Palaeobotanist 50 (2001) : 213-224
0031-0174/2001/213-224 $2.00

A note on geological explorations through early expeditions to the Eastern Karakoram, the Shaksgam Valley and the Western Tibet since early half of the Nineteenth Century

RAJEEV UPADHYAY* AND ANSHU K. SINHA

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.
Email: rajeev_up@yahoo.com

(Received 31 July 2001; revised version accepted, 21 May 2002)

ABSTRACT

Upadhyay R & Sinha AK 2001. A note on geological explorations through early expeditions to the Eastern Karakoram, the Shaksgam Valley and the Western Tibet since early half of the Nineteenth Century. Palaeobotanist 50(2 & 3) : 213-224.

Based on informations available, through early expeditions since the early half of the nineteenth century, on the Central Asian mountain massifs, the present document is aimed towards depicting the significance of these poorly known regions in a larger framework of palaeogeography and accretion of the Indian and Peri-Gondwanian microcontinents with the Asian landmass.

Key-words—Eastern Karakoram, Shaksgam Valley, Western Tibet, Central Asia, Karakoram Fault.

विगत नवीं शती के पूर्वार्द्ध से आज तक पूर्वी कराकोरम, शक्सगाम घाटी तथा पश्चिमी तिब्बत के प्रारंभिक खोज अभियानों में भू-गर्भीय उत्खनन

राजीव उपाध्याय एवं अंशु कुमार सिन्हा

सारांश

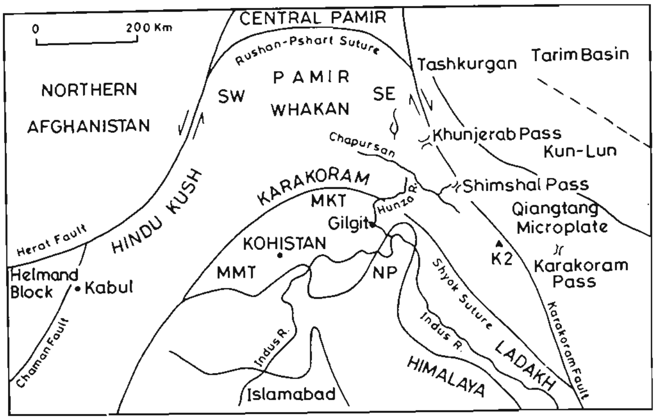
प्राप्त सूचनाओं के आधार पर मध्य एशियाई पर्वत श्रेणियों के गिरिपिण्डों (मैसिफ़) के विगत नवीं शती के पूर्वार्द्ध से आज तक हुए खोज अभियानों के आधार पर प्रस्तुत शोध पत्र में इन अल्प ज्ञात क्षेत्रों के पुराभौगोलिक एवं एशियाई भूखण्ड के साथ भारतीय एवं परिगोण्डवाना सूक्ष्म महाद्वीपों के अभिवर्धन को एक वृहत् परिप्रेक्ष्य में व्याख्यायित करते हुए इनके महत्त्व को प्रदर्शित किया गया है।

संकेत शब्द—पूर्वी कराकोरम, शक्सगाम घाटी, पश्चिमी तिब्बत, मध्य एशिया, कराकोरम भ्रंश.

INTRODUCTION

The Karakoram is an ~800 km long, 150 km wide remote region in Central Asia (Fig. 1) and its geology is still partially unknown (Searle, 1991; Gaetani, 1997). The limits of the Karakoram block are still only approximately defined. The western limit of Karakoram with east Hindu Kush is proposed along the Tirich Mir fault or the Chitral fault where serpentinized ultramafic rocks have been found (Gaetani *et al.*, 1996; Zanchi *et al.*, 1997). To the north, the boundary with south Pamirs is poorly defined, as access to the Wakhan part of Afghanistan is still difficult for various reasons. But a limit along the Kilik fault has been proposed (Zanchi, 1993; Gaetani, 1997), as this fault thrusts Permo-Carboniferous sediments over northern Karakoram Cretaceous sediments, and can be followed westwards to the western Karakoram (Kafarskyi & Abdullah, 1976; Buchroithner & Gamerith, 1986). According to Shvolman (1981) and Ruzhentsev and Shvolman (1981) the main Karakoram mountain lies between the Main Karakoram Thrust and the Rushan-Pshart suture zone, which divides the southeast Pamir from the central Pamir (Fig. 1). Terrains located on the eastern side of the Karakoram Fault have been included in the Karakoram by several authors (Desio, 1991, 1977; Gergan & Pant, 1983; Thakur & Mishra, 1984; Searle, 1991; Sinha *et al.*, 1999). But this interpretation is still debated, as Gaetani *et al.* (1990a, b) proposed that the sedimentary successions of the Shaksgam Valley could belong to the south Pamirs, as also supported by descriptions of the Qiangtang area by Chinese scientists. Recently, Sinha *et al.* (1999) proposed that the boundary between the eastern Karakoram and Qiangtang may lie somewhere in the Depsang Plain. However, most Indian geologists consider the area between the Karakoram Pass and the lower Shyok River as eastern Karakoram (Thakur, 1981; Gergan & Pant, 1983; Srimal, 1986; Rai, 1991; Bagati *et al.*, 1994; Sinha, 1997; Sinha *et al.*, 1999). Moreover, it is still open the definition of the eastern termination and connection of the eastern Karakoram to part of the Tibetan Plateau (personal communication with Prof. Gaetani, Italy). To the south, the boundary between the Karakoram block and Ladakh terrain is defined by a complex suture zone closed in the Upper Cretaceous (the Shyok Suture Zone) and reactivated during the Tertiary (Upadhyay *et al.*, 1999; Rolland *et al.*, 2002).

The Karakoram is composed of two east-west striking belts separated by the axial batholith of Mid-Cretaceous to Upper Tertiary age (Debon *et al.*, 1987; Upadhyay *et al.*, 1999). The northern sedimentary belt is formed by Carboniferous to Cretaceous terrigeneous sediments and limestones (Gaetani *et al.*, 1990a, b; Gaetani, 1997; Sinha *et al.*, 1999). The southern Karakoram belt is known as the Karakoram Plutonic-Metamorphic Complex (Searle, 1991; Desio *et al.*, 1985; Sinha & Upadhyay, 1997; Sinha *et al.*, 1999) and the northern sedimentary belt is known as the Karakoram Tethys (Thakur, 1981; Gergan & Pant, 1983; Sinha *et al.*, 1999).



MMT= Main Mantle Thrust, MKT=Main Karakoram Thrust, NP=NangaParbat

Fig. 1—General tectonic map of Pamir, Kun Lun, Karakoram, Kohistan and Ladakh showing the location of Karakoram fault and different central Asian microcontinental blocks or terranes (modified after Gaetani, 1997).

The Karakoram, located in a central tectonic position of central-eastern Asian blocks, is a key region for a better understanding of the geodynamics of Central Asian blocks during the Lower Palaeozoic (Searle, 1991; Gaetani, 1997; Rolland *et al.*, 2002). Therefore, a detailed geological exploration of the eastern Karakoram mountain system is important to understand the large scale geological processes, palaeogeographic distribution and northern extent of the Gondwana-land and accretion of Peri-Gondwanian Asian microcontinents vis-à-vis India-Asia collision. It is noteworthy to mention here that, as compared to the Himalaya, the geological aspects of the Karakoram mountains are still poorly known, therefore, in the following sections a brief recap of systematic developments of the idea on Central Asian mountain massifs and an understanding of the initial geological explorations through early geological expeditions to the eastern Karakoram, Shaksgam Valley and western Tibet since the early half of the nineteenth century have been provided to understand recent scientific activities, led by different international groups, in these remote regions.

INITIAL EXPEDITIONS

Since the early half of the nineteenth century the eastern Karakoram and adjoining mountain ranges of Central Asia (Fig. 1) have had fascinated the curious explorers and mountain climbers to unravel the occult and mysticsm of these magnificent group of mountains. Therefore, the early explorations were made to identify the Karakoram-Turkestan trade route and to collect first hand information about the large concentration of huge glaciers and mountains, several peaks raising to more than 8,000 m height (K2, 8,611 m), situated in the region.

Systematic record of exploration in the eastern Karakoram mountain could be recapitulated after 1821, when Moorcroft

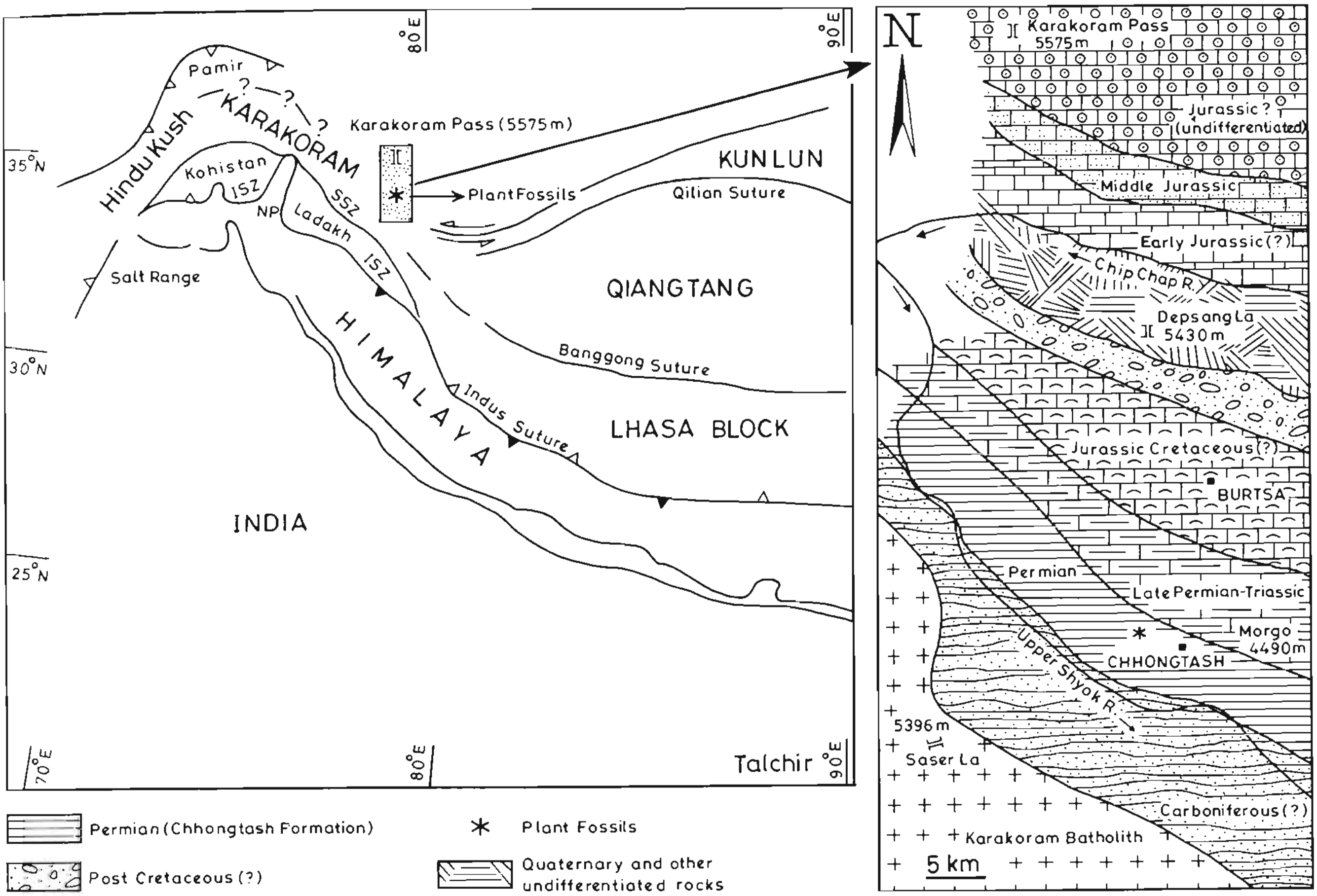


Fig. 2—Left: Simplified geological sketch map of central Asia showing present geotectonic position of western Himalaya, Karakoram, Hindukush, Pamir and Kun Lun mountain ranges; their tectonic subdivisions and location of major sutures, microcontinental fragments (modified after Searle, 1991). Shaded box, study area (Upadhyay *et al.*, 1999); SSZ, Shyok Suture Zone; ISZ, Indus Suture Zone; NP, Nanga Parbat; *Location of the Early Permian plant fossils and palynomorphs (Upadhyay *et al.*, 1999). Right: Simplified geological map of the eastern Karakoram between Saser La and Karakoram Pass showing the geological setting of the plant-bearing Chhongtash Formation and other geological entities in the eastern Karakoram block (Upadhyay *et al.*, 1999).

passed near the snout of the Siachen Glacier. He reported the existence of Siachen Glacier in the Karakoram region. Afterwards, Vigne attempted to reach the Bilafond La in 1835 from the west. It was Strachey who stepped on to the Siachen Glacier in 1848 and Drew in 1849. Significant contributions were made during the second half of the nineteenth century by Von Schlagintweit brothers (1861-66), Lydekker (1883), members of Forsyth expeditions and Drew in 1875. These workers gave the first accurate information on those parts adjoining the Karakoram trade routes, and revealed the presence of marine Mesozoic formations in the region. Earlier, Stoliczka (1865) and later Stoliczka (in Blanford, 1878) for the first time provided valuable geological information collected during his second Yarkand mission. Unfortunately, Stoliczka died on the way back from Karakoram pass, during his second expedition, as a result of his exhaustive traverse (personal communication with Prof. Maurizio Gaetani, Italy) in the most arduous Karakoram and adjoining Central Asia. A monument has been built at Leh in Ladakh by the Geological Survey of India to salute the soldier of geology- the Stoliczka.

The first topographic work in the Chang-Chen Mo and Lingzi-Thang regions of the western Tibet had been done as early as 1858, when Montgomerie of the Survey of India (1922) carried his triangulation series into the upper Indus Valley. Godwin-Austin (1884) and various travellers, including Deasy (1901) and Hedin (1906) had provided enough data for the Survey of India to publish a set of maps on the scale of one inch to four miles. The southern border of the Tibetan Plateau was touched by Hayden's reconnaissance survey of southern Tibet in 1903 and 1922 (Hayden, 1915), and its northern border by the Russian Tibet expedition under the leadership of Pevtsov (Pevtsov *et al.*, 1892-1896). But the geological information of the greater part of the Chang-Thang (western Tibet) is largely the result of one man's work. During his expeditions in the years 1894-1897, 1899-1902, and 1906-1908, Hedin collected systematically specimens of the rocks encountered along his routes, carefully recording their exact position and visible extension, besides preparing the route maps and landscape sketching (Hedin, 1904 -1907). The results of which published in his great work in nine volumes between 1916-1922.

Earlier, Ryall of the Survey of India sketched the lower part of the Siachen Glacier in 1861 and estimated its length as a mere sixteen miles. It is very surprising to learn that when the early explorers and mountain climbers were trying to explore the Siachen Glacier and adjoining region, the neighbouring Shaksgam Valley has remained geographically unknown until 1887. It was Sir Francis Younghusband (1887, cf. Desio *et al.*, 1991) who was travelling with a carvan from Peking, entered the Shaksgam Valley via the Aghil pass and left it via the eastern Muztagh pass. There exist no record whether any other expeditions with scientific purposes had travelled Younghusband's route in Sinkiang, between the Kun Lun mountain chain and that of Aghil, before 1926 (Desio, 1936, Desio *et al.*, 1991). Two years later, Francis Younghusband had a second journey to the Karakoram in 1889. Approaching from the Urdok Valley in the north, he surveyed the massive glacier from Turkestan La and deduced the main axis of the Karakoram range, which later confirmed by Longstaff in 1909. Therefore, Longstaff alongwith Neve and Lt. Slingsby were the first to traverse the length and breadth of the Siachen Glacier. They further established the size of the Siachen up to the Turkestan La, its northern limit. Subsequently, Collins and McInnes of the Survey of India, Worksman and Grant Peterkin surveyed the region during 1911-1912 and marked prominent peaks and glaciers in the eastern Karakoram.

A new era began in the exploration of eastern Karakoram, western Chang-Thang and adjoining Shaksgam Valley with the reconnaissances and multidisciplinary work carried out by the trained geologists of the Italian expeditions under the leadership of Filippo De Filippi in 1912-14; Duke of Spoleto in 1929 alongwith Desio and Umberto Balestreri; Giotto Dainelli (1932, 1933); the Dutch expeditions under Visser in 1922, 1925, 1929-30 (Visser, 1934), the German expeditions under Trinkler in 1927-28 and De Terra (1932) and the British expedition under Shipton in 1937. These scientific expeditions provided the first hand geological account of the eastern Karakoram and adjoining Yarkand region. They further stated the presence of Mesozoic sedimentary rocks around the Karakoram pass and adjoining region. In 1926 the northern slopes of the Aghil were explored by Kenneth Mason's expedition (Mason, 1938). Trying to define the Shaksgam River, Mason crossed the Karakoram pass down to Shaksgam, but he was stopped by the Kyagar Glacier for reaching the upper Shaksgam Valley. Therefore the stretch of valley between Kyagar Glacier and Urdok Glacier had remained unexplored until 1929 (Desio *et al.*, 1991). However, Mason (1938) provided the definition of Karakoram in a geographic sense which was later modified by Desio *et al.* (1991). This definition, though, hardly coincides with the possible boundaries of the 'geological' Karakoram (Gaetani, 1997). Interestingly, in 1929 Duke of Spoleto alongwith Ardito Desio and Umberto Balestreri, however, for the first time explored the remote and geologically unknown region of the Shaksgam Valley. The Duke of Spoleto was the expedition leader and he never crossed the range. He always remained on the Baltoro Glacier (personal communication Prof. Gaetani, Italy). This was followed by Wyss expedition in 1935 and Shipton and Auden expedition in 1937.

The scientific expedition led by Filippo De Filippi in 1912 was one among the largest and most comprehensive before the first world war. It included geodesy, geophysics, geology, meteorology and climatology. Later on, the multidisciplinary geological expedition led by Norin in 1932 was one among the most successful effort as far as preliminary geological and palaeontological investigations are concerned. They for the first time covered an area between Yarkand and western Tibet via Karakoram pass. The detailed geological informations of these remote region were later published in a monograph by Norin in 1946. Similarly, the geological and palaeontological reports and the data obtained from the Shaksgam Valley by various expeditions were published over a large span of time (Desio, 1930a, b, 1936, 1979, 1980; Desio *et al.*, 1991; De Terra, 1932; Auden, 1938; Wyss, 1940; Fantini Sestini, 1965; Gaetani *et al.*, 1990a, b; Gaetani, 1997).

PLATE 1 ⟶

1. Panoramic view of the Indus Suture Zone and the Indus River near Leh in Ladakh. Foreground area belongs to the Ladakh batholith and the background area belongs to Indus Forearc sediments.
2. A view of Shyok Suture Zone along the Nubra River Valley shows tectonic juxtaposition of the Shyok Ophiolitic Melange and the Karakoram batholith.
3. Location of the Karakoram Fault along the Nubra River and field juxtaposition of Karakoram metasediments and the Karakoram batholith.
4. Snow covered mountains, glacier and glacial lake near Saser La in the eastern Karakoram. Snow covered mountains belongs to the Karakoram batholith.
5. A view of Karakoram batholith with glacier, glacial lake and moraines in the eastern Karakoram.
6. Karakoram batholith is intruding into the recrystallized limestone of Saser Brangsa Formation (Carboniferous-Permian) in the eastern Karakoram.
7. Photograph showing the plant fossil and palynomorphs bearing Permian Chhongtash Formation in the eastern Karakoram (Original photography by RU and present displayed version is scanned from the cover page of BSIP, Lucknow Annual Report 1998-1999).


A
Indus Forearc Sediments
Indus River
Ladakh Batholith
B
Karakoram
Batholith
ShyokOphioliticMelange
Nubra River
C
Karakoram Metasedimen
Karakoram Batholit
Nubra River
Karakoram Fault
D
Karakoram Batholith
E
Karakoram Batholith
Glacial Moraines
F
Limestone
arakoram Batholith
Triassi
Permian
Carboniferous
Saser La
5356m
G
Triassic
Permian Chhongtash Formation

PLATE 1

A NEW ERA WITH NEW DIMENSIONS

Followed by the above mentioned preliminary geological reconnaissance a new era began with the new generation of geoscientist who carried out detailed multidisciplinary expeditions to the remote parts of the Karakoram mountains and Tibetan Plateau. These detailed multidisciplinary investigations indicate that there exists a number of accreted terranes and/or microplates between India-Eurasia collision zone. In the following section a brief highlight of some of these recent scientific information is given.

The Scientific expedition led by Prof. Desio in 1988 is one among the most significant one. The scientific reports of this expedition along with earlier works were published by Desio *et al.* (1991).

It is amazing to note that Prof. Desio—a pioneering stalwart in the geological exploration of the central Asian mountains, worked for more than six decades in the most ardous NW Karakoram and Shaksgam Valley. He is also known for his contribution to unravel the geological mystiques of K2 group of mountains. The summit of K2 has been scaled by Compagnoni and Lacedelli on 31 July, 1954 under the leadership of Prof. Desio's expedition to the Baltoro Basin in the Karakoram. On 18 April 2001 Prof. Desio has actively and successfully seen 104 springs. Unfortunately, on December 12, 2002 the legendary climber, a great geologist and explorer travelling all over the world died at the age of 104 years. Prof. Desio was born in 1897. We salute Prof. Desio—a key figure in the exploration of central Asian mountain massifs, for his outstanding contribution to the earth sciences as a whole. Amazingly, he was a geologist who has seen developments in the earth sciences for three centuries i.e., the later half of nineteenth century, twentiath century and now entered into the twenty first century.

According to Desio *et al.* (1991) the geological transect from Kun Lun to Karakoram could be divided into a number of microplates. These microplates are: 1. *Kun Lun Microplate:* This microplate includes the Kun Lun crystallines and its Late Palaeozoic granitoid intrusions or pre-Jurassic various granitoid types (Matte *et al.*, 1996) and the Palaeozoic Bazar Dara Slates. 2. *Qiangtang Microplate:* The area south of the Kun Lun microplate and east of the Karakoram Fault have been assigned to the Qiangtang microplate (Chang *et al.*, 1988). But recently Parrish and Tirrul (1989) considered this area belonging to the Lhasa microplate. However, Desio *et al.* (1991) decipher the presence of red sandstones and anhydrites of the Surukwat Thrust Sheet as one among the significant unit to represent the Qiangtang affinity. Earlier, Leeder *et al.* (1988) assigned that the widespread red sandstone were derived during the Jurassic from the newly formed Kun Lun Range, and considered typical for the Qiangtang microplate within the Shaksgam Valley. 3. *SE Pamir-Karakoram Microplate:* It includes Permian to Triassic and Middle Jurassic Shaksgam Sedimentary belt, the Cretaceous calc-alkaline Suget Granodiorite and the Sarpo Laggo-K2 Metamorphics. The Karakoram Fault and associated vertical faults are also dissecting the Shaksgam Sedimentary Belt in the region (Gaetani *et al.*, 1990a, b). Desio *et al.* (1991), however, also indicated that the Shaksgam Sedimentary Belt is eventually crossed by the Karakoram Fault alignment east of the Khunjerab pass. As a consequence they proposed that the Karakoram Fault does not represent a microplate boundary between the Karakoram and Qiangtang microplates. They further stated that, if it exists, should lie eastwards of Shaksgam. This is still an unresolved question. To find such answer we have to explore the geology of the Chhongtash- Depsang Plain-Karakoram pass-Locqzang mountains region and adjoining Lingzi-Thang. However, Gaetani *et al.* (1990a, b) and Desio *et al.* (1991) further stated that the Shaksgam Sedimentary Belt shows intermediate affinities between the Karakoram and Qiangtang microplate and its evolution moves from a Karakoram style to a Qiangtang style. In northern Karakoram, Gaetani (1997) provided a 400-Ma record of the evolution of a continental block, largely under marine conditions, from the Ordovician to the Cretaceous. He further identified six tectono-sedimentary cycles in the northern Karakoram.

The 1985 Royal Society-Academia Sinica Tibet Geotraverse was organised, between Lhasa-Golmud by a team of geoscientists from United Kingdom and China under the leadership of Profs. Chang Chengfa, Robert Shackleton, John F. Dewey and Yin Jixiang. This multidisciplinary expedition has provided very significant information about the tectonic evolution of Tibetan Plateau. The scientific results of this expedition was published by the Royal Society of London in 1988. According to Dewey *et al.* (1988) the Tibetan Plateau, between the Kun Lun Shan and the Himalaya, consists of terranes accreted successively to Eurasia. The northern most, the Songban-Ganzi Terrane was accreted to the Kun Lun along

PLATE 2 →

1. A camp site in the vicinity of Jurassic-Cretaceous Burtsa Formation in the eastern Karakoram.
2. Panoramic view of Jurassic-Cretaceous Formations and post Cretaceous Qazil Langer Formation in the eastern Karakoram.
3. Rimo Glacier, the source of Shyok River near Gypshan in the eastern Karakoram with Jurassic rock formations.
4. Depsang La and Depsang Plain (5430 m) points to western termination of Tibetan Plateau.
5. Karakoram Pass (5575 m), a water divide between the southern Depsang Plateau and northern Yarkand Valley. Background mountains belong to Loqzung Group of mountains of Desio (1974, 1991).
6. A close-up view of Karakoram Pass and Locqzang mountains in the eastern Karakoram.


A
Triassic
Morgo Camp Site
4490 m
B
Jurassic-Cretaceous
Qazil Langer Formation
Post Cretaceous
22 8 '95
C
Rimo Glacier
Shyok River
Jurassic
Gypshan
D
Jurassic-Cretaceous
Post Cretaceous
Depsang La
5430 m
Depsang Plain
E
Karakoram Pass
5575 m
F
Loquzang Mountains
Karakoram Pass

PLATE 2

the Kun Lun-Qinling Suture during the Late Permian. The Qiangtang Terrane accreted to the Songban-Ganzi along the Jinsha Suture during the Late Triassic or earliest Jurassic, the Lhasa Terrane to the Qiangtang along the Banggong Suture during the Late Jurassic and, finally, peninsular India to the Lhasa Terrane along the Zangbo Suture during the Middle Eocene. They further proposed that thickening of the Tibetan crust is almost double the normal thickness which may be due to northward-migrating north-south shortening and vertical stretching during the Middle Eocene to earliest Miocene indentation of Asia by India.

In recent years Wadia Institute of Himalayan Geology, Dehradun, India has organised some expeditions to the Eastern Karakoram region. The expedition route lies between the Nubra Valley and Karakoram Pass. Preliminary but significant results of these expeditions were partly published by Gergan and Pant (1983), Bagati *et al.* (1994), Sinha *et al.* (1999). Earlier, Neptune Srimal of the Geological Survey of India also provided important information on the Shyok Suture and eastern Karakoram batholith (Srimal, 1986). According to these expedition reports there exists two major litho-tectonic divisions i.e., (1) Karakoram Plutonic-Metamorphic Complex; (2) Karakoram Tethyan Facies (Fig. 2, Pl. 1, 2). These tectonic divisions are supposed to represent a time span from Carboniferous-Permian to Late Cretaceous (Fig. 2, Pl. 1, 2). The sedimentary sequences between the Depsang Plain and the Karakoram Pass region holds a very close similarity with those exposed in the adjoining Lingzi-Thang and Loqzung mountains. Therefore this region should be considered as one among the most crucial zone to locate the boundary between the Karakoram terrane and Qiangtang microplate. Up-to-date there has been very scanty data available which further enhanced the missing gaps to compare this region with the eastern and western part of the Tibet. However, according to Sinha *et al.* (1999) the sediments of the eastern Karakoram Tethyan Zone are more or less similar to the adjoining Permian-Cretaceous Shaksgam Sedimentary Belt of the NW Karakoram in Sinkiang Province, China and adjoining geological sequences of the western Qiangtang block of western Tibet.

PLANT FOSSILS AND PALYNOMORPHS IN THE KARAKORAM, WESTERN TIBET AND WEST KUN LUN

Significantly, the recent discovery of the Early Permian (Artinskian, ~ 270-265 Ma) marine Gondwana sediments with plant remains and palynomorphs in the Chhongtash Formation of the eastern Karakoram (Upadhyay *et al.*, 1999) suggest that during Early Permian time the Karakoram was a Peri-Gondwanian microcontinent at latitudes of *ca* 35^0 south, somewhere between the Indian Plate and the Qiangtang-Lhasa microcontinent (Upadhyay *et al.*, 1999). The recorded plant fossils are *Noeggerathiopsis*, *Samaropsis* seed, a portion of *Gangamopteris* leaf, some unidentifiable plant types and a portion of a large equisetalean stem (Upadhyay *et al.*, 1999). The plant fossil bearing samples have yielded abundant palynomorphs of Early Permian age (Upadhyay *et al.*, 1999). The Karakoram microcontinent is not a part of the Indian Plate because it lies north of the Shyok and Indus Sutures. The Karakoram microcontinent was welded to Asia around 130-120 Myr ago (Dewey *et al.*, 1988) as part of Peri-Gondwanian collage with the southern margin of Asia (Upadhyay *et al.*, 1999). Unidentified plant remains have also been recorded by Norin (1946) from the Permian Horpatso Formation of western Tibet, deposited ~600 km further east of Chhongtash.

In a similar breakthrough Tongiorgi *et al.* (1994) recorded a sedimentary sequence of the Karakoram microplate which is overlying a granite pluton near Ishkarwaz (upper Yarkhun Valley, Chitral, Pakistan). This sedimentary sequence contains abundant acritarchs of the late early Arenig-early late Arenig (early Ordovician) interval. The palynological assemblages of Karakoram show a marked similarity to the cold water Peri-Gondwana assemblages; i.e., to those of Li Jun's *Arbusculidium-Coryphidium-Striatotheca* 'Mediterranean' Bioprovince (Tongiorgi *et al.*, 1994). Similarly, Amerise *et al.* (1998) recorded new acritarch samples from Vidkot locality, close to the Yarkhun River, to the southeast of Baroghil, Chitral in northwestern Pakistan. According to them the acritarch assemblages confirm the early Arenig age to the lowermost part of the succession. The upper age limit for younger stratigraphic levels at Vidkot could extend up to late Arenig on the occurrence of *Dicrodiacrodium* sp. cf. *D. normale* and *Arkonia tenuata*. The palynomorph assemblages from Vidkot also show clear affinity with the cool water Mediterranean microflora recorded earlier by Tongiorgi *et al.* (1994) from the Ishkarwaz.

Interestingly, while going back to the annales of geological exploration of western Tibet (Norin, 1946) it could be recapitulated that still there exists scant information as far as the floral and palynological records of Central Asian massifs are concerned. However, significant information regarding the presence of plant fossil bearing horizons of these remote regions have been arrived after the publication of a monograph by Norin in 1946. According to him, the Qara-Tagh Highland between the Chipchap Valley and the Qara-Tagh-Su in northewestern Tibet, Wyss (1940) has collected fossils from several Middle and Upper Jurassic horizons at a large number of places but, unfortunately, nothing has as yet been published about the stratigraphy (Norin, 1946). In April 1932, Norin crossed the Qara-Tagh over a pass situated only one or two km to the west of the Qara-Tagh-Davan of Visser and followed the narrow valley of Qara-Tagh-Su and Shu-Lunspo-Lungpa to the Qaraqash Valley. Near the pass where the tributary from pass joins the main valley follow black, richly plant-bearing shales which grade into light grey, gravelly sandstone with a basal conglomerates-several meters thick (Norin, 1946). This plant fossils bearing horizon is situated ~50 km NNE of the Karakoram Pass and ~90 km NNE from the Chhongtash locality from where Upadhyay *et al.* (1999) recorded Early Permian plant remains and palynomorphs. The following plant species were determined by Prof. Halle, Stockholm, in 1934 (Norin, 1946): *Neocalamites* (?) sp., *Klukia exilis*, *Sphenopteris* sp. (one small fragment rather similar to the Wealdon species *Sphenopteris* (*Ruffordia*) *goepperti*), *Cladophlebis* sp., *Nilssonia orientalis*, *Nilssonia* cf. *mediana*, *Ginkgo digitata*, *Ginkgo sibirica*, *Baiera* sp. (*B. gracilis*), *Podozamites lanceolatus*, *Pityophyllum* cf. *nordenskioldii*. This is a typical Mesozoic flora, probably Middle Jurassic (*Klukia*), though it may possibly be younger (Norin, 1946). In additional note on this floral assemblage in 1943, Halle states "According to Oishi (1940) and others, some of the species occur in beds assigned to the Upper Jurassic and even Wealdon. The species determined as *Klukia exilis* may possibly be identical with *Cladophlebis* (*Klukia* ?) *koraiensis* Yabe from the Upper Jurassic Tetori Series".

The development of the western Kun Lun (Norin, 1946) during the early Mesozoic is registered in thick deposits of continental sandstones, shales and conglomerates, the Yarkand Group of De Terra (1932) which are the molasse deposits of the rapidly decaying Variscan ranges (Norin, 1946). In the lower part of Yarkand Group occurs a bed of good coal about 0.5 m thick at the outcrop. The black shale associated with the seam contains plant fossils abundantly. In 1934, Prof. Halle, Stockholm, identified the following species (Norin, 1946): *Cladophlebis* sp., *Nilssonia* cf. *simplex* Oishi, *Nilssonia* or *Pterophyllum* sp., *Phoenicopsis speciosa, Pagiophyllum* ? sp. (cf. *Elatocladus heterophylla* Halle), *Problematicum*. The age of this flora is undoubtedly Mesozoic, most probably Jurassic (Norin, 1946). The upper division of the Yarkand Group begins with reddish sandy shales followed by yellow marls with a Lower or Middle Jurassic flora (*Coniopteris hymenophylloides*, *Taeniopteris vittata*, *T. de Terrae*, *Podozamites lanceolatus* and *Phoenicopsis* cf. *speciosa*). The coal bearing Mesozoic series appears again with entirely different facies near the top of the Kun Lun main range at the head of the Tisnaf Valley below Yangi davan (Norin 1946).

Therefore, on the grounds of above mentioned observations it could be deciphered that up to date there exists two localities of the Ordovician (Arenig) palynomorphs in the marine formation of NW Karakoram (Chitral, Pakistan, Togiorgi *et al.*, 1994; Amerise *et al.*, 1998), one locality of Early Permian plant fossils and palynomorphs in the marine Chhongtash Formation of the eastern Karakoram (Upadhyay *et al.*, 1999), one locality each of Permian and Jurassic plant fossils from the marine formations of the western and the northwestern Tibet (Norin, 1946) and one locality of Jurassic plant fossils bearing continental deposits in the Kun Lun (Norin, 1946).

REGIONAL TECTONIC FEATURES OF THE KARAKORAM, THE WESTERN TIBET AND THE KUN LUN

Based on geological information across western Tibet to Tarim traverse Matte *et al.* (1996) depicted that the Kun Lun was the site of a Mid-Palaeozoic collision. At least three phases of post-Palaeozoic accretion have thickened the blanket of sediments that covers western Tibet. A major part of western Qiangtang have remained stable, since the Mid-Mesozoic. Strike-slip motion along the Karakoram and Altyn Tagh faults has been coeval with overthrusting in the Himalayas and Kun Lun. Such slip partitioning and the volcanism, appear to result simply from northward subduction of India and southward subduction of the Tarim as Tibet is extruded eastwards by India's penetration into Asia (Matte *et al.*, 1996).

Recent geological investigations across Nubra-Shyok River valleys in northern Ladakh (Upadhyay *et al.*, 1999; Chandra *et al.*, 1999) suggest that similarity exists between the Shyok Suture of northern Ladakh and the Northern Suture of Kohistan. It is likely that the Kohistan and the Ladakh units evolved as a single tectonic domain during the Cretaceous-Palaeogene. The Shyok Suture is older than the Indus Suture and closed sometimes between 100-75 Ma. The accretionary processes in the Karakoram region began prior to the final closure of the Indus Suture. Subsequently, collision, suturing and accretion of the Indian Plate along the Indus Suture Zone (50-60 Ma) and the formation of the Nanga Parbat-Haramosh syntaxis separated Kohistan and Ladakh. The different phases of magmatic growth in the Ladakh and the Karakoram have acted as a role of stitching pluton to bind the Indian and Asian plates together. The Holocene-Recent dextral offset along the Karakoram-fault reshaped and rejuvenated the tectonic structures and the architecture of the entire Karakoram, the Shyok Suture and the adjoining Indian Plate region.

The active Karakoram fault with ~120 km dextral offset can be traced along the Shyok Suture in northern Ladakh and adjoining Karakoram and extends further north-west to Pamir. This active, normal-dextral fault is the greatest geomorphic boundary between the Ladakh, Karakoram and western Tibet. The northern segment of the Karakoram fault terminates in the extensional Muji Basin along the border between Tadjzhikistan and Xinjiang (Searle, 1996). Based on geochronological data Zhou *et al.* (2001) indicated that the Karakoram strike-slip faulting occurred from 6.88±0.36 to 8.75±0.25 Ma. The cumulative displacement from Muztag Ata to Muji is about 135 km. The dextral strike-slip offsets of the central part of the Karakoram fault have been accommodated in the north by three splays arcing westward through the central Pamir: the Rangkul, Murghab and Karasu faults (Searle, 1996). In the central Karakoram ranges of north Pakistan and the Shaksgam region of southern Xinjiang, the Karakoram fault slices through the

Permian and early Mesozoic sediments of the north Karakoram terrain and the Karakoram batholith (Desio, 1979; Searle, 1991). The fault runs along the Shaksgam Valley, north of the highest peaks of the Karakoram-K2, Broad Peak and the Gasherbrum range. Across the border in northern Ladakh, the alignment of the 70 km-long Siachen Glacier and the Nubra-Shyok Valley into which it flows has been controlled by the Karakoram fault (Upadhyay, 2001). Based on Ar/Ar dating of micaceous segregation of the sheared Karakoram batholith exposed along the Nubra Valley, Bhutani and Pande (2002) suggested that the age of activation of Karakoram fault in this region is 13.9±0.1 Ma. The slip rate on the Karakoram fault as inferred by Gaur (2002) using GPS Geodesy and cosmic ray exposure ages of an offset debris flow in Ladakh, are ~4 mm/yr. Along the western margin of Pangong Tso Lake, the Karakoram fault splays into two main branches. The eastern splay appears to control, by damming, the outflow channel of the lake, which itself is a drowned river valley (Searle, 1996). There is abundant structural evidence of dextral shear to the south of Pangong Lake in the Nganglong Kangri range, with foliations swinging into alignment with the Karakoram fault (Searle, 1996). Armijo *et al.* (1989) suggested that the Shiquanhe fault branching off the Karakoram fault, transferred displacement along the northern part to a system of minor strike-slip faults and rifts in west central Tibet.

Further southeast, along the floodplains of the Indus and Gar rivers, the NW striking, steeply NE dipping Karakoram fault marks the base of the Ladakh range front. Cumulative scarps tens of meters high across Late Pleistocene moraines, 2 km high triangular facets, and perched glacial valleys attest to rapid vertical throw on the fault (Matte *et al.*, 1996). Dextral offsets of 300-400 m of post-glacial fans and channels imply a Holocene slip rate of the order of 3 cm/yr (Liu Qing, 1993). Such motion has produced the conspicuous ~120 km offset of the Indus River course (Searle, 1996; Liu *et al.*, 1993; Gaudemer *et al.*, 1989). Recent uplift along the fault has exhumed strongly sheared gneisses parallel to the active fault trace in the region.

Acknowledgements—*We would like to thank Department of Science and Technology, Government of India for the generous support received to successfully complete the Karakoram Project No. ESS/CA/A9-32/93. RU is grateful to the CSIR, New Delhi for providing financial assistance for research under its Scientists' Pool Scheme and to the authorities at the Birbal Sahni Institute of Palaeobotany, Lucknow for providing facilities for carrying research at the BSIP Lucknow. Careful reviews by Prof. Maurizio Gaetani and an anonymous reviewer have much improved the submitted version of this manuscript.*

REFERENCES

Amerise C, Quinatavalle M & Tropepi R 1998. Palynological dating (Arenig) of the sedimentary rocks overlying the north Karakorum crystalline basement near Vidkot, Chitral, Pakistan. CIMP Newsletter 55: 25-26.

Armijo R, Tapponnier P & Tonglin H 1989. Late Cenozoic right-lateral strike-slip faulting in southern Tibet. Journal of Geophysical Research 94: 2787-2838.

Auden JB 1938. Geological results. *In*: Shipton E (Editor)—The Shaksgam Expedition 1937. Geographical Journal 91: 335-336.

Bagati TN, Rai H, Kumar R & Juyal KP 1994. Expedition report on the Geology of Eastern Karakoram, India. Journal of Himalayan Geology 5: 56-92.

Bhutani R & Pande K 2002. 40Ar-39Ar age of the Karakoram fault activation: simultaneity with extensional regime in Tibet. Journal of Asian Earth Sciences Special Suppliment 20: 4.

Blanford WT 1878. "Scientific results of the second year and mission" geology based upon the collection and notes of the Late Ferdinand Stoliczka, Calcutta.

Buchroithner M & Gamerith H 1986. On the geology of the Tirich Mir area, Central Hindu Kush (Pakistan). Jahrb Geologische Bundesanstalt 128: 367-381.

Chandra R, Upadhyay R & Sinha AK 1999. Subduction and collision related magmatism in the Shyok Suture and eastern Karakoram. Palaeobotanist 48: 183-209.

Chang CF, Shackleton RM, Dewey JF & Yin J 1988. The Geological Evolution of Tibet, reports of the 1985 Royal Society-Academia Sinica geotraverse of the Qinghai-Xixang Plateau. Philosophical Transactions Royal Society London A327: 1-413.

Dainelli G 1932. "My expedition in the Eastern Karakoram 1930" Himalayan Journal IV: 46-54.

Dainelli G 1933. La Serie dei terreni, in Relazioni Scientifiche della Spedizione Italiana De Filippi nell Himalaia, Caracorume Turchestan Cinese (1913-1914, II, v. 2, Bologna, Zanichelli, 458-542.

Deasy HHP 1901. In Tibet and Chinese Turkestan, London.

Debon F, Le Fort P, Dautel D, Sonet J & Zimmermann JL 1987. Granites of western Karakorum and northern Kohistan (Pakistan): a composite Mid-Cretaceous to upper Cenozoic magmatism. Lithos 20: 19-40.

De Filippi F 1912. "La Spedizione nel Karakorum e nall Imalaia occidntiale 1909" with appendix by Novarese: V. on the Geology of Bologua.

De Terra H 1932. "Geologische Forschunge in Westlischen Kun-Lun und Karakorum-Himalaya", Wissensch Ergebn. d. Dr. Trinklerschen E4. Zentralasien Expedition. Reimer and Vohsen, Verlin, II: 1-196.

Desio A 1930a. Itinerari Geologici Percorsi durante la Spedizione Geografica Italiana nel Karakorum, 1929. Appunti geologici e geografici, Bullettin Royal Society of Geography Italy, Roma 7: 163-181.

Desio A 1930b. Geological work of the Italian Expedition to the Karakoram. Geographical Journal 75: 402-411.

Desio A 1936. La Spedizione Geografica Italiana nel Karakorum. Storia del Viaggio e Risultati eografici. *In*: Colloquium Conference Aimone di Savoia Aosta Duca di Spoleto, Arti Grafiche Bertarelli, Milano: 1-620.

Desio A 1974. Karakoram Mountains. Geological Society London, Special Publication 4: 255-266.

Desio A 1977. The work of the Italians in the scientific exploration of the Karakorum (central Asia). Accademia Nazionale Dei Lincei, Roma 231: 1-22.

Desio A 1979. Geological evolution of the Karakoram. *In*: Geodynamics of Pakistan, Geological Survey of Pakistan: 111-124.

Desio A 1980. Geology of the Upper Shaksgam Valley, North-East Karakoram, Xizang (Sinkiang), Italian Expedition to The Karakorum (K2) and Hindukush, Prof. Ardito Desio leader, scientific report, Brill, Leiden, III 4: 1-196.

Desio A, Caporali A, Gaetani M, Gosso G, Palmieri F, Pognante U & Rampini L 1991. Geodesy, geophysics and geology of the upper Shaksgam valley (NE Karakoram) and south Sinkiang. EV-K2-CNR, Italian expedition to the Karakoram, 1988, Scientific reports, Consiglio Nazionale delle Ricerche, Milano (Italy): 1-201.

Dewey JF, Shackleton RM, Chang Cheng Fa & Sun Yiyin 1988. The tectonic evolution of the Tibetan Plateau. Philosophical Transactions Royal Society London A327: 379-413.

Fantini Sestini N 1965. Permian fossils of the Shaksgam valley, Italian Expedition to the Karakoram (K2) and Hindukush, Prof. A, Desio leader, Scientific Reports, Brill. Leiden 4: 149-215.

Gaetani M 1997. The Karakorum Block in Central Asia, from Ordovician to Cretaceous. Sedimentary Geology 109: 339-359.

Gaetani M, Jadoul F, Nicora A, Tintori A, Pasini M & Kanwar SAK 1990a. The north Karakoram side of the Central Asia geopuzzle. Geological Society America Bullettin 102: 54-62.

Gaetani M, Gosso G & Pognante U 1990b. A geological transect from Kun Lun to Karakorum (Sinkiang, China): the western termination of the Tibetan Plateau, Preliminary note. Terra Nova 2: 23-30.

Gaetani M, Le Fort P, Tanoli S, Angiolini L, Nicora A, Sciunnach D & Khan A 1996. Reconnaissance geology in Upper Chitral, Baroghil and Karambar districts (northern Karakorum Pakistan). Geologische Rundschau 85: 683-704.

Gaudemer Y, Tapponnier P & Turcotte DL 1989. River offsets across active strike-slip faults. Annales Tectonics 3: 55-76.

Gaur V 2002. Convergence rates across the Western Himalayan, determined from GPS measurements and cosmic ray exposure dating of debris flows and moraines. Addenda Abstracts 17th Himalayan-Karakoram-Tibet Workshop (Gangtok, Sikkim, 25-27 March, 2002): 17-20.

Gergan JT & Pant PC 1983. Geology and stratigraphy of Eastern Karakoram, Ladakh. *In*: Thakur VC & Sharma KK (Editors)—Geology of Indus Suture Zone of Ladakh: 99-106. Wadia Institute of Himalayan Geology, Dehradun, India.

Godwin-Austin HH 1884. The mountain systems of the Himalaya and neighbouring ranges. Proceedings of Royal Geographical Society London 6.

Hayden HH 1915. Notes on the geology of Chitral, Gilgit and the Pamirs. Records Geological Survey of India 45: 271-335.

Hedin S 1904-1907. Scientific results of a journey in central Asia 1899-1902. I-VI, Maps I-II, Stockholm.

Hedin S 1917-1922. Southern Tibet. I-IX, Atlas of Maps I-II, Stockholm.

Kafarskyi KA & Abdullah J 1976. Tectonics of north-east Afghanistan (Badakhstan, Wakhran, Nurestan) and relationship with the adjacent territories. Atti Convegni Lincei Roma 21: 87-113.

Leeder MR, Smith AB & Jixiang Y 1988. Sedimentology, palaeoecology and palaeoenvironmental evolution of the 1985 Lhasa to Golmud Geotraverse. Philosophical Transactions Royal Society London A327: 107-143.

Liu Q, Tapponnier P, Bourjot L & Zhang Q 1993. Kinematics of recent faulting along Muji-Tashkorgan graben, northern extension of the Karakoram fault. European Union of Geosciences VII, Strasbourg, France: 4-8.

Lydekker R 1883. The geology of the Kashmir and Chamba Territories and the British district of Kaghan. Memoir Geological Survey of India 22: 223-244.

Mason K 1938. Karakoram nomenclature. Himalayan Journal 10: 86-125.

Matte P, Tapponnier P, Arnaud N, Bourjot L, Avouac JP, Vidal P, Qing Liu, Yuaheng Pan & Wang Yi 1996. Tectonics of western Tibet, the Tarim and Indus. Earth and Planetary Science Letters 142: 311-330.

Norin E 1946. Geological Exploration in Western Tibet. Report of Sino-Swedish expedition, Stockholm, Sweden, Aktiebolaget Thule 29: 1-240.

Oishi S 1940. The Mesozoic flora of Japan. Journal Faculty of Science Hokkaido Imp. University Series IV, V: 2-4.

Parrish RR & Tirrul R 1989. U-Pb age of the Baltoro granite, northwest Himalaya, and implications for zircon inheritance and monazite U-Pb systematics. Geology 17: 1076-1079.

Pevtsov MV, Boganovich KU, Kozlov PK & Roborovski VY 1892-1896. Results of the Tibet expedition 1889-1890, under the leadership of Pevtsov MV. I-III, St. Peterburg.

Rai H 1991. The Shyok valley (Northern Ladakh, India): An entrapped and compressed marginal oceanic basin. Journal of Himalayan Geology 2: 1-15.

Rolland Y, Picard C, Pecher A, Carrio E, Sheppard MF, Oddone M & Villa IM 2002. Presence and geodynamic significance of Cambro-Ordovician series of SE Karakoram (N Pakistan). Geodinamica Acta 15: 1-21.

Ruzhentsev SV & Shvolman VA 1981. Tectonic zoning of the Pamirs and Afghanistan. In: Sinha AK (Editor)—Contemporary Geoscientific Researches in Himalaya, BSMPS Publication Dehradun 1 : 53-59.

Searle MP 1991. Geology and Tectonics of the Karakoram Mountains. John Wiley and Sons Chichester, 358p.

Searle MP 1996. Geological evidence against large scale pre-Holocene offsets along the Karakoram fault: Implications for the limited extrusion of the Tibetan plateau. Tectonics 15: 171-186.

Shvolman VA 1981. Relicts of the Mesotethys in the Pamirs. Himalayan Geology 8: 369-378.

Sinha AK 1997. The concept of terrane and its application in Himalayan and adjoining region. *In*: Sinha AK, Sassi FP & Papanikolaou D (Editors)—Geodynamic Domains in Alpine Himalayan Tethys: 1-44. Oxford and IBH Publication Company Private Limited, New Delhi/A.A. Balkema, Rotterdam.

Sinha AK & Upadhyay R 1997. Tectonics and sedimentation in the passive margin, trench, forearc and backarc areas of the Indus Suture zone in Ladakh and Karakoram : a review. Geodinamica Acta 10: 1-12.

Sinha AK, Rai H, Upadhyay R & Chandra R 1999. Contribution to the geology of the eastern Karakoram, India. Geological Society of America Special Paper 328: 33-44.

Srimal N 1986. India-Asia collision : implications from the geology of the eastern Karakoram. Geology 14: 523-527.

Stoliczka F 1865. A brief account of the geological structure of the hill ranges between the Indus valley in Ladakh and Shahdula on the frontier of Yarkund Territory. Records Geological Survey of India 7: 12-15.

Survey of India 1922. Triangulation of India and Adjacent Countries (Data complete to 1921). Sheet 52A, Office of the Trigonometerical Survey, Dehradun.

Thakur VC 1981. Regional framework and geodynamic evolution of the Indus Tsangpo Suture Zone in Ladakh Himalayas. Transactions Royal Society of Edinburgh, Earth Science 72 : 89-97.

Thakur VC & Misra DK 1984. Tectonic framework of Indus and Shyok suture zones in eastern Ladakh, NW Himalaya. Tectonophysics 101 : 207-220.

Tongiorgi M, Di Milla A, Le Fort P, & Gaetani M 1994. Palynological dating (Arenig) of the sedimentary sequence overlying the Ishkarwaz granite (Upper Yarkhun valley, Chitral, Pakistan). Terra Nova 6 : 595-607.

Upadhyay R 2001. Seismically induced soft sediment deformational structures in the Shyok Valley, northern Ladakh and eastern Karakoram, India. Current Science 81 : 600-604.

Upadhyay R, Sinha AK, Chandra R & Rai H 1999. Tectonic and magmatic evolution of the eastern Karakoram, India. Geodinamica Acta 12: 341-358.

Upadhyay R, Chandra R, Sinha AK, Kar RK, Chandra S, Jha N & Rai H 1999. Discovery of Gondwana plant fossils and palynomorphs of Late Asselian (Early Permian) age in the Karakoram Block. Terra Nova 11: 278-283.

Upadhyay R, Chandra R, Rai H, Jha N, Chandra S, Kar RK & Sinha AK 1999. First find of the Early Permian Lower Gondwana plant remains and palynomorphs from the Chhongtash Formation (Upper Shyok Valley), eastern Karakoram, India. Palaeobotanist 48: 7-18.

Visser Ph C 1934. The Karakoram and Turkestan Expeditions of 1929-30. Geographical Journal 84: 1-821.

Von Schlagintweit HA & Von Schlagintweit R 1861-66. Results of a scientific mission to India and High Asia 4, Atlus Trubner, London.

Wyss R 1940. Geologie. *In:* Visser C & Visser-Hooft J (Editors)—Wissenschaftliche Ergebnisse der Niedarlandis chen expedition in den Karakoram, 1922, 1925, 129-30, 1 nd 1935, usw, Bed III, Leiden, E. Brill, 2: 1-548.

Zanchi A 1993. Structural evolution of the North Karakorum cover, North Pakistan. *In:* Treloar PJ & Searle MP (Editors)—Himalayan Tectonics, Geological Society London Special Publication 74: 21-38.

Zanchi A, Gaetani M & Poli S 1997. The Rich Gol Metamorphic Complex: evidence of separation between Hindu Kush and Karakorum (Pakistan). CR Academy of Science Paris 325: 877-882.

Zhou Y, Xu R, Yan Y & Pan Y 2001. Dating of the Karakorum strike-slip fault. Acta Geologica Sinica 75: 10-18.