EVIDENCE FOR TRANSHEMISPHERIC DISPERSION OF AN EJECTA DEBRIS-JET BY A HIGH-VELOCITY TANGENTIAL IMPACT ALONG THE AUSTRAL-INDIAN OCEAN AT 4 KYR BP. M.-A. Courty[1], B. Deniaux[1], G. Cortese[2], A. Crisci[3], X. Crosta[4], M. Fedoroff[5], F. Guichard[6], K. Grice[7], P. Greenwood[8], F. Lavigne[9], M. Mermoux[10], D. C. Smith[11], B. Peucker-Ehrenbrink[12], F. Poitrasson[13], R. Poreda[14], G. Ravizza[15], M. H. Thiemens[16], U. Schärer[17], A. Shukolyukov[18], M. Walls[19] and P. Wassmer[9]. [1]UMR 5198, CERP 66720 Tautavel, FR, courty@tautavel.univ-perp.fr. [2] Alfred Wegener Inst., Columbusstrasse POB 120161 27515 Bremerhaven. DEU. [3]CMTC, 1260, rue de la piscine - BP 75, 38402 Saint Martin d'Hères FR. [4]UMR-CNRS 5805 EPOC, Av. Facultés, Univ. Bordeaux I, 33405 Talence FR. [5]ENSCP, 11 rue Pierre et Marie Curie, 75231 Paris, FR. [6]CNRS-CEA-UVSQ, Bât. 12, Ave de la terrasse, 91198 Gif/Yvette, FRA. [7]Curtin Univ. Technology, Perth, WA, 6845, AU. [8]University of WA, 35 Stirling Hwy, Crawley, 6009, AU. [9]UMR 8591 , Univ. Paris 1, Meudon, FR. [10]LEPMI-ENSEEG, Univ. Grenoble, 38042 Saint-Martin d'Hères, France. [11]MNHN-minéralogie & CNRS UMR7072 Univ. Paris VI, 61 rue Buffon, 75005 Paris, FRA. [12]Department of Marine Chemistry and Geochemistry,Woods Hole MA , USA. [13]CNRS- UPS- IRD, 14-16, avenue Edouard Belin, 31400 Toulouse, FRA. [14]Dept. of Earth and Environmental Sciences, 227 Hutchison Hall, University of Rochester, Rochester, NY 14627, USA. [15]Dept. of Geology & Geophysics, SOEST, University of Hawaii, Manoa, USA. [16]Chemistry and Biochemistry, Univ. California, San Diego 92093, USA. [17]Geochronologie-Geosciences AZUR, Univ. de Nice-Sophia Antipolis, Parc Valrose 06108 Nice, FRANCE. [18]Scripps Inst. Oceanography, Univ. California, San Diego, USA. [19]Univ. Paris XI, Bât. 510, Orsay, FRA.

Introduction: In the absence of recent analogues and of real-scale experiments, empirical data on young, small impact events are critical for better understanding the complexity of cratering processes on Earth. Even if not severely biased by erosion or weathering, their fingerprints are often ambiguous in contrast to the major impacts. This difficulty is illustrated by our search on the 4 kyr BP impact that has long been confused with a climate or a volcanic event [1]. Coherent evidence for meteoritic materials, shock-melting of marine sediments and sea-water vaporisation now help to elucidate the series of impact-processes in the southern hemisphere and their global effects at 4 kyr BP.

Data processing and analytical methods. The spatial pattern of the 4 kyr BP ejecta emplacement with its two distinctive proximal and distal components has been identified from deep-sea records across the two hemispheres. Its inter-regional to local variability has been investigated by random tests in various continental settings and soil surveys in western Europe, the Middle East, Asia & South America. High resolution stratigraphical records and refined chronology of the 4 kyr BP event have allowed determination of the timing of the ejecta-emplacement and the related effects on seas, coasts, lands, and humans. The microfacies and petrography of the 4 kyr BP signal were thoroughly characterized using optical and environmental electron microscopy techniques (SEM/EDX). The organic and mineral markers were defined using various techniques: XRD, Raman micro-spectrometry, WDS, HRTEM, EELS, GC-IR-MS, isotopes (C, O, S, Pb, Fe, Cr), noble gas measurement.

Results. The 4 kyr BP signal common to all marine and continental archives is defined by a unique suite of exotic micro-debris formed of filaments, flakes, spherules, beads, vesicular glass and angular clasts. It also comprises fist-sized to large debris consisting of layered tektites, pillow-like slabs, highly vesiculated glazed glassy materials and one 10 kg vesicular block of metal-rich basaltic breccia (~3). The coarse end-member is erratically distributed throughout the Mediterranean basin, occurring as linear-shaped small concentrations (~500 m^2) over a burnt soil surface and mixed with carbonised plant material. The vesiculated glazed blocks (VGB) are morphologically similar to previously reported impact-generated glasses debated to trace the proximal dispersion of a cratering event or a large aerial burst [2, 3, 4]. The VGB display a close juxtaposition of flow-textured glass, strongly to weakly heated sedimentary clasts, partly devitrified glass and basaltic microbreccia with vesicles filled by spherules, metallic mounds and fibrous filaments. This phase heterogeneity is similar to the compositional range of the 4 kyr BP micro-debris. The synchronous deposition of the coarse and fine end-members of the 4 kyr BP signal is supported by the increased concentration of micro-debris around glazed blocks at a few metres scale. Their genetic filiation is established from the occurrence within distant sites of similar organic, mineral and metallic markers with unique characteristics. The nearly intact clasts derive from fined-grained and clast-supported unconsolidated materials with sedimentary, volcanic, igneous and metamorphic components. Their marine origin from the southern Austral latitudes is established from the occurrence of an Antarctic micro-faunal assemblage (heated diatoms and radiolarian) in the marine clasts.

Quartz showing pdf, diaplectic transformation and ballen-pattern, and amorphised dropped-shape zircons with structural anomaly provide strong shock metamorphic indicators. They are only encountered in the flow glass domains of the VGB. The transition from intensely fractured quartz grains and partly-amorphised carbonate clasts to the blue flow-glass indicates high pressure shock-dispersion of the fine-grained sediments. The role of a reduced metal-rich carbonaceous phase on shock-melting is suggested by the concentration of CVD-like diamonds associated to hexagonal graphite and hydrocarbons, euhedral iron phosphide (barringerite), iron sulphide and metal blebs (Ni, Cu, Zn, Fe) in the blue flow-glass. The different types of basaltic breccia share in common a complex imbrication of crystallised and glassy phases with common Mg-Cr-Si spinel and various unusual minerals, i.e. silicophosphates, Na-Ca phosphate (buchwaldite). They always contain metal segregation often as spherical blebs, euhedral particles of diamond and graphite, and, volatile-rich hydrocarbons within the crystals and in the interstitial glass. A similar metal/diamond/graphite/hydrocarbon association is also identified in the 4 kyr BP micro-debris as clusters of nano-sized diamonds at the surface and within C-rich vesicular forsterite, as hexagonal graphite, C-rich metallic splash (Fe-Cr, Fe-Cr-Ni, Cr film) at the debris surface, and graphite-associated metallic Fe segregation. Green carbonaceous fibres with chaoite nano-platelets are always encountered, often coating the micro-debris and vesicles of the coarse ones.

The similar negative ΔO17 anomaly (-0.197 o/oo) obtained in three basaltic breccia from distant regions is completely consistent with either ureilites or carbonaceous chondrites [5]. The high carbon content, the type of diamond and graphite inclusions [6]. and the mass independent fractionation anomaly of the carbon-associated sulphur are in agreement with the ureilite group. The diversity and complexity of the petrographical assemblage of the basaltic breccia (blocks and related small fragments) would designate a heterogenous impact breccia derived from an ureilite-type precursor.

Discussion. The identification of distinctive terrestrial and meteoritic components can be used to interpret the spatial variability of the 4 kyr BP signal with respect to impact processes and ejecta emplacement. The proximal emplacement of the impact-ejecta is defined in the Austral ocean (Adelie Land and Kerguelen Plateau) by the thickest 4 kyr BP signal (7 to 12 m deposits in deep-sea cores). The abundant re-melted meteoritic components, complex grains resulting from shock-melting of the meteoritic and terrestrial components, flow-glass, carbon-injected shocked quartz, and heated marine microfossils (all of local origin with metal splash), provide the characteristics of crater ejecta from an oceanic impact affecting marine sediments on the continental plateau. The range of target materials would match clastic sediments formerly derived from the Antarctic mountains. It synchrony with severe disruption of the north-eastern Kerguelen plateau (up to 50° S) would trace the regional effects of the impact-shock wave. A second type of proximal impact-ejecta seems to correspond to the thinner 4 kyr BP signal in the inter tropical zone (<1 m). Its erratic distribution, abundance of meteoritic components with sea-salt incrustation, metal-splashed planktonic faunal assemblage coming both from Antarctic and subtropical waters, and vitrous carbon (GCF type) with melted marine materials would derive from vaporisation of sea water and of the volatile components of the meteoritic breccia. Its linkage to a unique wild-fire on the Reunion Island and to a giant tsunami along the north-west Sumatra coast would have respectively expressed effects of the fireball and the shock wave generated along coasts by the high velocity propagation of the ejecta along a low-angle impact trajectory. In contrast, the erratic fallout of blocks and dispersed debris throughout the northern hemisphere clearly represent the distal ejecta emplacement. Their preferential occurrence in the northern Mediterranean basin would potentially match the expected concentration of distal ejecta at the antipode [7]. Evidence for splashed ejecta-melt synchronous to thermal effects at the host surface indicate a long distance transport of high-velocity hot fragments of the ureilitic breccia with entrained target materials. The occurrence of marine micro-fossils both derived from antarctic and subtropical waters in vesicles of the blocks support their contact with vaporized sea-water whilst being propelled in the ejecta debris-jet. The comprehensive record of the 4 kyr BP event seems to match a tangential high velocity impact by a highly disrupted and evaporated projectile [8] that possibly produced a series of shallow craters on the continental plateau and lands along its long trajectory. The similar age, location and vesicular glass with CVD-like diamond and probable Mg-Cr-Si spinel [9] suggests a plausible correlation of the 4 kyr BP impact with the Henbuy crater field.

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