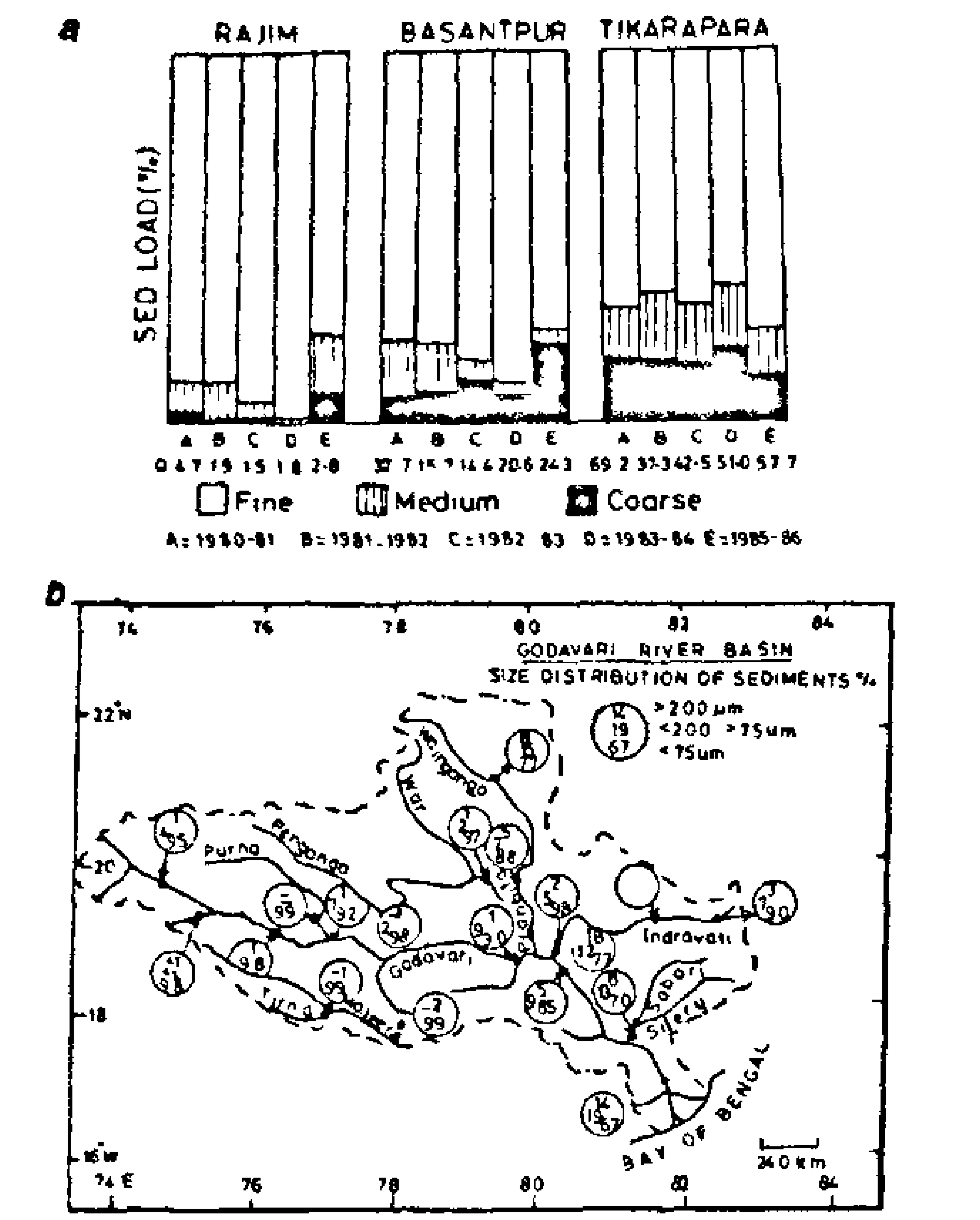

Figure 3. Control of grain size on sediment load of a, Mahanadi and b, Godavari rivers.

stream in several Indian rivers. Variations in sediment load is primarily due to variation in individual size population of sediments. Figure 3 illustrates this point for the Mahanadi and Godavari rivers. Individual size variations of sediment load are generally more pronounced in the downstream region, rather than near the catchment areas, as has been shown for a number of rivers in India[6].

Data from the Indian rivers indicate that erosion and deposition of sediments in the sub-continent is controlled by (i) basin geology and geomorphology, (ii) river discharge and its time and special variabilities (iii) type of urban activities, and (iv) intensity of physical weathering as reflected in the sediment size population. All these factors do not necessarily play the same important role for various rivers.

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Palynostratigraphy of lake deposits of Himalaya and palaeoclimate in Quaternary period

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This paper is the synoptic analysis of palynological data on Himalayan lacustrine sediments covering Kashmir, Ladakh, Himachal Pradesh, Kumaun, Nepal, Darjeeling and Sikkim. Reconstructed palaeovegetation and deduced palaeoclimatic inferences cover mainly Quaternary period, discussed separately for Western, Central, and Eastern Himalayan regions.

Introduction

PALYNOSTRATIGRAPHY provides insight into the conditions of past vegetation and its development in time and space, and thus helps in the reconstruction of palaeoclimate. For example, recovery of Larch (*Larix*) pollen[1] and some *Sphagnum*[2] taxa from Western Himalayan sedimentary profiles, which do not exist in the region today, were very much present until about 1000 years B.P. Their complete disappearance from Western Himalaya and their present distribution in the Central and Eastern Himalaya, is possibly a result of shifting or migration to better situations, attributable to the climatic change. This implies that Western Himalaya is becoming warmer and drier.

Systematic Quaternary palynological studies in the Indian subcontinent started in the mid-fifties at Birbal

Sahni Institute of Palaeobotany, Lucknow. The investigations made so far encompass Kashmir, Ladakh, Himachal Pradesh, Kumaun, Nepal, Darjeeling and Sikkim (Figure 1).

Western Himalaya

Kashmir Himalaya

Palynostratigraphical studies of the Karewa sedimentary deposits at Dubjan[3] has unfolded a palaeovegetation history dating back to about 3.8 million years[4–8]. The Dubjan palynofossils indicate a succession of three assemblages of vegetation pattern, namely the grassland phase, the mixed chirpine with broad-leaved forests, and the grassland flora. This pattern corresponds to the climatic fluctuations from warm-temperate and moderate-humid through warm-temperate and less humid, to cool-temperate with higher precipitation. However, the pollen analysis from another locality Hirpur-I reveals the temperate-humid climate in the beginning, changing to cool-temperate-humid, and ultimately to cool-dry.

Similarly, the pollen analysis from Hirpur Loc. III covering a span of 3.7–2.63 m.y. has demonstrated fifteen vegetational zones, reflecting climatic changes oscillating from subtropical warm-dry to warm-temperate-humid in the beginning, and later on towards the top, oscillating from cool-temperate-moist to cool-temperate dry.

Pollen sequence of the Karewa studied at Krachipathra, embracing a span of 2.4 – 2.2 m.y., indicates a cool temperate climate with little variation in precipitation. The pollen analysis of the Karewas at Sarnar (covering 0.7–0.6 m.y.) likewise suggests a cool temperate climate. However, the Baltal palynofossils (covering a short period of 0.6–0.3 m.y.) indicate five cold climatic spells alternating with temperate phases.

The pollen analysis of the bogs of Botapathri in the Kashmir Valley suggests a cool-temperate phase around 10,000 years B.P., followed by gradual warming between 7000–4000 years B.P. This is inferred from higher amounts of thermophilous broad-leaved elements. The climate finally changes to cool-temperate climate towards the top of the sequence.

The pollen sequence from Toshmaidan has unravelled a succession of three well-marked vegetation i.e. (i) Conifers, (ii) *Quercetum mixtum* and (iii) Conifers, implying a period of increasing warmth followed by a period of maximum warmth and finally the period of decreasing warmth.

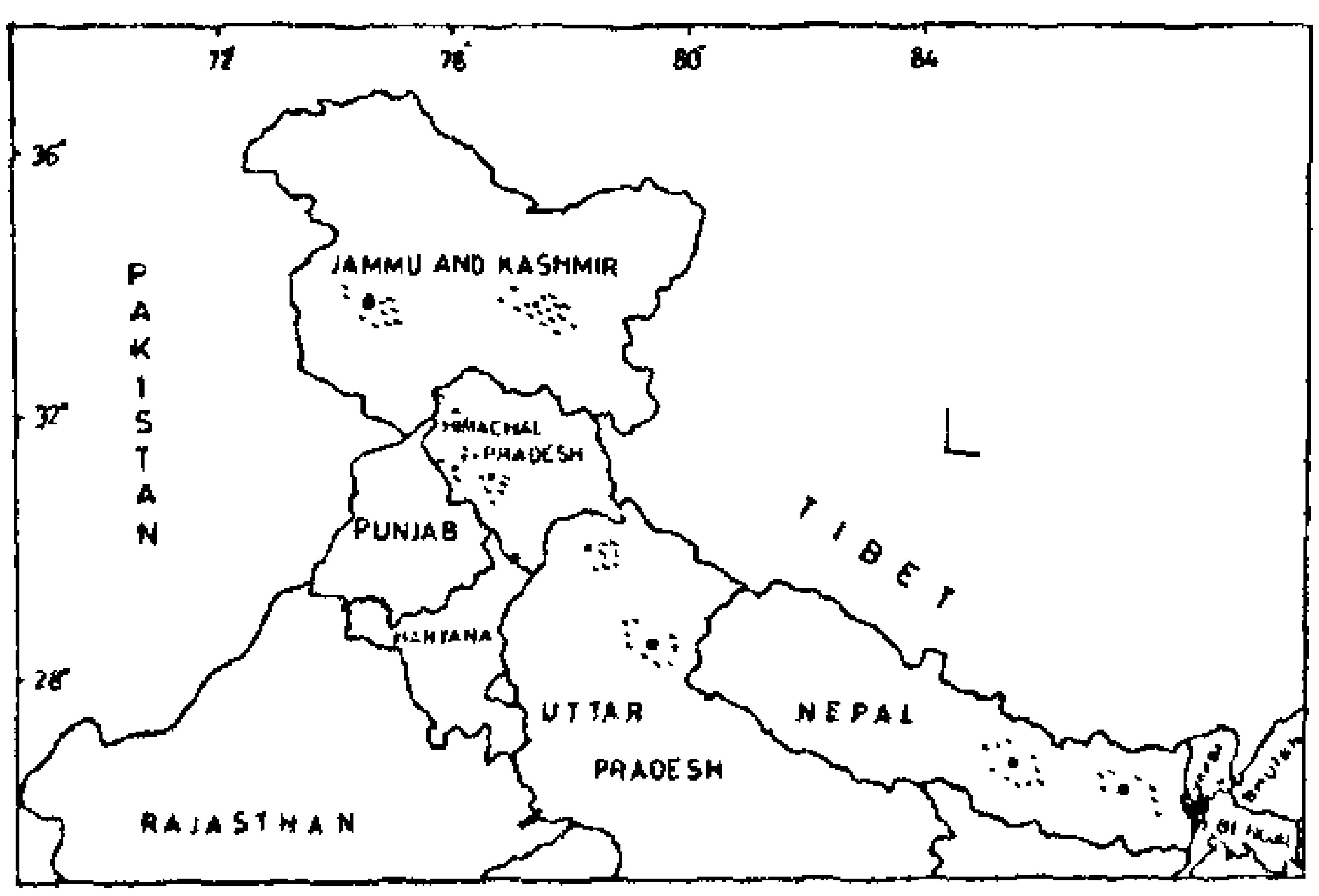

Figure 1. Locations of investigated lake sites/areas in the Himalaya.

Ladakh

The pollen studies carried out on the sediments of the Tsokar Lake situated in the alpine belt of Ladakh[9] covered a vegetation history of the period 30,000–9000 years B.P. The conditions of alpine steppes demonstrate persistence of cold and dry climate in the last 30,000 years, but with four spells of expansion of the *Juniperus*-community in the temporal span of 30,000–28,000 years B.P., i.e. 21,000–18,000 years B.P., 15,000 years B.P. and 10,000 years B.P. during amelioration of the climate.

Himachal Pradesh

Comparative evaluation of the pollen diagrams for lake sediments from different climatic or altitude zones in Himachal Pradesh[10,11–13] reveal that palaeovegetation pattern in the Himachal sector does not differ much from place to place with respect to aspects. Rather there is concordance of subtropical and temperate zones in the late Holocene period. Furthermore, the older oak-pine forests around Khajiar Lake in the temperate zone, were gradually replaced by temperate-zone forests of deodar 1200 years ago. Similarly, around Rewalsar and Parasram lakes in the subtropical zone, the oak-pine mixed forests growing 4,000 years B.P., were replaced by pine forests around 1400 years B.P. At Marhi[14], *Betula* ('bhojpatra') was, the chief arboreal of the high altitude open forests, together with Cyperaceae grasses forming the ground cover vegetation during the early Holocene, pointing to a cool moist climate in the region. It was about 8000 years B.P. that oak and fir invaded the region, culminating in the growth of forests of *Quercus-Abies-Betula*. Thus, there was a change to a warm-moist climate, which reverted to cool-moist climate as is reflected by the preponderance of Cyperaceae-*Betula*.

Kumaun Himalaya

The pollen analytic studies of Holocene deposits from subtropical belt of Kumaun Himalaya[15–17] reflect three-fold climatic fluctuations, i.e. period of increasing warmth, period of optimum warmth and period of decreasing warmth, as evidenced by the existence of pine forests in the beginning, followed by broad-leaved oak forests during mid-Holocene and thereafter reverting to dominating pine forests in the region.

However, the recent pollen studies carried out for the bottom sediments of the Naukuchiya Tal and Sat Tal (lakes)[18,19] have demonstrated that around 4000 years B.P., oak-chirpine mixed forests dominated the vegetation of the region indicating warm and humid climate. Around 1000 years B.P., the climate became relatively less humid as evidenced by the reversed dominance of two arboreals in the existing chirpine-oak mixed forests. On the basis of gradual increase in the pollen frequencies of grasses, Cheno/Ams, and other culture pollen from soils, it is inferred that around 500–600 years B.P., there were agricultural activities in the region.

Central Himalaya

Kathmandu Valley

The palynostratigraphical investigations of the lacustrine deposits from Sankhu, Kalimatti, Manihara, and Thimi[20] have demonstrated that in the Kathmandu Valley in central Nepal some 40,000 years ago oak-pine forests dominated the vegetation under warm humid climate, giving way later to the cold and dry climate. Around 25,000 years B.P. the oak-pine forests returned as a result of amelioration of climate; thereafter they were replaced by grasslands under the impact of cold and dry climate which lasted until about 17,000 years B.P.

Eastern Himalaya

Darjeeling

Recent palynostratigraphical investigations of the lacustrine deposits from the temperate belt of Eastern Himalaya reveal vegetation history covering the last Glacial Maximum and Holocene periods. The pollen analysis of a profile from Lake Mirik[21,22] in the Darjeeling area shows that around 20,000 years B.P. there were open grasslands under cold and dry climatic conditions. Around the mid-Holocene period, the grasslands were replaced by mixed broad-leaved forests, dominated by *Quercus*, *Alnus*, *Betula* and *Corylus* as the climate became comparatively warm and moist.

Sikkim

Interpretation of a lake-deposit profile from Khechipiri in Sikkim shows that around 2500 years ago, mixed broad-leaved forests dominated the vegetation under warm and moist climate and, around 1000 years back, *Alnus* acquired dominance over *Quercus*, and there was increase of *Rhododendron*. These facts demonstrate that the climate had become more moist.

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