
Abstract ID : **282**

# Aerosols and Ancient History in Arctic Ice

## Content

Recent analytical advances enable rapid development of accurately dated aerosol records from ice cores. Coupled with state-of-the-art atmospheric aerosol transport and deposition models, such records offer the potential to use detailed, quantitative evidence from glacier ice archives to inform archaeological and historical studies.

Prior to widespread fossil fuel burning starting in the late 18th C, anthropogenic lead emissions were linked closely to silver mining and smelting, and therefore indicative of economic activity. Here we used high-depth-resolution measurements in an array of 17 ice cores, recently expanded to include records from three Greenland coastal dome cores, to develop a 3000-year record of Arctic lead pollution, providing an annually resolved proxy of European silver production extending from the Iron Age through European antiquity, the Middle Ages, and into the Modern Period. The array stretches ~2200 km west to east from 56oW to 95oE, and ~1600 km south to north from 66oN to 81oN, and so represents nearly half the Arctic.

Despite large differences in site characteristics including elevation and snowfall rate, the magnitude of change in lead pollution during the past three millennia was similar across the array, documenting exponential, 250- to 300-fold increases in Arctic lead pollution from the early Middle Ages to the 1970 industrial peak. Decadal to multi-decadal variations in deposition throughout the broad Arctic array indicate common, large-scale changes in European and later North American emissions, with historically documented mining activity in southern Europe during antiquity and northern Europe during the Middle Ages and early Modern period precisely reflected in the ice-core records.

Growth in lead pollution – and so silver production – during the Early and High Middle Ages was surprisingly robust, with comparisons to European climate records suggesting that mining and smelting activities were sensitive to climate stresses and social unrest. However, comparisons with European historical events and economic indicators, such as grain prices and tree felling rates, suggest that decadal- to century-scale changes in Arctic pollution were dominated by the impacts of plague. These included the great 2nd-C Antonine Plague and 3rd-C Plague of Cyprian during antiquity, as well as plagues during the 2nd Pandemic of the Late Middle Ages and pre-industrial Modern period.

Implementation of pollution abatement policies such as U.S. Clean Air Act of 1970 resulted in pronounced 80% declines in overall Arctic lead pollution by the end of the 20th C. Decreases in industrial emissions associated with the 1991 dissolution of the Soviet Union and economic contraction of Eastern Europe in the late 20th C likely contributed to the sharp pollution drop in the Russian Arctic as well. Even after recent ~80% declines, however, modern Arctic lead pollution remains ~60-fold higher than at the beginning of the Middle Ages.

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**Track Classi ication:** Progress in proxy development and interpretation