The study of atmospherically deposited Spheroidal Carbonaceous Particles (SCP) from the Kongsfjorden, Svalbard

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Abstract

The surface sediment samples of Kongsfjorden were analyzed for the Spheroidal Carbonaceous Particles (SCP) in an attempt to document the SCP in the environment other than previously studied inland lakes and snow and also to understand the probable source of industrial atmospheric pollution. The SCP are derived from the combustion of fossil fuels at high temperatures and are not produced naturally. They are chemically inert in both sediment and water and thus provide the indestructible record of atmospherically deposited pollutants in remote areas and anthropogenic impact on pristine environments. The SCP were recovered from different locations of the fjord and were classified according to their size range (small particles, 5-10 µm – large particles, 20-50 µm). The characterization of the spherical carbonaceous particles (shape, size, morphology, color *etc.*) was done under the light microscope. The detailed morphological features and chemical composition of SCP were studied using Scanning Electron Microscope equipped with Energy Dispersive X-Ray (SEM-EDX). The result shows that in term of a source of pollution in the area, long-range transportation is the major source of pollution but local sources cannot be ignored. This is a first attempt to study the SCP from the Kongsfjorden.

Key words: pollution, sediment, long-range transport, Arctic, SEM-EDX

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Introduction

The Spheroidal Carbonaceous Particles (SCP) were studied from the high Arctic fjord, 'Kongsfjorden' of Svalbard. The SCP are composed of elemental carbon and produced by incomplete combustion of fossil fuel. The industrial combustion of fossil fuels leads to the formation of SCP which are atmospherically transported and depos-

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ited from local to regional scale. The high carbon elemental composition of SCP renders it chemically inert to changes in water and sediment chemistry providing them high preservation potential. The characteristic porous and spheroidal structure of SCP differentiates them from other carbonaceous particles which are produced from the burning of wood, charcoal or biomass. Their size varies from 2-20 µm and occasionally they can be larger than 50 µm (Ruppel et al. 2013). SCP have been used as tracers of atmospherically deposited pollutants and their spatial distribution agreed well with pattern of sulphur and polycyclic aromatic hydrocarbons (PAHs) (Wik et Renberg 1991, Rose et Juggins 1994, Broman et al. 1990). SCP are transported to long distances and have been reported from the lake sediments, ice core and surface snow samples of Svalbard (Hicks et Isaksson 2006), lake sediments of Greenland (Bindler et al. 2001), lake and marine sediments from King George, Island Antarctic peninsula (Martins et al. 2010, Rose et al. 2012) and lake sediments of Ellesmere Island Canadian Arctic (Doubleday et al. 1995) far from the industrialized regions.

SCP have been identified as part of Black Carbon (BC) (Rupel et al. 2013). The term Black carbon (BC) was introduced by Novakov (1984) for a variety of charred substances produced by the incomplete combustion of biomass and fossil fuel (Goldberg et al. 1985). BC can be grouped into larger chars, which are aromatic residues reflecting the structure of the burned material or the nature of the burning process, and smaller particles known as soot are combustion condensates formed in the vapour phase (Novakov et al. 1984, Goldberg et al. 1985, Hedges et al. 2000, Masiello et Druffel 1998, Elmquist et al. 2006, Ruppel et al. 2013). The burning of fossil fuel has lead to rise in anthropogenic greenhouse effect and resulting radiative forcing. The radiative forcing from Black carbon on snow and ice has recently been assessed in the IPCC AR5 ([1]). This radiative forcing results in two to four times large Global Mean Surface Temperature change per unit forcing as compared to CO_2 because all the forcing energy is directly transferred to the cryosphere, generating a positive albedo feedback to climate. As a result BC related positive albedo feedback forms a significant forcing in the Arctic and other ice-covered regions.

SCP cannot directly affect the ecosystem instead they serve as carriers and medium of transport for pollutants such as PAHs. The pollutants are adsorbed to the surface of SCP (*e.g.* Wey et al. 1998, Ghosh et al. 2000) and the porosity of SCP increases the available adsorption surface rendering them suitable for transportation. Long-term monitoring and environmental proxy data from glacial ice, peat, terrestrial and marine sediments is critical in ascertaining the long-term trend of pollutant deposition as sediments provides a chronological and conformable record of atmospherically deposited pollutants. The sedimentary record of SCP is more robust and complete because it is devoid of any post-depositional chemical alteration (Rose et al. 1999).

The main objective of this paper is to study the presence of SCP in the surface sediments of Kongsfjorden, Ny-Ålesund, Svalbard and to identify the probable source. The study of SCP from varied depositional environments will provide important information on the spatial occurrence of the particles which can be temporally assessed for the Anthropocene, a period of industrialization and human-induced perturbations to the climate.

Study Area-Kongsfjorden

The Svalbard archipelago lies between 76° and 81° N and 10° and 30° E just about in the centre of the North Cape of Norway and the North Pole. Kongsfjorden is a glacial fjord located on the west coast of Svalbard which connects to Forlandssundet of the Greenland Sea (Fig. 1). It is an open fjord with the absence of sill and presence of a deep trench, due to which the fjord is directly influenced by the shelf processes. The 250 m deep trench connects the shelf to shelf break and allows the exchange of water from West Spitsbergen Current (WSC) to the Kongsfjorden (Hop et al. 2006, Svendsen et al. 2002). The fjord is 26 km long and the width ranges from about 3 km to 8 km with a maximal depth of about 400 m. The fjord is highly interconnected with neighboring water masses on the West Spitsbergen shelf; including Atlantic water (Svendsen et al. 2002).

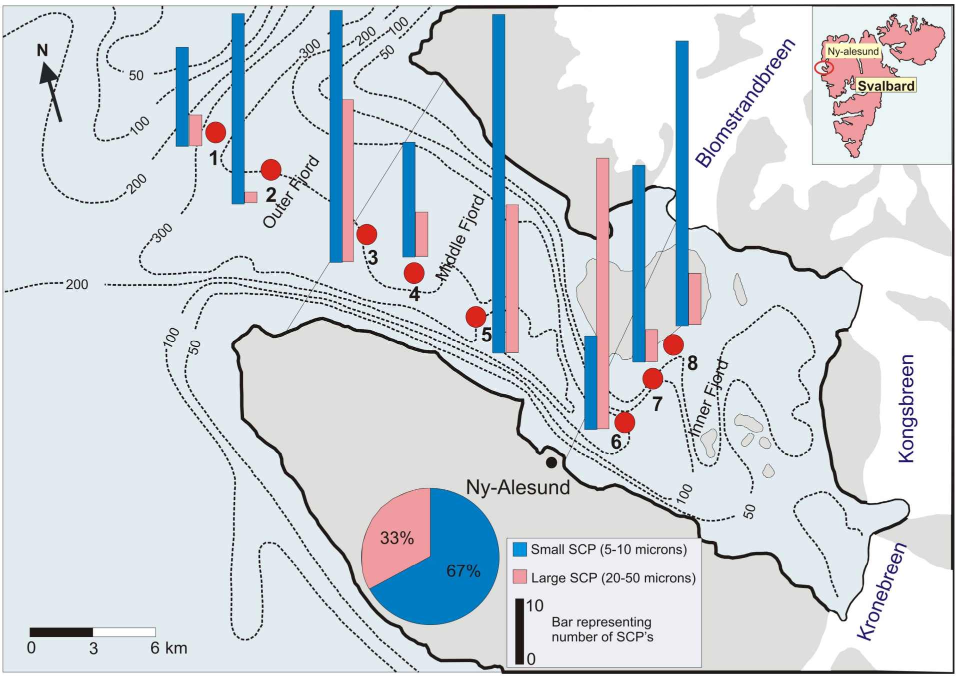

Fig. 1. Map of Kongsfjorden (modified after Piquet et al. 2010) with sampling locations and location wise SCP count data in the outer, middle and inner fjord. The pie diagram depicting the percentage of small and large SCP. Inset shows the location of Kongsfjorden at Svalbard Map.

Material and Methods

In order to fulfill the objective of the study, surface sediment samples were collected along a transect at 8 locations from the outer, middle and inner part of the Kongsfjorden, during the summer of 2012. The samples were collected using a grab sampler and extracting the top 5 cm of sediment. After collection, the samples were freeze-dried (Rose 2008) and were carefully packed in the clean environment of marine laboratory at Ny-Ålesund. The packed samples were transported back to the laboratory of National Centre for Antarctic and Ocean Research, Goa for further analyses.

The SCP were extracted following the 'sequential chemical attack' method of Rose et Juggins (1994). This method involves a sequential acid treatment of Nitric Acid (HNO3), Hydrofluoric Acid (HF), and Hydrochloric Acid (HCl) resulting in the respective removal of organic matter, siliceous material, carbonates and bicarbonates. This procedure concentrates the carbonaceous material (charcoal, soot, SCP, *etc.*), pollen grains, and a few persistent minerals as a suspension in water and removes > 99% of the initial sediment mass (Rose et Juggins 1994). A known fraction of the resulting suspension was evaporated onto a coverslip and prepared as a temporary mount slide for the light microscopy. The SCP grains were counted and studied under the light microscope on the optimal perspective level of 400X magnification. The grains with diameter 5-10 μm were categorized under the small particle size because they can be transported on a regional scale and those with diameter 20-50 μm were classed as large size grains as these have a local source and are not capable of long-range transport (Ruppel et al. 2013).

The morphology and elemental composition of SCP were analyzed through Scanning Electron Microscope equipped with EDS SEM-EDS. The extracted sediment samples were mounted on glass stubs and were coated with a thin layer of platinum using a sputter coater. Observations of the surface morphology and chemical analyses of SCP were performed using a JEOL JSM-6360LV 5500 Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray Spectroscope (EDS). The SEM was operated at an accelerating voltage of 10-20 KV for morphology analyses while 20 kV for chemical analyses and with beam current of 500 pA. EDS was performed to quantitatively analyze the concentrations of C,O, Na, Cl, Al, Si, S, Cl, K, Ca, Ti, Mn, Fe, Co, Ni, Cu, and Zn. SCP concentration was calculated in percentage.

Results

The SCP were recovered from the Kongsfjorden surface sediments collected along a transect covering the outer, middle and inner part of the fjord. The SCP were counted and grouped based on their size as small (5-10 μm) and large (20-50 μm). The categorization of SCP into small and large particles is based on the rationale that particle size less than 10 μm is capable of long-range atmospheric transport in contrast to large particles of size greater than 30 μm which are not transported to long distance and have a local source (Rose et al. 2012, Vukić et al. 2006). A total of 345 SCP particles were recovered from the collected sediment samples. The large proportion of the recovered SCP were of small size with total count of 223 particles as compared to large sized 113 particles. The sample locations 1, 2 and 3 were in the outer part of the fjord and have 15, 28, 37 respectively, small particles and 5, 2, 24 respectively large particles (Figs. 2 and 3). Middle fjord sample locations 4 and 5 have 17, 50 respectively small particles and 7, 22 respectively large particles (Figs. 2 and 3). The sample locations 6, 7 and 8 are in the inner part of the fjord and have 14, 29 and 42 respectively small particles and 40, 5 and 8 respectively large particles (Figs. 2 and 3). The overall total count data of the SCP shows that the proportion of small particles is high than large particles at all the sampled locations except location 6 (Fig. 1). The small particles are present in a high amount (67%) as compared to large particles (33%) (Fig. 1). The morphological analysis using SEM has revealed that the surface of the recovered SCP is porous, rough/irregular, convolute and layered type (Fig. 4). The obtained X-ray spectra show that Carbon is the main constituent of the recovered SCP (Fig. 4).

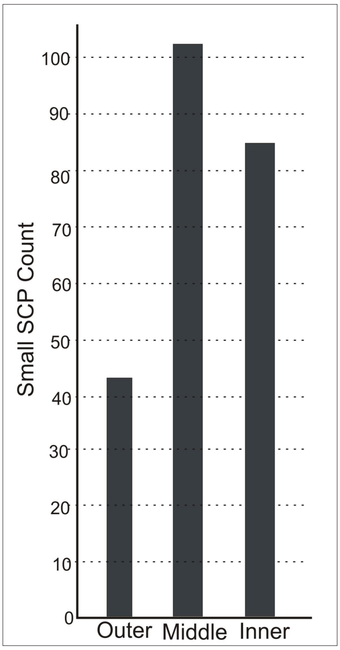

Fig. 2. The counts of small SCP in the outer, middle and inner part of the fjord.

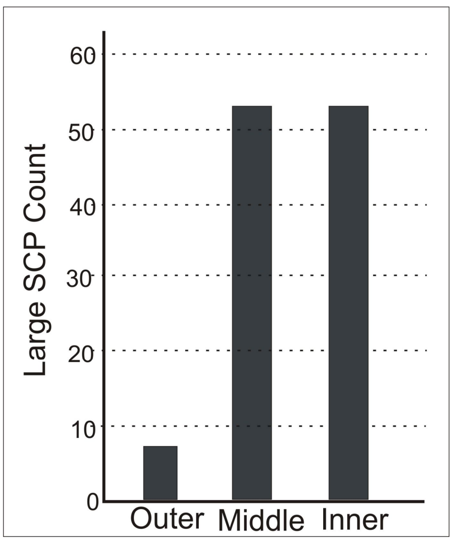

Fig. 3. The counts of large SCP in the outer, middle and inner part of the fjord.

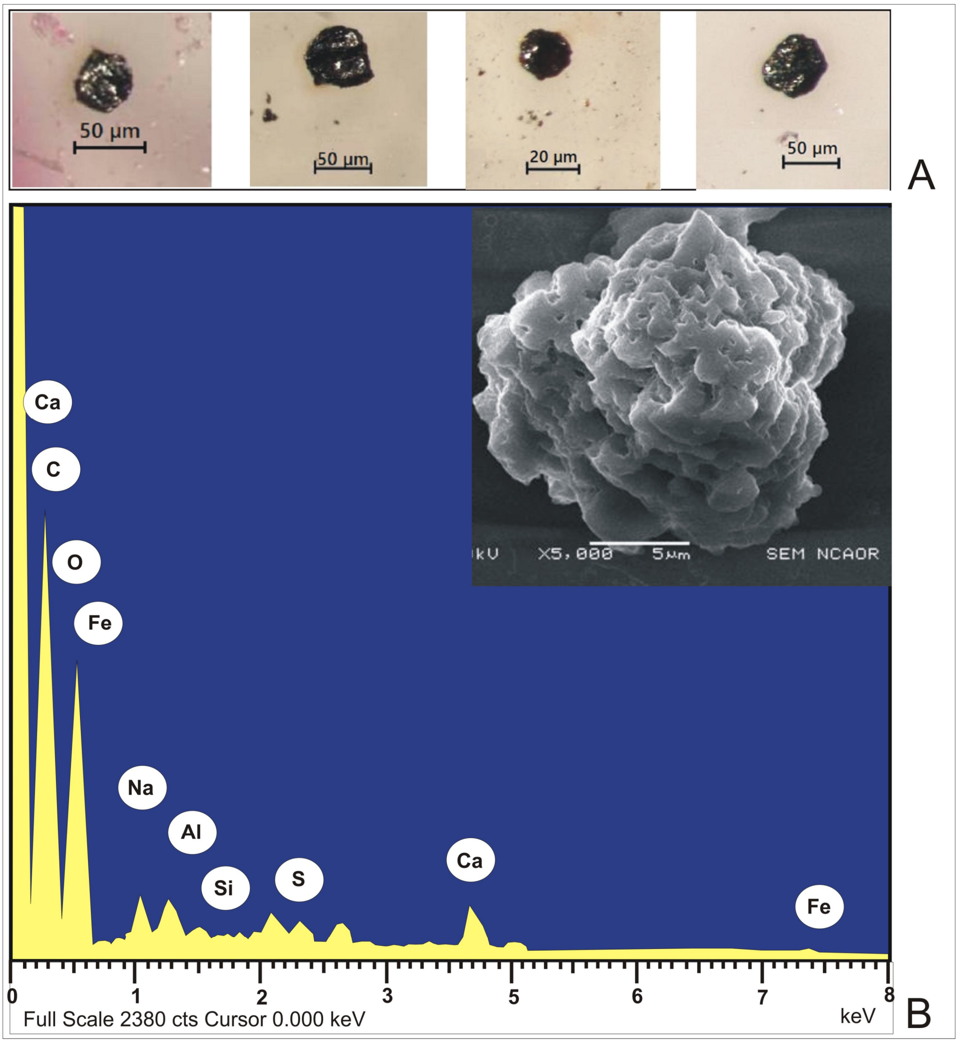

Fig. 4 A and B. Light Microscopy and. Scanning electron microscopy photomicrographs of Spheroidal Carbonaceous Particles

Discussion

The SCP data of Kongsfjorden shows that based on the size quantification small (5-10 µm) and large (20-50 µm) (Fig. 3) particles are present at all the locations, however, there is an abundance of small particles over large. Locations 1 and 2 at the outer part of the fjord have recorded the lowest number of SCP (Fig. 1). The number SCP increases as we move inward into the fjord and the location 5 in the middle fjord records highest number (96) of recovered total SCP count Fig. 1. The inner fjord locations 6, 7, and 8 lies across the fjord from the southern side of the fjord towards the northern side and are closest to the glaciers draining the fjord Fig. 1. The location

6 displays highest number (40) of large and lowest number (14) of small SCP recovered at any location of the fjord Figs. 2 and 3. The total numbers of SCP recorded in the inner fjord (locations 6-8) are 138, out of which 85 are small. It is observed that the small SCP are more concentrated towards the middle fjord whereas equal numbers of large SCP are recovered from middle as well as the inner fjord Figs. 2 and 3.

The observed location wise variation in the recovered SCP is due to the hydrodynamic processes of the Kongsfjorden. The deposition of sediments in the outer part of the fjord is affected by the exchange of water between the shelf and fjord leading to low SCP counts in this part. The inner fjord region is affected by glacial melt water flow active during the summer season. The middle fjord is relatively less turbulent and thus contains more SCP as compared to both outer and inner fjord.

The distribution of SCP in the surface sediments of Kongsfjorden is dominated by the presence of small SCP with twice the number small SCP (232) to that of large particles (113). The dominance is possibly due to industrial source located far away. The dominance is a result of long distance atmospheric transport of these particles from their place of origin. Ny-Ålesund is geographically remote and is isolated from major sources of atmospheric pollution. However, Mitchell (1956) have shown that despite its isolated position it has been affected from significant long range atmospheric transportation from the former Soviet Union, western Europe, and North America in the first report of 'Arctic Haze' (*e.g.* Rahn et Shaw 1982, Pacyna et Ottar 1985, Barrie 1986, Heintzenberg 1989, Jaworowski 1989, Maenhaut et al. 1989, Grodzinska et Godzik 1991, Beine et al. 1996, Burkow et Kallenborn 2000). The aerodynamic nature of SCP facilitates long range transport over thousands of kilometers under favorable conditions such as stability of the atmosphere, wind velocity (Hanna 1985, Yamartino 1985, Bubník et al. 1998), the topography of the terrain, the height of the smokestack (*e.g.* Bubník et al. 1998), and particle shape and density (Bednář et Zikmunda 1985, Yamartino 1985, Querol et al. 1996).

The large SCP are less than small particles but the amount is considerable enough to identify the probable local source. Ny-Ålesund and its nearby places Longyearbyen, Svea and Barentsburg are mainly dependent on fossil fuel for electric power supply. Emission of these power plants includes different particles (SCP, soot, fly ashes, *etc.*) and these power plants could be the major local pollution sources on Svalbard (Aamaas et al. 2011, Jartun et al. 2009, Hicks et Isaksson 2006, Rose 1995, Rose et al. 2004).

Conclusions

The recovery of SCP in the surface sediments of Kongsfjorden in significant numbers suggests that the region is being affected by atmospherically deposited pollutants originating in far-off industrialized regions. The local source of the atmospheric pollution is also significant and needs further detailed assessment. More studies are required to understand the spatial and temporal trends of the SCP during the Anthropocene.

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[1] IPCC AR5 Report (https://www.ipcc.ch/report/ar5/).