AMOUNT OF EXTRATERRESTRIAL MATERIAL IN THE K/T BOUNDARY SEDIMENTS.

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Introduction. The global mass of extraterrestrial material at the K/T boundary was estimated (1) from amount of Ir with provided that Ir came into the K/T sediments with fallout spread evenly over the Earth. However the studied K/T sections are clear distinct each other in Ir content (2). It suggests that the surface and stratigraphical Ir distributions should be controlled by processes of lateral transport and sedimentation but not deposition of the fallout from the atmosphere. In the paper we consider constraints on the global Ir mass and the element fractionation at the K/T boundary taking into account the effects of these processes.

Surface distribution of Ir. The lateral transport must lead to redistribution of Ir on the Earth surface. In this case the global Ir mass, M, can be expressed as

$$M = \int_0^Z x(s)ds = \sum_0^5 x_j \Delta s_j = \bar{x}\cdot Z \qquad (1)$$

where s is a square with a surface density of Ir, x, Z is the Earth square, and $\bar{x}$ is a mean value of x. The main problem is how to find $\bar{x}$ because the population of the measured values of x is not representative for the Earth surface. Obviously for estimation of $\bar{x}$ we need to establish a type of the x distribution, s = f(x), and to show that the measured data are representative in some part of the distribution. As a first step it can be suggested that the measured data are representative only for areas of sedimentation (70% of the Earth surface), while x = 0 on the continents. Then using literature data (2-5) and the corrected x values of 580, 340 and 44 (ng/cm) for the Turkmenia SM4, MB5 and MB3 sections, respectively (6), we found $M = 3.5\cdot10^{20} \pm 2\cdot10^{20}$ (2σ) ng. In general case the law of the x distribution should permit that x = 0 at s ≠ 0, and x→∞ at s→0. The exponential distribution seems to be most available because it allows s to be high at x = 0. The χ^2 test of the observed x distribution shows that it can be approximated by the exponential law at x > 20-30 ng/cm . Then using the features of the exponential distribution one can find that

$$s_y = \int_0^\infty h\cdot\exp(-hx)dx = \exp(-hy) \qquad (2)$$

$$\bar{x}_y = \exp(hy)\cdot\int_y^\infty xh\cdot\exp(-hx)dx = y + 1/h \qquad (3)$$

$$M = Z\cdot\int_0^\infty x\cdot h\cdot\exp(-hx)dx = 1/h \qquad (4)$$

where s_y is a quota of the earth surface with x > y, $\bar{x}_y$ is a mean value at x > y, and h is a parameter. The $\bar{x}_y$ value can be estimated from the measured data on x. It is 120 ± 60 (2σ) ng/cm² at x > 30 ng/cm . Substituting this value, the Eqns.(3) and (4) yield $M = 4.6\cdot10^{20}$ ng with the 2σ interval of $(1.6-7.6)\cdot10^{20}$ ng. Then using Eqn. (2) a quota of the Earth surface containing > 30 ng/cm² of Ir can be computed to be 0.72 with the 2σ interval of 0.37-0.82.

Stratigraphical distribution of Ir. The measured values of x are found by integration of Ir concentrations, C, through the stratigraphical sequence. Hence it is important to find a theoretical expression of the integral for estimation of the global Ir mass. As a first approximation it can be suggested that a rate of Ir sedimentation is a linear function from Ir content in a basin of sedimentation, i.e. deposition of Ir is controlled by first order kinetics. Then assuming that time, t, can be expressed as h/v, the stratigraphical Ir distribution is given by

$$C = C_0 \exp(-h/vk) \qquad (5)$$

where h is distance (thickness) from the K/T boundary, v = dh/dt is a rate of sedimentation, C_0 is Ir content at the K/T boundary at h = 0 or t = 0, and k is a parameter similar to a residence time. In fact the observed stratigraphical distribution of Ir (5-8) follows roughly Eqn. (5). The deviations from the law can be resulted from secondary processes, i.e. bioturbation and diffusion, or a change of v and k during sedimentation. Integration of C leads to the statement

$$x = d\cdot\int_0^\infty C(h)dh = d\cdot v\cdot k\cdot C_0 \qquad (6)$$

where d is a density of sediments. Finally taking into account Eqns. (1) and (5) the global Ir mass can be expressed as

$$M = d\cdot v\cdot k\cdot C_0\cdot s_B = U\cdot k\cdot C_0 = d\cdot C_0\cdot s_B h/(\ln C_0 - \ln C) \qquad (7)$$

where $s_B = 0.7Z$ is a total square of basins of sedimentation, $U = s_B\cdot dm/dt$ is a global rate of sedimentation, and others are global mean values of parameters used in Eqns. (5) and (6). It is important that the global Ir mass can be expressed to be dependent on the parameters of Ir stratigraphy only (C and h). Obviously the thickness (h) of Ir anomaly should not be usually less than 5 and higher than 30 cm when C = 0.1 ppb. It leads to $M = 7\cdot10^{19} - 10^{21}$ ng of Ir, if $C_0 = 15.5 \pm 8.2$ (2σ) ppb as a mean value of the maximum Ir contents in the K/T sediments. This M value is

compatible with the statistical estimations. Then using the statistical estimation of M ($4.6 \cdot 10^{20}$ ng) and Eqn.(7) one can calculate the k value to be 1500 y with the 2σ interval of 340-5200 y at the rate of sedimentation, U, equal to the erosion rate of $2 \cdot 10^{16}$ ga^{-1} (9). It suggests that the half amount of Ir should be deposited by usual geological processes for 1000 y (240-3600 y).

Element fractionation. When written for other elements Eqn. (5) shows that element fractionation would take place during sedimentation, if the elements had different values of k. In fact using Eqns. (5) and (7) and assuming that the K/T bolid has chondritic composition at $5 \cdot 10^{20}$ ng of Ir, a rate of sedimentation is $5 \cdot 10^{-3}$ cm/y, and the k values are equal to the residence times of the elements in the ocean, one can calculate the element profiles at the K/T boundary. It is of interest that $1/C_0$ and h (thickness of element anomaly at $C/C_0 = 0.5$) tend to be higher in the order Fe, Co, Sc, Ti, Cu, Zn, Ni, Cr, V, As, Sb, Au, Re. Moreover the C_0 values of Fe, Co, Sc and Ti ($k < 100$ y) are higher than the chondritic contents of the elements, and their h values are less than 1 cm. In contrast the C_0 values of As, Sb, Au and Re ($k > 10^4$ y) are very low, and their h values more than 70 cm. Hence anomaleous contents of such elements could not be identified at the K/T boundary. However so heavy element fractionation is not observed in the K/T sediments. It suggests that the element k values were not very different during the K/T sedimentation. To estimate the real K/T values of k one can receive from Eqns. (5) and (7) written for any pairs of elements (for example, for Ir and Ni) that

$$C_{Ni} = (C_0^{Ir})^{(1-b)} \cdot b \cdot (W_{Ni}/W_{Ir}) \cdot (C_{Ir})^b \qquad (8)$$

where $b = k_{Ir}/k_{Ni}$, W_{Ir}, W_{Ni}, C_{Ir} and C_{Ni} are the Ir and Ni contents reduced for terrestrial background in the K/T bolid and the K/T sediments, respectively. Then using the K/T element concentrations (1,4,5,10-15) normalized to the Al content, it can be shown by regression analysis that the k values of Os, Pd, Pt, Re, Fe, Ni, Co, Cr, V, Ti, Cu, As and Sb are mostly in the range of 1000-3000 y, if $k_{Ir} = 1500$y. In contrast the residence time of the elements in the ocean vary 7 orders of magnitude (9). The difference suggests that the K/T bolid material was deposited without significant fractionation, and the composition of the K/T sediments is controlled mainly by simple mixing of the extraterrestrial and crust components. The regression analysis based on equations like (8) allows us to estimate the element concentrations in the K/T object. When computed at 500 ppb of Ir they are: Fe 22, Ti .83, Ni 0.5 (wt.%); Cr 2800, Co 750, V 637, Cu 400, As 200, Sb 45, Pt 1.7, Pd 1.2 (ppm); Au 412, Os 425, Re 260 (ppb). These concentrations are close to those in chondrites except for Ti, Sb, As, Re and V which could come into the K/T sediments from terrestrial sources during formation of the K/T anomaly. However the similar element pattern at other concentrations can be in Fe-FeS bodies or a cometary material.

Conclusion. The global amount of Ir estimated by the different methods resides in the range of 10^{20} - 10^{21} ng, the mean to be about $5 \cdot 10^{20}$ ng. We do not need the fallout scenario to calculate the Ir mass. The observed element concentrations, their surface and stratigraphical distributions at the K/T boundary can be explained by usual processes of sedimentation and lateral transport. During the processes the element fractionation was not significant. The chemistry of the K/T sediments is controlled mostly by mixing of the extraterrestrial and crust components. The cosmic material can be considered to be chondritic component, but cometary or Fe-FeS components are also possible. The mass of the chondritic K/T bolid is in the range of $2 \cdot 10^{17}$ - $2 \cdot 10^{18}$ g, the mean to be 10^{18} g.

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