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News & Views

The selection of a primary marker for the Anthropocene

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Since *Homo sapiens* appeared, the planet has experienced continuing environmental changes [1,2]. In 2000, Crutzen and Stoermer [3] systematically analysed the global changes caused by human activity over the previous 300 years and suggested that the Holocene epoch ended in the 1750s and a new geological age, the Anthropocene, began. Afterwards, the Anthropocene drew a lot of attention from both scientific community and the general public. The recognition and placement of the Anthropocene/Holocene boundary has been a subject of heated debates over the past two decades. At the 35th International Geological Congress (2016; IGC), the Anthropocene Working Group (AWG) recommended the Anthropocene to be formalised with an epoch rank, with the 1950s as its lower boundary [4]. Recently, the AWG voted this recommendation and they plan to submit this proposal to the International Commission on Stratigraphy (ICS) by 2021. Although a lot of imprints found in stratigraphic sections support this view, some studies have also suggested the early Holocene, the 16th century, or the late 18th century as the starting date of Anthropocene.

Like other geological epochs, the Anthropocene has to be formally defined by a Global Boundary Stratotype Section and Point (GSSP). A suitable primary marker is therefore important for determining a robust GSSP. Proposed markers include presence of novel materials (such as plastics and SCPs), geochemical materials (such as heavy metal, radiogenic, and $NO_3^- + \delta^{15}N$), and changes in biological species in the stratigraphic record. To date, $^{239+240}Pu$, spheroidal carbonaceous particles (SCPs), plastics, and $NO_3^- + \delta^{15}N$ are among the most widely discussed markers. According to the selection criteria of GSSP, we suggest the primary marker should be related to human activities, well preserved, and globally synchronized and distributed.

The Anthropogenic nuclides in the environment are mainly from nuclear-weapon tests. The nuclear-weapon tests started from 1945 and significantly increased during the 1950s and the early 1960s. The test sites have a wide distribution around the world, and the nuclides fallout from these tests have been widely distributed by the atmospheric circulation. We consider $^{239+240}Pu$ as a superior primary marker compared to other nuclides because of their long half-lives (24,110 years for ^{239}Pu, and 6563 years for ^{240}Pu). Both ice cores and corals are reliable archives of $^{239+240}Pu$. The $^{239+240}Pu$ records in six ice-cores from different latitudes all showed a peak value in the 1950s (Fig. 1) [5–9], which could also be observed in coral profiles [10,11]. It should be noted that Pu may be migratory and transferrable in tree rings and water environments as well.

SCPs are by-products of high-temperature fossil-fuel combustion (>1000 °C), which are mainly associated with industrial development [12]. SCPs first appeared in the environment after the Industrial Revolution in the late 18th century. Their concentrations increased sharply after WWII as a result of increasing demand for electricity and the rising consumption of fossil fuels. In the late 20th century, the implementation of clean-air legislation and improvements in particle arrestor technology contributed to a reduction of SCPs. Many geological achieves like ice cores, peatlands, lake, and marine sediments have recorded the SCPs variations. However, the asynchronous industrial development made the regional differences of variations in SCPs. For example, a rapid increase of SCPs in the Euro-American region occurred during 1950s–1960s, about 10 years earlier than that in the African-Asian region.

Plastics are one of the novel materials that appeared in 1907. The light weight, flexibility, and low prices of plastics have resulted in their wide applications in industry, agriculture, building construction, etc. The global plastic production have significantly increased since the 1950s. At the same time, increasing production and disposal have caused serious white pollution in the world. Global water bodies are important gathering places for plastic. Also, lower temperature and lack of UV light in the deep sea allow microplastics to be preserved in the seabed for centuries to millennia [13]. Consequently, presence of plastics in geological record may have the potential to be considered as a primary marker. Nevertheless, few studies of plastic sedimentary profiles have been conducted. To verify plastics as a possible Anthropocene marker, more research on sedimentary profiles is required.

The use of fossil fuels and nitrogen fertilizer have profoundly affected the global nitrogen cycle, which could be recorded in

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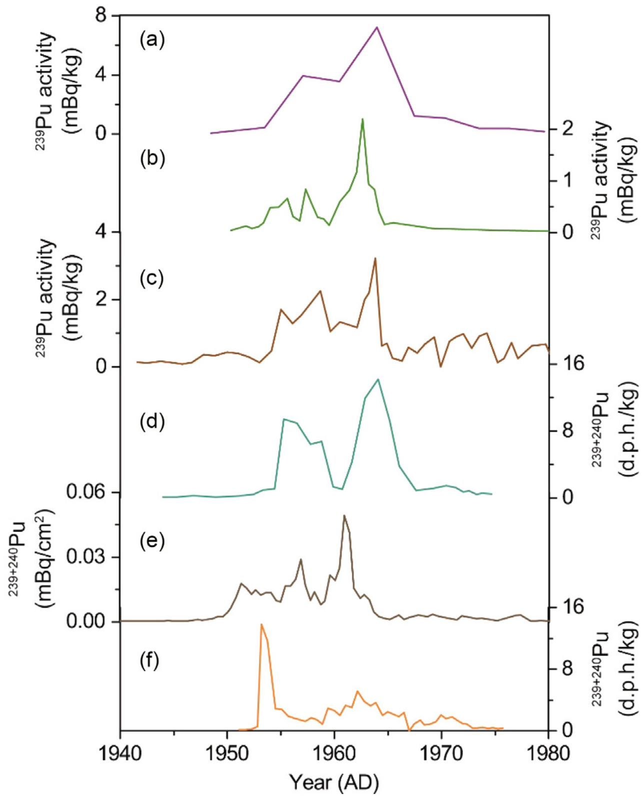

Fig. 1. Ice-core $^{239+240}Pu$ and ^{239}Pu records. The ice cores were collected from (a) Belukha glacier (49.81°N, 86.58°E) in Altai Mountains [5], (b) Dome Du Gounter (45.84°N, 6.84°E) [6] and (c) Colle Gnifetti (45.93°N, 7.88°E) [6] in the Alpine Mountains; (d) South Dome (60.53°N, 44.58°W) [8] and (e) Ellesmere Island (80.7°N, 73.1°W) [9] in the Arctic; (f) Ross Ice Shelf (82.37°S, 168.67°W) [7] in the Antarctic.

stratigraphic environments reflected by NO_3^- or $\delta^{15}N$ variations. A wide range of NO_3^- and $\delta^{15}N$ records have been studied but not all of the variations are controlled by anthropogenic impacts. Because of nitrate photolysis, some nitrates may be lost and redistributed, resulting in post-deposition changes in nitrate or $\delta^{15}N$ records, particularly in low-accumulation sites [14]. Variations in $\delta^{15}N$ values in aquatic sediments could be influenced by climate change and biological activities. Tree rings may also be influenced by climate change [15]. In addition, as nitrogen is an essential nutrient for tree growth, plant physiology could also affect the tree-ring nitrogen records.

In addition to the four aforementioned potential markers, heavy metals like lead are also significantly influenced by anthropogenic activities. Mining and smelting, coal burning, and the combustion of leaded gasoline caused increasing lead pollution in the environment. Pb concentration records from different regions reflect regional industrialisation, which commenced in Western Europe and eventually spread globally. Therefore, Pb concentrations in global stratigraphic environment display an asynchronous temporal pattern, appearing ~20 years earlier in the Euro-American region than the African-Asian region.

In summary, all the aforementioned markers have long-term preservation potential and widespread distribution, but not all have globally synchronized variations. $^{239+240}Pu$ is perhaps the most suitable primary marker owing to its globally synchronous peak in the 1950s. Regional differences of SCPs and Pb concentrations in geological facies preclude their use as primary markers, but they can be secondary markers. NO_3^- and $\delta^{15}N$ are not appropriate markers because they could be significantly influenced by climate change. Further research on plastics in sediments is required to assess their applicability as an Anthropocene marker.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.scib.2019.09.019.

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