, employing laboratory experiments/numerical models, indicate that the fate of the impactor is dependent on impactor size, velocity and angle of impact, as well as the target properties [28, and references therein]. These simulations imply that if the (oblique) impact angle is ≤ 30° the most of impactor dust would be deposited at paleodistal sites. In contrast, subvertical impacts lead to less impactor dust at these sites than observed. In addition, the impactor fraction which escapes Earth (having velocity greater than escape velocity) depends on impact angle and the impactor velocity. According to this modelling, impact angles of about 45° best fit observed worldwide Ir mass of 2 - 2.8×10^{11} g.

It is also interesting to mention that the experimental data infers that the deposition time of the ejecta layers of the most prominent marine KPB deposits did not exceed an upper limit of 100 years [15, and references therein]. If this is correct than the infall rate of the Chicxulub asteroid dust may have been as much as a factor of about 10^5 higher in comparison to the flux of cosmic dust on the present day Earth of 10^{10} g yr^{-1} [29, 30].

Conclusions. The estimation of the mass (10^{13} - 10^{14} g) of the stratospheric submicron dust originated from the Chicxulub KPB impact is probably greatly depleted. On the other hand, the much highest mass estimation (ca. 10^{17} g) is more plausible.

Acknowledgents. I thank le Ministere Francais de l`Education National, de l`Enseignement Superieur et de la Recherech for funding support for my stay at Université Pierre et Marie Curie (Paris).

References

[1] K. O. Pope, Impact dust not the cause of the Cretaceous–Tertiary mass extinction. Geology, 30 (2002) 97-102.
[2] L. W. Alvarez, W. Alvarez, F. Asaro, H. V., Michel, Extraterrestrial cause for the Cretaceous-Tertiary extinction. Science, 208 (1980) 1095-1108.
[3] O. B. Toon, K. Zahnle, D. Morrison, R. P. Turco, C. Covey, Environmental perturbations caused by the impacts of asteroids and comets. Rev. of Geophys., 35 (1997) 41-78.
[4] J. R. Moore, H. R. Hallock, J. W. Chipman, M. Sharma, Iridium and osmium fluences across the KPg boundary indicate a small impactor. 44th Lunar and Planetary Science Conference (2013), 2405.
[5] J. Smit, J. Hertogen, An extraterrestrial event at the Cretaceous-Tertiary boundary. Nature, 285 (1980) 198-200.
[6] A. R. Hildebrand, G. T. Penfield, D. A. Kring, M. Pilkington, A. Y. Camargo, S. B. Jacobsen, W. V. Boynton, Chicxulub crater: a possible Cretaceous/Tertiary boundary impact crater on the Yucatan Peninsula, Mexico. Geology, 19 (2013): 867-871.
[7] A. Shukolyukov, G. W. Lugmair, Isotopic evidence for the Cretaceous-Tertiary impactor and its type. Science, 282 (1998) 927-929.
[8] F. T Kyte, A meteorite from the Cretaceous/Tertiary boundary. Nature, 396 (1998) 237-239.
[9] A. Trinquier, J.L. Birck, C. J. Allegre, The nature of the KT impactor. A ^{54}Cr reappraisal. Earth Planet. Sci. Lett., 241 (2006) 780-788.
[10] G. Quitte, E. Robin, S. Levasseir, F. Capmasi, R. Rocxhia, R. J.L. Birck, C. J. Allegre, Osmium, tungsten, and chromium isotopes in sediments and in Ni-rich spinel at the KT boundary: Signature of a chondritic impactor. Meteor. & Planet. Sci., 42 (2007) 1567-1580.
[11] L. Qin, J. Xia, R. Carlson, Q. Zhang, Chromium stable isotope composition of meteorites. 46th Lunar and Planet. Sci. Conf., 2015.
[12] X.Wang, N. J. Planavsky, C. T. Reinhard, H. Zou, J. Ague, Y. Wuc, B. C. Gill, E. M. Schwarzenbach, B. Peucker Ehrenbrink, Chromium isotope fractionation during subduction related metamorphism, black shale weathering, and hydrothermal alteration. Chem. Geol. 423 (2016)
[13] S. Goderis, R. Tagle, J. Belza, J. Smit, A. Montanari, F. Vanhaecke, J. Erzinger, Ph. Claeys, Reevaluation of siderophile element abundances and ratios across the Cretaceous–Paleogene (K–Pg) boundary: Implications for the nature of the projectile. Geochim. Cosmochim. Acta, 120 (2013) 417-446.

[14] P. I. Premović, Experimental evidence for the global acidification of surface ocean at the CretaceousPaleogene boundary: the biogenic calcite-poor spherule layers. Int. J. Astrobiol., 8 (2009) 193-206.
[15] P. I. Premović, Distal “impact” layers and global acidification of ocean water at the Cretaceous-Paleogene boundary [KPB]. Geochem. Intern., 49 (2011) 55-65.
[16] O. B. Toon, J. B. Pollack, T. P. Ackermant, R. P. Turco, C. P. McKay, M. S. Liu, Evolution of an impactgenerated dust cloud and its effects on the atmosphere. Geol. Soc. Am. Spec. Paper, 190 (1982) 187-200.
[17] R. Tagle, J. Berlin, A database of chondrite analyses including platinum group elements, Ni, Co, Au, and Cr: Implications for the identification of chondritic projectiles. Meteor. & Planet. Sci., 43 (2008) 541-559.
[18] S. Donaldson, A. R. Hildebrand, The global fluence of iridium at the Cretaceous–Tertiary boundary. Meteor. & Planet. Sci., 36 (2001) A50.
[19] B. Schmitz, Origin of microlayering in worldwide distributed Ir-rich marine Cretaceous/Tertiary boundary clays. Geology, 16 (1988) 1068-1072.
[20] F. T. Kyte, B. F. Bohor, D. M. Triplehorn, B. Schmitz, Comments and replies on" Origin of micro-layering in worldwide distributed Ir-rich marine Cretaceous/Tertiary boundary clays". Geology, 18 (1990) 87-94.
[21] E. Pierazzo, A. N. Hahmann, L. C. Sloan, Chicxulub and climate: effects of stratospheric injec-tions of impact-produced S-bearing gases. Astrobiology, 3 (2003) 99-118.
[22] J. Morgan, C. Lana, P. A. Kearsley, B. Coles, C. Belcher, S. Montanari, E. Diaz-Martinez, A. Bar-bosa, V. Neumann, Analyses of shocked quartz at the global K-T boundary indicate an origin from a single, high-angle, oblique impact at Chicxulub. Earth Planetary Science Letters, 251 (2006) 264–279.
[23] O.A. Korchagin,V.A.Tsel.movich, Cosmic particles (micrometeorites) and nanospheres from the Cretaceous-Paleogene (K/T) boundary clay layer at the Stevns Klint Section, Denmark. Dokl. Earth Sci., 437(2011) 449-454.
[24] P. I. Premović, N. R. Đorđević, M. S. Miljković, Silver and Silver Microparticles of the Cretaceous-Paleogene Boundary Sediment of Fish Clay (Hojerup, Stevns Klint, Denmark). Geochem. Intern., 54 (2016) 378-385.
[25] E. Robin, L. Froget, C. Jehanno, R. Rocchia, Evidence for a K/T impact event in the Pacific Ocean. Nature, 363 (1993) 615-617.
[26] F. T. Kyte, Tracers of the extraterrestrial component in sediments and inferences for Earth's accretion history. Geol. Soc. Am. Spec. Paper, 356 (2002) 21-38.
[27] A. M. Vickery, H. J. Melosh, Atmospheric erosion and impactor retention in large impacts: Appli-cation to mass extinctions. Geol. Soc. Am. Spec. Paper, 247 (1990) 289-300.
[28] N. Artemieva, J. Morgan, Modeling the formation of the K–Pg boundary layer. Icarus 201 (2009) 768–780.
[29] S. G. Love, D. E. Brownlee, A direct measurement of the terrestrial mass accretion of cosmic dust. Science, 262 (1993) 550-553.
[30] C. S. Gardner, A. Y. Liu, D. R. Marsh, W. Feng, J. M. C. Plane, Inferring the global cosmic dust influx to the Earth’s atmosphere from lidar observations of the vertical flux of mesospheric Na. J. Ge-ophys. Res. Space Physics, 119 (2014) 7870-7879.