CHAPTER ONE

Introduction
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Prologue

The Indus-Tsanjpo Suture Zone is a crustal megalineament that is regarded by some (Le Fort, 1975; Molnar and Tapponnier, 1975; Gansser, 1977) as representing the boundary between the Indian plate and the Eurasian plate. The suture extends from Hindu Kush mountains of Afghanistan in the west to Mishmi hills of Assam in the east over a distance of more than 2500 km. It is supposed to be representing a palaeosubduction zone along which ophiolitic rocks have been obducted on to the continent. The ophiolites of this belt constitute the Indus Ophiolite Belt of the Indian stratigraphy.

The rocks of this belt are characterised by the presence of ophiolites and ophiolitic melanges, plutonic volcanic rock associations, and flysch and molasse sediments. The lithounits are best exposed in Ladakh, where a complete geological section through the northwestern part of the Himalayas from Kashmir to Tibet can be observed. It is for this reason, the Ladakh region of Kashmir has attracted the attention of geologists from world over, for more than a century.

From the review of literature it was found that the ophiolites along this suture occur discontinuously and host rich chromite deposits at certain localities. Considering the areal extent of these rocks, it was felt that the ultramafic suite of this ophiolite may be a potential source of chromite in future. It was also apparent from the literature, that, although a lot of work on different aspects of the geology of Indus Suture Zone has already been carried out by both, the Indian and foreign geologists, the ultramafic rocks of this belt and the associated chromite deposits have not received the attention they deserve, both as regards their petrology as well as the genesis of chromite.
mineralisation. Consequently, not much information regarding the geological setting, the mode of occurrence, the controls of ore localisation, mineralogy and genesis of these deposits is available so that it can be used for developing the known deposits and in discovering new ones. The author, therefore, decided to study the petrography and the geochemistry of the ultramafic rocks and the associated chromite deposits.

Ophiolite Concept

The term ophiolite originates from Greek root "Ophi" meaning a snake or serpent. As the sheared serpentinites from orogenic belts have a green shiny surface with a snake-skin-like texture, these rocks were called "Ophiolites". Benson (1926) in a survey of basic and ultrabasic rocks introduced the term Alpine-type to include ophiolites and similar bodies in orogenic belts. The ultramafic rocks from orogenic belts were also referred to as 'green rocks' by Sues (in Carmichael, 1974), and these along with other rocks were included under Alpine-type ultramafics (Benson, 1926). Steinmann (1926), recognised a group of closely associated rocks, represented by serpentinites, gabbros, suillites and amphibolites and collectively called them "ophiolites". Just as the term was used as a group name, it was also used as a field term for
convenience during mapping and within it, were included rocks as diverse as cherts, pillow lavas and serpentinites. Thus the term ophiolite was very loosely used for many kinds of rocks.

In 1972, the Geological Survey of America, Penrose Field Conference (Anon., 1972) formulated the currently accepted definition of the term, "ophiolite", which includes a distinctive assemblage of mafic to ultramafic rocks. It was also suggested that the term should not be used as a rock name or a lithological unit. The modern consensus of view on ophiolites is that they represent segments of the ocean floor. This concept evolved after the development of the sea floor spreading hypothesis. This hypothesis requires that new oceanic lithosphere generates at spreading centres.

Recent work on the ocean floor mainly based on the efforts of JOIDES Deep Sea Drilling Program (D.S.D.P.) and seismic refraction studies indicated that oceanic lithosphere is made up of a four layered structure. Various models have been proposed to explain this layering. One of the model, proposed by Hess (1962) is called the igneous model and is illustrated in Fig. 1.1. As more and more data were accumulated on structure, petrology, igneous stratigraphy, associated sediments on ocean floor and the ophiolitic rocks, it was realised that many of the on-land mafic-
Fig 1.1: Structure of the oceanic crust.

(after Coleman, 1977)
ultramafic ophiolite suite of rocks were compatible with the igneous model of the oceanic crust. It is now widely accepted that ophiolites represent remnants of the oceanic lithosphere which has been tectonically emplaced or obducted onto continental or island-arc margins (Dietz, 1963; Gass, 1968; Coleman, 1971; Dewey and Bird, 1971). Ophiolitic rocks are now recognised along ancient sutures which represent the site of palaeoocean basins which have since been vanished by consumption of oceanic crust along destructive margins or subduction zones.

The ophiolites today are found in various types of settings. They are found located with continental crust on both sides, viz., the Vourinos Complex in northern Greece (Moores, 1969), Bay of Imlind Complex in Newfoundland (Church and Stevens, 1971) and such other areas. However, in other parts of the world such as Papua and New Caledonia (Coleman and Irwin, 1974) the ophiolites have been thrust on to a continental margin at the same time being attached to the oceanic plate from which they may have been derived (Kothery, 1982). There are other occurrences such as those in Troodos Massif in Cyprus (Gass, 1968) and Macquarie Island (Varne and Rubenach, 1973) where the ophiolites appear to be autochthonous and represent uplifted portions of the ocean floor.
In a completely developed ophiolite such as the Troodos Complex in Cyprus (Moores and Vine, 1971) four rock units are recognised in order of ascending stratigraphic position.

(i) Ultramafic Complex: made up of peridotites and dunites which usually exhibit a metamorphic tectonic fabric.

(ii) Gabbroic Complex: made up of peridotites and gabbros which are layered at the base and grade upwards into isotropic gabbros. They are intruded by trondhjemites and felsites.

(iii) Sheeted-dyke Complex: made up of low-K tholeiitic diabase dykes which generally have one chilled margin.

(iv) Volcanic Complex: Constituting low-K tholeiitic pillow lavas.

These rock units are generally associated with sedimentary rocks represented by bedded cherts, shales, and minor carbonates. The contact of the gabbroic complex and the underlying ultramafic complex is usually interpreted as the "Fossil Moho". This
layered sequence compares well with the model of the oceanic crust proposed on the basis of geological and geophysical evidences (Kondie, 1979).

There is a growing uncertainty that ophiolites may not be characteristic of the present day oceanic crust that forms the basement for the great ocean basins such as the Pacific, Atlantic and Indian ocean (Coleman, 1984; Hall, 1983; Moore, 1982). However, on careful observations, it becomes apparent that all ophiolites are the result of a common igneous process. They all have been generated in areas of extension and have been derived from basaltic magmas that formed in the upper mantle. The absence of older continental crust and the presence of tectonised depleted peridotitic mantle at their base points to their formation at spreading centres.

Recent studies of these rocks in various parts of the world have shown that the ophiolites generate in diverse tectonic setting. Using actualistic concepts various tectonic settings have been recognised for the development of oceanic crust. The ophiolites are today considered to develop along spreading centres such as (i) Mid-ocean ridges, (ii) Back-arc basins (iii) Fore-arc basins and (iv) Small ocean basins.
The Indus Ophiolite is a dismembered ophiolite that occurs along the Indus Suture Zone of Ladakh and forms a part of the Tethyan ophiolite belt. This ophiolite belt extend westwards into Pakistan and Afghanistan, and towards east it continues in Assam and southwards into the Bay of Bengal, where it is exposed on Andaman and Nicobar Islands. The ophiolites of this belt are believed by some (Dewey and Bird, 1970; Powel and Conaghan 1973b, 75) to have been emplaced on to the continent by obduction during continent-continent collision along a Himalayan-type margin. According to others (Shankar et al., 1976; Frank et al., 1977; Tahirkheli et al., 1979) they are the result of collision of an island-arc and a continent along an Irian-type margin (Valdiya, 1984).

Previous Work

The earliest reference to the geology of the area is by Stoliczka (1866), who studied sections between river Sutlej to Indus. Later, Drew (1875) and then Lydekker (1883) studied the geology of Kashmir and Chamba territories.

Oldham (1883), Hayden (1907) and Middlemiss (1911) have also made some contributions to the geology of this area. McMohan (1901) studied the petrography of the ultramafic rocks from Ladakh. In 1913-14 an Italian expedition led by Pillioppi studied parts of this
area. The important results of the expedition were published by Dainelli (1934). Until this time very little was known about the geology of the area and the available information was very scanty.

The period 1935 onwards was a turning point in the geological exploration in this area. De Terra (1935) may be sighted as a pioneer worker who for the first time recognised flysch deposits in Kargil area. He also gave an account of the volcanic rocks occurring along this belt. The volcanic rocks from Ladakh were also described by Auden (1935). With this available information Wadia (1937) carried out systematic mapping in Burzil-Astor-Deosai area of the Indus Belt. He named these volcanics as 'Dras Volcanics' and suggested a lower Cretaceous to Cenomanian age for the extrusives on the basis of fossil 'Orbitolina' recovered from the limestone bands and lenses that occur within the volcanic rocks. Other contributions to the geology of the area are by Auden (1928) and Norin (1946).

Then came the classic work of Heim and Gansser (1939). They undertook two excursions in this region particularly from Manglang pass to as far as north of Kailas and from Balchadhura to upper Sutlej that is from Himalaya to Trans-Himalaya (Tibet). Their excellent work on the geology of this area laid down a
foundation for future work. They reported exotic blocks within Tertiary lavas, Triassic and older formations in place of Tertiaries and counter thrust of contorted metamorphic flysch over the non-metamorphic horizontal Kailas conglomerate. They also described the ophiolitic melange belts of Kiogar, Junjba and Amlanj-La in southern Tibet.

Gansser (1959, 64, 74, 77) was the first worker who developed the concept of Indus Suture Line, which represent a line of collision between the Indian and the Eurasian plate. He adopted the term 'ophiolitic melange' and applied it for the peridotites of the 'Indus Tectonic Belt', which is represented by narrow steeply dipping thrusted bands of peridotites and associated rocks. It is now widely accepted that the Indus Suture Zone (Thakur, 1981) represents the site of Cretaceous subduction along which large portion of Tethyan oceanic crust was consumed (Dewey and Bird, 1970; Powel and Conaghan, 1973; Gansser, 1977; Bally et. al, 1980; Shackleton, 1981). Discoveries of high pressure metamorphic belt represented by glaucophane bearing schists associated with ophiolitic melange zones in Ladakh, supports the above contention. (Frank et al., 1977; Virdi et al., 1977).
Since about 1970 a lot of information on the various aspects of the geology of the Indus Suture Zone is available. This has been mainly due to the efforts of the Geological Survey of India, Wadia Institute of Himalayan Geology, establishment of Academia Sinica exchange programme with French geologists and opening of the Indian part of western Tibet i.e., Ladakh to foreign geologists. As a result, a number of English language synthesis of Chinese geology have become available (Bally et al., 1980; Schackleton, 1981). The western part of the Indus Suture Zone, in Pakistan has also been studied by Pakistani and British geologists under a joint project. A number of publications have appeared on the geology of Kohistan-Karakoram area (Tahirkheli and Jan, 1979; Coward, 1982).

Stratigraphy and evolution of the Indus Suture Zone has been worked out in considerable details by the geologists of the Geological Survey of India and Wadia Institute of Himalayan Geology. The earliest effort to evaluate the stratigraphy of the area was by Gupta and Kumar (1975), number of general, regional studies have been also carried (Tewari, 1964; Nanda and Singh, 1977; Shah et al., 1976; Shankar et al., 1976; Frank et al., 1977; Fuschs 1977, 1979; Sharma and Kumar, 1978). Srikantia and Dhargava (1978), and Srikantia and Raxdan (1980).
carried out detailed mapping along this belt and revised the stratigraphy of the region. They suggested that rock formations of the Indus Tectonic Belt (Srikantia and Bhargava, 1978) which is equivalent to Indus Tectonic Zone of Srikantia and Kazadan (1980) form two separate belts. The lithological units comprising them being designated as the Indus Group in the northern part and the Sangeluma Group in central Ladakh. The latter group contains ophiolitic rocks along with the sediments and is equivalent to the Dras Volcanic Group of Searle (1983) and to the Sumdo Formation of Shankar et al., (1974, 1976) and Sirkantia and Bhargava (1978).

Geochemistry of the Dras Volcanics has been investigated by Gergan (1978), Shah and Gergan (1978), Gupta et al., (1982) and Honegger et al., (1982). On the basis of these studies they proposed an island-arc origin for the volcanics. Radhakrishna et al., (1983) studied the geochemistry of the ultrabasic and volcanic rocks from Dras and suggested a cumulate origin for the ultramafic rocks.

Prasad et al., (1976-80) assessed the economic potentialities of the chromite deposits associated with the ultramafic rocks of this belt. Vardarajen and Jhingran (1977) and Varadrajan (1965) studied the petrochemistry of the ultramafic rocks and associated chromite deposits.
from Dras-Tasgham area. Varadarajan (1985) suggested that the ultramafites form a zoned ultrabasic complex and are intrusive within the Dras Volcanics. He classified the chromite deposits as of Alaskan-type formed by fractional crystallisation and gravity settling under turbulent magmatic conditions.

The petrology of the gabbroic rocks associated with the ultramafics from Chainiyund and Kargil has been studied by Rai and Pande (1983).

In recent years a number of workers have attempted radiometric dating of the rocks from the Indus Suture Zone. Sharma et al. (1978) reported a K-Ar whole rock age of 77.5 ± 1 Ma. for a Dras Volcanic rock from Chiktan nala.

The granitic rocks along this belt constitute the Ladakh Plutonic Complex (Gansser, 1979) and corresponds to the Kailas Tonalite Complex of Kumaun, south Tibet (Heim and Gansser, 1939) and the Kangdese magmatic belt, south of Lhasa (Shackleton, 1981). It is generally referred to as the Ladakh Batholith or the Trans-Himalayan Batholith. Compositionally the intrusion varies from tonalite and granodiorite to granite, although most of the batholith appears to be a biotite-or hornblende-rich granodiorite. Radiometric dating on
the rocks of the Ladakh Plutonic Complex have been dated Cretaceous to Eocene age. Saxena and Miller (1972) gave a K-Ar age on biotite of 48.4 ± 1.7 Ma. Brookfield and Reynolds (1981) reported two 40 Ar /39 Ar ages of 42 and 39 Ma. Desio (1973) quotes Rb-Sr ages of 48 and 38 Ma for the Ladakh-Deosai batholith in Pakistan, and an 40 Ar /39 Ar age range of 56-40 Ma for the rocks near Gilgit. Honegger et al., (1982) reported Rb-Sr age on micas and K-Ar ages for the same samples. Age of Ladakh granite of Shey varies between 45 and 60 Ma and that at Mount Somau near Kargil is between 70 and 79 Ma. Zircons from biotite-granodiorite from Kargil gave a U-Pb date of 103 ± 3 Ma. (Honegger et al., 1982).

Recent expeditions by Chinese geologists in Tibet (Compilation group 1976; Cheng-Chieng Fa et al., 1977, Huon Chincheng, 1977) have shown that Alpino-Himalayan tectonics extend into Tibet and far into Central Asia. Powell (1979) has proposed a 'Greater India' whose northern continental margin lies approximately 150 km north of southern edge of the Tibetan plateau. Stocklin (1980) includes Tibet in the vast 'Tethys Himalayan domain' extending from Iran Afghanistan to the Himalaya and Tibet. These suggestions are related with Crawford's (1974) interpretation of the Indus Suture Zone. According to him the 'Indus Suture Line' is an intracontinental
mantle reaching fracture of Permian to Jurassic age and does not represent the junction between Indian and Eurasian plates.

**Purpose of Work**

It is clear from the review of previous work, that most of the studies have been restricted mainly to sedimentology and to work out the stratigraphy of this belt. Petrology of the granitic rocks has also received considerable attention. However, the mafic and ultramafic rocks of this belt although described have not received the attention they deserve. The petrography and the major and trace element geochemistry of the ultramafic rocks of the belt have not been subjected to detailed scrutiny. Moreover, the chromite deposits associated with the ultramafic rocks, have also not received due attention from earlier workers. The different aspects of these deposits such as the geological setting, the mode of occurrence, the controls of ore localisation, the texture and structures, mineralogy, classification and the genesis have not been studied in detail. The purpose of the present work, therefore, was to study all these aspects.

**The Area**

In an attempt to study all the aspects of these rocks outlined above, an area in northwestern
Ladakh, where the ophiolites and the associated chromite deposits are best developed and exposed was selected. From the location map (Fig. 1.2) it is seen that the area is situated in the extreme north of the Indian territory. It is included in the Survey of India topographic sheet Nos. 47 N 15, 52 B/2, B/7 and B/11 and is bounded by longitudes $75^\circ 43'$ and $76^\circ 32'$ E and Latitudes $34^\circ 22'$ and $34^\circ 27'$ N. Towards north the area is bounded by the Pakistan territory and towards the south by the mountain ranges of Great Himalaya. Thus, the area is a almost E-W running narrow belt that extends from Dras in the west to Lamayuru in the east.

The area is approachable either by road or by air. The Srinagar - Leh road is the only all weather road which connects the important localities from the area. The western most of these localities is the Dras village which is about 146 km northeast of Srinagar, the capital of Jammu and Kashmir. The easternmost locality Lamayuru is about 315 km from Srinagar. The other important localities from the area which are situated between Dras and Lamayuru are Karjil, Pashkyum, Shergol and Mulbekh.

The area can also be approached by air. The Indian Airlines operates a regular flight service from
Srinagar to Leh. From Leh the area is only approachable by Leh-Srinagar road. The easternmost locality Lamayuru is about 125 km west of Leh.

Climate

The Ladakh region of Jammu and Kashmir of which the area forms a part can be categorised in general as a cold desert which is situated at an altitude of 4000 to 5000 m above MSL. Being at high altitude the oxygen percentage in the air is less than 16 per cent. The area enjoys two climatic seasons, summer and winter. The summer extends for a period of five months from May to September by then winter starts to set in. The rest of the year from October to April is an intense freezing winter. The diurnal variation in temperature is extreme. During summer the maximum temperature at mid-day is about 32 to 40°C while the night temperature are anywhere between zero to -4°C. The temperatures during the winter are generally subzero. At Dras, which is the second coldest place on earth, after Siberia, the minimum temperature recorded during the winter of 1986 was -70°C. The precipitation in the area is mainly as snow-fall. Rainfall is very scanty. The total rainfall during the year is not more than 10 mm. During the major part of the year the area is covered by glacial ice sheets which clear of from the lower reaches of
mountains during mid-summer i.e., the months of July/August. However, during summer remnant patches of ice can be seen in the river valleys and on the valley slopes. Especially on way to Dras from Srinagar, the road is cleared through thick ice cover which is seen at many places along the road sections. The geology along the valleys therefore, is generally concealed by fluviolacustrine deposits which occur as river terraces. It is only along the higher reaches that the rock exposures are available. The area does not have any vegetation. Few shrubs and occasional trees can be seen along the cultivated river terraces. The cultivation is mainly of rice (Oryza Sativa) some vegetables such as potatoes (Solanum tuberosum), onion (Allium cepa L.) etc. are also grown.

Method of Study

The present study was undertaken to investigate all the aspects of the chromite mineralisation and the ultramafic host rocks. For the purpose of present investigation the northwestern part of the Indus Ophiolite Belt was selected. It is a linear tract roughly extending from Dras in the west to Lamayuru in the east. Representative areas from this belt were carefully selected. Those areas, where the mafic and ultramafic rocks of the ophiolite are best exposed were carefully
chosen and further studies were concentrated only to these areas. Field work was carried out along some selected systematic traverses, which were planned and executed within limits permissible by the ruggedness of the terrain and vagaries of climate. The traverses were mainly restricted to foot and mule tracks and to the road and stream cuttings.

The area was studied with the help of panchromatic black and white LANDSAT-1 imageries on 1:250,000 scale in band No.5 and 7. During these studies it was possible to know the major dislocations in the area and the major lineament pattern. Field work was carried out in selected areas along this belt. During the field work the lithological and the tectonic contacts of the lithonit units were checked, attitudes of foliations, lineations, joints, faults and shear zones were also noted. Special attention was mainly paid to the sampling of the ultramafic rocks, as the associated chromite deposits and the gabbroic rocks.

The ultramafic rocks were subjected to detailed scrutiny to study the compositional variation within them, and to investigate the mode of occurrence, and the textures and structures shown by the chromite ores. The various structures exhibited by the chromite ores were sketched, photographed and their attitude measured and noted. Samples of chromite ore and the host rock were
also collected. In certain sections the ultramafic rocks also host magnesite mineralisation, this was also studied in the field.

The field work was carried out during two field expeditions to Ladakh, each of over 45 days duration between 1984 to 1986. A total of about 100 days were spent in the field. The field mapping was carried out on a scale of 1: 50,000.

The samples of the rock types collected during the field work were subjected to laboratory investigations. Petrography of the rocks and the ore minerals was studied in microsections and polished sections. Model analyses of the rocks was carried out of Rosiwal method, on the lines suggested by Cheyes (1954), 56) optical properties of the minerals were determined with the help of four-axes Universal State. The anorthite content of the plagioclase was determined with the help of Universal State using Slemmon's (1962) curves.

Rock samples were chemically analysed for their major element compositions by the rapid analyses method of silicate rocks of Shapito and Brannock (1956) using U.S.C.S. rock standards (Flanagan, 1967). Ten chemical analysis of the different rock types are included in this work. Chemical compositions of the different minerals
phases was determined with the help of electron probe microanalyser. Fifty seven Chemical analyses of the different minerals are included in the present work.

In order to identify the different mineral phases present in fine grained mineral viz., serpentine, zeolites, chromites, and wollastonites, they were subjected to X-ray diffraction, infrared spectroscopy and Mossbauer spectroscopy. The surface morphology of the chromites, zeolites, and serpentine was studied under Scanning Electron Microscope.