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# Wisconsin/Würm Glacial Stage Ice in the Subtropical Dunde Ice Cap, China

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ABSTRACT: The insoluble microparticle concentrations and size distributions and oxygen isotope abundances ($\delta^{18}$ 0) in two 1-meter ice cores from the margin of the Dunde ice cap (38° 06 'N; 96° 24 'E; 5325 masl) drilled in 1986 and three ice cores drilled to bedrock at the summit of the ice cap in 1987 suggest the presence of Wisconsin/Würm Glacial Stage (LWGS) ice in the subtropics. A Sino-American research group recovered three ice cores 136, 138 and 139 m in length from the summit of the Dunde ice cap in the Qilian Shan which are providing long, high temporal resolution climatic and environmental records for the NE section of the Tibetan Highlands. Particulate concentrations, conductivity and $\delta^{18}$ 0 are the ice core constituents best established as indicators of the glacial/interglacial transition. The analyses of two shallow cores from the margin reveal a 14-fold increase in particulate concentration which is correlative with a 1‰ to 5‰ decrease (more negative) in $\delta^{18}$ 0. The lower 10 to 13 m of three ice cores drilled to bedrock at the summit contain a ten-fold increase in dust (both soluble and insoluble) and a 1.2‰ decrease in oxygen isotopes. Additionally, the morphological properties of the particles in the LWGS ice are identical to those of the thick, extensive loess deposits of central China which accumulated during the cold, dry glacial stages of the Pleistocene. When the climatic and environmental records are fully extracted from the three deep cores they will provide a very detailed record of variations in particulates (soluble and insoluble), stable isotopes, net balance, pollen and perhaps atmospheric gases of $CO_2$ and methane through the Holocene into the last glacial in the subtropics on the climatically important Tibetan Plateau.

## Introduction

The inter-annual fluctuations in the summer monsoon over SE Asia have a profound socio-economic impact. The importance of the Qinghai-Tibetan plateau as a heat source for the atmosphere is well documented (Flohn 1957, 1965 and 1968; Koteswaram 1958; Murakami 1981; Virgi 1979; Yah 1981; Luo and Yanai 1983; Reiter 1983; Lau and Li 1984). The climatic regime of E Asia, the tropical Pacific and North America are strongly affected by the thermal and dynamical forcing by this extensive, elevated land mass. Numerical simulations with a global atmospheric circulation model lead Barnett et al. (1988) to suggest that large variations in the amount of snowfall over Eurasia in the spring time are linked to the strength of the Asian summer monsoon. Kuhle (1987) presents the principle of the relief-related origin and termination of ice ages which is directly dependent on changes in albedo due to changes in the amount of snow and ice cover on the Qinghai-Tibetan plateau. Thus, it is important to study not only the impact of the Qinghai-Tibetan plateau on the atmosphere through large-scale thermal forcing, but it is essential to establish a high temporal resolution record of long-term climate on the plateau.

High temporal resolution terrestrial records of climate, some extending into the Late Wisconsin/Würm Glacial Stage (LWGS), are relatively abundant in polar latitudes. These have been extracted from pollen sequences (Woillard and Mook 1982; Birks 1981; Birks and Mathews 1978), lake sediments (Eicher et al. 1981; Eicher 1980; Eicher and Siegenthaler 1982) and from ice cores (Dansgaard et al. 1982; Lorius et al. 1979; Hammer et al. 1985; Herron and Langway 1985; Paterson et al. 1977; Thompson 1977; Thompson and Mosley-Thompson 1981). On the other hand, there is a dearth of such records in the tropics and subtropics. The first evidence of remnant, glacial-stage ice in the subtropics was found in the Dunde ice cap (38° 06 'N; 96° 24 'E; 5325 masl) in the Qilian Shan (Fig 1) in 1986 and has

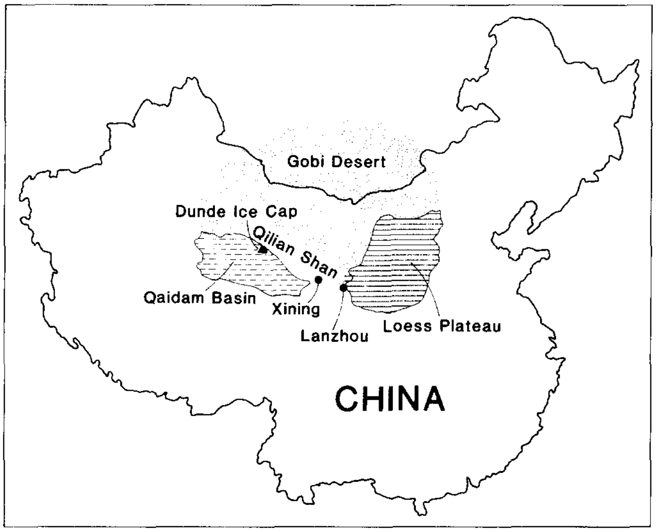


Fig 1 The Dunde Ice Cap is located in the Qilian Shan of the north-central Tibetan Highlands.

been confirmed by three ice cores drilled to bedrock in the summer of 1987. The Dunde ice cap stretches 11.1 km from NNE to SSW and the width varies from 2.5 to 7.5 km covering a total area of 60 km$^2$.

The Dunde ice cap has been the focus of a multi-year (1984; 1986; 1987) field and laboratory investigation under the auspices of a Sino-American glaciological program. The central objective of has been to recover a high quality record of the climatic and environmental changes preserved in the Dunde ice cap (Thompson et al. 1988). From June 1 through September 3, 1987, an expedition consisting of five Americans and 30 Chinese spent 50 days studying the Dunde ice cap. The program represented the cultimation of nine years of effort directed toward the extraction of ice cores from the Qinghai-Tibetan Plateau, China. It is anticipated that these cores will provide long histories of general environmental conditions including droughts, volcanic activity, changing moisture sources, glacier net balance and possibly temperature. The first cooperative three month field research program was conducted in the Tien Shan and Qilian Shan in 1984 by the Lanzhou Institute of Glaciology and Geocryology (LIGG) and the Byrd Polar Research Center (BPRC) at The Ohio State University. This program resulted in the selection of the Dunde ice cap as the best initial site for recovery of ice core climate and environmental records. A two-month cooperative study from mid-July to mid-September in 1986 resulted in the recovery of shallow ice cores up to 34.5 m in length, a survey of snow accumulation through detailed snow pit studies, monopulse radar sounding to determine ice thickness, and the establishment of a detailed strain network for ice flow and snow accumulation measurements.

During the 1987 field season three ice cores, 136, 138 and 139 m in length, were retrieved (Fig 2). The drilling of multiple cores is essential in order to distinguish between the local glaciological noise and the climatological record preserved in the ice cores. The work on the Devon Island cores (Paterson et al. 1977) and two Quelccaya ice cores (Thompson et al. 1985; 1986) illustrates problems which arise when climatic interpretations are made from a single ice core record. Fourteen boxes containing 83 m of frozen ice core were successfully returned to BPRC in 1987.

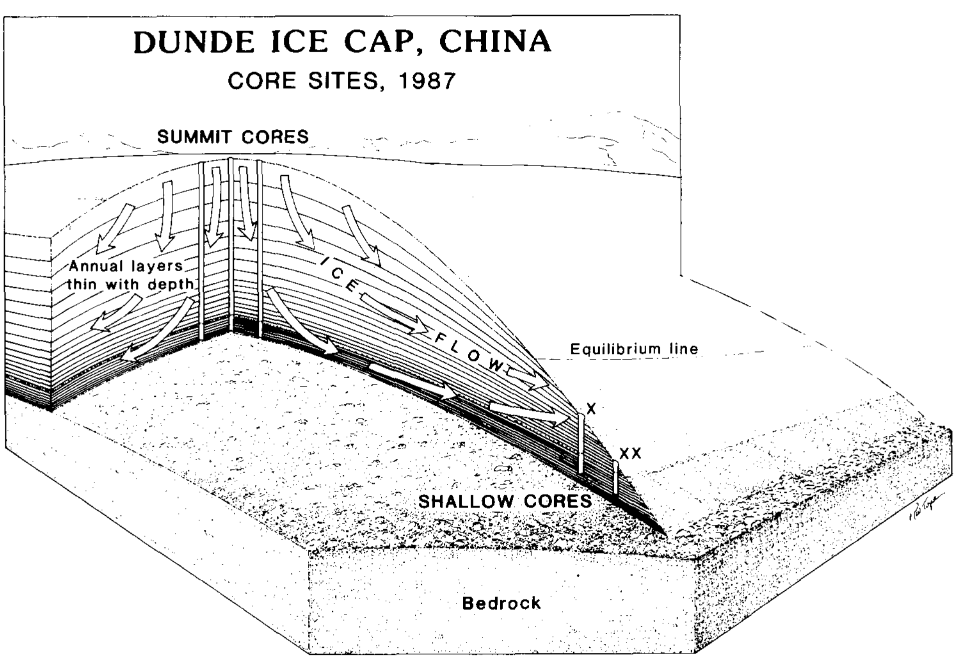


Fig 2
This schematic illustrates the theoretical flow of an ice which is frozen to its bed. Note the thinning and spreading of annual layers. The relative positions of the 1980 shallow cores X and XX are shown along with the location of the three cores drilled to bedrock in 1987.

The first core, 139 m, was cut and prepared in the field and 3600 water samples were divided and returned to both LIGG and to BPRC. The second core, 136 m in length, was shipped frozen to the LIGG for laboratory analysis. The third core, 138 m, was processed so that the top 55 m was cut and prepared in the field and the resulting 1600 water samples were returned to BPRC. The lower 83 m (where the stratigraphic layers are compressed) were returned in excellent condition to BPRC. A combination of man-hauling, horses, trucks, refrigerated truck and airplanes was required to transport these ice cores 12,500 miles from the Dunde ice cap to their final destination.

A light-weight, portable, field laboratory was established on the summit of the Dunde ice cap. Two saws, a band-saw and a chop-saw, equipped with stainless steel blades were used to section the ice core samples. A light table was modified to accomodate a camera which was used to photographically record the ice core stratigraphy.

The three cores to bedrock were recovered by a light-weight drilling system powered by a two cycle ultralight aircraft engine attached to a 220 volt generator. The system was designed by the Polar Ice Coring Office (PICO). In each borehole a detailed temperature profile was established at five meter intervals (Fig 3). Bottom temperatures in all three boreholes ranged between −4.6 to −4.7° C, indicating that the ice cap is polar.

Late in the 1986 ablation season an abrupt contact line between the clean and dirty ice was noted along the E margin of the ice cap. To further investigate this (see T in Fig 4), two 1-meter ice cores were drilled through this boundary. These cores contain a very sharp transition between the overlying relatively clean ice and the underlying dirty ice (Fig 4). Both cores were analyzed for microparticle concentrations and size distributions, liquid conductivities and $\delta^{18}$ 0. The very high concentrations of particules in the dirty sections of the ice cores, necessitated an eight-fold dilution prior to analysis by the Coulter Counter technique (Thompson 1977). Microparticle concentrations in the lower sections of core X and core XX increase 12 to 14 times above the levels in the overlying clean ice (Fig 5). In both cores $\delta^{18}$ 0 shows a 1‰ decrease (more negative) correlative with the increase in particulate concentrations. The most negative $\delta^{18}$ 0 value (−15‰), in the deepest sample, is 5‰ more negative than the least negative value in the overlying clean ice.

LWGS ice in deep ice cores from the polar regions is characterized by both a marked decrease in $\delta^{18}$ 0 (Dansgaard et al. 1982; Lorius et al. 1979; Paterson et al. 1977; Lorius et al. 1985; Barkov et al. 1977; Johnsen et al. 1972) and a correlative and sharp increase in the concentrations of insoluble particulates (Thompson and Mosley-Thompson 1981; Thompson et al. 1981; Koerner 1977; De Angelis et al. 1987). A schematic of the first order ice flow envisioned for Dunde, a typical dome-shaped, non-temperate ice cap, illustrates the thinning and spreading of the annual accumulation layers by plastic deformation (Fig 2). By this mechanism the old basal ice under the summit can be exposed at the

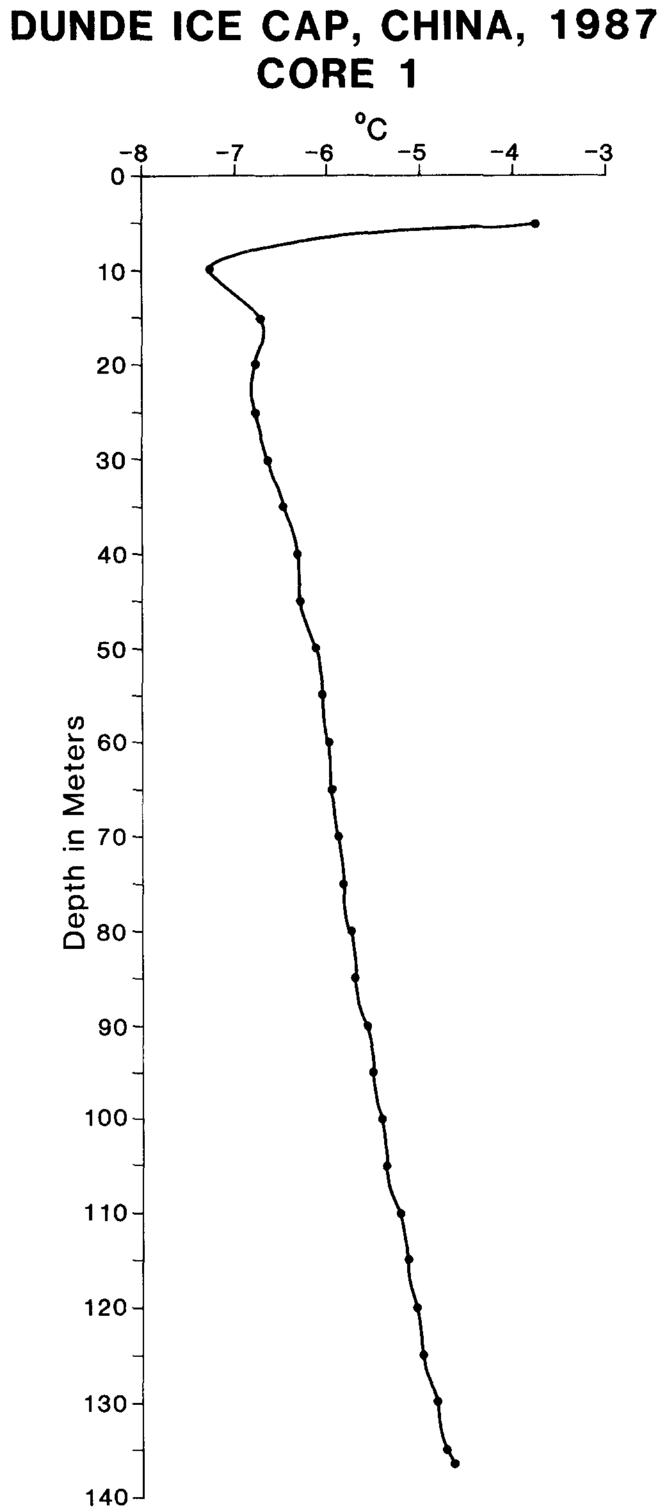


Fig 3 Temperature profile measured at 5 m depth intervals from the Core 1 borehole on the summit of Dunde ice cap in 1987. The temperature profile indicates the ice cap is "polar" throughout with a bottom temperature of −4.7° C.

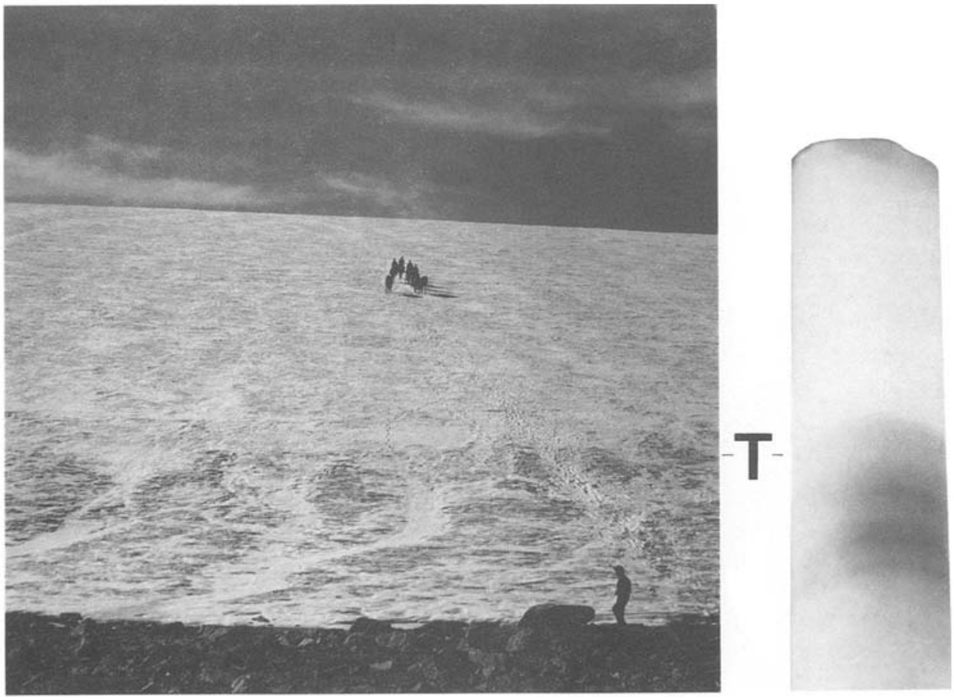


Fig 4
The left photograph illustrates the marked difference between the cleaner interglacial ice and the underlying dirty glacial ice. The latter is about 6 m thick. This abrupt transition (T) is also evident in the ice core (right) drilled through the boundary.

surface on the flank where cores X and XX were retrieved.

Scanning electron microscope examination of the size distribution and morphology of individual particles revealed that the particles from the overlying clean ice (Fig 6A) are similar to those in samples collected from pits at the ice cap summit. The large increase in particles associated with the dirty ice is evident in Fig 6B. The size distributions and morphologies are identical to those of loess particles (Fig 6C) collected from a Pleistocene loess sequence near Xining which is 800 km SE of the ice cap along the W margin of the China Loess Plateau (Fig 1). During the Pleistocene, loess formations measuring up to 335 m in thickness were deposited near Lanzhou. The Pleistocene loess is composed principally of subangular to rounded silt grains (diameters from .005 to .05 mm). The major periods of loess deposition were the cold, dry and windy periods of the Pleistocene (Liu et al.1987; Derbyshire 1983), and therefore, the presence of identical particles in the dirty ice of the Dunde ice cap support the hypothesis that LWGS ice is present. Wang et al. (1978) note that the prevailing NW wind direction at Lanzhou from October to May carries particulates similar in grain size and mineralogy to the Pleistocene loess. Thus, the tremendous increase in concentration of windblown dust above current levels is a very compelling argument for the proposed Pleistocene age. Moreover, the presence of loess in the glacial stage ice of Dunde ice cap at 5400 m in the Tibetan Highlands is irrevocable evidence for the aeolian origin of the Chinese loess deposits.

The continuous analysis of particles, chemistry, stable isotopes, pollen and net balance records for three deep ice cores (136, 138 and 139 m) are currently underway. Fig 7 presents the analysis of 70 randomly analyzed samples from the 3600 collected samples on this core, plotted with depth in the 139.6 m core from the summit of the Dunde ice cap. This record clearly shows a period of reduced $\delta^{18}$ 0 values and higher soluble dust concentration from approximately 25 m to 60 m depth. Similar features appear at depths of 70 to 80 m and at 100 to 110 m. These may correspond to three previous neoglacials in addition to the period of very high dust concentration and more negative $\delta^{18}$ 0 for the lower 10 m of the core.

Continuous analysis of the dust concentrations in the lower 40 m of the core now indicate the glacial/interglacial transition occurs between 129 and 130 m depth. The very detailed analyses of these cores are continuing. The monsoon climate in the Qilian Shan mountain ranges produces an annual cycle in atmospheric dust concentration which leads to the deposition of an annual dust layer in the Dunde ice cap (Thompson et al. 1988). These annual dust layers and annual $\delta^{18}$ 0 will aid in the precise dating of at least the upper half of these ice cores. These records will provide the first ice core records of the variations in drought, volcanic activity, and net accumulation associated with the monsoons. In addition, vegetation fluctuations into the last glacial stage may be extracted from the pollen records.

The Dunde ice cap is uniquely placed in a desert environment between the highest Chinese desert, the

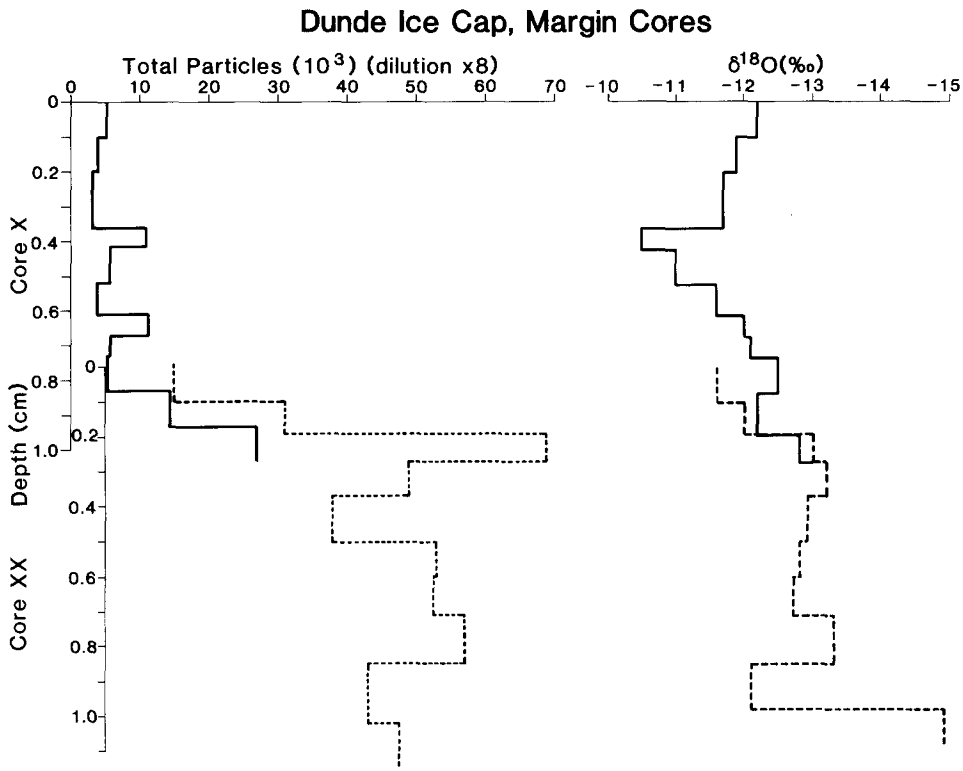


Fig 5
Microparticle concentrations (2 to 40 $\mu$m in diameter ml$^{-1}$) and $\delta^{18}$ 0 were measured for cores X (solid line) and XX (dashed line) drilled along the margin of the Dunde ice cap at positions schematically illustrated in Fig 2. The very high particulate concentrations in the dirty ice made it necessary to dilute the microparticle samples 8 times.

Qaidam Basin, to the S, and the Gobi Desert to the N (Fig 1). The reconstructed environmental record should contain a long history of dust production from these deserts, in addition to the other essential climatic information on the geographical distribution of such events as the Younger Dryas and the "Little Ice Age."

Acknowledgements

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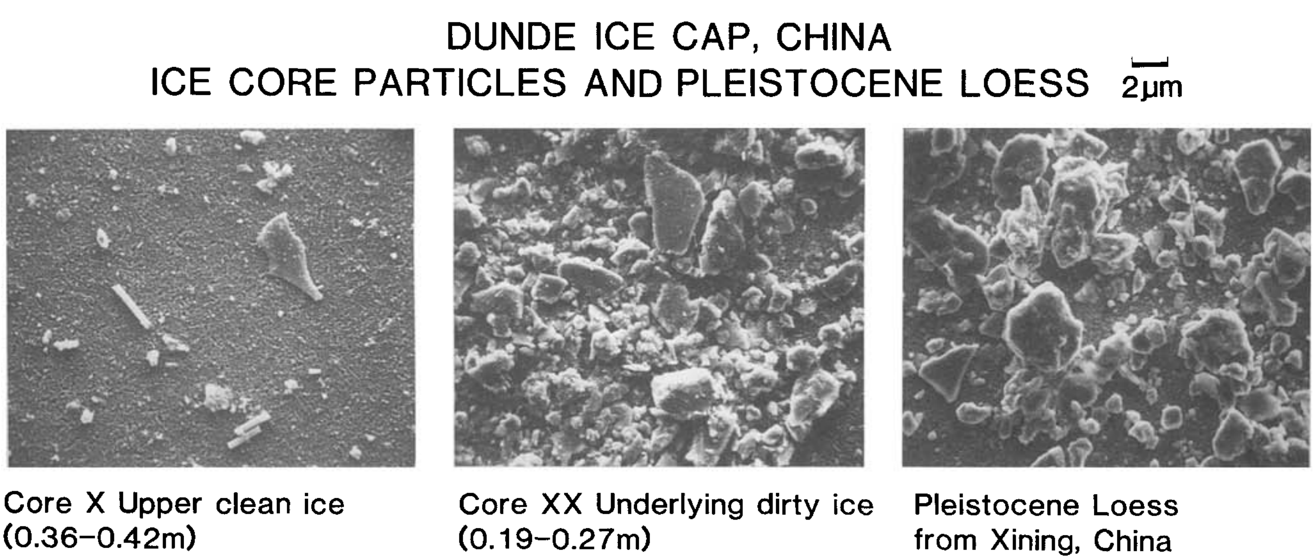
Fig 6 Scanning electron micrographs of particles from the upper clean sections of core X (A), the dirty section of core XX (B) and from a Pleistocene loess deposited 800 km SE of the Dunde Ice Cap during the cold and dry phases of past glacial stages (C) are presented. The similarity in morphology and size distribution of the loess and the particulates from the dirty ice supports the suggestion that the dirty, basal ice layer is of Late Wisconsin age.



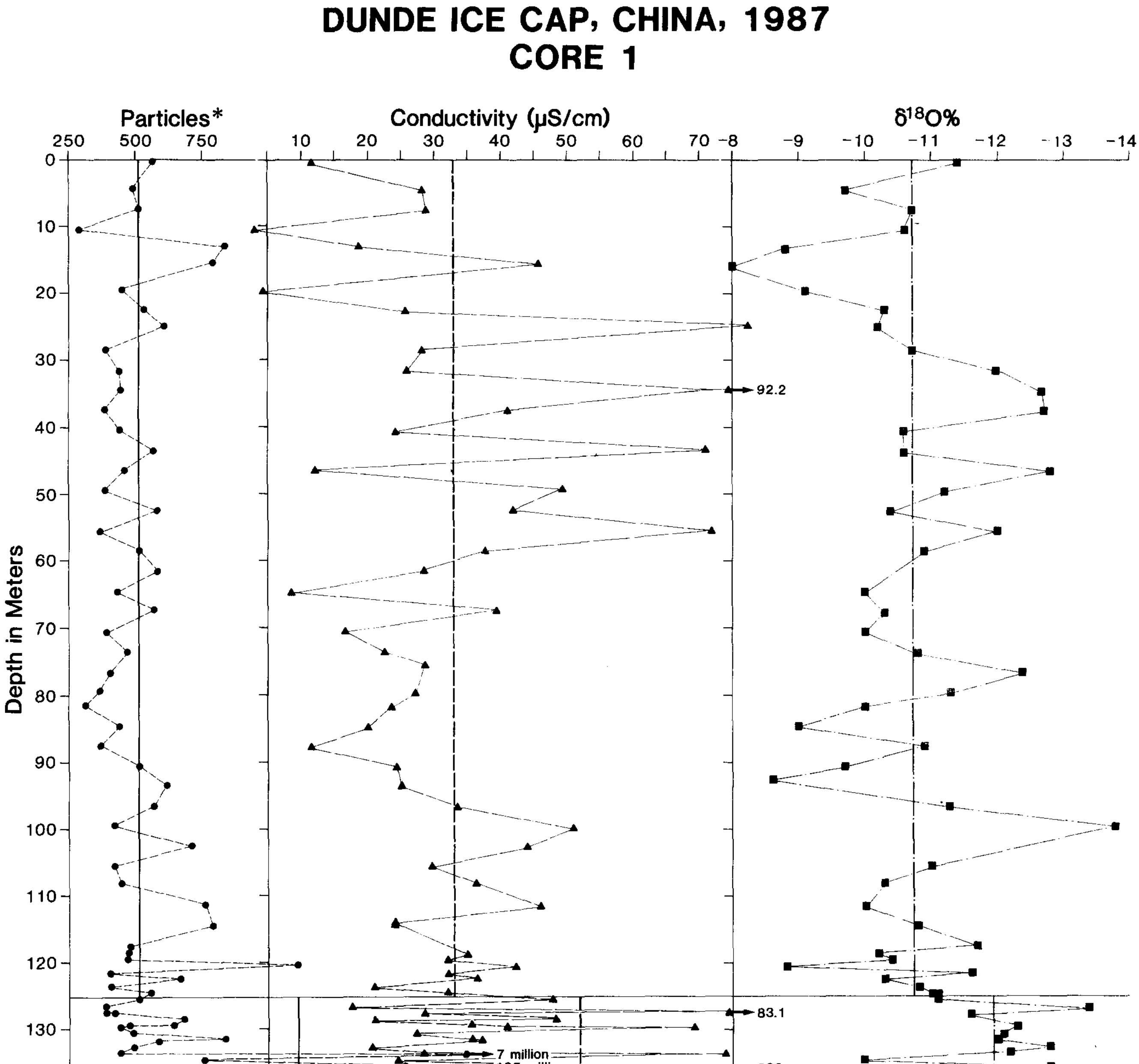



Fig 7 Preliminary analysis of 65 randomly selected samples from the 3600 samples collected from core 1. The measurements of total particles, conductivity and $\delta^{18}$ 0 are plotted with depth in core. The vertical lines through the profiles indicate the relative means of each parameter for the interglacial and glacial. The marked increase in dust and decrease in oxygen isotopes is readly apparent in the lower 10 m of the core.

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