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Obituary for Paul J. Crutzen

Johan Rockström

Stockholm Resilience Centre, Stockholm, Sweden

Editorial

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Author for correspondence:
Johan Rockström,
E-mail: Johan.Rockstrom@pik-potsdam.de

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If we are forced to pick the most significant scientific message to humanity over the past decade, the insight that we have entered a new geological epoch, the Anthropocene, ushered in by our own species, is certainly among the top candidates. This insight was proposed by Paul Crutzen in the year 2000 (Crutzen & Stoermer, 2000).

The Anthropocene is defined by the mounting evidence that humanity, and our modern industrial metabolism, now constitutes the largest driver of change in the state of our planet (Crutzen, 2002). A mindboggling thought that with our own hands we can destabilise the entire Earth system, and thereby jeopardise the future for all people on our planet. Up until now, we have once come close to the brink, when our industrial emissions of chlorofluorocarbons (freons or CFCs) threatened to destroy Earth's protective stratosphere ozone layer. Again, Paul Crutzen was among the core group of scientists that identified this planetary threat, and contributed to disarming it (with the signing of the Montreal protocol in 1987).

So, taking stock of the Anthropocene to date, which we entered in the early 1950s, there are few to whom we should be so grateful as to Professor Paul Josef Crutzen, who sadly passed away on 28 January 2021.

Paul Crutzen was a prominent atmospheric chemist, former Director of the Atmospheric Chemistry Department at the Max Planck Institute for Chemistry in Mainz, Germany and of the Atmospheric Chemistry Division at the National Center for Atmospheric Research in Boulder, USA. As a young scientist, he completed his PhD at the Department of Meteorology at Stockholm University (supervised by Professor Bert Bolin, who established the IPCC), where in 1970, he discovered the important role of nitrogen oxides (NO and NO_2) in the destruction of ozone (O_3) in the stratosphere, and identified their biosphere sources. In this way, he showed for the first time that chemicals produced at the Earth's surface actually affected the ozone layer some 25 km higher up. For his groundbreaking research showing how human activities deplete the protective ozone layer, he was awarded the Nobel Prize in Chemistry in 1995, together with Mario J. Molina and F. Sherwood Rowland. This fundamental scientific insight sparked a hitherto unprecedented political leadership, resulting in the worldwide ban on ozone-depleting substances in the form of the Montreal Protocol. Today, more than 30 years later, we are finally observing a significant recovery of the life-protecting stratospheric ozone layer over Antarctica.

At times, Paul shared with his closest peers his assessment of how incredibly close we were to a disastrous, irreversible outcome for humanity. When industry was developing chemical refrigerants and aerosol propellants (for refrigerators, air conditioners, etc.) the choice fell on chlorine, resulting in the ozone-depleting chlorofluorocarbons (CFCs). But, according to Paul, the industry might just as well have chosen bromine as a cooling agent, since it is equally effective and readily available. Chance had it that Cl was chosen rather than Br. When the dust had finally settled on the science of how these substances deplete ozone, the world had already emitted so much that a dangerous ozone hole over Antarctica had appeared. What if the industry had selected bromine instead? A nightmarish thought, according to Paul, since on an atom by atom basis bromine is almost 100 times more dangerous for ozone than chlorine. This would certainly have meant that humanity would have experienced a disastrous ozone hole well before the scientific understanding had caught up. Without warning, humanity would have been faced with a catastrophic ozone hole everywhere during all seasons, very likely before atmospheric chemistry researchers had developed the necessary knowledge on causes, ways of measuring, and identification of potential solutions. To quote Paul from his 1995 Nobel Lecture (Crutzen, 1995): 'Noting that nobody had given any thought to the atmospheric consequences of the release of Cl or Br before 1974, I can only conclude that mankind has been extremely lucky …'.

The most important insight of this narrow escape from disaster was, according to Paul, that 'we should always be on our guard for the potential consequences of the release of new products into the environment'. Paul was an early pioneer of exercising caution in the face of low probability but potentially catastrophic risks.

During his entire life, he recognised with extraordinary clarity and humility the need for us humans to be careful with the Earth system. When we started the research on developing the planetary boundaries framework in 2007 (Rockström et al., 2009), Paul was actively involved, arguing not only for the need to recognise stratospheric ozone as one of the planetary

boundaries, but also strongly reminding us of the close biophysical and geochemical interactions between our living biosphere and the abiotic systems such as the atmosphere and stratosphere.

When John Schellnhuber organised the first Nobel Symposium on Global Sustainability in Potsdam in 2007 (hosted by Chancellor Angela Merkel), Paul was among one of the most active Nobel Laureates in drafting the Nobel Cause statement, which supported the need for a scientific target – a planetary boundary for climate – of staying below 2 °C of global warming (and as we know, it took until 2015 before it was finally adopted). In 2011, I was part of organising the 3rd Nobel Symposium in Stockholm (hosted by the King of Sweden), where Paul again displayed his aura of scientific soft diplomacy and his remarkable ability to frame and win an argument. At the time, UN Secretary General Ban-Ki moon was preparing for Rio + 20 in Rio de Janeiro in 2012. He set up a High-level Panel on Global Sustainability (the UN GSP), chaired by Presidents Tarja Halonen (Finland) and Jakob Zuma (South Africa). At a critical moment in their work, they came to Stockholm and joined Paul and the 20 or so Nobel Laureates gathered at the Swedish Royal Academy of Sciences for the 3rd Nobel Symposium on Global Sustainability. Here Paul and fellow Nobel Laureates presented the evidence for the need for a new paradigm of global sustainable development, truly integrating people and planet in the Anthropocene. The result was a plan, presented at Rio + 20, which laid the groundwork for the UN Sustainable Development Goals (SDGs), in which the world adopted for the first time a plan for all countries to integrate human aspirations (eradicate poverty and hunger and enable healthy and wealthy development) with Earth system stability (on water, biodiversity, climate and oceans). Of course, we can never prove a direct causal link between Paul and the Nobel dialogue in Stockholm and the adoption of the SDGs in the UN General Assembly. However, there is no doubt in my mind, that Paul's deep thinking, his way of articulating humanity's challenges, and his authority as one of the world's most respected global change scientists helped tip the scales.

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