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Aerial and surface effects of cosmic airbursts: recent events and geological archives

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For long questioned as a reality of the Earth history, impact hazards generated by low-altitude airbursts from hypervelocity asteroid impacts are now speculated to occur frequently. However, except the 2000 km^2 of blasted forest left by the Tunguska explosion in central Siberia, scarcity of observational data constraints our view on effects of the high-temperature debris jet that colliders are expected to generate by entry in the Earth atmosphere at hypersonic speed. In addition, controversies on hypothetical traces of past cosmic airbursts have up so far weakened the interest of geological archives to correctly estimate the threat that they would exert on ecosystems and human populations in a near future. We present a refined understanding on effects of cosmic airbursts that we have achieved by comparing analytical data from recent cosmic events, laboratory experiments and past records. The first ones correspond to the 1864 May 14^{th} low altitude disintegration of the Orgueil carbonaceous chondrite, the 1908 June 30^{th} high altitude Tunguska airburst, the 2008 January 25^{th} and the 2011 August 2^{nd} high altitude meteor airbursts in Southern France. The experimental data refer to a series of collision from 4.1 to 7.9 km/s by a steel projectile on to a 40 mm thick aluminium target which have been performed at the CEA Gramat Center (France) with the hypervelocity Persephone light-gas gun. The geological data comprise : (1) Zamanshin, Lybian, Egyptian Dakhleh and Tasmanian Darwin impact glass and vesicular breccia of the Australian Henbury crater field; (2) anomalous debris layers associated : at 4 kyr BP and 125 kyr BP in Adelie land (Antarctica) marine cores (MD03-2601 and (MD03-2603); at 4 kyr BP, 11.8 kyr BP and 0.8 Ma from flood plain, karstic, coastal deposits, lake and marine cores from West France, West Asia, South China, Sumatra and Java (Indonesia). The analytical data consist of an in situ characterisation at meso to nano scales of mineral, metal and carbonaceous phases using Environmental SEM with EDS, Raman and FTIR micro-spectrometry, XRD, AFM, TEM, Tof-SIMS, nano-indentation, elemental and isotope analyses. All the studied materials share in common the occurrence of carbon-linked metals (CM) in the form of blebs, spherules, films, and of nano-structured composite polymers (NSCP) with distinctive elastic and plastic properties. Based on the Persephone experiments, these carbonaceous compounds are assumed to be specific products from successive reactions in the thermal plasma that formed by mixing of the high-pressure hydrogen gas and the vaporized phases from the projectile, part of the target and the projectile holder (polycarbonate and polystyrene): (1) coating deposition under transient high pressure and transient heating traced by the imbrication at microscales of graphite/graphene-like shocked graphite for the CM; then, (2) coagulation by ballistic collisions between hydrocarbon gas molecules and nano-sized inclusions for the NSCP. The recent events show NSCP of low C^{14} activity, close imbrication of NSCP and CM to eclectic debris from industrial activities, volcanism, biomass burning and marine aerosols, and association of the later to a thin nano-structured polymer film at the ground. This indicates surface sputtering of a cold dusty plasma that condensed by mixing of the high-pressure and coagulation products, which formed in the thermal plasma of the airburst, with nearly intact atmospheric aerosols. The geological

situations share in common the close imbrication of NSCP, CM and intact debris, and their association in terrestrial records with a thin nano-structured polymer film coating the soil surface and the vegetation. Differences in the nano-structure, thermal and mechanical properties of the NSCP, and in size distribution and composition of their nano-inclusions reveal the major effects of the dust atmospheric-loading at the exact time of airburst on production processes of new compounds from the thermal and dusty plasmas. For example, the abundant NSCP of low C^{14} activity with metal-doped lignite-like compounds, volcanic components and marine aerosols, which have been traced at ca. 4 kyr BP through vast regions, is shown to result from production by airbursts of hydrocarbon species from methane emission of deep origin, during a period of intense cyclonic and volcanic activities. The recent events have provided diagnostic criteria to interpret the anomalous debris layers from geological situations, with their joint occurrence of NSCP and CM markers, to have instantaneously accumulated from erratic violent hailstorms and heavy rains, in response to the sudden atmospheric loading by carbonaceous aerosols. The similar thermal and mechanical properties of the NSCP, that synthetized from the thermal plasma in experiments, with the ones from recent airbursts or from geological situations of various ages, are shown to result from their singular nano-structure and presence of antioxidant nano-inclusions. These characteristics would explain their chemical and biological inertness, resistance to solar radiation and hydrophobicity. Thus, the data presented here suggest that cosmic airbursts have the potential to suddenly initiate a complex suite of environmental changes which would operate at their own timing: (1) atmosphere instability by competing nucleation and condensation processes in response to dust emission, particularly effects of photocatalyzers - e.g. nano-sized TiO^2 and soot - on rapid changes of UV radiation; (2) land-surface instability by more common extreme storms and enhanced sensitivity to erosion, siltation, firing, ice and snow melt, due to the sudden production of hydrophobic and pyrogenic organic compounds, and of dark impurities with lower albedo and greatest irradiance. Anthropogenic activities, with the marked increase of UV-sensitive atmospheric aerosols, might have created similar conditions to the ones of past dusty episodes that seem to have initiated the most severe effects of cosmic airbursts. The potential of cosmic airbursts for massive delivery of nano-sized particles, particularly heavy metals and oxydant components, might represent the most serious threat for the living world and for human health.