EXPLORATION AND EXTRACTION OF PLACER GOLD AND SILVER IN THE TERRACES OF BAGROT VALLEY, GILGIT AGENCY NORTHERN PAKISTAN

By

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ABSTRACT

The upper reaches of Chitral, Gilgit and the Indus River in northern parts of Pakistan are well known for the placer gold occurrences. The extraction of gold by gold-washers through primitive tools has been practiced since long period in the region. Due to the recent advancement in technology, there has been a rapid growth in gold production from placer deposits world over, yet mining of placer gold in Pakistan has not been give due consideration. The study of the placer deposit of Bagrot valley has, therefore, been carried out to determine the mineralogy of these placer deposits, which could help in investigating the source rock for gold and also to design methods for the extraction of placer gold in a more economic manner.

The placer deposits of the study area are mainly composed of glacio-fluvial and fluvial sediments deposited in the form of terraces of various sizes. Representative samples of the sediments from each terrace in Chirah, Farfooh and Bulchi villages of the Bagrot valley were collected during fieldwork. These samples were partly panned in the field before bringing these to the laboratory for further processing. All the samples were splitted into different portions for mineralogical and chemical studies and gravity separation. The mineralogical studies were conducted by the binocular microscope, the gold and silver concentration were determine by using Atomic Absorption Spectrophotometer and the gravity separation was performed by the Shaking Table. Mercury amalgamation and cynidation techniques were used for the extraction of fine-gold while the coarse-gold has been extracted by the gravity separation method.

The glacio-fluvial and fluvial terraces of the study area have similar mineralogy with only difference in the size and shape of the gold particles in concentrates. The fluvial terraces have smaller size and more roundness in shape as compared to those of glacio-fluvial terraces. The sediment load in both types of terraces is mainly composed of rock fragments, magnetite, quartz, biotite, muscovite, chlorite and epidote. Garnet, tourmaline, amphibole, pyroxene, olivine, pyrite and chalcopyrite are present in lesser amount while zircon and sphene occur in trace amount.

Chemically maximum gold and silver have been noticed in the concentrates while rest of the media (middling and Tail) have negligible gold and silver. Both mineralogical and chemical studies suggest that gold in the source rock is present as coarse-grained native form and, therefore, the gravity separation method is the most appropriate method for the extraction of placer gold in the area.

The size and morphology of gold in the concentrates of both glacio-fluvial and fluvial terraces of the study area have been evaluated to understand the

proximal or distal nature of the gold source. The general characteristics of studied gold particles suggest that gold in glacio-fluvial and fluvial terraces has been derived and transported from a distal source at least more than a few tons of Kilometers, up-stream.

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DEDICATED

To

Ruth Elizabeth Conaghan

Who Touched My Soul

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CHAPTER 1

INTRODUCTION

GENERAL

The occurrence of placer gold in the upper reaches of the Chitral and Gilgit and along the Indus River in Northern Areas of Pakistan has been reported by Austromineral in 1976 and 1978. The occurrence of placer gold has been proved through drilling and panning along the Indus and Gilgit river in northern areas of Pakistan (Austromineral, 1978). These placer deposits occur as thin pockets of heavy mineral concentrate.

Alluvial placer deposits may be the products of either modern or ancient glacio-fluvial system with their position relevant to present river system helping to determine weather they are modern or paleo-placer deposits. Ancient deposits are usually buried under alluvial accumulation, or may be lifted to the level of watersheds and exposed in old river terraces above modern river channels (Jamsrandorj and Diatchkov, 1996). The alluvial placer deposits of northern Pakistan are generally recent in age.

Gold washing has been a practice since a long period along the Indus and Gilgit rivers in northern areas of Pakistan. Presently, there are more than 200 families who are directly involved in this job. However, only few families have adopted this profession as a part time activity. These gold washers use primitive tools for extraction of gold from the Indus sands. Therefore, in spite of working hard throughout the year, their income is a few thousand rupees annually. They use panning and mercury for the extraction of course gold while fine, ultra-fine and invisible gold is thrown into the river along with other residual material containing high amount of mercury and other heavy metals. It is causing pollution in our main rivers, which is certainly destroying the environment.

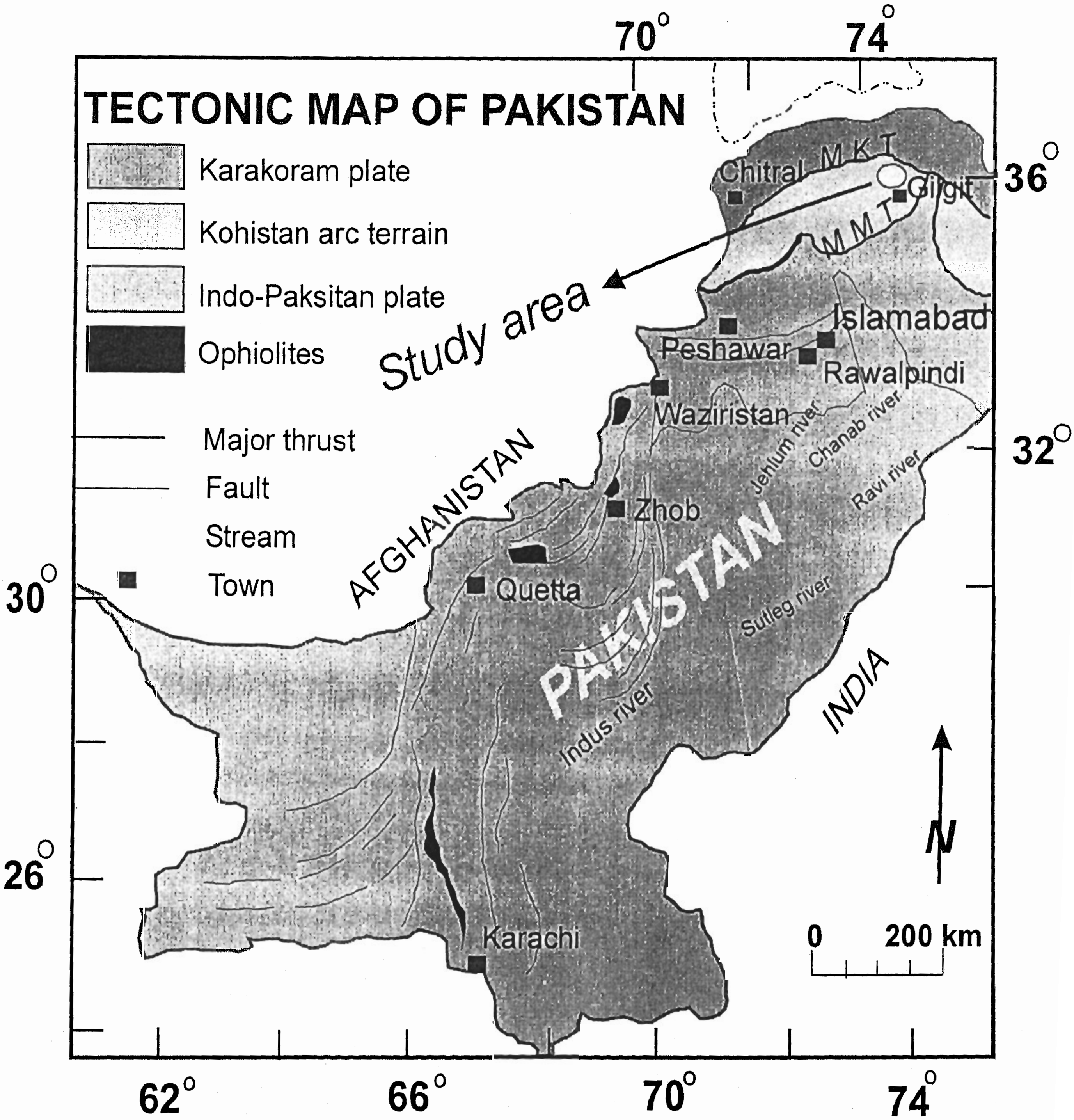
This study is mainly based on the exploration and extraction of gold which includes determination of characteristics of placer gold particle such as size and morphology, bulk mineralogy and chemistry of panned concentrates and the techniques involving mechanism of extraction of placer gold in the Bagrot valley. The idea is to find out ways and means, which can reduce the wastage of gold and the recovery of maximum placer gold from the fluvial and glacio-fluvial deposits covering the vast area of northern Pakistan.

LOCATION OF THE AREA

Bagrot Valley, partly covering toposheet Nos. 42L/5 and 42L/9, is located at a distance of about 30km NE of Gilgit City (Fig.1) and is surrounded by three Peaks i.e., Rakaposhi (7788m), Bilchar Dubani (6134m) and Diran (7273m). Among these, Dubani and Diran Peaks are situated between Bagrot and Haramosh Valley. The Bagrot Valley consists of seven small villages with a population of about 12000 inhabitants. However, the study area comprises of only three villages, which are Chirah, Bulchi and Farfooh (Fig.2).

ACCESSIBILITY AND TRANSPORTATION

The area is easily accessible through every kind of transportation from Gilgit, by a metalled road up to Oshikhan Das. From Oshikhan Das a 16km un-metalled road leads to Chirah Village, which is the last settlement in the Bagrot Valley. Chirah village is very close to the snout of the Hinarchane Glacier, which feeds regular material to the Bagrot river. Jeep services throughout the year are operating from Gilgit to all the villages of the Bagrot Valley.



Generalized Tectonic map of Pakistan, showing the location of the study area (modified after Kazmi and Rana 1982).

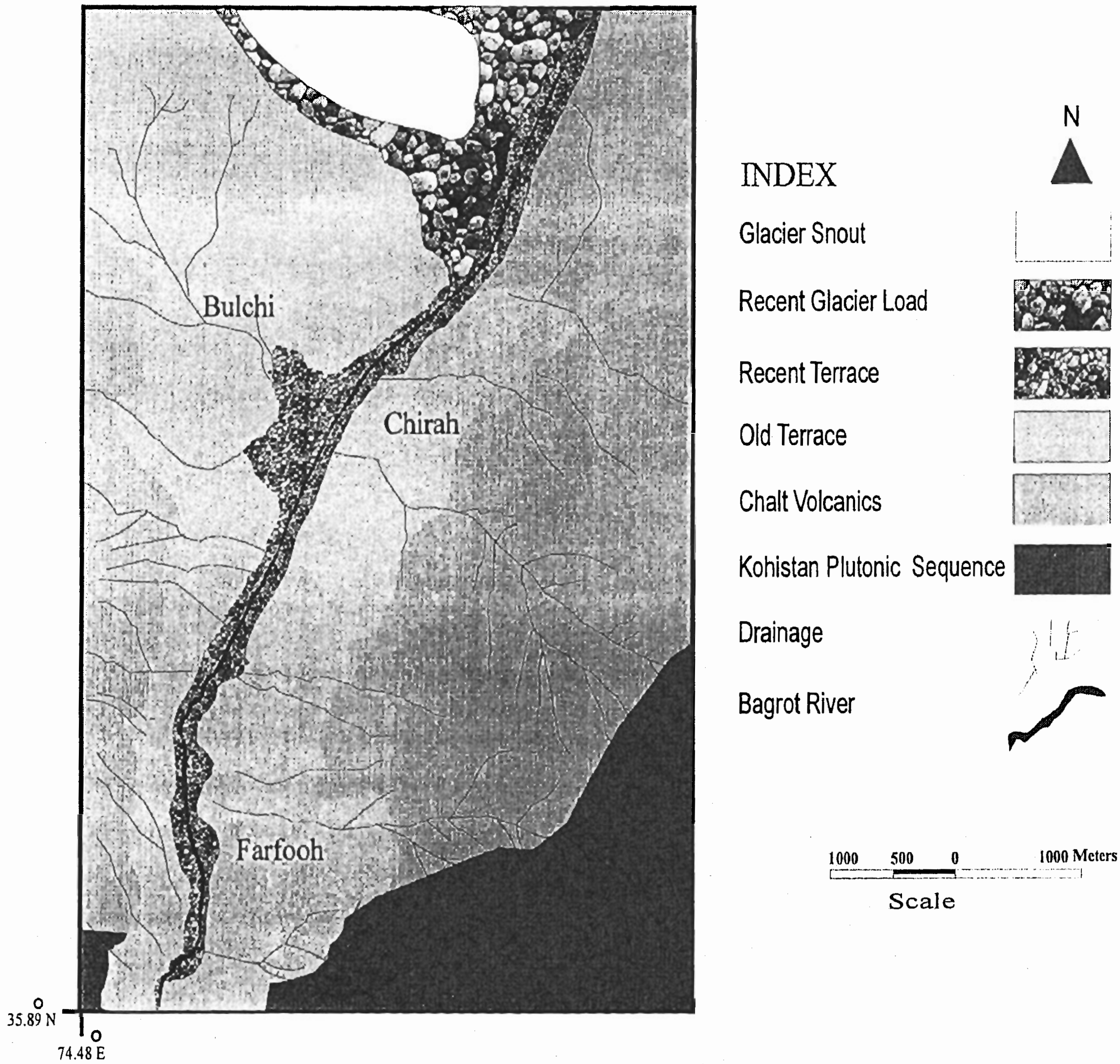


FIGURE. 2. GEOLOGICAL MAP OF PART OF THE BAGROT VALLEY, GILGIT NORTHERN PAKISTAN.

CLIMATE, VEGETATION AND FOREST

Bagrot Valley is surrounded by high mountains and has only one exit for water discharge into the Gilgit river. The annual rainfall is few inches because the Mount Bilchar Dubani works as a barrier for the monsoon to the northeast of Bagrot Valley. However, monsoon dropped appreciable precipitation around the Haramosh and Bagrot Valleys, which are close to the Nanga Parbat area. As a result these two valleys have more vegetation in the entire Karakoram Region. In the Karakoram Range Haramosh Valley has thickest forest and Bagrot Valley is the second one in having a thick forest. At lower reaches the area is mostly dry and barren but at moderate altitude the area has vegetation in the form of alpine meadows and small forest, especially pine trees while at high altitude the area is covered with snow. The Bagrot valley has plenty of fruits, especially walnuts, apricots, apples and pears.

CULTURE

Northern areas of Pakistan have unique culture. Within the region there are few valleys, where the people have preserved their old traditions and culture. Bagrot Valley is one of them, where people still follow their ancient customs. They speak shina language and consider it as a pure region of shinaky culture. Their sources of income are limited. People are trustable, brave and hard workers. Their main occupation is farming and cattle grazing.

PURPOSE OF STUDY

The aims and objectives of this study are as fallows:

1. To determine the mineralogy of the placer Concentrates, Middling and Tails in order to evaluate the heavy minerals and gold in the three different sampling media.

2. To determine the characteristics of visible gold in order to estimate the distance of the source rock.
3. To determine gold and silver in various sampling media of the terraces by different techniques.
4. To establish techniques for maximum recovery of gold and silver.
5. To investigate environmental impacts of the process involved, especially the use of mercury and cyanide.

PREVIOUS WORK

Detail geological work has been carried out in the Northern part of Pakistan including the sampling area (Bard et al., 1980; Butler and Prior, 1988; 1989; Chamberlain et al., 1991; Coward et al., 1982; 1986; 1987; Butler et al 1989; Hansan, 1989; Kazmi and Jan, 1997; Khan, 1988; Khan et al., 1989; 1994; 1983; Searl, 1991; Sear et al., 1996; Shah and Shervais, 1999; Tahirkheli, 1982; Tahirkheli and Jan, 1979; 1996; Zeitler et al., 1989; 1993; Zeitler and Chamberlain, 1991). However, no work has been done so far on the terrace of the Bagrot valley in regard to the mineralogy of heavy mineral concentrates and placer gold and silver extraction. However, the following work has been done with regard to mineral exploration in the northern region of Pakistan. Tahirkhali (1974) worked on alluvial gold prospects in the Chitral and Gilgit areas and along the Indus river in the northern parts of Pakistan. Investigation of placer mineral deposits along the Indus, Gilgit, Hunza and Chitral rivers have been conducted by workers from the geological survey of Pakistan (Ahmad et al., 1975 Ahmad and Chaudhry 1976). The Austromineral (1976 & 1978) also did some work on the placer gold in the northern parts of Pakistan including the area around Bagrot valley.

Gold exploration, and mineral analysis project has been conducted by using the geochemical survey of stream sediments in the Chitral, Gilgit and Skardu regions of the northern Pakistan under the auspicious of Australian

Agency for International Development (AIDAB) in collaboration with Sarhad Development Authority (SDA) and Pakistan Mineral Development Corporation (PMDC) of Pakistan (Sweatman et al.,1995). Halfpenny and Mazzucchelli (1999) have carried out reconnaissance survey by conducting the regional multi-element drainage geochemistry in the Himalayan Mountain, northern Pakistan.

CHAPTER 2

REGIONAL GEOLOGY

The regional geology of the study area is determined in context to the major tectonic terrains formed due to the subduction of Indo-Pakistan plate underneath the Eurasian plate. These terrains are from north to south as Karakoram plate, Shyok or Northern Suture Zone (NSZ), Kohistan Island Arc, Indus Suture Zone or Main Mantle Thrust (MMT) and Nanga Parbat Haramosh Massif (Fig. 1).

KARAKORAM PLATE

The Karakoram plate is a complex assemblage of rock bodies formed by repeated collisions of continental blocks and plates, from Jurassic to late Cretaceous. The Karakoram plate may be roughly subdivided into three main belts, from south to north:

1. The southern metamorphic belt, which comprises a variety of rocks, from low-pressure andalusite facies to intermediate-pressure kyanite + sillimanite facies. Westwards it also includes non-metamorphic sedimentary rocks (Ivanac et al., 1956; Matsushita and Huzita, 1965; Gaetani et al., 1996).

2. The Karakoram Axial batholith covers approximately 30% of the range. At least three major intrusive episodes may be identified. A mid-Cretaceous episode of widely exposed sub-alkaline to calc-alkaline intrusions probably related with subduction of the Neotethys at the southern margin of Karakoram plate (Crawford and Searle, 1992, Debon et al., 1987). A minor Eocene episode of biotite, amphibole-granite and andalusite represented by the Batura sub-alkaline granite of Eocene age (Le Fort et al., 1983; Debon et al., 1987; Crawford and Searle, 1992. The Batura plutonic unit, which is centered around the Batura

glacier, consists essentially of biotite and hornblend granodiorites. Debon et al. (1987) gave it a separate status based on its Rb-Sr whole rock isochron age of 43±3 Ma. The third episode is represented by a suite of leucogranitic sheets and intrusions of batholithic dimensions e.g., Baltoro pluton unit (Searle, 1991) which is Miocene in age.

3. The northern sedimentary belt, which can further be subdivided into several thrust sheets both in west (Chitral) and in the east (Hunza Valley) (Zanchi and Gaetani, 1994). The most complete sequence consists of a 5-7 km thick sedimentary succession, which is transgressive on a Pre-Ordovician crystalline basement (Le Fort et al., 1995). The succession consists of lower Paleozoic strata in the Baroghal pass area, but starts from Permian in most of eastern Karakoram. It remained mostly under marine condition up to the early Cretaceous. The Batura unit is similar to the Hunza plutonic unit except that the latter has no biotite. The samples are mainly un deformed, metaluminous to per aluminous granite with plagioclase, quartz, K-feldspar, biotite, hornblend, epidote, sphene, allanite, occasional garnet, and accessory apatite, zircon and opaque minerals.

SHYOK SUTURE ZONE (SSZ) MAIN KARAKORAM THRUST (MKT)

The Shyok suture zone separates the Karakoram plate to the north from the Kohistan-Ladakh terrane to the south. Along the Karakoram Highway in the Nagar valley it is exposed around Chalt village. The northern suture is a melange, consists of serpentine, quartzose sandstone and volcanic and limestone conglomerate blocks in a graphitic shale matrix locally containing biotite and chlorite (Pudsey et al., 1985, Pudsey, 1986). It reduces to a fault zone only 150m wide near Yasin (Coward et al., 1986), but in Hunza, it enlarges again up to 4 km (Pudsey, 1986).

The orientation of blocks and slaty cleavage define the strong planer fabric of the zone, but in places a linear fabric is also present.

In the Ishkoman valley and Hunza the volcanics and sediments of the Kohistan arc are folded into steeply inclined northward verging folds with associated thrusts. These folds have a gentle plunge and steep axial planer cleavage. The thrusts have probably formed at the same time as the folds, and the suture zone is related to this northward thrusting (Coward et al., 1986).

The Shyok melange contains late Cretaceous blocks of limestone and younger marine rocks are absent both in the melange or in its vicinity. Thus the youngest marine strata is Late Cretaceous. The deformation related with Shyok suture deforms 102 Ma old Matum Das Pluton in the Hunza valley suggesting that the suture was formed after 102 Ma (Petterson and Windley, 1985). Fabric associated with the Shyok suture is cut by 75 Ma old Jutal basic dykes (Coward et al., 1986), suggesting that the Shyok suture has to be older than 75 Ma is, and younger than 102 Ma.

KOHISTAN ISLAND ARC

The Kohistan -Ladakh terrane developed in response to northward-directed subduction of Neotethys ocean lithosphere during the Cretaceous (Searle et al., 1987). The Kohistan arc covers an area of 36,000 km^2 in Himalaya, southern Karakoram and Hindukush. The arc is splited into Kohistan and Ladakh as its western and eastern parts, which are separated by the late Tertiary north verging Nanga Parbat-Haramosh massif. The Kohistan arc is terminated against the Karakoram Plate along the Shyok suture in the north and against the Indo-Pakistan plate along the Indus suture or Main Mantle thrust in the south. Thus the two sutures along its northern and southern boundaries bound the arc. To understand the geology of the Kohistan arc, it can be divided into (1) volcano-sedimentary units, (2) mafic-ultramafic complexes and (3) Kohistan batholith.

1. Volcano-sedimentary units

The volcano sedimentary unit can be grouped in to Yasin sediments, Chalt volcanics, Gilgit formation and Kamila amphibolite.

Yasin sediments: Hayden (1914) reported a group of sediments comprising sandstone, fossiliferrous shaly limestone and conglomerate unconformably overlying a succession of volcanics near the village of Yasin in north-central part of the Kohistan terrane. Ivanac et al. (1956) lumped these sediments with a suite of lavas, tuffs and agglomerates, and assigned them the name Yasin Group. Tahirkheli (1979, 1982) used the term Yasin Group only for the sedimentary part and included the volcanic component into his Chalt Volcanic Group. Additionally he recognized the presence of sediments all along the Shyok suture. Pudsey et al. (1985) and Pudsey (1986) have done further detailed work on the Yasin Sediments. She mapped a synclinal belt nearly 20 km long east of Mastuj, and continuous through Yasin and Hunza to the east. In the Yasin area she divided the group into a lower sedimentary unit (~1 km thick), comprising conglomerates, sandstones, tuffs, slates reddish limestone and grey slates (distal turbidites) and an upper fine-grained unit (up to 2 km thick) comprising red, purple, green and grey shales with interbeded greenstone (tuff). This division, however, does not apply everywhere. In the Ishkoman valley, the sediments are almost devoid of limestone and consist of slates, silty quartzites and pebble-cobble conglomerates. In the Hunza valley the Yasin Group comprises mainly terrigeneous clastics and volcanoclastics in the form of distal turbidites and slates with massive grey wackes predominant in the lower part.

The stratigraphy of the Hunza valley is tectonically repeated south of Gilgit in the Jaglot area (Khan et al., 1993). Here a thick sequence of slates (comprising turbidites mudstones, siltstones and quartzites), with a thick marble horizon in the middle, occupies the core of the regionally extensive Jaglot syncline (Coward et al. 1986). Though the sediments have not yielded any fossils, their stratigraphic position above the Chalt Volcanic Group, which in turn overlies the Gilgit Formation, suggests a sound correlation with the Yasin Group. Westward in Chitral area, Pudsey et al. (1985) recognized a succession of volcanics and sediments south of the Shyok suture, which they divided into Gawuch Formation at the base, Purit Formation in the middle, and Drosh Formation on the top.

Chalt volcanics: The Chalt Volcanic Group (Petterson and Windley, 1985, 1991) or the Rakaposhi volcanics (Tahirkheli, 1982) are found to the NW and NE of Nanga Parbat immediately to the south of the Shyok suture. These volcanics occur in a 330 km long belt oriented E-W to SW-NE and are about 30 km wide (Petterson et al. 1991). The Yasin group of sediments, which have fossils of Albian-Aptian age (100Ma), overlies them. These volcanics and sediments form the upper part of the Kohistan arc. The Chalt volcanics comprise a succession of island arc tholeiites and calc-alkaline rocks, which vary in composition from basaltic komatites, boninites and high-Mg andesites to calc-alkaline basalts, andesites, dacite and rhyolites. Pillowed and un Pillowed lavas, tuffs, volcanic brecia and conglomerates are common.

The metamorphic grade of the volcanic rocks decreases westwards from high greenschist-amphibolites facies at Hunza to low greenschist-facies near Ishkoman. Coward et al. (1982) and Pudsey (1986) have given a brief description of the volcanics at Hunza, which are tight to isoclinally folded with upright fold style. Presence of a strong subduction component reflected in depleted high-field strength elements together with occurrence of boninites have been used by Khan et al., 1997 to suggest a fore-arc origin for the Chalt volcanics. However, previous workers referred that they belong to island arc (Petterson et al., 1991) back arc basin set up (Khan et al., 1996).

Gilgit Formation: Occurrences of high-grade metasediments (paragneisses, migmatites and schists) in the Kohistan terrane are mentioned in several reports, but were always considered either localized or anomalous. Coward et al. (1987) recognized a group of metasediments from south of Gilgit in the core of a major antiformal fold, which they considered to represent "stratigraphically lowest metasediments" in the Kohistan terrane. These metasediments were recently studied in detail in terms of their stratigraphic relations and were formally classified as the Jaglot Group (Khan et al., 1994). The stratigraphic unit forming the basal part of the Jaglot Group is termed Gilgit Formation, which comprises a sequence of medium- to high-grade paragneisses, migmatites, schists and quartzites. Other lithologies include amphibolites and calc-silicates. The amphibolites are frequent and form laterally continuous horizons. Although some of the amphibolites may be transposed dykes and sills, others are definitely derived from basic tuffs and volcanic flows. One such horizon in the Sai Nala (northwest of Jaglot) comprises a four-meter thick sequence of stretched pillows. The calc-silicate horizons are common in the upper part of the formation, above the pillowed-amphibolite horizon.

The rocks of the Gilgit Formation show evidence of regional metamorphism up to sillimanite grade. The topmost unit in the Gilgit formation is biotite schist grading downward into garnetiferous schists, and kyanite and sillimanite gneisses. In the deeper levels the paragneisses have undergone anatexis, giving rise to migmatites. The Gilgit Formation is overlain by the Gashu-Confluence Volcanics (Khan et al., 1994), which are regionally equitable to the Chalt Volcanic Group of Petterson et al. (1991). The basal contact of the Gilgit Formation is not exposed at least in the east central Kohistan. There are indications, however, that the Chilas Complex under plated the formation. For instance, at the Gilgit River-Sai Nala Confluence, south of Jaglot, the paragneisses enclose a block of the layered basic rocks that resemble closely those of the Chilas complex. The northern contact of the Chilas complex is against a group of intercalated amphibolites and metapellites, as observed in the upper reaches of Kiner and Hudur valleys (Khan, 1988). Screens and xenoliths of biotite schists and paragneisses belonging to the Gilgit Formation are abundantly enclosed in the Chilas complex near its upper contact as observed in the east-central Kohistan (Khan, 1988; Khan and Jan, 1992).

Rocks showing strong resemblance in lithological characteristics and stratigraphic position to the Gilgit Formation are reported from other parts of Kohistan. A succession of sediments, metamorphosed up to sillimanite grade, is termed Katzarah Formation (Desio, 1978; Tahirkheli, 1982; Hanson, 1989) in the north central parts of Deosai, which is considered the western extension of the Kohistan terrane. The high-grade pelitic assemblage not only has a compositional similarity with the Gilgit Formation but occupies a similar stratigraphic position at the base of a volcano-sedimentary succession resembling Chalt Volcanic Group and Yasin Group of metasediments. In the west, equivalents of the Gilgit Formation are exposed in the Kandia, Swat and Dir valleys. In the Kandia valley, there are poorly described metasediments (Jan, 1970) and an isolated outcrop of high-grade rocks overlying epidote-amphibolites of the Kamila belt (Yamamoto, 1993). A succession of schists (termed Peshmal schists by Sullivan et al., 1993) occurs in the Swat valley (south of Kalam) and in Dir area overlying the Kamila amphibolites. A mineral assemblage comprising biotite-muscovite ±garnet ±clinopyroxe, a predominantly pellitic composition and a stratigraphic position above the Kamila amphibolite, suggest a sound correlation with the metasediments in the Gilgit Formation (Khan, 1997).

Kamila amphibolites: Amphibolites are the most voluminous lithology with early phase magmatic sequence in Kohistan arc. The main occurrence of the amphibolites, in the Kohistan sequence in the form of a linear belt intervening between the Indus suture in the south and the southern boundary of Chilas complex in the north, with a type section in the Indus valley to the south of the Kamila village in Kohistan district (Jan, 1979, 1988; Tahirkheli and Jan, 1979). These amphibolites are continuous to the east and west of the Indus valley forming the southern margin of the Kohistan arc and are intruded by mafic-ultramafic complexes locally (e.g. Jijal complex, Jan and Howie, 1981, Jan and Jabeen, 1990; Babusar ultramafics, Ahmed and Chaudhry, 1976; Chilas complex, Khan et al. 1989). The northern part lies directly at the southern contact of the Chilas complex in the footwall of the Jijal shear zone of Coward et al.

(1987) and Khan (1988) which is equivalent of the Kamila shear zone of Trealoar & Rex et al (1990). The amphibolites in the hanging wall of the Indus suture enclose lensoid masses of ultramafic rocks (e.g. Jijal and Tora Tigga). The amphibolite belt is commonly intruded by sheets of tonalite, and granite.

According to Tahirkheli (1979), Tahirkheli (1983), Bard et al. (1980), and Bard (1983) the Kamila amphibolite belt, which envelops the Jijal and Chilas ultramafic-mafic complexes serves as the basement of Kohistan island arc. Detailed mineralogy and geochemistry by Jan (1988), Khan (1988) Shah and Majid (1992), Shah et al., (1992) and Shah and Jan (1993) suggest a calc-alkaline nature of these amphibolites with a distinct similarity with volcanic rocks found in island arcs. Part of the amphibolite belt resting directly above the ultramafic body at babusar has been found to be of a tholeiitic character, but with a distinct trace element signature of an island arc. However, Khan (1997) has reported amphibolites from the area lying between Babusar and the Chilas complex to comprise mainly tholiitic basalts of ocean-floor affinity, which may represent pre-arc oceanic basement (Khan et al, 1993) or part of a back-arc assemblage (Khan et al, 1997). Treloar et al. (1996) have argued that this part of the amphibolite belt may represent oceanic island rocks.

2. Mafic-ultramafic complexes

Jijal Complex: Jijal complex is a tectonic wedge covering 200km^2 area along the southern margin of the Cretaceous Kohistan island arc. The complex is composed of garnet granulites and ultramafic rocks (Jan, 1979; Jan and Howie, 1981, Jan and Windley, 1990; Jan and Jabeen, 1990). The complex is separated from the rocks of Indian plate by the MMT.

The complex consists predominantly of garnet granulites derived from gabbros, troctolites and related rocks, which are locally layered. Ultramafic cumulate layers up to one meter wide and larger discordant bodies are found in granulites, (Jan and Windley, 1990).

Principal mass of the ultramafic rocks of the complex is found immediately north of MMT and is composed of pyroxinites, dunites and their gradational lithologies. Chromite is found in the dunites in the form of lenses, layers, and streaks. The complex has passed through phases of deformation; shearing and granulation are common; and the layers may be folded, pinched, swelled or terminated by faults.

The garnet granulites of the Jijal complex are divisible into plagioclase bearing and plagioclase free rocks. Garnet, plagioclase, clinopyroxene, quartz, rutile ± hornblende ± epidote are the most common basic assemblages (Jan and Jabeen, 1990). The plagioclase-free rocks are composed mainly of two or three of the phases, garnet, hornblende, clinopyroxene, epidote, but garnetite and hornblendite are the most common of these. According to Jan and Howei (1981) and Yamamoto (1993), the garnetiferous basic rocks in the Jijal Complex crystallized as layered gabbros, gabbronorites and anorthosites, which were transformed into garnet granulites during a phase of high pressure metamorphism (10-17 kbars, 700-950 °C, Yamamoto, 1993). Miller et al. (1991), in contrast, advocated an igneous nature of the garnetiferous basic rocks relating the garnet crystallization to the depth (~15 kbars) of magma emplacement and crystallization. In either case, the Jijal Complex represents one of the principal cumulate ultramafic-mafic bodies from the root zone of the Kohistan island arc terrane. Jan and Windley (1990) suggested crystallization from a primitive island-arc tholeiites magma.

A Sm-Nd garnet age of 103 ± 4 Ma was obtained from a sample of garnet granulites (M. Thirlwall in Coward et al. 1986), showing that crystallization occurred in an oceanic setting within Tethys, well before collision of Kohistan with either Asia or India.

Chilas Complex: This mafic-ultramafic complex occupies the central part of the Kohistan island arc and extends about 300 km from Dir in the west to Nanga Parbat in the East. It attains a maximum width of about 40km in the central part (Bard et al., 1980) have interpreted it as a lopolith. The Kargil complex in the Ladakh as having the same lithologies (Rai and Pande, 1983), is the eastern equivalent of Chilas complex. Jan and Howie (1981), Coward et al. (1982), and Bard et al., (1983) have suggested that the garnet granulites of the Jijal complex may be related to Chilas.

Homogenous gabbronorites and pyroxene diorite are the two main rock types having gradational relationship with each other. Locally the gabbronorites are layered and contain websterite-anorthosite layers. An association of dunites, peridotites, pyroxenites, minor chromitites, anorthosites, troctolites, olivine gabbros and gabbronorites (characterized by highly calcic plagioclase An > 85 mole%) occurs as lensoid bodies, covering up to 5 km^2 mainly in the east central part of the complex near Chilas (Jan, 1984; Khan et al., 1989). The gabbronorites make about 85% of the complex.

3. Kohistan Batholith

The Trans-Himalayan batholithic belt extends for about 2700 km from Afghanistan to Burma. It is bordered to the south by the Indus Tsangpo suture and on its north by the northern suture in the western Himalaya. It is commonly inferred that the northward subduction of the Tethyan oceanic plate under the Eurasian plate gave rise to the calc-alkaline magmas of the Andean-type Trans-Himalayan Batholith (Petterson and Windley, 1985). The Kohistan batholith is the most northwesterly component of the Trans-Himalayan batholith. It is located to the west of Nanga Parbat and is situated entirely within the Kohistan terrane, North-Pakistan. It is about 300 km long and about 60 km wide. Ivanac et al. (1956), Tahirkheli and Jan (1979) and Jan et al. (1981) identified the presence of a major belt of granitic rocks in the northern parts of the Kohistan terrane, which was later termed as the Kohistan Batholith by Petterson and Windley (1985) and

Coward et al. (1986). Except for local components, e.g. Matum Das, Jutal, Nomal, upper Swat Kohistan and north Gilgit ridge, the Kohistan batholith comprises undeformed or mildly deformed intermediate to felsic plutonic rocks. Furthermore, a large component of the Kohistan batholith intrudes the large-scale fold structures in the Gilgit formation, Chalt volcanics and the Yasin sediments, suggesting intrusion subsequent to accretion of the Kohistan terrane with the southern margin of the Karakoram plate.

The Kohistan batholith has been studied in detail in the Chilas-Gilgit-Hunza transect by Petterson and Windley, (1985) and Khan et al. (1994), and in Dir and Swat valleys by Jan and Mian (1971), Khalil and Afridi (1971), Jan and Asif (1983) and Sullivan et al. (1993). In Chilas-Gilgit-Hunza transect the principal body of the batholith is termed as Gor pluton by Khan et al. (1994). It is oriented NW-SE, and is up to 30 km wide and 60-70 km long and occupies the drainage divide between the Indus and Gilgit rivers. Some 15% of the pluton consist of other phases including granodiorite, granite and adamellite. The Gor pluton has a linear intrusive contact with the Chilas Complex in the south and Jaglot Syncline in the north.

Several plutons with circular to oblong outlines, intrusive into the Gilgit Formation or Chalt Volcanics, have been mapped by Petterson and Windley (1985) in the Gilgit and Hunza valleys. Of these the basic to intermediate phases are considered to be between 85 and 60 Ma (K/Ar and Ar-Ar age data of Coward et al., 1986; Treloar et al., 1989). Granites age between 60 to 40 Ma, on the basis of Rb-Sr whole-rock isochron of three plutons (Gilgit 54±4 Ma, Shirot 40±6 and Gindai 59±2). Phases of aplite-pegmatite leucogranites sheets intrude the earlier phases of the Kohistan batholith in the vicinity of Indus-Gilgit confluence. This swarm of acid sheets has yielded 34±14 and 29±8 Ma Rb-Sr whole-rock ages (Petterson and Windley, 1985).

The Kohistan Batholith in the upper Swat valley comprises several discrete plutons in the age bracket of 80-30 Ma (Sullivan, 1993). Two groups are distinguished, a southern and a northern. The southern group of plutons is exposed in the vicinity of Kalam and forms basement for a succession of late Paleocene-early Eocene sediments and volcanics. The principal pluton, in this group, occurs in the form of an east-west trending belt between Asrit in the south and Kalam in the north, occupying a discrete stratigraphic level just above the Chilas Complex. A basic migmatites zone at Asrit, comprising hornblende-plagioclase pegmatite veins and dykes in the (Kamila) amphibolite protolith, mark the roof zone of the Chilas Complex. The pluton comprises quartz diorites, tonalite and granodiorites. An ^{40}Ar-^{39}Ar date from a granodiorite within the pluton, indicates 78±1 Ma age for the cooling of the hornblende (Treloar et al., 1989). North of Kalam, the Matiltan granitic pluton is intruded into the Mankial Metavolcanics (Chalt Volcanics) and is considered to be equivalent to the other two plutons in this group. The northern group of plutons occurs in the hangingwall of the thrust, which marks the northern boundary of the Utror Volcanics. These plutons range in composition from quartz diorite to adamellite. Gabral and Ankar Gol plutons are type examples. Treloar et al.(1989) report a ^{40}Ar-^{39}Ar age of 48±1 Ma for the Gabral pluton. In the upper reaches of Matiltan valley, there are gneissose quartz diorites/tonalites which may be the equivalent of the 102 ±4 Ma Matum Das pluton

INDUS SUTURE ZONE (ISZ) OR MAIN MANTLE THRUST (MMT)

The Indian plate is truncated against the Cretaceous Kohistan island arc along the ~65 Ma old suture zone termed as the southern suture or Main Mantle Thrust (MMT), Tahirkheli et al; 1979; Bard, 1983, Treloar et al., 1989). The MMT is the westerly extension of the Indus suture. It is an irregular but generally northward dipping thrust, folded around later structures developed in the underlying Indian plate. The suture is intensely deformed but it is mostly expressed a parallel shistosity. Several melanges containing ultramafic rocks, piemontite schists, blueschists and green schists have been reported all the way from Bajaur, through Dargai (Hussain, 1984), Shamozai near Mingora (Shams, 1980; Kazmi et al; 1984), and Shangla - Alpurai and Allai (Shah and Majid, 1985; Jan and Shams, 1977) to Babusar Pass (Chamberlain et al.,1991).

Jan and Jabeen (1990) have reported several mafic ultramafic complexes along the Indus suture (MMT) in Pakistan. Some of these complexes are closely associated with the Kohistan arc sequence and represent cumulates in the bottom of the Kohistan arc, e.g., Chilas, Tora Tigga, and Jijal complexes. Others, such as those of Shangla and Allai Kohistan, occur in tectonic melanges along the suture and represent sub-arc/oceanic lower crust/upper mantle. The Dargai ophiolite may be a klippe that overrides the Indian plate some 30km south of MMT.

The paleomagnetic data show that the northward movement of the Indian plate decreased from 14.9 + 4.5 cm yr^{-1} to 5.2 + 0.8cm Yr^{-1} in 70 - 40 Ma. (Pierce, 1978). The initial contact between India and Kohistan-Ladakh arc is considered to be 55 Ma by (Klootwijk et al; 1979) but the recent data as given in Kazmi and Jan (1997) shows an age of 65Ma. The uplifting of the Indus suture zone (Zeitler et al; 1982) eroded all the unmetamorphosed sediments bordering it, thus no stratigraphic evidence is found to constrain the time of formation of the suture. The age of the suture is determined from the available isotope data and the evidence from Ladakh, where some good stratigraphic sections are preserved.

NANGA PARBAT HARAMOSH MESSIF

The Nanga Parbat Haramosh Massif, located in the northernmost part of the Western Himalayan Syntaxis manifests itself as an anomalous north-south extension of Indian crust that ranges from the foothills of the Himalaya in to the Karakoram within the massif are 1.85 Ga. Indian basement gneisses (Zeitler et al., 1989) and cover rocks of unknown age (Butler and Prior, 1988).

The Nanga Parbat Haramosh Massif (NPHM) is central to the India–Asia collisional oregen in northern Pakistan, the NW physiographic termination of the Himalayan chain marked by the peaks Nanga Parbat (8125m) and Haramosh 1 (7490m). The NPHM consists of Indian rocks locally exhumed from beneath a fossil island arc terrain, the Kohistan-Ladakh Arc (KLA), a series of late Cretaceous and Eocene amphibolites, volcanics and plutons (Tahirkheli et al. 1979; Coward et al; 1982). The Kohistan and Ladakh Arc is separated from the Himalayan rocks by the Main Mantle Thrust (MMT)(Tahirkheli et al; 1979) whose surface trace form a large bend around Nanga Parbat Haramosh Massif. The massif is a tectonic half window exposing Early Proterozoic gneisses of the Indian plate and Indian Passive margin metasediments. The Syntaxis area also marks the general region of orogenic kinking around which the Himalayan chain bends and is characterized by the presence of crustal-scale north-trending antiformal structures (Hazara, NPHM) which deform the main Himalayan thrust (e,g; Wadia 1932; Mish 1949;Treloar et al; 1989, Butler et al; 1989).

Following the overthrusting of the Kohistan arc and consequent Early Tertiary metamorphism, the NPHM experienced a rapid accelerated unroofing. Ar-Ar and fission–track cooling ages suggest that in the interval between 25 to 10 Ma the massif was cooled at the same rate as neighboring Kohistan (i.e., 10-15^{0}C/m.y). However, over the past 10 Ma it has experienced a more rapid denudation than Kohistan at a mean rates of about 5 mm/year and cooling rates locally exceeding 70^{0}C/m.y. (Zeitler 1985; Zeitler et al; 1993). This unroofing was accommodated initially along ductile shearing and later along cataclastic faulting on its margins, with local strike-slip motion along the Shahbatot Fault. The Raikot or Liachar Fault on its western margin carried the massif back over Kohistan and Quaternary sediments (Lawrence and Ghauri, 1983; Bulter and Prior, 1988; Zeitler and Chamberlain, 1991; Smith et al., 1992).

Migmatites containing up to 5 cm thick stringers of granite (partial melting products) are abundant in the core of the massif (Zeitler et al; 1992).

Leucogranite dykes and pegmatite are common in the western part of the massif. They are up to 2m in thickness, but rarely form kilometer-sized stocks. They cross-cut the dominant metamorphic foliation in the massif and the shear fabric associated with the late faulting on the edge of the massif. Although undeformed in hand specimens, they show deformation textures in thin sections.

The pelitic rocks in the massif consist of the assemblage sillimanite-potash feldspar-cordierite formed at 650 ± 50 c, 6±1 kbars. The leucogranites consist of typical S-type anatectic assemblage of two feldspar-quartz-two micas-sillimanite-cordierite-garnet-tourmaline-apatite-zircon formed at 600^0c, 4.1±1 kbars. Zeitler et al. (1993) suggests that the NPHM has undergone a recent metamorphic episode culminating in extensive partial melting (under- water/under-saturated environments), as recently as about 1.0 Ma. The rapid denudation is considered to be at least partly responsible for initiating decompression melting and high-grade metamorphism.

Young leucogranites occur throughout the massif. Tourmaline-bearing leucogranites form abundant dykes and sheets, possibly representing stock-works above a large Leucogranite intrusion in the northern part of the massif (Butler et al; 1992). There is also a coarse-grained homogeneous body (Jutial Leucogranite), at least 3km in diameter, exposed on the east side of the Phurparash Valley. Considered to have formed at about 700^0C, it consists of near minimum-temperature melt composition of equal proportions of quartz, oligoclase and perthite, with two micas, zircon and apatite. Tourmaline, where present, is skeletal and quartz grains may show weak orientation. Sheets of similar Leucogranite, 1-2 m thick, occur in the neighboring host rocks, together with a muscovite-tourmaline facies that rarely contains biotite and garnet. Geochemical data are available on the northern leucograninte (Butler et al. 1992). Like leucogranite of Himalaya, these have a distinct geochemistry: high (>70%) silica (SiO2) and alkalies (k and Rb), and depleted Ca, Sr, Y and Zr. The peraluminous nature of the analysis and Rb/Sr ratios of 2 to 8 are consistent with vapour absent melting of metasediments involving incongruent of muscovite. The leucogranintes have high Th content; double of the reported for other leucograninte from the Himalaya. Butler et al. (1992). Regard that this reflects a similarly high Th content in the protolith. Enhanced internal heat in the protolith gneisses will enhance the rate of melting production.

CHAPTER 3

LOCAL GEOLOGY OF BAGROT VALLEY

The geology of Bagrot valley is mainly composed of the rocks of the Chalt Group (Searl et al., 1996). In the study area, the Chalt metvolcanics of this group (Plate 1) are mainly covering the study area along the eastern and western part of the Bagrot river. However, a small exposure of ultramafic rocks is also exposed in the south-western portion of the study area (Fig. 2). The terraces of glacio-fluvial (Plate 2) and fluvial (Plate 3) sediments generally cover the Chalt volcanic in the area.

Chalt group

The Chalt group consists of a very heterogeneous sequence and is commonly exposed in the surroundings of upper Gilgit and lower Hunza area. It consists of alternating meta-sediments and volcanics. The association of meta–sediments with tuffs and basaltic to andesitic lavas is well observed in the Bagrot valley. The large number of diorites and granites, which belong to younger igneous phase, are intruded into the Chalt group. In the upper reaches of the Bulchi and Chirah villages the Chalt group consists of thin bedded slates and yellowish pyrite-bearing schists, chlorite-epidote-hornblende schist with intercalation of thin beds of grey to yellowish carbonates and marbles. Towards north there is a succession of phyllites, quartzite-phyllites, and sericite-schist, which show a continuous transition from basaltic lavas tuff to the chlorite and sericites schists.

In Bagrot valley north of Datuche village and near the Gutumi glacier a formation of metamorphic rocks strikes approximately E-W and dips towards the south. It consists of phyllites, sericites-chlorites schists with quartz stringers and lenses carrying sulfides. These rocks also attained higher metamorphic grade, such as garnet–staurolite schists and gneisses in certain places of Bagrot valley.

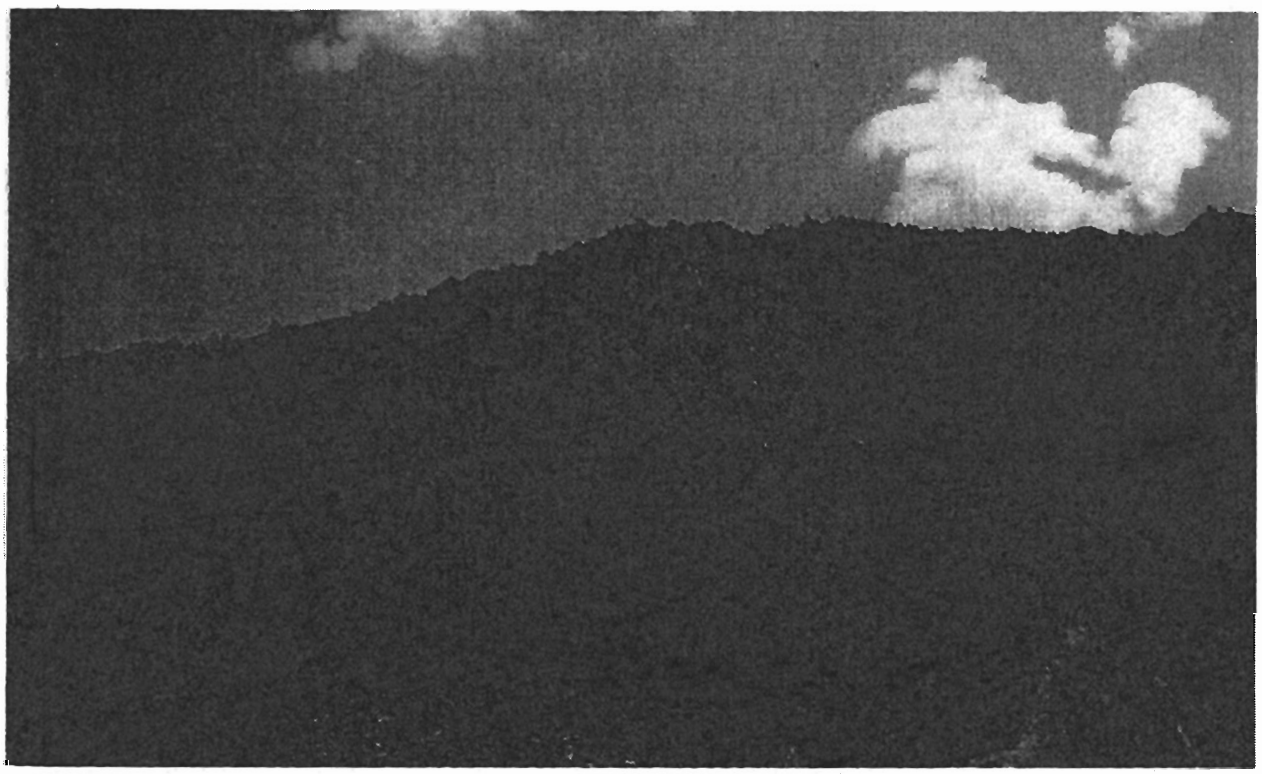


Plate No 1 Photograph showing rocks of the Chalt group exposed along the eastern and western sides of Bagrot river

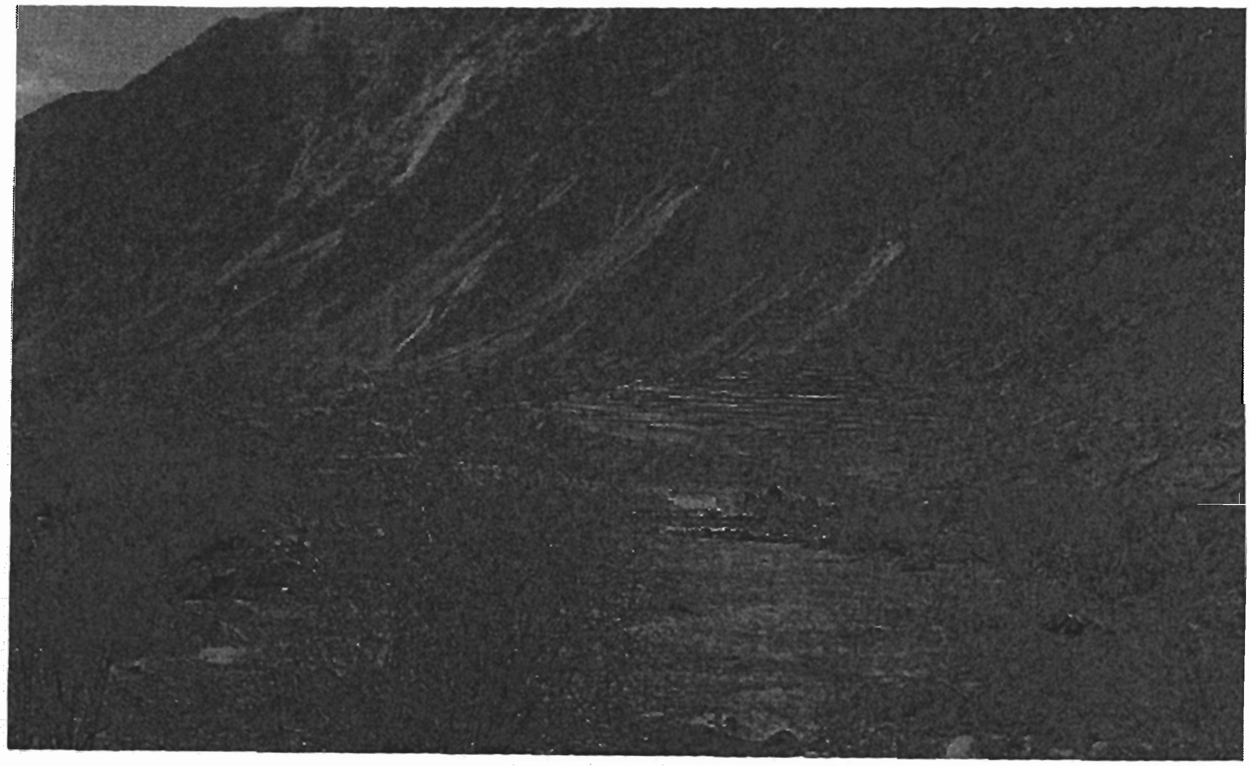


Plate No 2 Photograph showing the glacio-fluvial sediments of the terrace No 1 at Chirah village

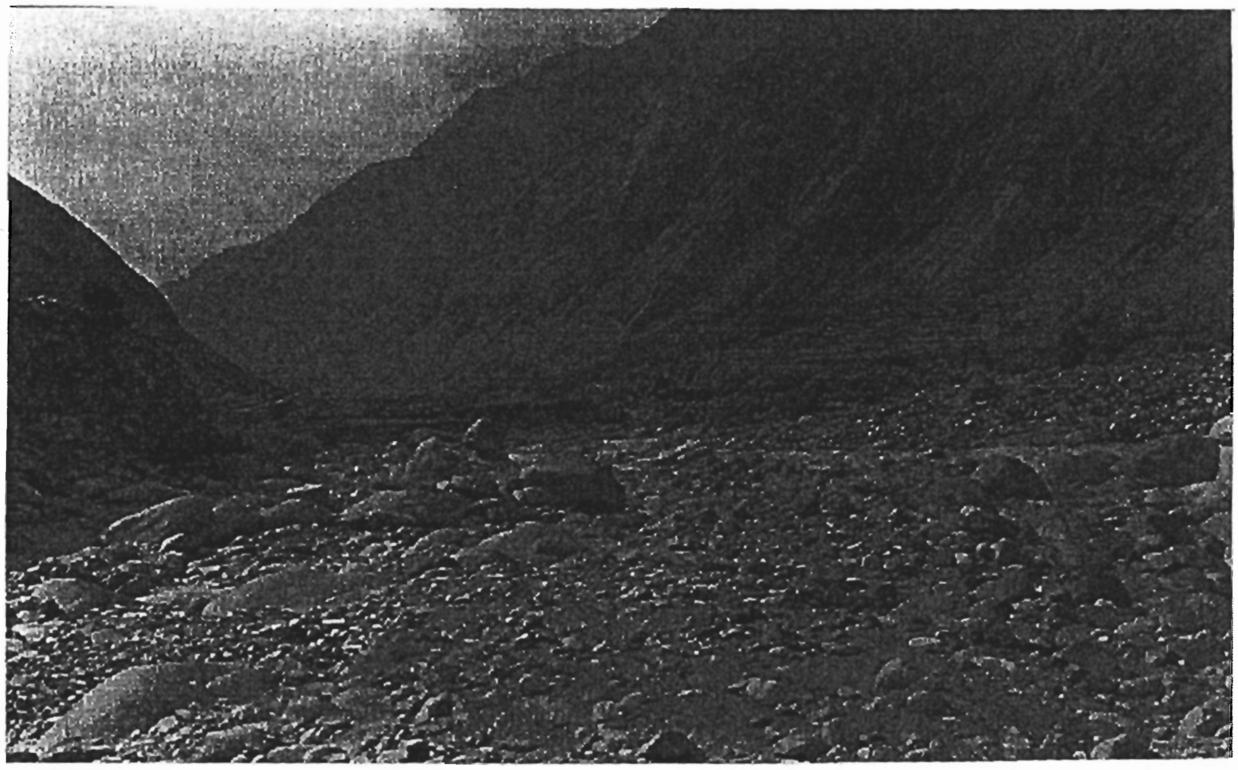


Plate No 3 Photograph showing the fluvial sediments of the terrace No 3 of Chirah village

Ultramafic rocks

Ultramafic rocks are mainly exposed south of Datuche village in Bagrot valley. Dunite and pyroxinites are the main rocks with minor amount of peridotites. These rocks are intruded by course-grained norite/hornblendite dikes. The ultramafic rocks of the Bagrot valley are the part of Dobani-Dassu ultramafic lineament strip of Pecher and Lefort (1998).

CHAPTER 4

METHODOLOGY

FIELD METHODOLOGY

Two types of terraces, glacio-fluvial and fluvial, were identified in the Bagrot valley. A rough sketch of the terraces in Chirah, Bulchi and Farfooh villages of the Bagrot valley is drawn where the location of each sample is marked (Fig. 3). The terraces of Chirah village are the old terraces containing glacio-fluvial sediments while the terraces of Bulchi and Farfooh villages are young terraces containing fluvial sediments.

Detailed floats (boulders, gravel, pebbles etc.) study was conducted to understand the general geology of the Bagrot valley (Plate 4). Before taking sediment samples each terrace was thoroughly visited to locate potential sites for gold and silver concentrates. Length and width of each terrace were measured to know its size in term of reserve. Thickness of vertical sections (Plate 5) in old terraces was also measured.

A systematic technique was adopted to collect sample through a random pattern from all terraces. The sample at each spot was taken at a depth of six feet below the surface in such a way that each sample may represent the bulk concentration of sampled terraces (Plate 6). The over size particles were screened out through a sieve of # 7 mesh size and the sieved material was put in a container (Balti) until it was filled. This material, having a weight of about 20kg, was then partially panned through panning techniques (Plate 7) and was stored in the polythene bags. These sample bags were marked with systematic numbers such as CT, BT and FT for terraces of Chirah, Bulchi and Farfooh villages respectively. The vertical sections at Chirah village were marked as CTV.

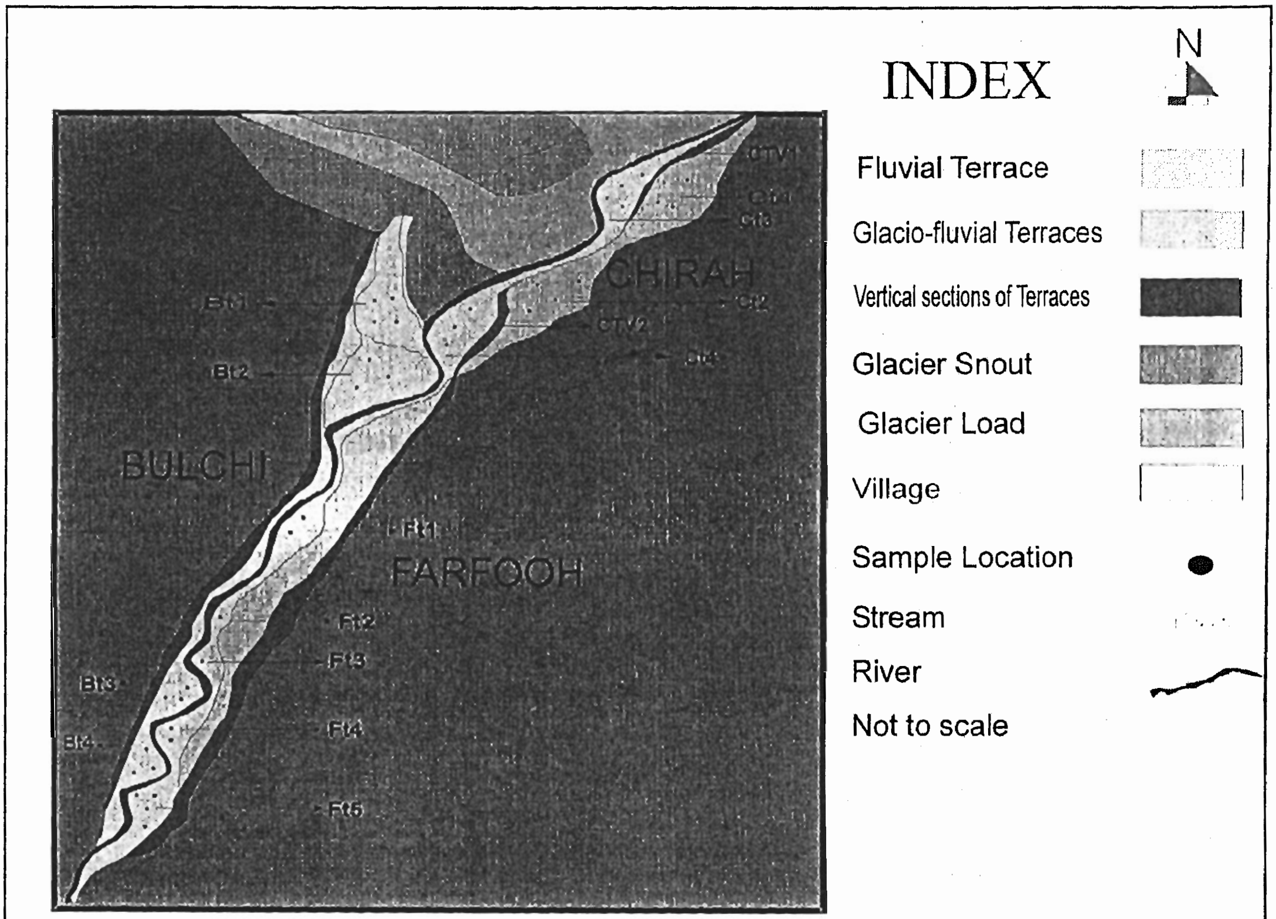


Fig. 3. SAMPLE LOCATION MAP OF THE STUDY AREA.

No- 50-c

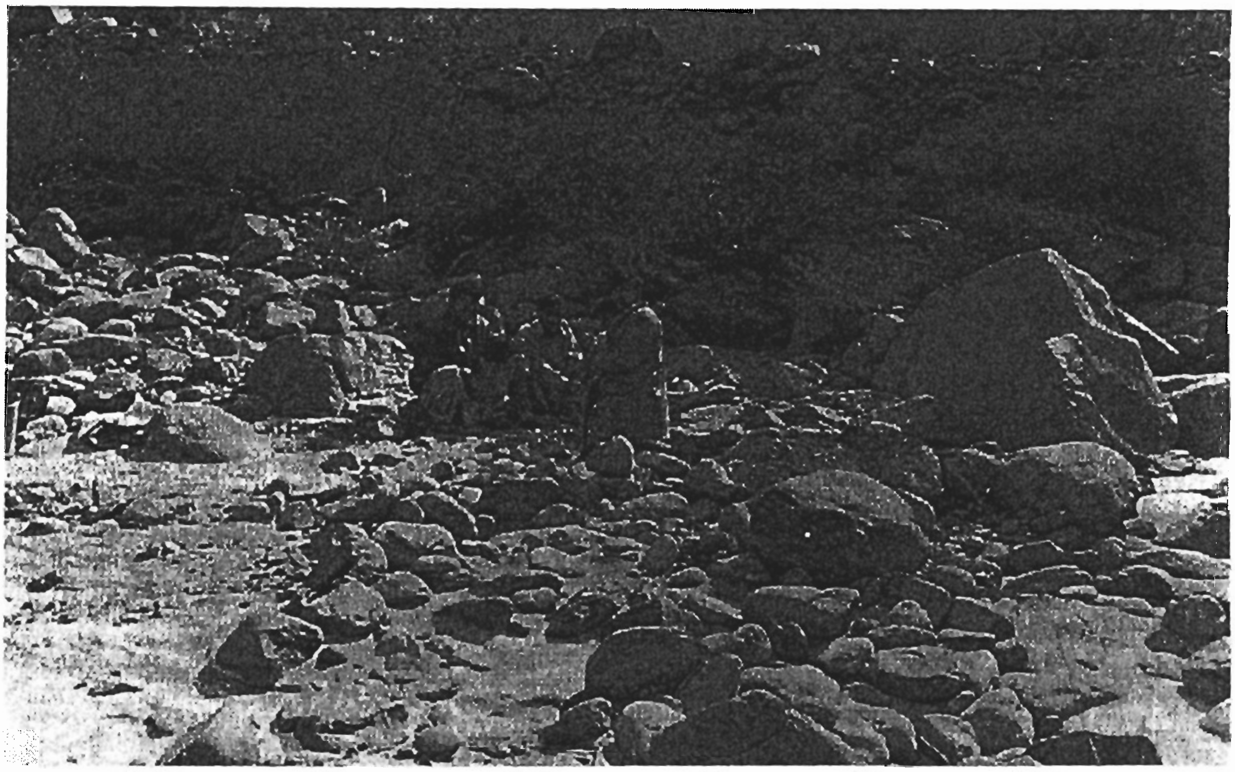


Plate No 4 Photograph showing the floats(boulders, gravels and pebbles etc.) along the Bargot River in Chirah village

Plate 5. Photograph showing the vertical section of glacio-fluvial terrace in Bagrot valley.

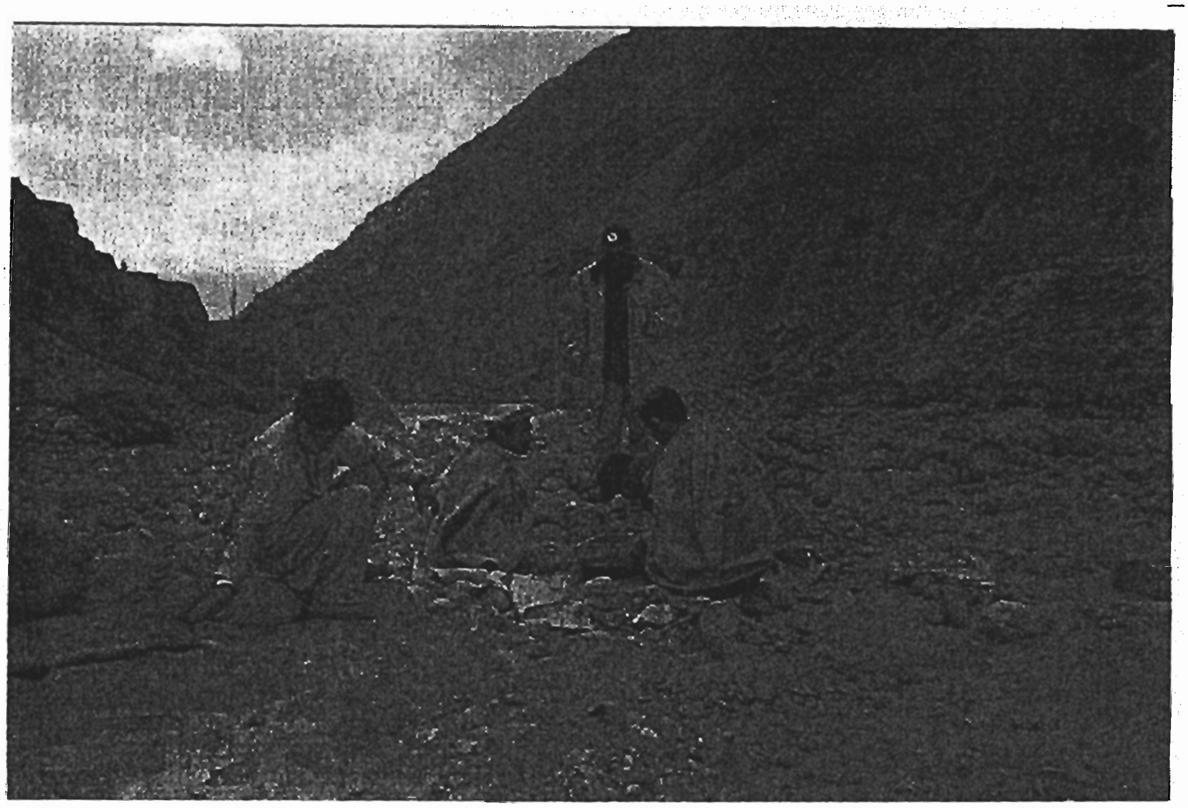


Plate 6. Photograph showing the sample collection from the fluvial sediments in the Bagrot valley.

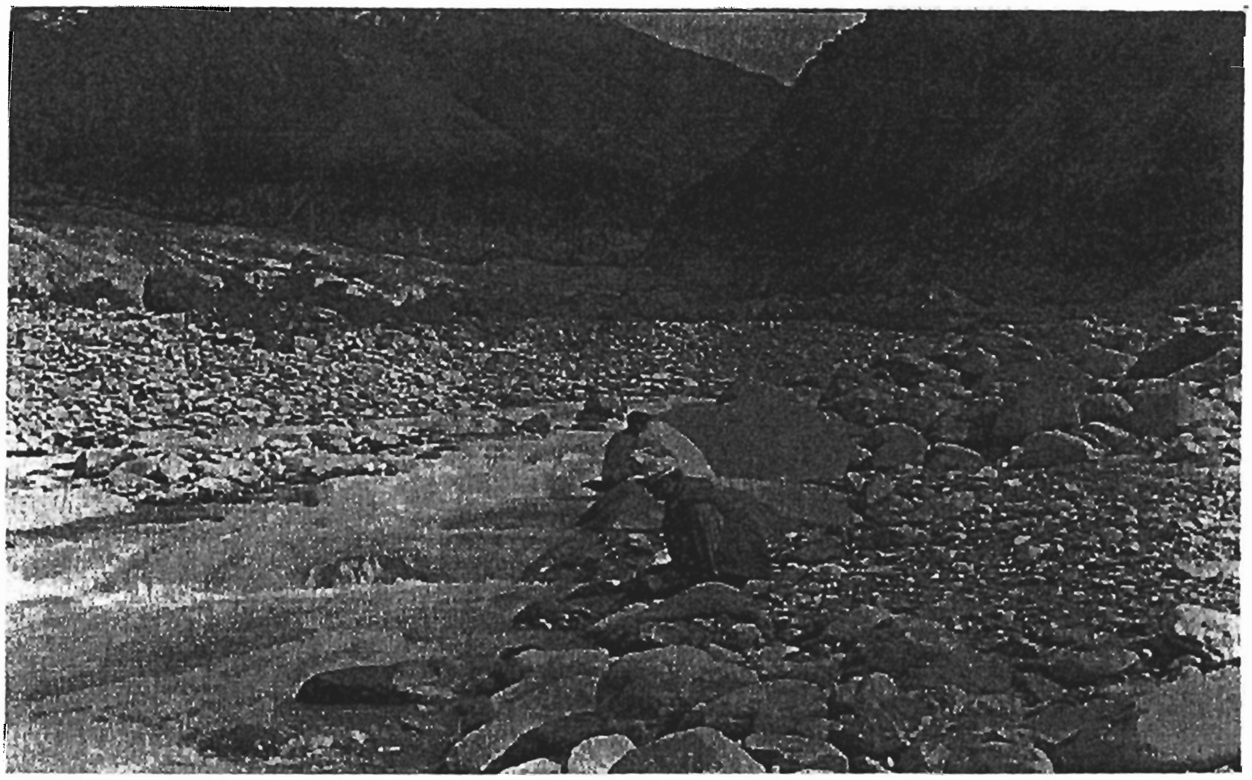


Plate No 7 Photograph showing the panning of sample along the Bagrot river

Sample Numbering of different terraces as shown in the location map (Fig.3) is as under:

One sample (CT1-P1) from terrace No 1 (CT1), One sample (CT2-P1) from terrace No 2 (CT2), Two samples (CT3-P1 and CT3-P2) from terrace No 3 (CT3), and one sample (CT4-P1) from terrace No 4 were collected from the Chirah village. Two samples (CTV1-P1) and (CTV2-P1) from the vertical sections of terrace No1 and terrace No.2, respectively were also taken from the Chirah village.

One sample each (BT1-P1, BT2-P1, BT3-P1 and BT4-P1) from the terraces NO 1,2,3,and 4 respectively were collected from the Bulchi Village.

One sample each (FT1-P1, FT2-P1, FT3-P1, FT4-P1 and FT5-P1) from terrace No 1,2,3,4 and 5 respectively were collected from the Farfooh village.

The details of weight of samples taken from different terraces in Chirah, Bulchi and Farfooh villages are given below:

A. Terraces of Chirah village

From Chirah village, seven samples were collected from two types (glacio-fluvial and fluvial) of terraces (Fig. 3). The weight of samples collected during filed is as follows:

CT1-P1 = 61.10 kg
CT2-P1 = 64.20 kg
CT3-P1 = 63.12 kg
CT3-P2 = 48.12 kg
CT4-P1 = 45.20 kg
CTVI-P1 = 51.30 kg
CTV2-P1 = 61.12 kg

A total of about 394 kg of sediment samples from four terraces and two vertical sections at Chirah village were sampled in the field and transferred to the Mineral Testing Laboratory (MTL), Peshawar for further processing on shaking table.

B. Terraces of Bulchi village

In Bulchi village, samples were collected from four different terraces (Fig. 3). These are having the following weights:

BT1-P1 = 62.10 kg
BT2-P1 = 58.20 kg
BT3-P1 = 49.73 kg
BT4-P1 = 58.12 kg

Four samples of sediments having total weight of about 228 kg were collected from the four terrace of Bulchi village. All these samples were transferred to MTL, Peshawar for further processing on shaking table.

C. Terraces of Farfooh village

In Farfooh village, five terraces were sampled (Fig.3). These samples have the following weights:

FT1-P1 = 51.20 kg
FT2-P1 = 60.13 kg
FT3-P1 = 53.20 kg
FT4-P1 = 57.12 kg
FT5-P1 = 49.80 kg

Five samples of sediments, having total weight of 271 kg were collected form the five terraces of Farfooh village. All these samples were transferred to the MTL, Peshawar for further processing on shaking table.

LABORATORY METHODOLOGY

Sixteen samples of sediments, having total weight of about 893 kg, collected from the terraces on both sides of the Bagrot river during field work were partially panned by manual panning and the panned material was then transferred to the MTL, Peshawar and were processed through shaking table in the metallurgical section of MTL for extraction of gold and silver. The details of the extraction and analytical processes are given in the form of flow sheet in the annexure-I and are discussed as under.

A. Metallurgical section

In the metallurgical section of the MTL, the samples were treated as follows:

Sieving: Samples were first sieved through a sieve of # 10 mesh sizes.

Splitting: After sieving, all the samples were split through splitting machine (Plate 8). The material was fed evenly across the top of the splitter so that it was randomly split into two approximately equal sizes and fractions on passing through the splitter. Fraction of 1/16th of the original sample was produced by repeated application of the procedure. Finally this fraction was riffled out through riffle box (Plate 9). This final riffled fraction was then divided in to three sub-samples by quartering and coning method. These samples are known as Head samples of chemical and mineralogical analyses and record keeping. In this way Head samples from each terrace and vertical section were obtained for various investigations. These test samples were put into small plastic bags after writing their relevant sample numbers as given in the field followed by Hd.Min, Hd.Ch

Plate No 8 Photograph showing the dry splitting machine

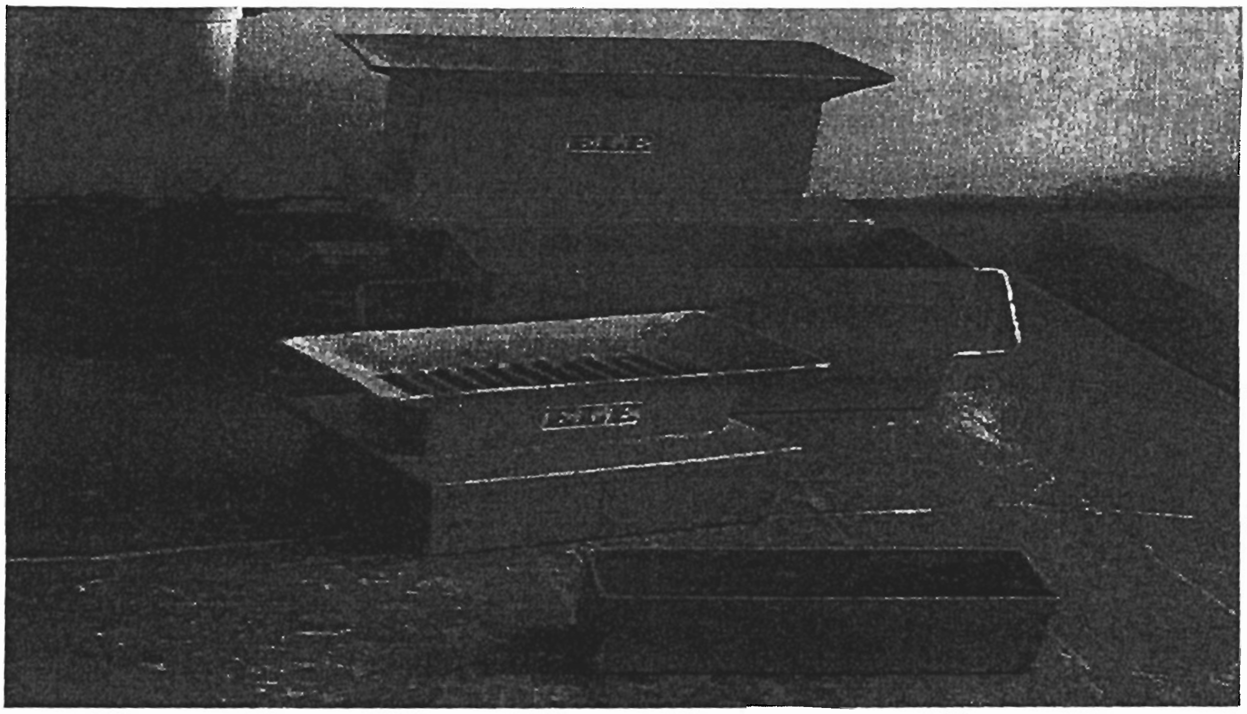


Plate No 9 Photograph showing the riffle box and Hd.Rc for mineralogical test sample, chemical test sample and record keeping sample respectively. For example:

CT1-P1/Hd.Min = Head sample for mineralogical test of sample No.1 from terrace No 1 of Chirah village.

CT1-P1/Hd.Ch = Head sample for chemical analysis of sample No. 1 from terrace No 1 of Chirah village.

CT1-P1/Hd.Rc = Head sample for record keeping from sample No. 1 of terrace No. 1 from Chirah village.

Similar nomenclature was adopted for the samples of other terraces of Bulchi and Farfooh villages.

The bulk of the sample left after taking samples for mineralogical test, chemical analyses and record keeping during splitting and riffling was named as processing sample.

Shaking table: Shaking table (Plate 10) is a concentration device that consists of plane surface, shaking with different motions in the direction of the long axis and washed out the material at right angle to the direction of motion. The feed material is then washed down the slope by the stream of water and is separated as Concentrate, Middling and Tail below the slope according to the size and density.

Sampling: The processing samples of each terrace and vertical section were separately passed through shaking table. After passing through the shaking table three products namely Concentrate, Middling and Tail were separated by gravity separation method. These three media were then dried in oven and were further sampled for mineralogical and chemical analyses and record keeping through the method of quartering and coning. These samples were then marked as the field

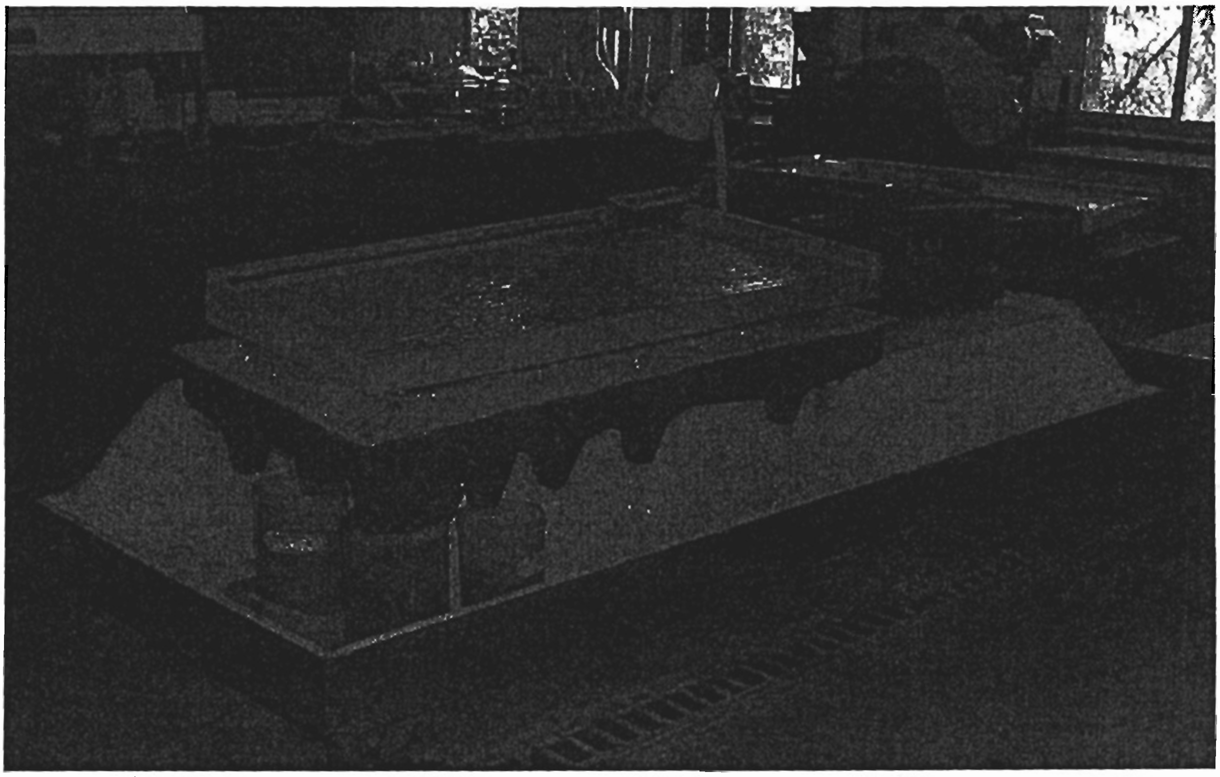


Plate No 10 Photograph showing the Shaking table sample number followed by Con, Mid and Tl for Concentration, Middling and Tail respectively. The following nomenclature was used for simplicity. For example:

1. Samples for Mineralogical investigation were named as:

CT1-P1/Min.Con = Concentrate of sample No 1 of Chirah terrace No.1 for mineralogical test.

CT1-P1/Min.Mid = Middling of sample No. 1 of Chirah terrace No. 1 for mineralogy test.

CT1-P1/Min.Tl = Tail of sample No. 1 of Chirah terrace No. 1 for mineralogical test.

2. Samples for chemical investigation were named as:

CT1-P1/Ch.Con = Concentrate of sample No. 1 of Chirah terrace No. 1 for chemical analysis.

CT1-P1/Ch.Mid = Middling of sample No. 1 of Chirah terrace No. 1 for chemical analysis.

CT1-P1/Ch.Tl = Tail of sample No 1 of Chirah terrace No. 1 for chemical analysis.

3. Sample for record keeping were named as:

CT1-P1/Rc.Con = Concentrate of sample No. 1 of Chirah terrace No. 1 for record keeping.

CT1-P1/Rc.Mid = Middling of sample No. 1 of Chirah terrace No. 1 for record keeping.

CT1-P1/Rc.Tl = Tail of sample No. 1 of Chirah terrace No. 1 for record keeping.

After taking the representative samples for mineralogical and chemical analyses and record keeping from the Middling and Tail media, the rest of the portions of Middling and Tail were discarded. The Concentrates of all the terraces from Chirah village were mixed together to get a bulk Concentrate and was named as Chirah Concentrate. Similarly this process was adopted for the terraces of Bulchi and Farfooh villages. In this way, the bulk sample Concentrates obtained from the terraces of Bulchi and Farfooh villages were named as Bulchi and Farfooh Concentrates.

Finally the concentrates named as Chirah, Bulchi and Farfooh were mixed and sieved through a sieve #18 mesh size and was named as Bagrot concentrate (BRC).

Mercury amalgamation: The Bagrot concentrate was put in a glass jar for tumbling in tumbling Machine (Plate 11). It was kept in tumbling machine for 30 minutes and then transferred into a bottle. Mercury was added to it and placed in a bottle rolling machine (Plate 12). The rolling process was continued up to one hour. During this time the mercury catches maximum gold. The mercury was then separated from the sample by manual panning. Residue left after separation of mercury was named as Bagrot Residue (BRR). Samples from the Bagrot Residue were taken for mineralogical test, chemical analysis and record keeping and Sample numbers were marked as BRR/Min (Bagrot residue for mineralogical test), BRR/Ch (Bagrot residue for chemical analysis) and BRR/Rc (Bagrot residue for Record keeping). Gold-loaded mercury was put in a small crucible and placed in the retort furnace (Plate 13) at temperature of 550°C for 30 minutes and 650°C for 15 minutes. Mercury was heated in the furnace, which was evaporated and condensed in a flask that was linked through a pipe to a motor engine. Mercury recovered in this way was re-used. The gold left in the crucible was saved and was named as BRRG (Bagrot residue gold).

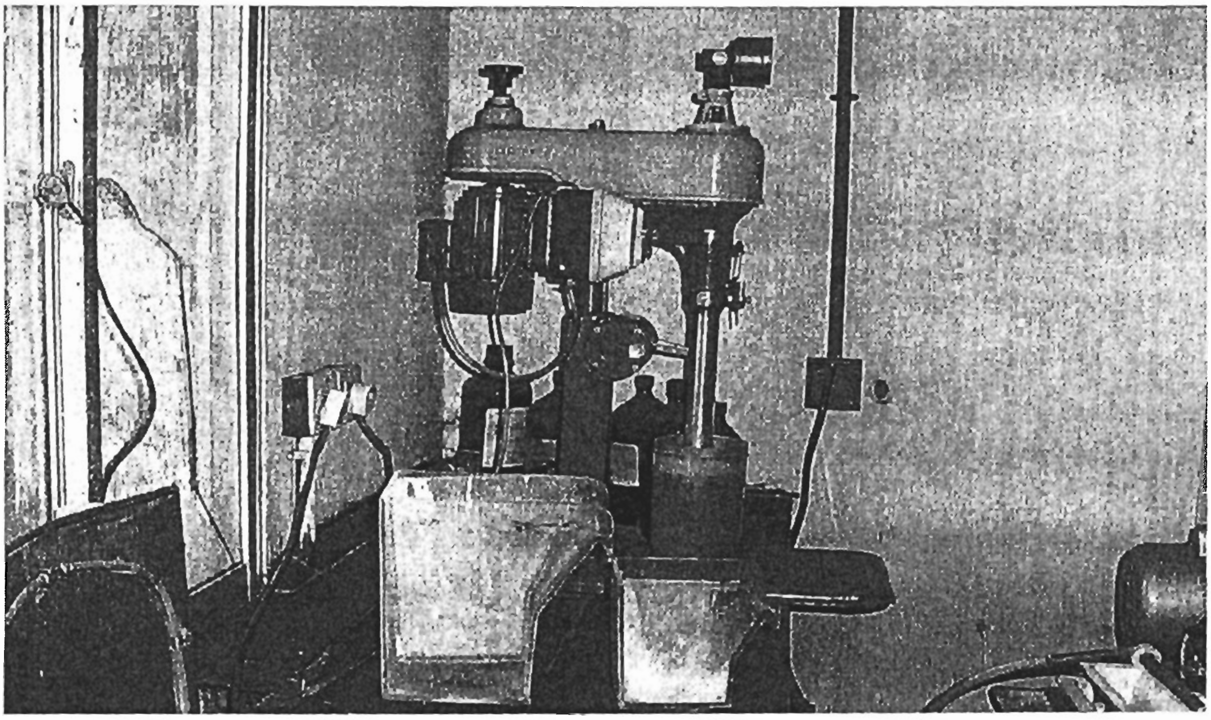


Plate 11. Photograph showing the Thumbling Machine.

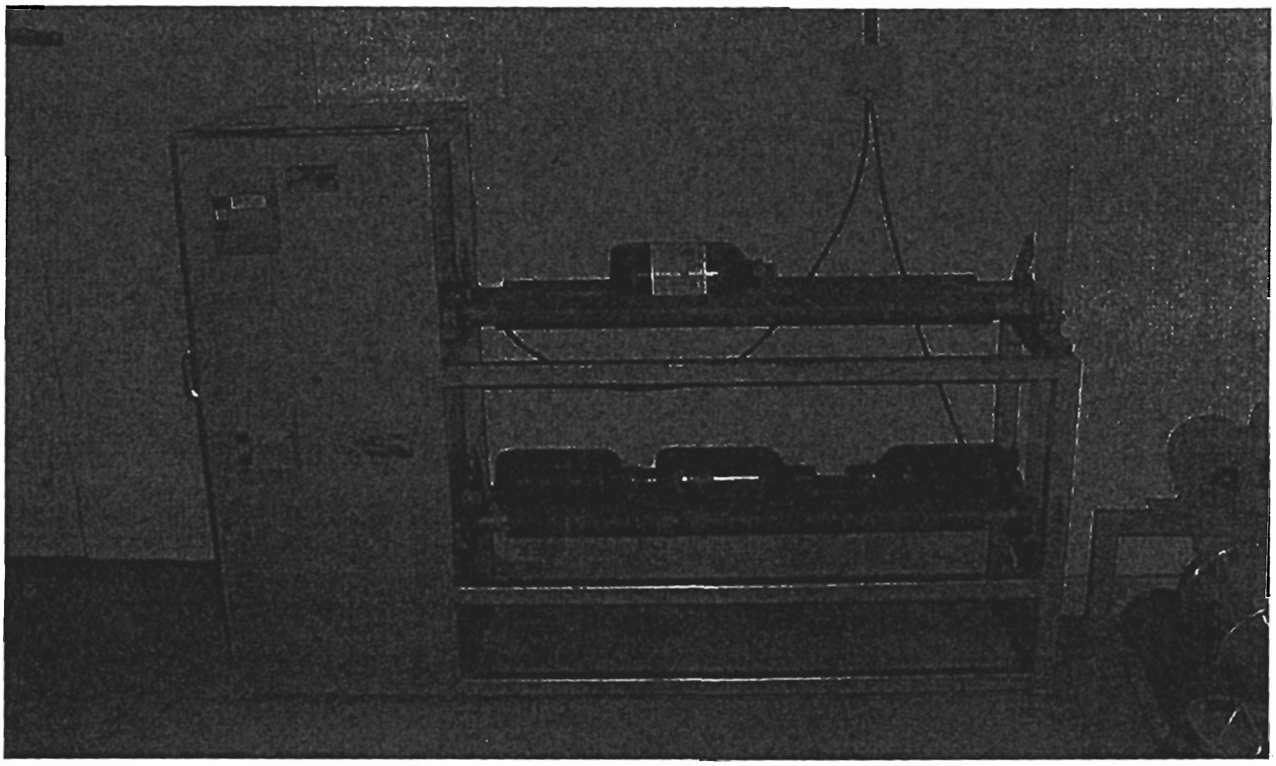


Plate 12. Photograph showing the Bottle Rolling Machine.

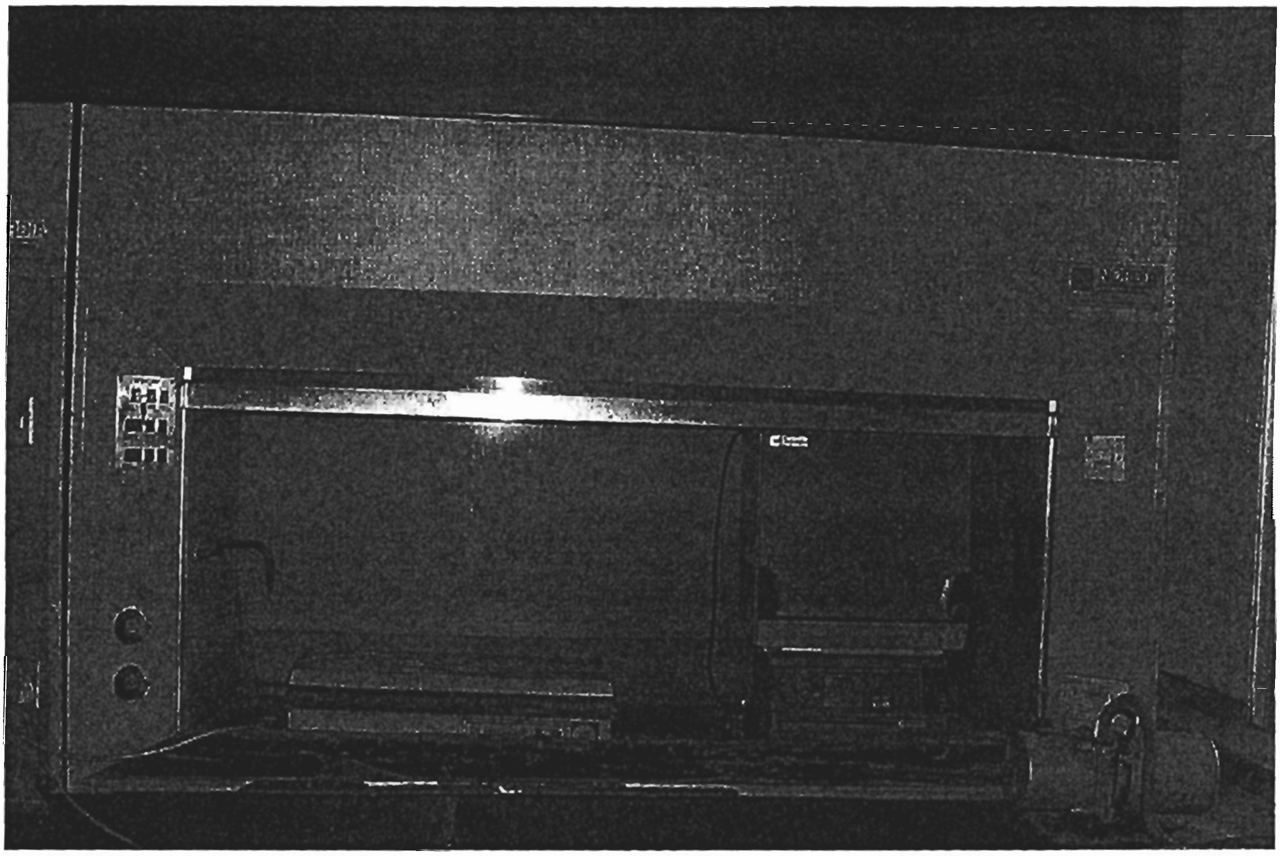


Plate 13. Photograph showing the Retort Furnace.

B. Chemical section

For chemical analysis, samples were powdered in the grinding machine up to –200 mesh size. 30g of powder sample from each sample stored for chemical analysis was weighed and put in different beakers. 50 ml of equa-regia (ratio of 3:1,HCl and HNO_3 respectively) was added and heated for 30 minutes. 30 ml of distilled water was added and heated until approximately 50 ml solution was left in the beakers. The contents of the beakers were then filtered and washed by 6N HCl into the test tubes to make the final volume of 50ml. The filtrate was then transferred to 250 ml reparatory funnels and same amount of distilled water was added to it. 20ml of Mithyle Isobutyle Ketone (MIBK) was added to the separatory funnels. The funnels were shaked by the shaking machine for 10 minutes. The lower layer was discarded through the separatory funnels. Then 20ml of 0.2NHCL was added to the MIBK in the reparatory funnels and shacked again for five minutes. The lower layer was again discarded and the MIBK containing extracted gold was stored in a glass bottle for the analyses by Atomic Absorption Spectrophotometer (Plate 14) for gold (Au).

For silver (Ag) analyses, 30g of sample was treated with 50 ml of equa-regia by heating for about two hours on low heat and the solution was made to 50 ml of volume with distilled water. This solution was directly run through Atomic Absorption for the determination of silver.

The analyses on atomic absorption were performed in the MTL, Peshawar and the Geochemistry laboratory of the National Centre of Excellence in geology, University of Peshawar.

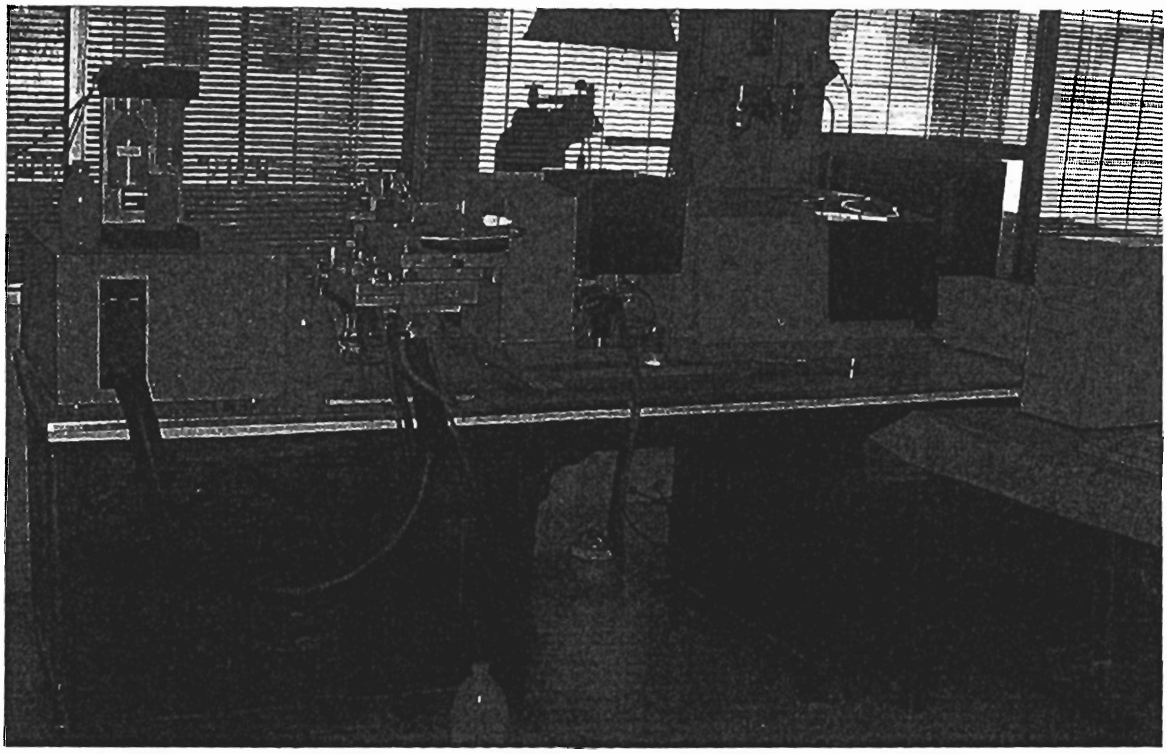


Plate 14. Photograph showing the Atomic Absorption Spectrometer

C. Mineralogical section

Each sample obtained through different metallurgical processes for the mineralogical tests was carefully examined under the binocular microscope. Gold size was identified and classified into piece, speck and color. Piece is >0.5 mm, speck is 0.3–0.5 mm and color is <0.3 mm. Gold was also checked for its form, shape, roundness and colour. Besides gold and silver other minerals, rock fragments and gems were also identified on the basis of their amount/percentage present in the sample such as dominant (>50%), major (10-50%), minor (1-10%) and trace (<1%).

D. Metallurgical work on the samples collected from Bagrot valley by PMDC-NA

A project between Sarhad Development Authority (SDA) and Pakistan Mineral Development Corporation, Northern Areas (PMDC-NA) was conducted for the extraction of gold in the Bagrot Valley placer deposits where the present scholar has carried out such studies. It is, therefore, pertinent to discuss the methodology and other studies conducted during the above mentioned project so that the results can be compared with the present study. The methodology adopted during the said project is given in annexure-II and discussed as follows.

Field methodology: Northern Area PMDC has collected and processed about 235 tons of sediments through pneumatic machine from the recent river terraces in Bagrot valley. As a result about 0.80 tons of concentrate was obtained in the field.

Laboratory methodology: The material collected during filed was transferred to the Mineral Testing Laboratory, Peshawar for further processing on sophisticated machines. During the metallurgical process, shaking table was used on experimental basis to extract coarse-gold and silver while fine and ultra-fine gold was extracted through cyanidation process.

0.80 tons of sample, collected during the field, was riffled out through splitting machine and the representative samples were separated after quartering and conning for mineralogical and chemical tests and record keeping while rest of material was processed through the shaking table for the recovery of coarse-gold. The Concentrate obtained from shaking table was processed through grinding / tumbling and mercury amalgamation, as described in the previous section, and the crude gold was obtained.

The Middling and Tail obtained through the shaking table and the residue material after recovery of crude course gold were processed by the cyanide / leaching test. During this test the sample is converted into a pulp by addition of tap water and sufficient lime to increase pH up to 11.5. Then 0.1%Sodium Cyanide (NaCN) was also added to it. During this cyanidation process 5ml sample of each pregnant solution was collected after 2,8 and 24 hours. These samples were analyzed by atomic absorption for gold and silver (The method of gold and silver determination is given in the previous section). On the completion of cynidation the pulp was filtered and the residue was thoroughly washed to ensure the transfer of all gold and silver into the pregnant solution. The residue was then dried and analyzed for gold and silver by fire assay technique. The pregnant solution was then transferred to tank containing activated carbon. The pH of sodium cyanide was maintained to 11.5 through out the process. After 24 hours the activated carbon loaded by gold and silver was filtered. The barren solution was then analyzed for gold and silver. The loaded carbon was then fired which resulted in the ash containing gold and silver. This ash was then mixed with flux, which gave gold and silver in the form of prill.

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CHAPTER 5

MINERALOGICAL AND CHEMICAL STUDIES OF SEDIMENTS FROM BAGROT VALLEY TERRACES

A. CHIRAH VILLAGE TERRACES

Chirah village is situated at the snout of Hinarchane Glacier, which is a source of feeding material to the Bagrot river. Along the bank of Bagrot river two types of terraces, glacio-fluvial and fluvial, are identified (Fig.3). Both types of terraces are present in the Chirah village. The mineralogical and chemical studies of these terraces are discussed below.

1. CHIRAH TERRACE No. 1 (CT1)

Terrace CT1 is a glacio-fluvial deposit, mainly composed of poorly sorted sand, gravel and conglomerate materials. Length of this terrace is 150 m with a width of 40 m. Thickness varies from place to place, however, maximum exposed thickness is about 6 m.

Float is mainly composed of diorite, granodiorite, carbonate schist, granite, basalt, chlorite schist, pyroxinite with veins of epidote and basalt with pyroxene phenocrysts and olivine aggregate.

Sample No. CT1-P1

Mineralogical Study

Head sample (CTI-P1/Min.Hd): Quartz and rock fragments are the dominant phases with lesser amount of magnetite, tetrahedral pyrite and chalcopyrite having brass-yellow colour. Biotite, muscovite, chlorite and epidote are in minor amount. These grains are generally irregular to sharp edged. Zircon and sphene occur in traces.

***Gold*:** No gold either in the form of piece, speck or color has been noticed.
Concentrate (CT1-P1/Min-Con): Octahedral magnetite is the most dominant (>90%) phase. Quartz, brass yellow coloured pyrite and chalcopyrite and garnet are present in minor amount. Traces of zircon and sphene are noticed.

Gold: One color (0.25 mm) of gold has been noticed, which is sub-angular to sub-rounded in shape and solid in form.

Middling (CT1-P1/Min.Mid): Middling is dominantly composed of quartz, chlorite, epidote, muscovite, biotite and fine-magnetite, while garnet occurs in trace amount.

***Gold*:** No visible gold is observed.

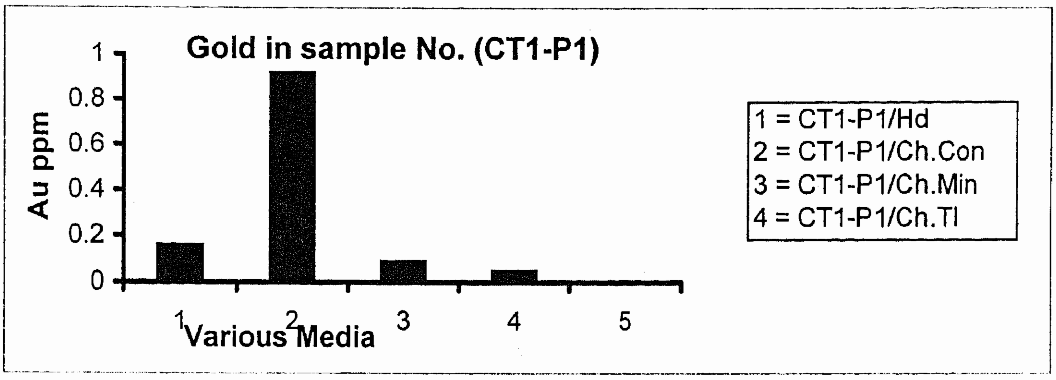
Tail (CT1-P1/Min.Tl): Tail has the same mineralogy as that of Middling and has no visible gold.

Chemical study

Table 1 and Fig. 4 show that the terrace No.1 has the maximum gold (0.92 ppm) in the Concentrates sample while the Head, Middling and Tail samples are having 0.16 ppm, 0.09 ppm and 0.05 ppm of gold respectively. Silver in all three media is, however, below the detection limit (<0.5ppm). The chemistry of all the three media is in accordance with the mineralogical studies as far as the gold concentration is concerned.

Table 1. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(CT1-P1) of Chirah terrace No. 1.

Sample No	Au ppm	Ag ppm
CT1-P1/Hd	0.16	<0.5
CT1-P1/Ch.Con	0.92	<0.5
CT1-P1/Ch.Mid	0.1	<0.5
CT1-P1/Ch.Tl	0.1	<0.5



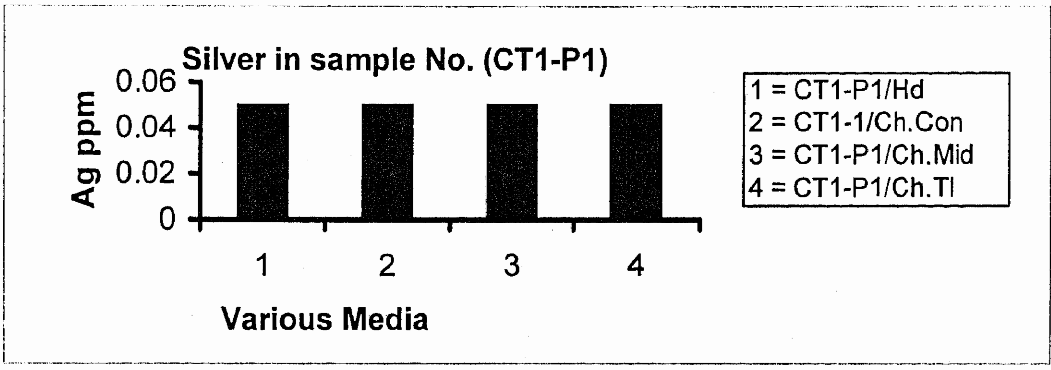


Fig. 4. Graphical presentation of the Au and Ag concentration in Head , sample, Concentrate, Middling and Tail of the sample No. 1 (CT1-P1) of Chirah terrace No. 1.

2. CHIRAH TERRACE VERTICAL SECTION No. 1 (CTV1)

Chirah terrace vertical section No. 1 (CTV1) is about 6 m thick and is mainly composed of glacio-fluvial deposits.

Sample No. CTV1-P1

Mineralogical study

Head sample (CTV1- P1/Min.Hd): The head sample contains variable proportions of quartz, rock fragments, magnetite, pseudopyrite (Show oxidation effects), pyrite, epidote, chlorite, muscovite, biotite and carbonates.

***Gold*:** No visible gold has been noticed.

Concentrates (CTV1-P1/Min.Con): Octahedral grains of magnetite are dominant (>90%) with minor amount of rock fragments, brass-yellow pyrite, chalcopyrite, quartz and garnet. Tourmaline and sphene occur in traces.

Gold: One color (0.3 mm) of gold having light yellow colour with solid form and angular to sub-rounded shape has been noticed.

Middling (CTV1- P1/Min.Mid): It is dominantly (>70%) composed of quartz, rock fragments, biotite, muscovite, and epidote with lesser amount of fine-magnetite, pyrite, malachite and carbonates.

Gold: No visible gold is present

Tail (CTV1-P1/Min.Tl): In Tail, the rock fragments and carbonates are dominant with lesser amount of muscovite, biotite and quartz.

Gold: No visible gold is found.

Chemical study

It is clear from Table 2 and Figure 5 that the Concentrate of this sample has higher amount of gold (0.89 ppm) as compare to that of Head sample (0.27 ppm), Middling (0.09 ppm) and Tail (0.05 ppm). The silver is, however, below the detections limit (<0.5 ppm) in all the three media.

3. CHIRAH TERRACE No. 2

Chirah terrace No. 2 is the extension of Chirah terrace No. 1 (Fig. 3) and is glacio-fluvial in origin. This terrace is 100 m long and 50 m wide. It is mainly composed of poorly sorted sand, gravel and conglomerate materials. Floats are the same as that of the terrace No. 1. However; due to thick soil cover the floats are not exposed properly.

Sample No.CT2-P1

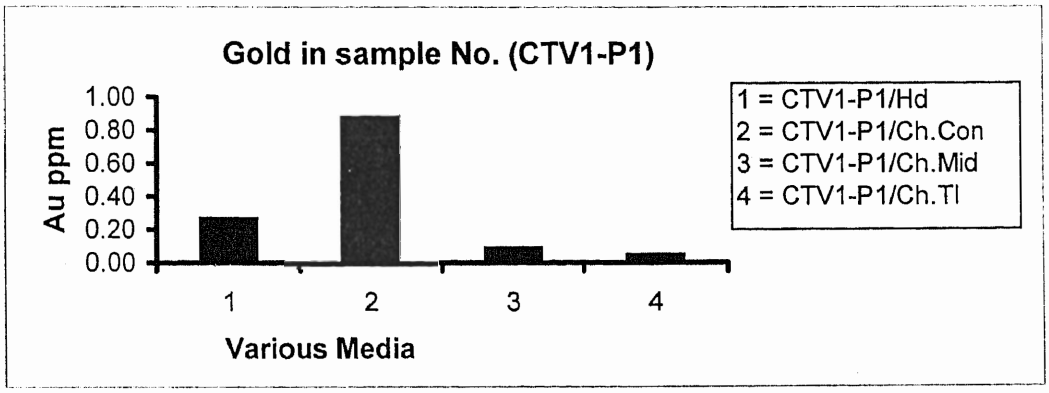
Mineralogical study

Head Sample (CT2-P1/Min.Hd): Quartz and rock fragments are the dominant phases with lesser amount of magnetite, brass-yellow colour pyrite, chalcopyrite, biotite, muscovite, epidote, pyroxene and garnet. Zircon, tourmaline and sphene are present in traces.

Gold: Two colors of gold are noticed with different shape and size. One color of gold has rounded to sub-rounded shape, solid form and light yellow

Table 2. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(CTV1-P1) of Chirah Vertical section No. 1.

Sample No	Au ppm	Ag ppm
CTV1-P1/Hd	0.27	<0.5
CTV1-P1/Ch.Con	0.89	<0.5
CTV1-P1/Ch.Mid	0.09	<0.5
CTV1-P1/Ch.Tl	0.05	<0.5



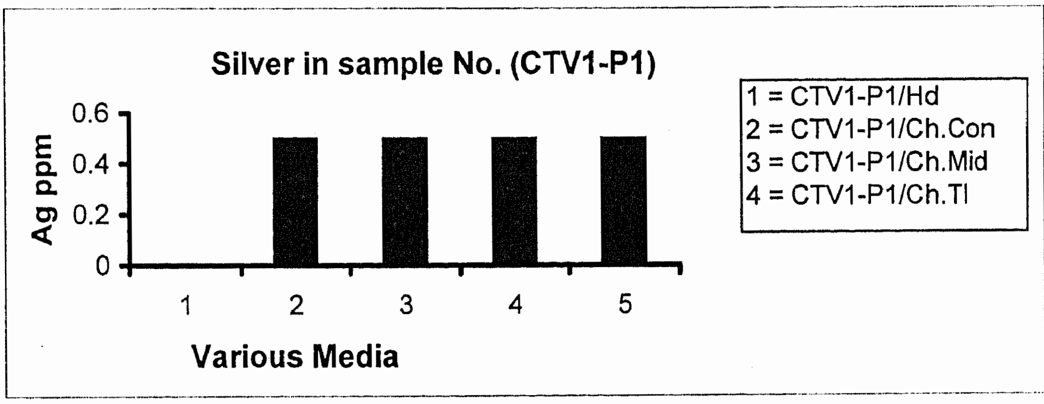


Fig. 5. Graphical presentation of the Au and Ag concentration in Head , sample, Concentrate, Middling and Tail of the sample No. 1 (CTV1-P1) of Chirah Vertical section No. 1.

colour while the other has pear to sub-angular shape, thick flaky form and dark yellow colour.

Concentrate (CT2- P1/Min.Con): Magnetite is the dominant phase (>90%) with about 2% pyrite and chalcopyrite. The remaining minerals include pyroxene, garnet, quartz, rock fragments, zircon, tourmaline and sphene.

Gold: One speck (0.4 mm) and two colors (<0.3 mm) are found. The speck is dark-yellow in colour having rectangular to sub-angular shape and solid form. Among the two colors, one color (0.3 mm) is nearly oval to sub-angular in shape, thick flaky in form and light-yellow in colour while the other color (0.28 mm) is elongated to angular in shape, solid in form and light- yellow in colour.

Middling (CT2-P1/Min.Mid): Middling is dominantly composed of epidote, quartz, muscovite, biotite, hematite and lesser amount of magnetite.

Gold: No visible gold has been identified.

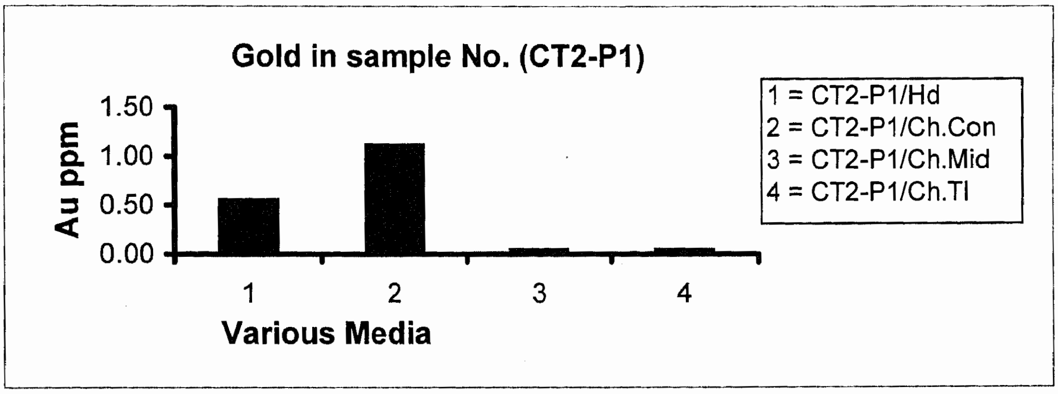
Tail (CT2- P1/Min.Tl): Tail has the same mineralogy as that of middling.

Chemical study

Table 3 and Figure 6 show that this sample of terrace No. 2 has 0.56 ppm and 1.12 ppm of gold in the and Head sample and Concentrate respectively while the Middling and Tail have negligible gold (0.05 ppm). This terrace has relatively high silver contents of 1.1 ppm and 0.7 ppm in the Concentrate and Head sample respectively.

Table 3. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No.1(CT2-P1) of Chirah Terrace No. 2.

Sample No	Au ppm	Ag ppm
CT2-P1/Hd	0.56	0.7
CT2-P1/Ch.Con	1.12	1.1
CT2-P1/Ch.Mid	0.05	<0.5
CT2-P1/Ch.Tl	0.05	<0.5



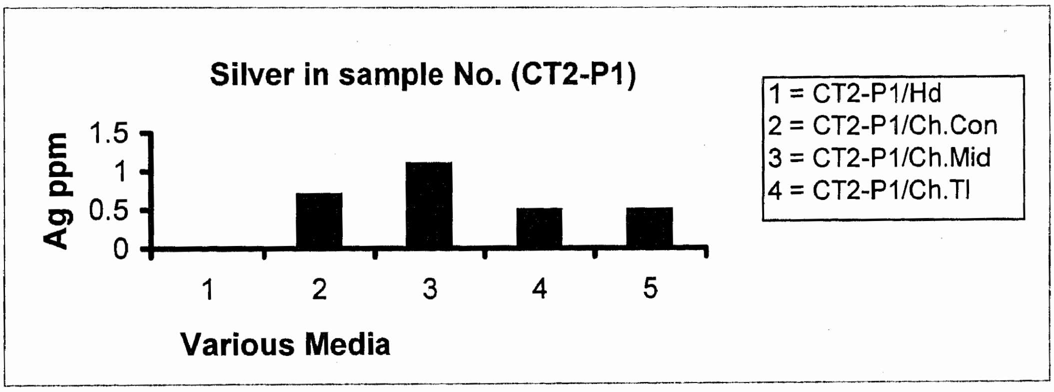


Fig. 6. Graphical presentation of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No.1 (CT2-P1) of Chirah terrace No. 2.

4. CHIRAH TERRACE VERTICAL SECTION No. 2 (CTV2)

Chirah terrace vertical section No. 2 is mainly composed of glacio-fluvial deposits with well-sorted sand, conglomerate and gravel materials. It has exposed vertical thickness of about 10 m.

Sample No. CTV2-P1

Mineralogical study

Head sample (CTV2- P1/Min.Hd): Quartz, magnetite, rock fragments, muscovite and biotite are the dominant minerals with lesser amount of pyrite, chalcopyrite, pyroxene, hornblende and garnet. Zircon occurs in trace amount.

Gold: No visible gold is noticed in the head sample.

Concentrates (CTV2-P1/Min.Con): Magnetite is the dominant (<95%) phase with minor amount of pseudomrphs of pyrite and chalcopyrite (showing oxidation effects), rock fragments, pyroxene, hornblende and garnet. Zircon and sphene occur in trace amount.

Gold: One speck and three colors of gold in different shapes and colours are noticed. Speck (0.45 mm) is dark-yellow in colour with sub-angular to sub-rounded in shape and solid in form. Among the three colors one color (0.25 mm) of gold is bright-yellow having irregular to sub-angular shape and flaky form. The second color (0.2 mm) of gold is light-yellow with pear to sub-angular in shape and solid in form while the third color (0.25 mm) has dark yellow colour with nearly rhomb to sub-angular in shape and flaky in form.

Middling (CTV2-P1/Min.Mid): It is mainly composed of muscovite, biotite, epidote and fine-grained magnetite.

Gold: No visible gold is present in Middling.

Tail (CTV2- P1/Min.Tl): It has the same mineralogy as that of Middling.

Chemical study

It is clear from the Table 4 and Figure 7 that the Concentrate sample of vertical section of terrace No.2 has high concentration of gold (1.08 ppm) and silver (1.5 ppm) as compare to those of Head sample, Middling and Tail.

5. CHIRAH TERRACE No. 3 (CT3)

Chirah terrace No. 3 is about 120 m long and 60 m wide and is mainly composed of fluvial sediments. Floats of this terrace are mainly carbonate-chlorite schist with lesser amount of granite, quartzite and diorite.

Two samples (CT3-P1 and CT3-P2) have been collected from this terrace and are described below.

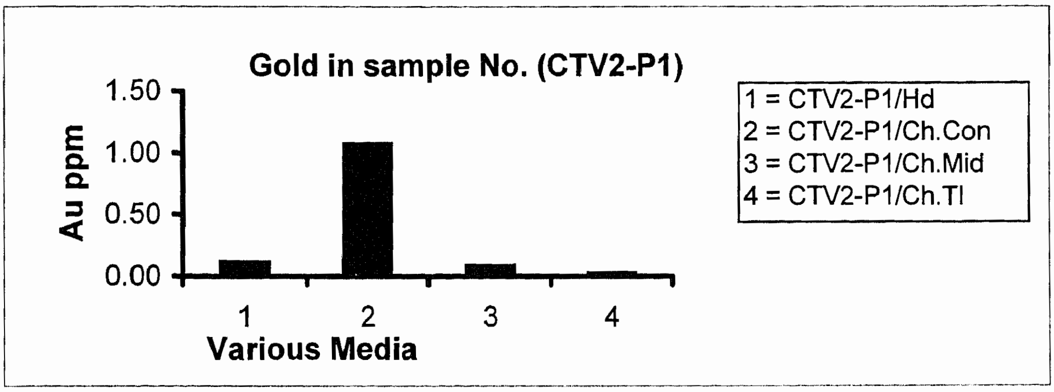
Sample No. CT3-P1

Mineralogical study

Head sample (CT3-P1/Min.Hd): Rock fragments and quartz are dominant phases with lesser amount of magnetite, biotite, muscovite, carbonates, pyrite, zircon and tourmaline.

Table 4. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(CTV2-P1) of Chirah vertical section No. 2.

Sample No	Au ppm	Ag ppm
CTV2-P1/Hd	0.12	<0.5
CTV2-P1/Ch.Con	1.08	1.5
CTV2-P1/Ch.Mid	0.09	<0.5
CTV2-P1/Ch.Tl	0.03	<0.5



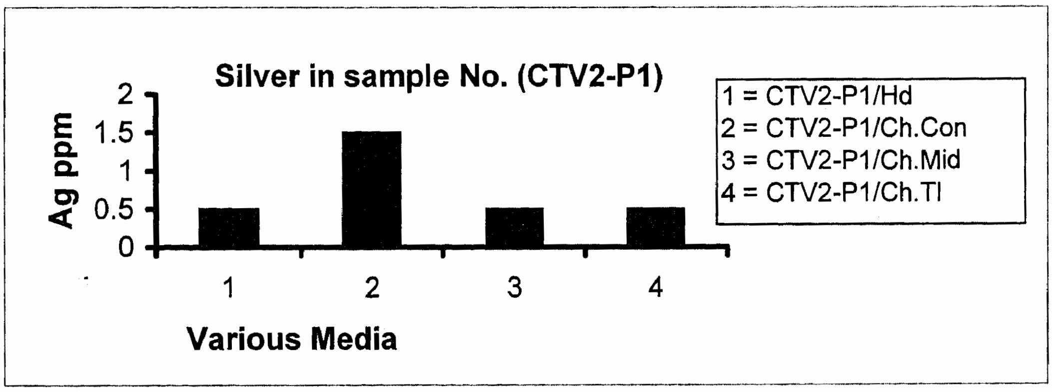


Fig. 7. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (CTV2-P1) of Chirah Vertical section No. 2.

Gold: No visible gold has been noticed in the head sample.

Concentrate (CT3-P1/Min.Con): Magnetite is the dominant phase, with subordinate amount of pyrite, chalcopyrite, rock fragments, quartz and garnet while zircon, tourmaline and sphene occur in trace amount.

Gold: No visible gold has been noticed in the Concentrate of this sample.

Middling (CT3-P1/Min.Mid): Quartz, biotite, muscovite and fine-grained magnetite are the dominant phases with traces of rock fragments, zircon and tourmaline.

Gold: No visible gold is present in the Middling.

Tail (CT3- P1/Min.Tl): The Tail has the same mineralogy as that of Middling but with different proportion of various phases.

Chemical study

It is clear from the chemical analyses that this sample of the terrace No. 3 has negligible amount gold in Head sample, Middling and Tail. However, the Concentrate has 0.70 ppm of gold. Silver is below detection limit in all the analyzed media of this sample (Table 5; Fig. 8).

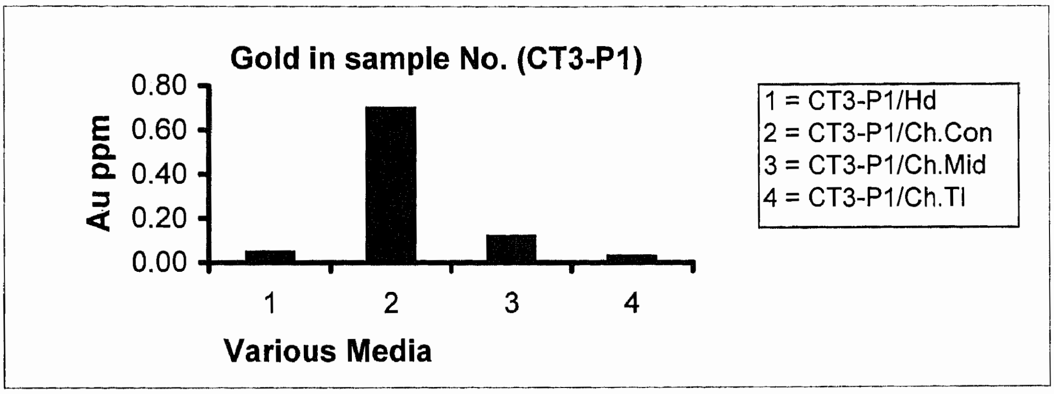
Sample No. (CT3- P2)

Mineralogical study

Head sample (CT3-P2/Min.Hd): Rock fragment, quartz, muscovite, biotite and magnetite are the dominant mineral phases with lesser amount of pyrite, chalcopyrite, hornblende, garnet and epidote. Zircon is present in trace amount.

Table 5. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1 (CT3-P1) of Chirah terrace No. 3.

Sample No	Au ppm	Ag ppm
CT3-P1/Hd	0.05	<0.5
CT3-P1/Ch.Con	0.70	<0.5
CT3-P1/Ch.Mid	0.12	<0.5
CT3 -P1/Ch.Tl	0.09	<0.5



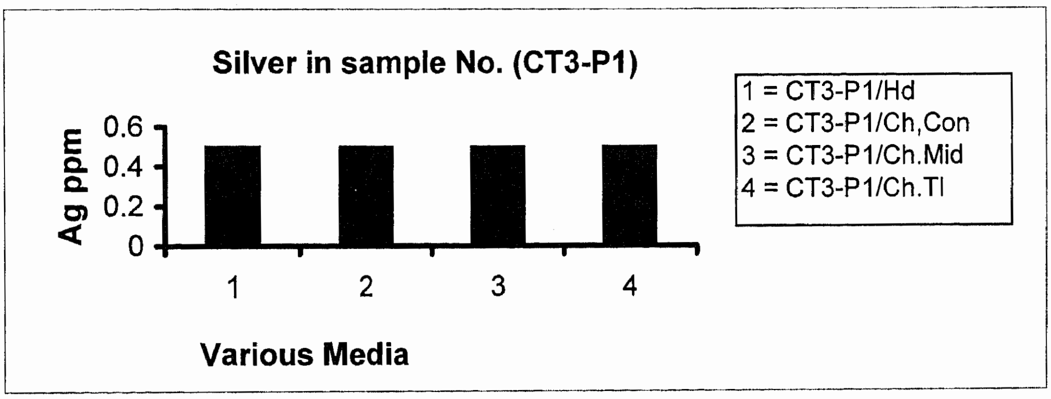


Fig. 8. Graphical presentatiopn of the Au and Ag concentration in Head sample,Concentrate, Middling and Tail of the sample No.1 (CT3 -P1) of Chirah terrace No. 3.

Gold: No visible gold is found in the head sample.

Concentrate (CT3-P2/Min.Con): Magnetite is the dominant phase (>90%) while the remaining mineral phases include pseudopyrite and chalcopyrite, hornblende, garnet, quartz, and zircon.

Gold: 4 specks and 7 colors of gold are identified. The specks are ranging in size from 0.35 mm to 0.4 mm. These are bright to dark-yellow and sub-rounded to rounded in shape and generally solid in form. The colors are ranging in size from 0.1 mm to 0.2 mm. These are light-yellow to dark-yellow in colour and are oval to sub-rounded and rounded in shape and flaky in form.

Middling (CT3-P2/Min.Mid): It is mainly composed of quartz, biotite, muscovite, and fine-grained magnetite.

Gold: No visible gold is present in Middling.

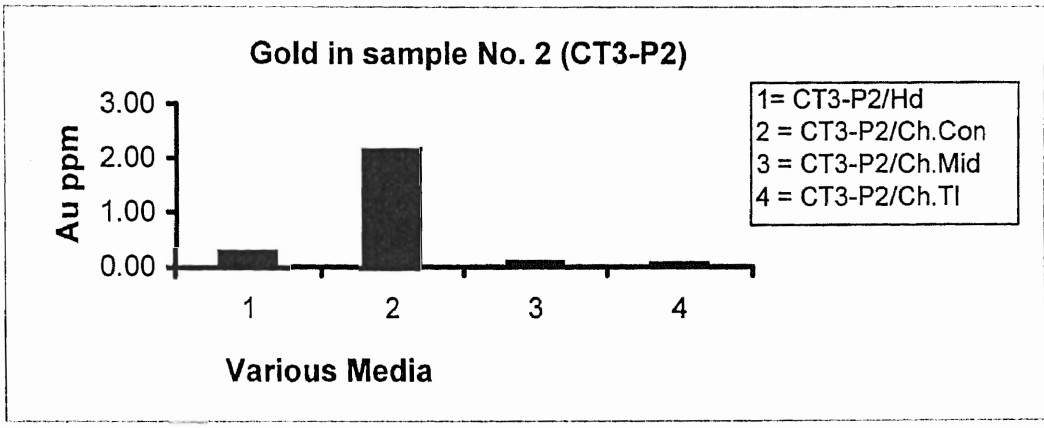
Tail (CT3- P2/Min.Tl): It has the same mineralogy as that of Middling.

Chemical Study

Table 6 and Figure 9 show that this sample of the terrace No.3 has high amount of gold (2.19 ppm) in the Concentrate. The Head sample has 0.31 ppm of gold while the Middling and Tail have 0.11 ppm and 0.08 ppm of gold respectively. Silver in the Concentrate is 1.5 ppm while rest of the sample media has silver below the detection limit.

Table 6. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 2 (CT3-P2) of Chirah terrace No. 3.

Sample No	Au ppm	Ag ppm
CT3-P2/Hd	0.31	<0.5
CT3-P2/Ch.Con	2.19	1.5
CT3-P2/Ch.Mid	0.11	<0.5
CT3 -P2/Ch.Tl	0.08	<0.5



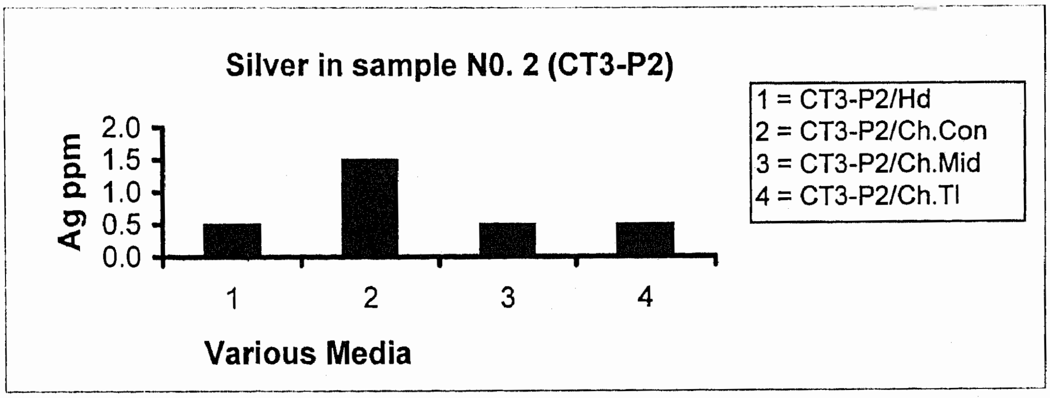


Fig. 9. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 2 (CT3 -P2) of Chirah terrace No. 3.

6. CHIRAH TERRACE No. 4 (CT4)

Chirah terrace No. 4, 100 m long and 50 m wide, is the extension of terrace No. 3 and is mainly composed of fluvial sediments having well-sorted sand, conglomerate and gravels. Float of this terrace is generally diorite, pyroxenite, basalt, and granite and epidote-chlorite schist.

Sample No. CT4-P1

Mineralogical study

Head sample (CT4-P1/Min.Hd): Quartz and rock fragment along with magnetite are the main constituent minerals while biotite, chlorite, muscovite pyroxene and epidote occur in minor amount.

Gold: One color of gold has been noticed in the Head sample. It is dark-yellow colour having angular to sub-angular shape and solid form.

Concentrate (CT4-P1/Min.Con): Magnetite and rock fragments are the main constituents (>90%) while pyrite, chalcopyrite, pyroxene and garnet occur in minor amount. Zircon is present in trace amount.

Gold: One speck and four colors of gold are noticed in the Concentrate of this sample. Speck is 0.35 mm in size and is dark yellow in colour having rounded to sub-rounded shape and solid form. The colors range in size from 0.1 mm to 0.2 mm. These flaky grains are of light-yellow to dark-yellow in colour and rounded to sub-rounded in shape.

Middling (CT4-P1/Min.Mid): Quartz, muscovite, biotite, chlorite, epidote and fine-magnetite are the dominant phases with traces of pyroxene and garnet in the Middling sample.

Gold: No visible gold is found in the Middling.

Tailing (CT4-P1/Min.Tl): The tail has the same mineralogy as that of middling.

Chemical study

It is clear from the Table 7 and Figure 10 that this sample of the terrace No.4 is having high concentration (1.14 ppm) of gold in the Concentrate and 0.28 ppm of gold in the Head sample while the Middling and Tail are having negligible amount of gold. The silver contents of Concentrate are 2 ppm while the Head sample has 0.8 ppm of silver. However, the silver contents in Middling and Tail are below the detection limit (<0.5 ppm).

B. BULCHI VILLAGE TERRACE S

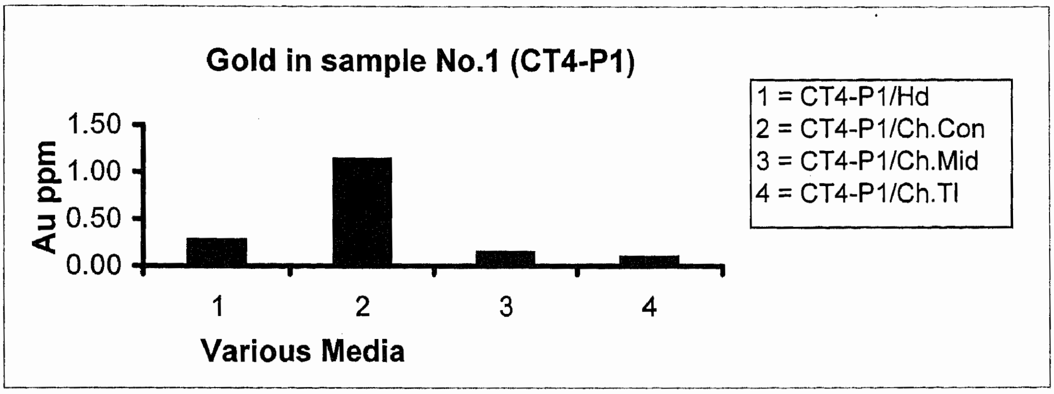
Bulchi village is situated opposite to the Chirah and Farfooh villages along the west bank of Bagrot river (Fig. 3). Bulchi village has three vast terraces, which are mainly composed of fluvial sediments. The mineralogical and chemical studies of these terraces are discussed below.

1. **BULCHI TERRACE No.1 (BT1)**

The terrace No.1 is the northern most terrace of the Bulchi village (Fig. 3). It is mainly composed of fluvial sediments and is about 180 m long and 50 m wide. Floats are dominantly composed of chlorite-carbonate schist, greenstone and phyllite with lesser amount of granodiorite, quartzite and dunite.

Table 7. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(CT4-P1) of Chirah terrace No. 4.

Sample No	Au ppm	
CT4-P1/Hd	0.28	0.8
CT4-P1/Ch.Con	1.14	0.2
CT4-P1/Ch.Mid	0.15	<0.5
CT4 -P1/Ch.Tl	0.10	<0.5



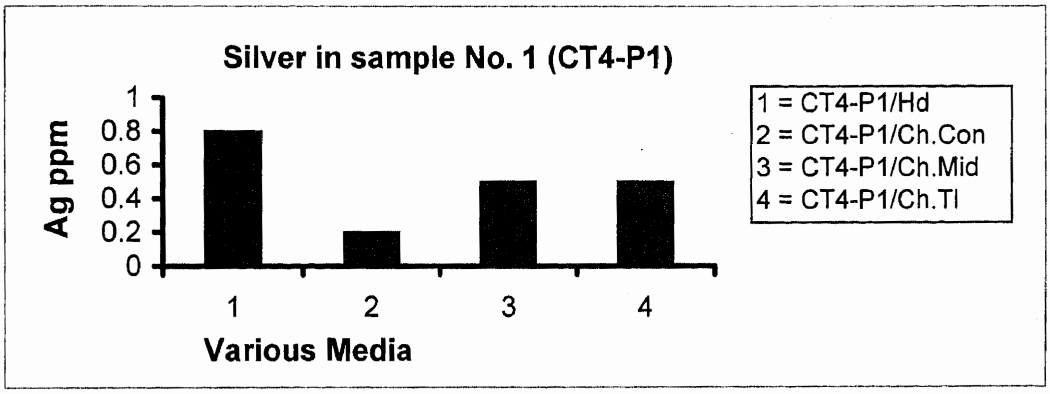


Fig.10. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (CT4 -P1) of Chirah terrace No. 4.

Sample No. BT1-P1

Mineralogical study

Head Sample (BT1-P1/Min.Hd): Quartz and rock fragments, magnetite, biotite, chlorite, muscovite are the dominant constituents while garnet, zircon, epidote and sphene occur as minor constituents.

Gold: No visible gold is present in Head sample.

Concentrate (BT1-P1/Min.Con): Magnetite having octahedral shape with black colour along with the rock fragments are the dominant phases (>90%) with lesser amount while pyrite, chalcopyrite and quartz. Zircon and garnet are present in trace amount.

Gold: One color (0.25 mm) of gold having light-yellow colour with sub-rounded shape and thin flaky form has been noticed.

Middling (BT1-P1/Min.Mid): Quartz, biotite, muscovite, chlorite, epidote, carbonate and fine-grained magnetite are present in variable amount as dominant phases.

Gold: No visible gold is noticed in the Middling.

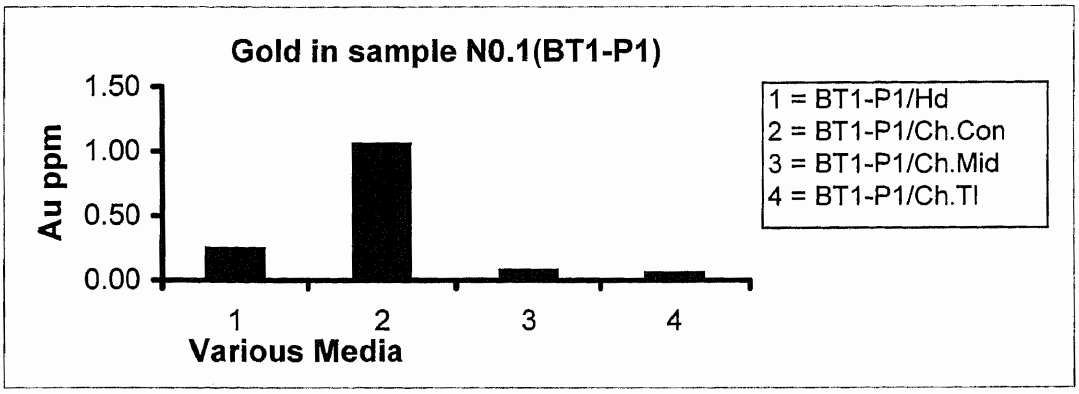
Tail (BT1-P1/Min.Tl): The tail has the same mineralogy as that of middling.

Chemical study

Table 8 and Figure 11 show that the Concentrate has 1.06 ppm of gold while the Head sample, Middling and Tail have 0.25 ppm, 0.08 ppm and 0.06 ppm of gold respectively. Silver in all four media is below the detection limit.

Table 8. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(BT1-P1) of Bulchi terrace No. 1.

Sample No	Au ppm	Ag ppm
BT1-P1/Hd	0.25	<0.5
BT1-P1/Ch.Con	1.06	<0.5
BT1-P1/Ch.Mid	0.08	<0.5
BT1 -P1/Ch.Tl	0.06	<0.5



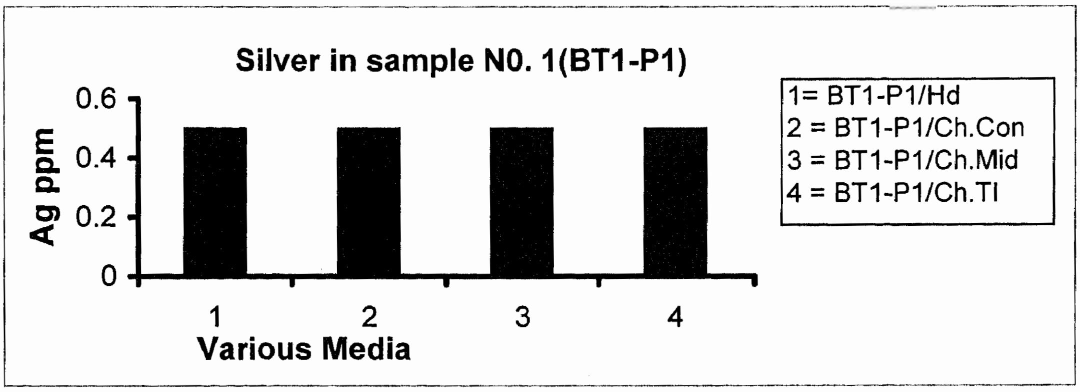


Fig.11. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (BT1 -P1) of Bulchi terrace No. 1.

3. BULCHI TERRACE No. 2 (BT2)

This terrace is the southern extension of terrace No. 1 of the Bulchi village. It is composed of the same kind of fluvial deposits, as those of terrace No 1. This terrace is about 300 m long and 50 m wide. Floats are dominantly chlorite-carbonate schist, greenstone, pyroxenite, and diorite, with an appreciable amount of quartzite, granite, diorite and granodiorite.

Sample No.BT2-P1

Mineralogical study

Head sample (BT2-P1/Min.Hd): It is mainly composed of quartz, rock fragments, magnetite, biotite, muscovite hornblende and epidote. Garnet, zircon and schrol are present in minor amount while sphene occurs in traces.

Gold: One color (0.2 mm) of gold has been noticed. It is dark-yellow in colour and having thick flaky form and rounded to sub-rounded shape.

Concentrate (BT2-P1/Min.Con): Magnetite and rock fragments are the main constituents (>90%) with lesser amount of pseudomorph of pyrite and chalcopyrite and Quartz. Zircon, apatite, tourmaline and sphene occur in trace amount.

Gold: One speck (0.4 mm) and one color (0.25 mm) have been observed in the Concentrate sample. Speck is bright-yellow in colour and angular to sub-rounded in shape and solid in form while the color is dark yellow in colour and has thin flaky form and oval to sub-rounded shape.

Middling (BT2-P1/Min.Mid): Biotite, muscovite, chlorite, epidote, quartz, hornblende and fine-magnetite are the main phases with traces of zircon, garnet, pyrite, and schrol.

Gold: No visible gold is present.

Tail (BT2- P1/Min.Tl): The Tail portion of the sample has the same mineralogy as that of Middling.

Chemical study

It is clear from Table 9 and Figure 12 that the Concentrate and Head sample have 1.36 ppm and 0.35 ppm gold respectively. The Middling and Tail have negligible amount of gold. Silver in all the four media is below detection limit.

4. BULCHI TERRACE NO. 3 (BT3)

Bulchi terrace No. 3 is situated in southern part of Bulchi village (Fig. 3). It is 80 m long and 60 m wide and is mainly composed of fluvial sediments. Floats are dominantly chlorite, greenstone, granite, granodiorite, quartzite and basalt.

Sample No.BT3-P1

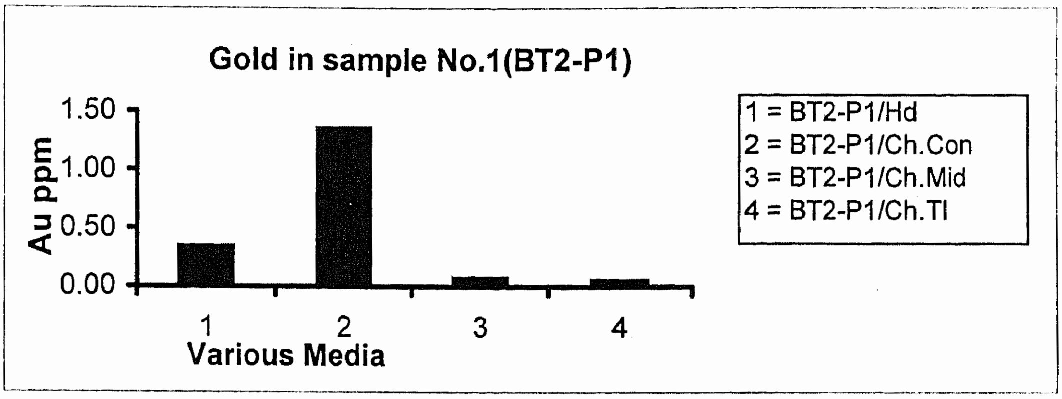
Mineralogical study

Head sample (BT3-P1/Min.Hd): Dominant phases include quartz, rock fragments, magnetite, biotite, chlorite muscovite pyroxene and epidote with traces of garnet and zircon.

Gold: No visible gold is present.

Table 9. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(BT2-P1) of Bulchi terrace No. 2.

Sample No	Au ppm	Ag ppm
BT2-P1/Hd	0.35	<0.5
BT2-P1/Ch.Con	1.36	<0.5
BT2-P1/Ch.Mid	0.08	<0.5
BT2 -P1/Ch.Tl	0.06	<0.5



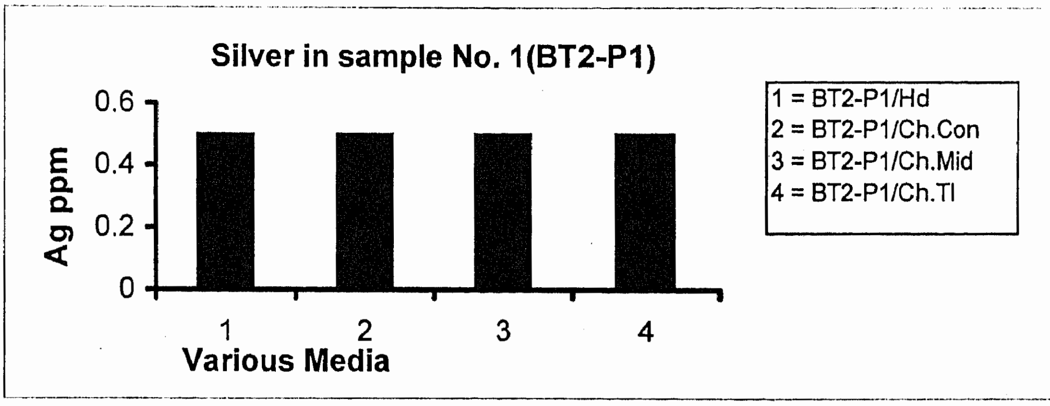


Fig.12. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (BT2 -P1) of Bulchi terrace No. 2.

Concentrate (BT3-P1/Min.con): Magnetite and rock fragment are the main constituents (>95%) while rest of the mineral phase includes quartz, pyroxene, garnet, zircon and tourmaline.

Gold: One speck (0.4 mm) and 5 colors (0.15 to 0.3 mm) of gold are identified. The speck is bright-yellow in colour and having angular to sub-rounded shape and solid in form. The colors are generally flaky with irregular, oval to pear and sub-rounded to round in shape.

Middling (BT3-P1/Min.Mid): Quartz, biotite, muscovite, epidote and fine-grained magnetite occur in variable proportion.

Gold: *No* visible gold is present.

Tail (BT3-P1/Min.Tl): Tail portion of the sample is having more or less the same mineralogy as that of Middling.

Chemical study

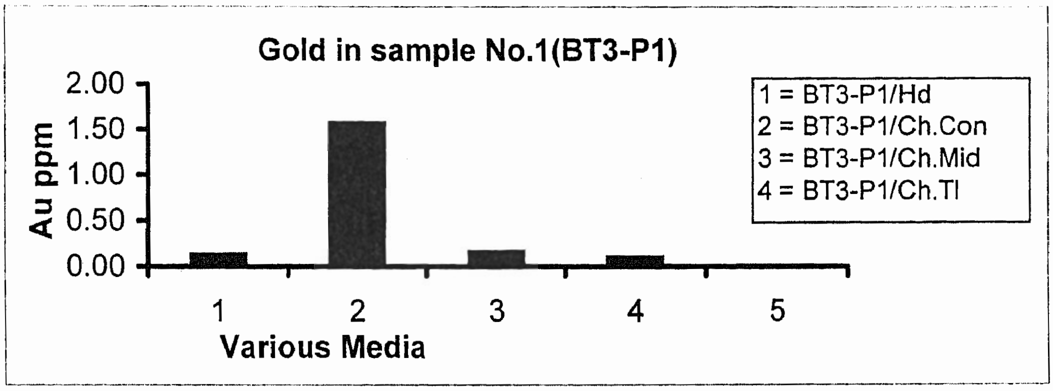
It is clear from the Table 10 and Figure 13 that the Concentrate has 1.58 ppm of gold while rest of the media has negligible amount of gold. Silver is below the detection limit in all the four media.

1. BULCHI TERRACE NO. 4 (BT4)

This terrace is the southern most extension of the Bulchi terraces (Fig. 3). It is composed of fluvial deposits and is about 130m long and 60m wide. Floats in this terrace mainly include diorite, granodiorite, pyroxenite, greenstone and quartzite.

Table 10. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1 (BT3-P1) of Bulchi terrace No. 3.

Sample No	Au ppm	Ag ppm
BT3-P1/Hd	0.14	<0.5
BT3-P1/Ch.Con	1.58	<0.5
BT3-P1/Ch.Mid	0.17	<0.5
BT3 -P1/Ch.Tl	0.11	<0.5



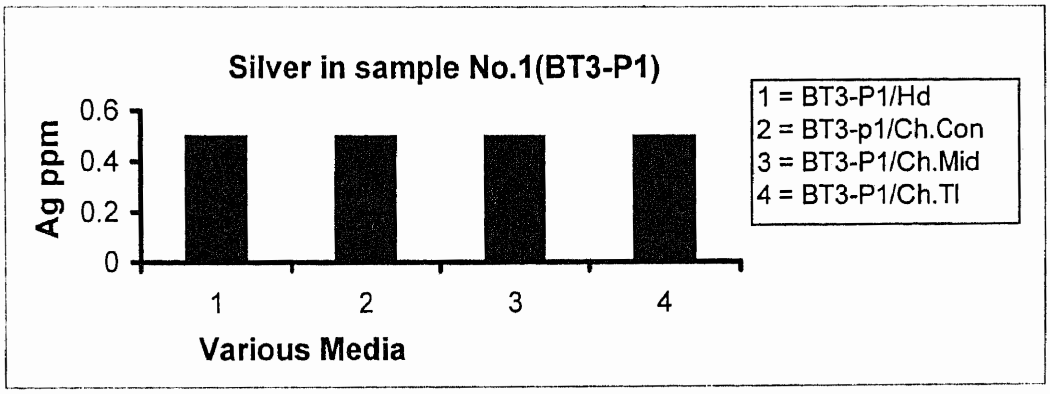


Fig.13. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (BT3 -P1) of Bulchi terrace No. 3.

Sample No.BT4-P1

Hard sample (BT4-P1/Hd): It is mainly composed of quartz, rock fragments magnetite, biotite, chlorite, muscovite, epidote, pyroxene, hornblende and pyrite in variable amount. Garnet, zircon and tourmaline occur in trace amount.

Gold: No visible gold is observed.

Concentrate (BT4-P1/Min.Con): Magnetite and rock fragments are the main constituents (>90%) while quartz, pyroxene, hornblende occur in minor amount. Zircon and tourmaline are present in trace amount.

Gold: Two colors of gold are noticed. These are flaky in appearance having dark-yellow colour and rounded to sub-rounded shape.

Middling (BT4-P1/Min.Mid): Quartz, biotite, muscovite epidote and fine-grained magnetite are the dominant phases with traces of pyroxene, hornblende and garnet.

Gold: No visible gold is found.

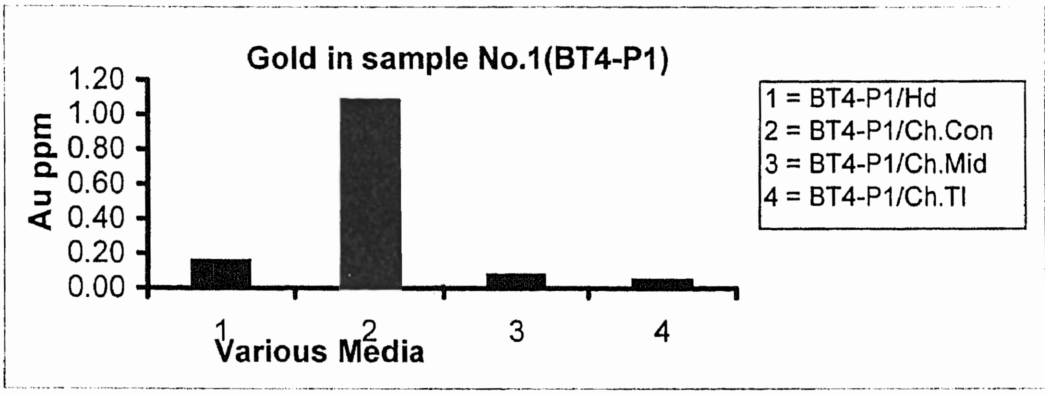
Tail (BT4-P1/Min.Tl): It has the same mineral composition as that of Middling but the minerals occur in different proportion.

Chemical study

Table 11 and Figure 14 show that Concentrate of this sample has 1.08 ppm gold while the other media are having negligible amount of gold. Silver is below the detection limit (<0.5ppm) in all the four media.

Table 11. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(BT4-P1) of Bulchi terrace No. 4.

Sample No	Au ppm	Ag ppm
BT4-P1/Hd	0.16	<0.5
BT4-P1/Ch.Con	1.08	<0.5
BT4-P1/Ch.Mid	0.08	<0.5
BT4 -P1/Ch.Tl	0.05	<0.5



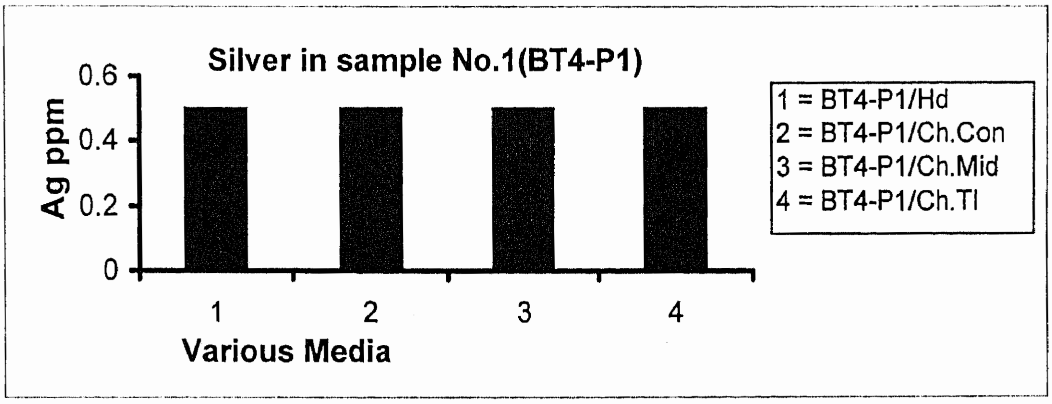


Fig.14. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentration Middling and Tail of the sample No. 1 (BT4 -P1) of Chirah terrace No. 4.

B. FARFOOH VILLAGE TERRACE S

There are five terraces in Farfooh village, which are lying on the eastern bank of Bagrot river and are relatively smaller in size (Fig. 3). These terraces are generally composed of fluvial sand, gravels and conglomerates. The mineralogical and chemical studies of the individual terrace are discussed below.

1. FAFOOH TERRACE No.1 (FT1)

This is the northern most terrace of the Farfooh village (Fig. 3). It is about 80 m long and 30 m wide and is mainly composed of fluvial sediments. Floats of this terrace are dominantly basalt, pyroxenite, chlorite schist, greenstone, marble, granite and diorite.

Sample No. FT1-P1

Mineralogical Study

Head sample (FT1-P1/Hd): It is mainly composed of rock fragments of chlorite-schist, biotite, muscovite, epidote, chlorite, hornblende, magnetite, and pyrite with traces of garnet and zircon.

Gold: No visible gold is noticed.

Concentrates (FT1-P1/Min.Con): Magnetite and rock fragments are the dominant constituents (>90%) while quartz and pseudomorphs of pyrite and chalcopyrite occur as minor phases while tourmaline occurs in traces.

Gold: One speck and two colors of gold are noticed in the Concentrate sample. Speck (0.35 mm) is light-yellow in colour and is sub-angular to sub-rounded in shape. Colors (0.1-0.2 mm) are bright-yellow flakes and are varying from oval, butterfly and rounded to sub-rounded in shape.

Middling (FT1-P1/Min.Mid): It is mainly composed of quartz, biotite, muscovite, chlorite, epidote, hornblende and fine-magnetite. Traces of garnet, sphene and zircon are present.

Gold: No visible gold is present.

Tail (FT1-P1/Min.T1): Tail has the same mineralogy as that of middling.

Chemical study

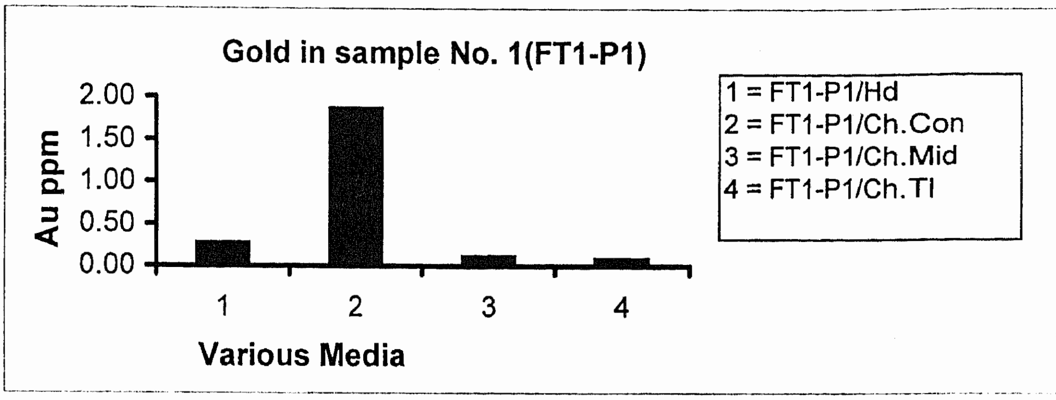
It is clear from the Table 12 and Figure 15 that both Concentrate and Head sample have 1.87 ppm and 0.28 ppm of gold respectively. Middling and Tail, however, have negligible amount of gold. Silver is below the detection limit in all the four media.

2. FAFOOH TERRACE NO. 2 (FT2)

This is the southern extension of terrace No.1 of the Farfooh village. It is 60 m long and 20 m wide and is composed of fluvial sediments. Floats of this terrace are mainly pyroxenite, diorite, granodiorite, chlorite-carbonate schist and phyllite.

Table 12. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(FT1-P1) of Farfooh terrace No. 1.

Sample No	Au ppm	Ag ppm
FT1-P1/Hd	0.28	<0.5
FT1-P1/Ch.Con	1.87	<0.5
FT1-P1/Ch.Mid	0.12	<0.5
FT1 -P1/Ch.TI	0.09	<0.5



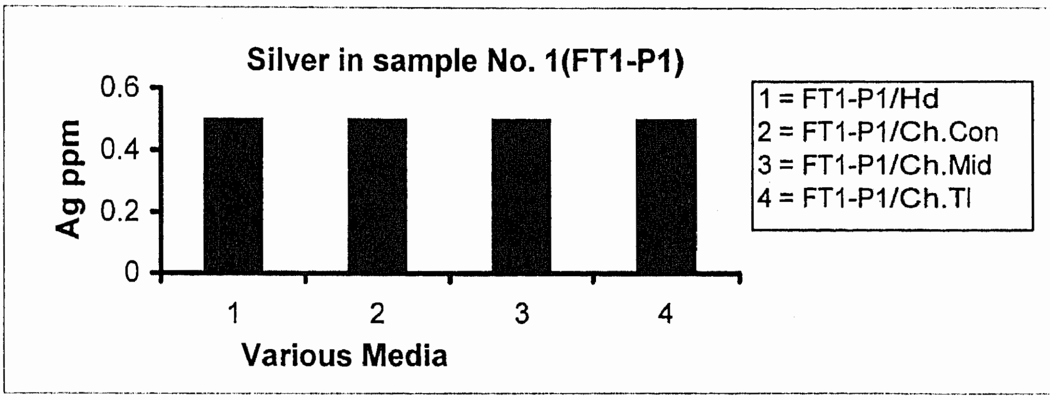


Fig.15. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (FT1 -P1) of Farfooh terrace No. 1.

Sample No. FT2-P

Mineralogical Study

Head Sample (FT2–P1/Min.Hd): Quartz, biotite, muscovite, chlorite, epidote, pyroxene, rock fragments and magnetite are the major constituents. Traces of garnet, tourmaline and zircon are also present.

Gold: No visible gold in noticed.

Concentrates (FT2-P1/Min.Con): Magnetite and rock fragments are the major constituents (>95%). The rest of the minerals include pyroxene, tourmaline, garnet, zircon, chalcopyrite and pyrite.

Gold: Three specks and four colors of gold are found. The specks are varying in size from 0.35 mm to 0.4 mm and are dark-yellow to bright-yellow in colour. The specks are angular to sub-rounded in shape. The colors are generally light-yellow and are in the form of flakes ranging in size from 0.2 mm to 0.3 mm. These are rounded to sub-rounded in shape.

Middling (FT2-P1/Min.Mid): Quartz, biotite, muscovite, chlorite, epidote, and rock fragments are the main phases with traces of garnet and pyroxene.

Gold: No visible gold is present.

Tail (FT2-P1/Min.Tl): Tail has the same mineralogy as that of Middling with varying proportion of minerals.

Chemical study

Table 13 and Figure 16 show that the Concentrate has high amount of gold (2.32 ppm) while the Head sample has 0.23 ppm of gold. The Middling and Tail, however, have negligible amount of gold. Silver in all the four sampling media is below the detection limit.

3. FAFOOH TERRACE NO.3 (FT3)

This terrace is the southern extension of terraces No. 2. It is 80 m long and 25 m wide and dominantly contains fluvial sediments, mainly sand, gravel and conglomerate. Floats of this terrace include pyroxene, dunite, hornblendite, quartzite and chlorite schist.

Sample No.FT3- P1

Head sample (FT3-P1/Min.Hd): Quartz, rock fragments, magnetite, biotite, muscovite, chlorite, epidote are the dominant phases with lesser amount of pyroxene, hornblende and olivine garnet, zircon and sphene occur in traces.

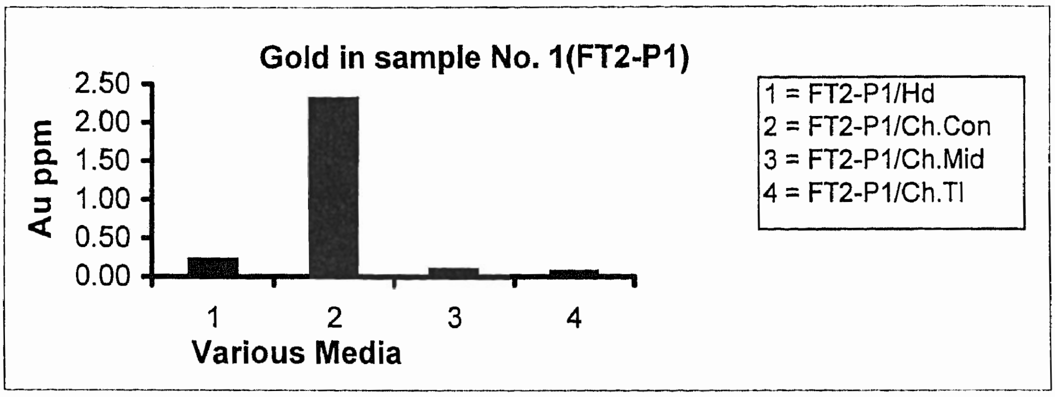
Gold: No visible gold is observed.

Concentrates (FT3-P1/Min.Con): It is dominantly (>80%) composed of magnetite and rock fragments with lesser amount of quartz, pyroxene, olivine, hornblende, chalcopyrite and pyrite. Garnet, zircon, tourmaline and sphene are present in traces.

Gold: Four specks and five colors are found in the Concentrate sample. The specks are varying in size from 0.35 mm to 4 mm and are irregular to sub-rounded in shape. The colors are generally <2 mm in size and are varying from pear, butterfly to sub-rounded in shape.

Table 13. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(FT2-P1) of Farfooh terrace No. 2.

Sample No	Au ppm	Ag ppm
FT2-P1/Hd	0.23	<0.5
FT2-P1/Ch.Con	2.32	<0.5
FT2-P1/Ch.Mid	0.10	<0.5
FT2 -P1/Ch.Tl	0.07	<0.5



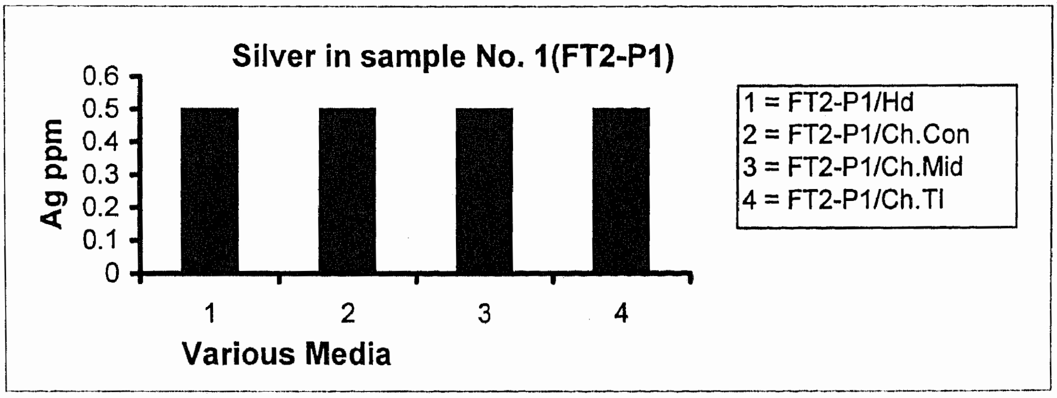


Fig.16. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (FT2 -P1) of Farfooh terrace No. 2.

Middling (FT3-P1/Min.Hd): It is mainly composed of quartz, biotite, muscovite, chlorite, epidote, rock fragments and fine-magnetite with traces of pyroxene and hornblende.

Gold: No visible gold is present.

Tail (FT3-P1/Min.Tl): The Tail has similar mineralogy as that of Middling.

Chemical Study

It is clear from the Table 14 and Figure 17 that the Concentrate of this terrace has the maximum gold (2.98 ppm) as compare to those of all the other terraces of Bagrot valley. The Head sample, Middling and Tail have 0.29 ppm, 0.13 ppm and 0.09 ppm of gold respectively. Silver in all the four sampling media is below the detection limit.

4. FAFOOH TERRACE NO.4 (FT4)

This terrace is the southern extension of the terrace No.3 in Farfooh village. It is about 100 m long and 20 m wide and is mainly composed of fluvial sediments (sand, gravel and conglomerate). Floats are mainly diorite, granodiorite, pyroxenite, chlorite-carbonate schist and phyllite.

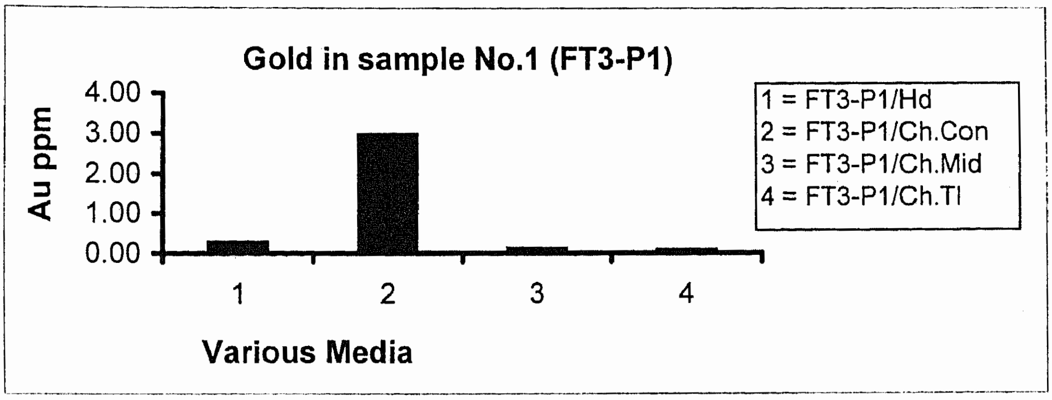
Sample No.FT4-P1

Head sample (FT4- P1/Min.Hd): The main mineral constituents include quartz, rock fragments, biotite, and muscovite, epidote with lesser amount of pyroxene, olivine and magnetite. Garnet, zircon, sphene and tourmaline occur in traces.

Gold: No visible gold is present.

Table 14. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(FT3-P1) of Farfooh terrace No. 3.

Sample No	Au ppm	Ag ppm
FT3-P1/Hd	0.29	<0.5
FT3-P1/Ch.Con	2.98	<0.5
FT3-P1/Ch.Mid	0.13	<0.5
FT3 -P1/Ch.Tl	0.09	<0.5



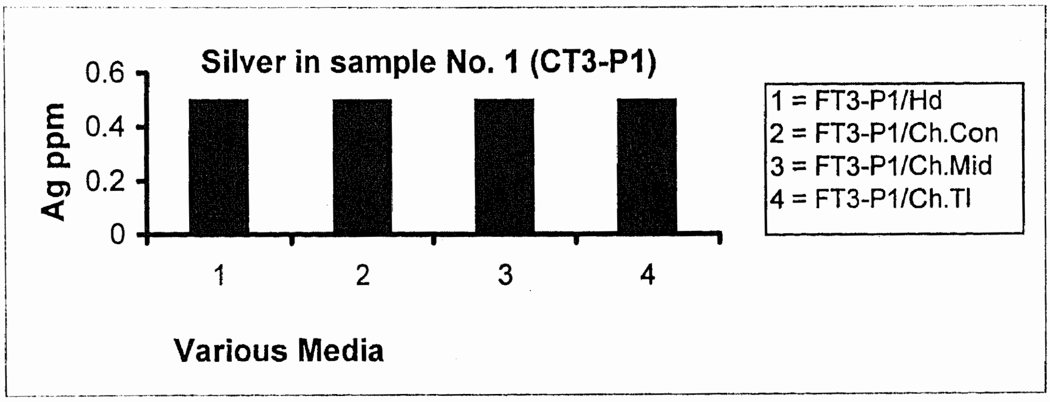


Fig.17. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (FT3 -P1) of Farfooh terrace No. 3.

Concentrates (FT4-P1/Min.Con): Magnetite and rock fragments are the dominant (>90%) mineral constituents with lesser amount of quartz, pyroxene and olivine. Garnet, zircon, sphene and tourmaline occur in traces.

Gold: One speck and two colors of gold are visible. Speck is bright-yellow in colour and is an elongated grain of about 0.35 mm in size. The colors (0.15-0.25 mm) are generally light-yellow with oval to rounded in shape and flaky in form.

Middling (FT4-P1/Min.Mid): Quartz, biotite, muscovite, epidote, rock fragments and fine-grained magnetite are the main constituents. Pyroxene and olivine occur in traces.

Gold: No visible gold is found.

Tail (FT4-P1/Min.Tl): Tail has the same mineral composition as that of Middling.

Chemical Study

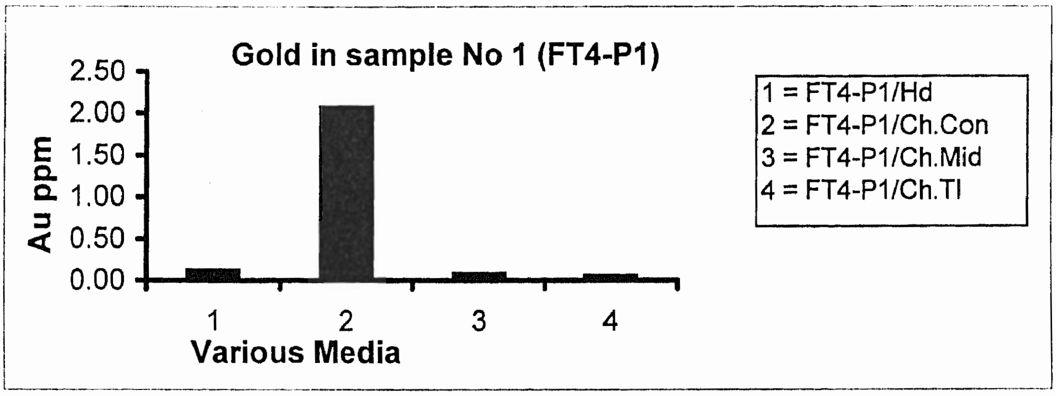
It is clear from Table15 and Figure 18 that the Concentrate of this terrace has 2.08 ppm of gold while the rest of the three sampling media have negligible gold. Silver in all the four sampling media is below the detection limit.

5. FAFOOH TERRACE NO. 5 (FT5)

This is the southern most and largest terrace of Farfooh village. It is 180 m long and 80 m wide and is mainly composed of fluvial sediments. Floats include pyroxenite, hornblendite, granite, granodiorite, greenstone, quartzite, and basalt.

Table 15. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(FT4-P1) of Farfooh terrace No. 4.

Sample No	Au ppm	Ag ppm
FT4-P1/Hd	0.13	<0.5
FT4-P1/Ch.Con	2.08	<0.5
FT4-P1/Ch.Mid	0.09	<0.5
FT4 -P1/Ch.Tl	0.06	<0.5



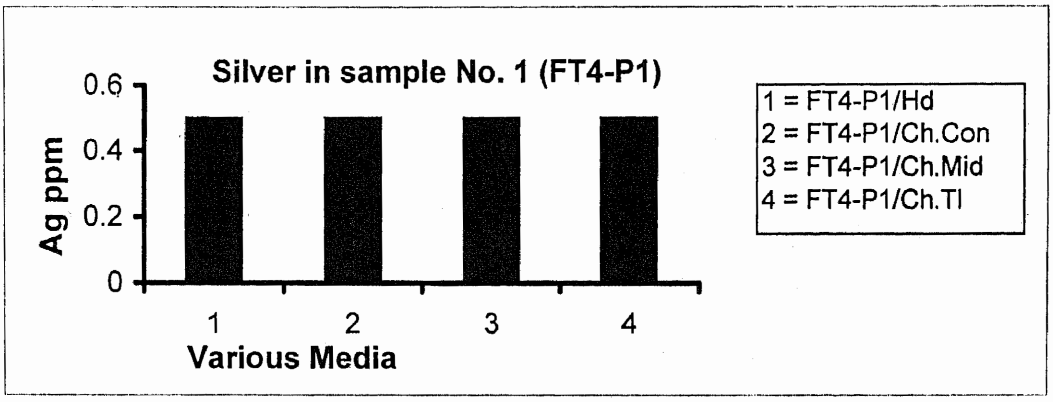


Fig.18. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (FT4 -P1) of Farfooh terrace No. 4.

Sample No.FT5-P1

Head Sample (FT5- P1/Min.Hd): Quartz, rock fragments, magnetite, biotite, muscovite, chlorite and epidote are the main constituents with lesser amount of

pyroxene, hornblende and garnet. Traces of zircon, sphene and tourmaline are also noticed.

Gold: No visible gold is noticed.

Concentrates (FT5-P1/Min.Con): Magnetite and rock fragments are dominant constituents (>90%) with minor amount of pyroxene, hornblende and garnet. Zircon, sphene and tourmaline occur in traces.

Gold: Four colors of gold varying in size from 0.2 mm to 0.3 mm are found. These colors occur as thin flakes of light-yellow to dark-yellow colour and rounded to sub-rounded in shape.

Middling (FT5-P1/Min.Mid): Quartz, biotite, muscovite, epidote, chlorite and fine-grained magnetite are the main constituents. Pyroxene and hornblende occur in traces.

Gold: No visible gold is noticed.

Tail (FT5-P1/Min.Tl): Tail has similar mineralogy as that of Middling but in different proportion.

Gold: No visible gold is noticed.

Chemical study

Table 16 and Figure 19 represent that the Concentrate of this sample has 1.42 ppm of gold while other three sampling media has negligible amount of gold. Silver in all the three sampling media is below detection limit.

BAGROT CONCENTRATE (BRC)

The Bagrot Concentrate is a mixture of the Concentrates of all the terraces of Chirah, Bulchi and Farfooh villages as discussed in the methodology (Chapter 4). The bulk of the Bagrote Concentrate was treated with the mercury amalgamation process as discussed in the Chapter 4. The final extract of gold recovered from the mercury after mercury amalgamation process is weighing 1.01g.

BAGROT RESIDUE (BRR)

The Bagrot Residue, obtained through the mercury amalgamation process of Bagrot concentrate (as discussed in methodology, Chapter 4), was studied both mineralogically and chemically.

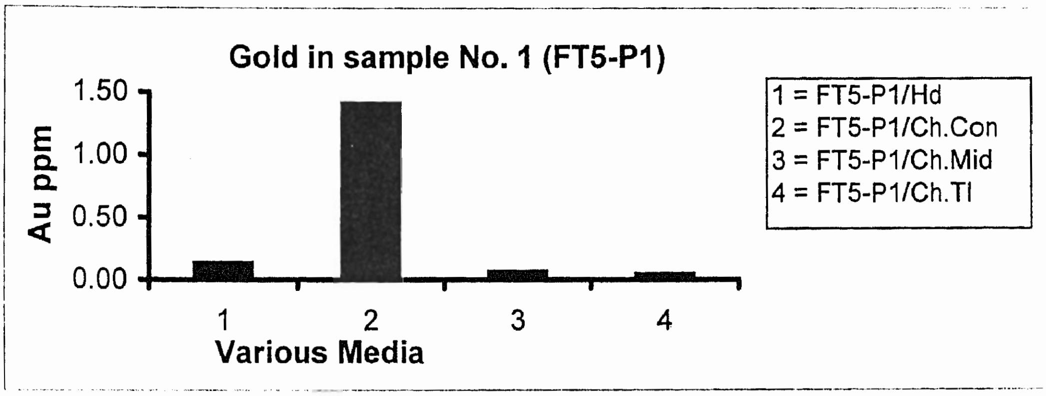
Mineralogical study

Magnetite, and rock fragments are the dominant (>85%) phases with lesser amount of quartz, pyroxene, hornblende, olivine, garnet, chalcopyrite and pyrite. Zircon, tourmaline, ilmenite and rutile occur in traces.

No visible gold has been noticed in the Bagrot residue, which suggests the complete amalgamation of gold in the mercury during the mercury amalgamation process as discussed in Chapter 4.

Table 16. Au and Ag concentration in the Head sample, Concentrate, Middling and Tail of the sample No. 1(FT5-P1) of Farfooh terrace No. 5.

Sample No	Au ppm	Ag ppm
FT5-P1/Hd	0.14	<0.5
FT5-P1/Ch.Con	1.42	<0.5
FT5-P1/Ch.Mid	0.07	<0.5
FT5 -P1/Ch.Tl	0.05	<0.5



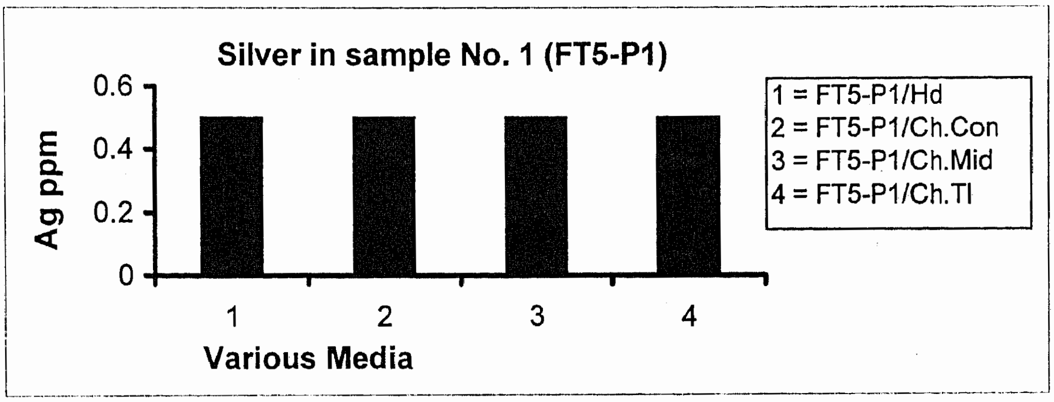


Fig.19. Graphical presentatiopn of the Au and Ag concentration in Head sample, Concentrate, Middling and Tail of the sample No. 1 (FT5 -P1) of Farfooh terrace No. 5.

Chemical study

The chemical analyses carried out on the Bagrot residue suggest the negligible amount of gold (0.21 ppm) and silver (0.5 ppm).

MINERALOGICAL STUDIES OF RESIDUE LEFT AFTER SLUICING BY GOLD WASHERS IN THE BAGROT VALLEY

In the Bagrot Valley, the gold washers usually carry out routine gold sluicing to extract gold for their livelihood by their own hand made sluice box (Plate 15). The residue left after sluicing was collected and studied both mineralogical and chemically.

Sample No. BR-GWR1

Mineralogical study

The residue dominantly contains quartz, rock fragments, biotite, muscovite, epidote, pyroxene, hornblende, garnet and fine-grained magnetite. Traces of zircon, tourmaline, appetite and sphene are noticed.

Gold: Three colors (0.15 to 0.3 mm) of gold are found having dark-yellow colour with rounded to sub rounded in shape and flaky in form.

Chemical study

The chemical analyses for gold and silver in this residue sample suggest that it contains 0.86 ppm of gold and 0.95 ppm of silver.

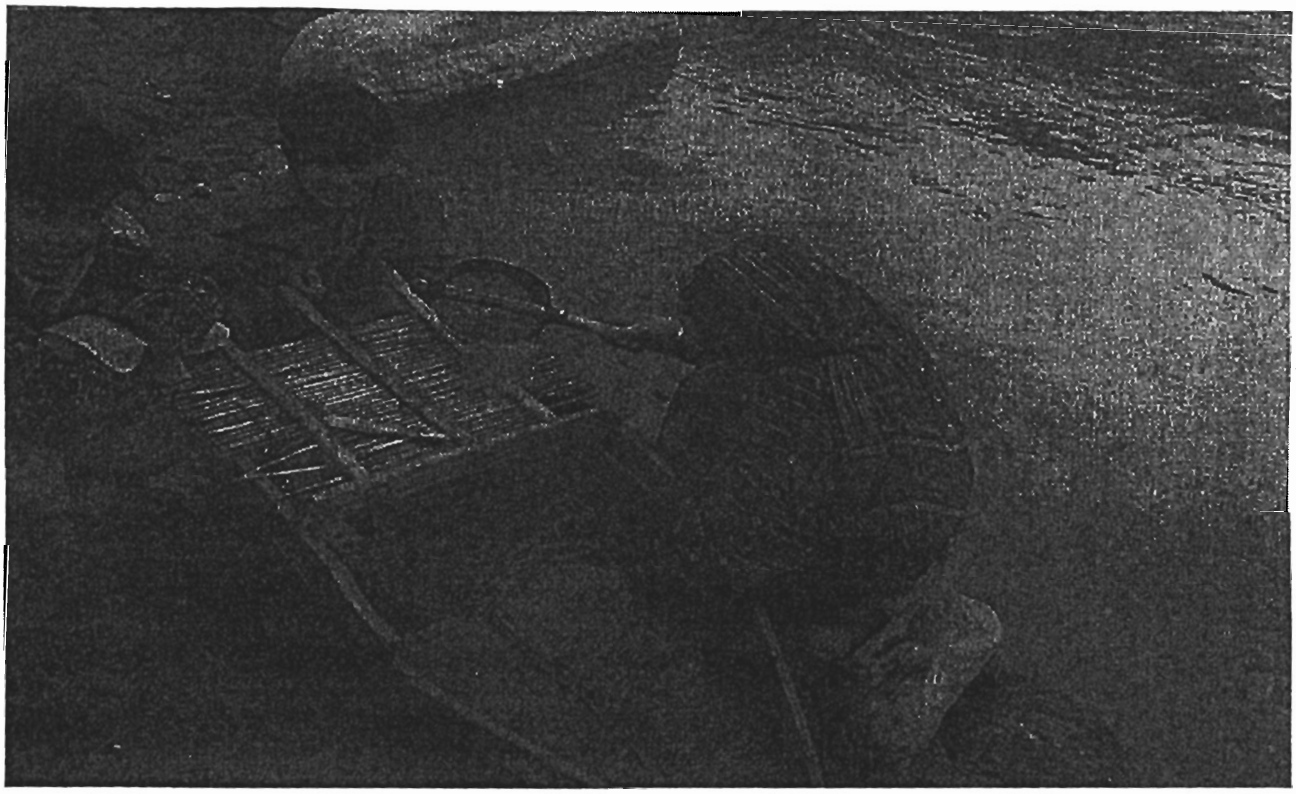


Plate No 15 Photograph showing the extraction of gold through sluicing by the gold washers of Bagrot valley

MINERALOGY AND CHEMISTRYT OF THE PMDC SAMPLES OF BARGROT VALLEY

Mineralogical studies

The Head sample, riffled out before processing through shaking table, and the portions of the Middling and Tail, obtained after passing through the shaking table, were studied under the binocular microscope for mineralogical studies.

Head sample: Rock fragments, magnetite, quartz, biotite, muscovite and chlorite, pseudo-pyrite and chalcopyrite are the main mineral phases while epidote, pyroxene and garnet occur in minor amount. Traces of zircon and tourmaline are also noticed.

Gold: One color of gold having light-yellow colour and angular to rounded in shape and flaky in from has been noticed.

Concentrate: Magnetite and rock fragments are the main constituents with lesser amount of pyrite, chalcopyrite, pyroxene and garnet. Zircon and tourmaline occur in trace amount.

Gold: Three specks (0.3mm to 0.45mm) and seven colors (0.1mm to 0.25mm) are counted. The specks are generally light-yellow in colour and rectangular to rounded in shape and solid in form. The colors are bright-yellow in colour and are irregular to sub-rounded in shape and flaky in form.

Middling sample: The Middling is composed of fine grained magnetite, quartz, biotite, muscovite, chlorite and epidote as dominant phase with lesser amount of pseudomrphs of pyrite and chalcopyrite.

Gold: one color (0.1 mm) of gold has been found which is yellow in colour, sub-rounded in shape and flaky in form,

Tail Sample: Tail has more or less the same mineralogy as that of Middling.

Chemical Study

0.80 tons of Concentrate of the Bagrot valley, obtained from 235 tons of sediments, has been processed through shaking table, mercury amalgamation processes and fire assaying (see Chapter 4). Table 17 shows the recovery of crude gold in Concentrates and Middling and Tail after mercury amalgamation process. It is evident that 11.10 g and 2.75 g of gold is recovered from the Concentrates and Middling and Tail respectively. This gives 13.85 g of course crude-gold. The percentage recovery of crude-gold in the Concentrate generally is more than 80%. The recovery of about 14 g of gold from the 235 tons of sediments is calculated as 0.06 g/ton or 0.06 ppm.

Table 17. Recovery of course-crude gold after shaking and mercury amalgamation.

Weight of sample in (Tons)	Recovered crude gold in Concentrate (in Grams)	Gold in Middling and Tails (in Grams)	Total gold recovered in (Grams)	Recovery of crude gold (in Percent)
0.8	11.1	2.75	13.85	80

CHAPTER 6

DISCUSSION

Mineralogical and chemical constraints

Mineralogically, no distinction could be possible between the glacio-fluvial and fluvial sediments of the Bagrot valley and are, therefore, discussed together. The sediments load of Bagrot valley generally contains rock fragments, magnetite, quartz, biotite, muscovite, chlorite and epidote as major constituent with lesser amount of garnet, tourmaline, amphibole, pyroxene, olivine, pyrite and chalcopyrite. Zircon and sphene occur in trace amount. Gold in the form of colors (< 0.3 mm) is present in almost all the samples while specks (0.3-0.5 mm) of gold have been identified in the sediments of few terraces. No pieces or nugget of gold has been found in the sediments of Bagrot valley. The heavy minerals and the gold particles are variably distributed among the three media (Concentrate, Middling and Tail) obtained after the gravity separation methods. Magnetite, rock fragments, pyroxene, olivine, tourmaline, garnet, amphibolite, pyrite and chalcopyrite are generally trapped in the concentrate while rest of the phases are washed into the Middling and Tail. Almost- all the colors and specks of gold are extracted in the concentrates and none of gold particles is noticed either in Middling or Tail. It is, however, noticed that the glacio-fluvial sediments have less number of gold particles in the concentrates as compared to those of fluvial sediments. The floats of rocks of the Chalt group (mainly the volcanic and chlorite-carbonate schist) are dominant while diorite, granodiorite, phyllite pyroxenite and quartzite are present in lesser amount. This confirms the occurrence of the rocks of Chalt group in the major portion of the catchement areas of the Bagrot valley.

Chemically the gold and silver contents in ppm have been determined in all the four media (Head sample, Concentrate, Middling and Tail) of the glacio-fluvial and fluvial sediments of the Bagrot valley. The maximum gold (0.89 ppm to 2.98 ppm) has been noticed in the concentrates while rest of the media has negligible amount of gold (Chapter 5). These observations are consistent with those of the mineralogy. In order to calculate the total recovery of gold in the bulk sample obtained during field, the concentration of gold in ppm has been recalculated in grams in all the four media and was added to the gold obtained from the bulk concentrate of the three terraces of the Bagrot valley after mercury amalgamation process (Table 18). It is clear from the Table 18 that 2.708 g of gold at the rate of 3 g per ton has been extracted from 893 Kg total load of sediments.

As majority of gold is recovered in the concentrates and a negligible amount is transferred to the light-fractions such as Middling and Tail, it is suggested that gold in the source bed rock is present in the coarse-grained

Table 18. The concentration of gold recalculated in grams in various sampling media of all the terraces of Bagrot valley. The total gold recovered from the sediments load of all the terraces is also given

Sample No.	Wt. In Kg	Head Sample Wt. In Grams	Concentate Wt. In Grams	Middling Wt. In grams	Tail Wt. In Grams
CT1-P1	61.1	0.01	0.056	0.005	0.003
CT2-P1	64.2	0.036	0.072	0.005	0.004
CT3-P1	63.12	0.021	0.044	0.008	0.006
CT3-P2	48.12	0.015	0.105	0.005	0.004
CT4-P1	45.2	0.013	0.052	0.007	0.005
CTV1-P1	51.3	0.014	0.046	0.005	0.003
CTV2-P1	61.12	0.007	0.066	0.006	0.002
BT1-P1	62.1	0.016	0.066	0.005	0.004
BT2-P1	58.2	0.02	0.079	0.005	0.003
BT3-P1	49.73	0.007	0.079	0.008	0.005
BT4-P1	58.12	0.009	0.063	0.005	0.003
FT-1-P1	51.2	0.014	0.096	0.006	0.005
FT-2P1	60.13	0.014	0.14	0.006	0.004
FT-3 P1	53.2	0.015	0.159	0.007	0.005
FT-4-P1	57.12	0.007	0.119	0.005	0.003
FT5-P1	49.8	0.007	0.071	0.003	0.002
TOTAL	893.76	0.225	1.313	0.091	0.061

Total sediment load = 893.76 Kg
Gold recovered in four sampling media = 1.688 g.
Gold recovered in the Bagrot concentrate = 1.01g.
Total gold recovered = 1.688+1.01 = 2.70g.

native form, which may be associated with sulfides in the quartz veins, and is not present as fine-grained gold (i.e., carline type). Due to the course (> 0.1 mm) nature of gold in both glacio-fluvial and fluvial sediments, the method of preparation of heavy mineral concentrate by shaking table or gravity table is more appropriate. This is the reason that the Middling and Tail have negligible gold. However, the residue left after sluicing by the gold washers has 0.86ppm of gold and 0.95ppm of silver. This suggests that the sluicing method adopted by the gold washers of Bagrot valley does not recover the maximum gold in the Concentrates. The shaking table technique is, therefore, more appropriate for the extraction of coarse-gold of the Bagrot valley. The objective of this method is to concentrate gold from a large sample into smaller sample that can be conveniently analyzed and thereby, overcome the sample representivity problem.

Both glacio-fluvial and fluvial sediments are the useful geochemical sampling media in the Bagrot valley for gold exploration. The heavy mineral concentrates can be used for gold prospecting with greater confidence in the area. The size and shape of the gold in the heavy mineral concentrates could very effectively be used as a guide for tracing out the source bed rock in the up-stream catchments basin.

Comparison of the results of PMDC-SDA joint venture and present study

It is evident from this study that two different sampling techniques were used for the collection of samples in the Bagrot valley. During the PMDC–SDA joint venture the large volume (235 tons) of sediment load was processed through pneumatic machine from one single spot. About 14 g (at the rate of 0.06 g/t) of gold has been recovered through this load at the end (Table 17). A different sampling strategy was adopted during the present study by collecting smaller size (45 kg - 64 kg) of sediment load from different spots along each terrace (for detail see Chapter 4). A total of 893 kg sediment load was collected from 16 different terraces (Table 18). A total of about 2.708 g (1.688 g + 1.02 g) of gold (at the rate of 3 g/t or 3 ppm) was recovered from this sediment load at the end (Table 18) The comparison of both the recovered gold contents from both the sampling techniques suggests that procedure of sample collection used during the present study is more useful and appropriate as far as the recovery of gold in the Bagrot valley is concerned. Treating very large number of sample for gold extraction is, therefore, not an appropriate method and should be avoided.

Gold characteristics to local bed rock mineralization

Information on gold particle size, shape, composition and progressive changes in the characteristics with increasing transport distance can, in many cases, be used to constrain the distance and direction to source rocks (Loen, 1993; 1995). Of course the presence of placer does not necessarily imply that mine-able hard rock deposits exist upstream because the source gold deposits could have been widespread, or could have been completely eroded away. However, placer gold can provide considerable information on source areas and placer studies should be added to the techniques used by exploration geologists to evaluate gold targets (Loen, 1993; 1995).

The characteristics of placer gold such as size and morphology (including flatness, surface texture and roundness) of the placer gold of Bagrot valley have been evaluated to understand the proximal or distal nature of gold source.

It is understood that there is a decrease in the size of placer gold particles with distance from source (Lindgren, 1933; Boyle, 1979). This reflects breakdown of particles and increasing transport of smaller particles. However, the relationship between size and distance is complicated because both the shape and size of the gold particles changes downstream. Flakes, which become more abundant downstream, are transported more easily than sphere (Kolesov, 1971). In addition, the maximum length of placer gold particles can increase downstream because of flattening, and then rapidly decrease because of folding (Loen, 1993; 1995).

Detailed measurements of the particle shape of placer gold are one of the most useful parameters for determining the transport distance to source rocks.

Gold crystallize in the isometric crystal system, and in primary gold deposits tends to form aggregates of octahedrons, dodecahedrons, cubes, globules, and rarely leaf and wire forms. However, these crystal shapes rapidly become modified because of the softness and ductility of gold. Therefore, the majority of placer gold particles in a sample are commonly represented by thin flakes within a few tens of kilometers (Loen, 1995).

Changes in the shape and size of the gold from the two types of terraces, fluvial and glacio-fluvial, in Bagrot valley have been studied very carefully based on various systems of classifications (Boyle, 1979; Herail, 1984; Freyssinet et al., 1989; DiLabio, 1990; Minter et al., 1993). The gold particles show clear differences in the shape, form and size in both types of terraces. The fluvial terraces have generally gold in the form of colors with size ranging from 0.1 to 0.2 mm sub-angular to rounded in shape and flaky to solid in form. Few specks of 0.4 to 0.5 mm size with angular to sub-rounded shape and solid form are also observed. Gold in the glacio-fluvial terraces generally occurs in the form of color with relatively coarser in size (0.2-0.3 mm), angular to sub-angular in shape and solid to flaky in form. The size and morphology of the gold particals in the Bagrot valley suggest that the gold in the glacio-fluvial and fluvial terraces has been derived and transported from a distal source at least more than a few tens of kilometer, up-stream. The source of gold in both types of terraces seems to be the same, however, the difference in size and morphology of the gold particles in the glacio-fluvial and fluvial sediments is due to the high-energy abrasion of the gold particles during the transport of the later sediments. This is evident in the rounded to sub-rounded and flaky appearance of gold particles in the fluvial terraces. The gold particles in the glacio-fluvial sediments have undergone less abrasion during transportation of glacio-fluvial sediments. These particles are, therefore, angular in shape and solid in form. There are no chances of gold bearing bed-rock underneath these terraces as no pieces and nuggets of gold have been observed.

To know the exact distance of bed-rock for the studied gold the calculation of Cailleux flatness index (F.1.) of Herail et al. (1990) and the determination of surface texture by Scanning Electron Microscope (SEM) technique for the studied gold particles is, however, very necessary. Beside this the acquisition of geochemical, geomorphic, sedimentological and fluvial paleocurrent data is necessary in order to construct the history of studied placer gold transport and concentration in the Bagrot valley. Though these kinds of studies are not a part of this research but could be conducted in future to pin point the source of gold in the region. These kinds of studies have revealed promising exploration targets else where in the world (see DiLabio 1990; Guisti, 1986; Herail et al., 1990; Loen, 1993; 1995).

RECOMMENDATIONS

The present study reveals that the sediments of Bagrot valley have the potential of economic gold if the appropriate methods are adopted for the extraction of gold. In this regard the following recommendations are made:

- Sluicing is the most common process of gravel treatment for placer/alluvial gold in many places of the world. The placer gold particle size (> 0.1 mm) in the Bagrot valley could very easily be recovered by sluicing. However, mechanized sluicing by using shaking table could be more effective and environmentally friendly mechanism for the extraction of placer gold in many areas of the northern parts of Pakistan including the Bagrot valley.

- The fine-gold which is usually washed out during sluicing can further be recovered by mercury amalgamation and cynidation process. But before extraction of fine-gold by this method, the local people should be well trained and educated in proper handling and disposing of the mercury and cyanide as these are hazardous chemicals.

- Metal detector is a very useful prospecting tool for finding small nuggets or a high concentration of flour gold. The sophisticated metal detectors have the capability of screening out ferrous metals to pin point the native metals (i.e., copper, silver, gold and platinum). It is also an excellent tool for prospecting glacial moraines. The use of metal detectors in the Bagrot valley will be very helpful in minimizing the time in locating the gold concentration where from the bulk material for gold extraction could be processed.

- In order to extract gold on large scale basis, a gold extraction plant as designed in the Figure 20 can be installed on the spot by proper engineering. This plant is mainly composed of 1) screening, agitating and mining unit, 2) the shaking table or gravity separation unit, 3) the tumbling unit and 4) the Furnace unit as shown in Figure 20. This plant can process tons of sediment load per day with a minimum labour and maximum recovery of coarse crude gold in a more efficient cost effective manner.

- The fine-gold washed out in Middling and Tail can be recovered through cynidation/leaching test by designing an environmentally friendly set up in the same place.

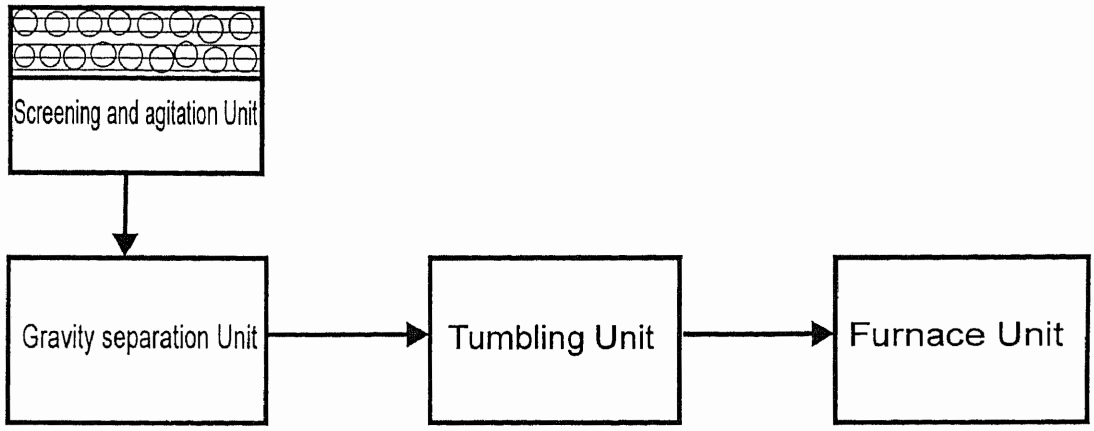


Fig. 20. A thematic diagram for the large scale extraction of gold and silver in the field.

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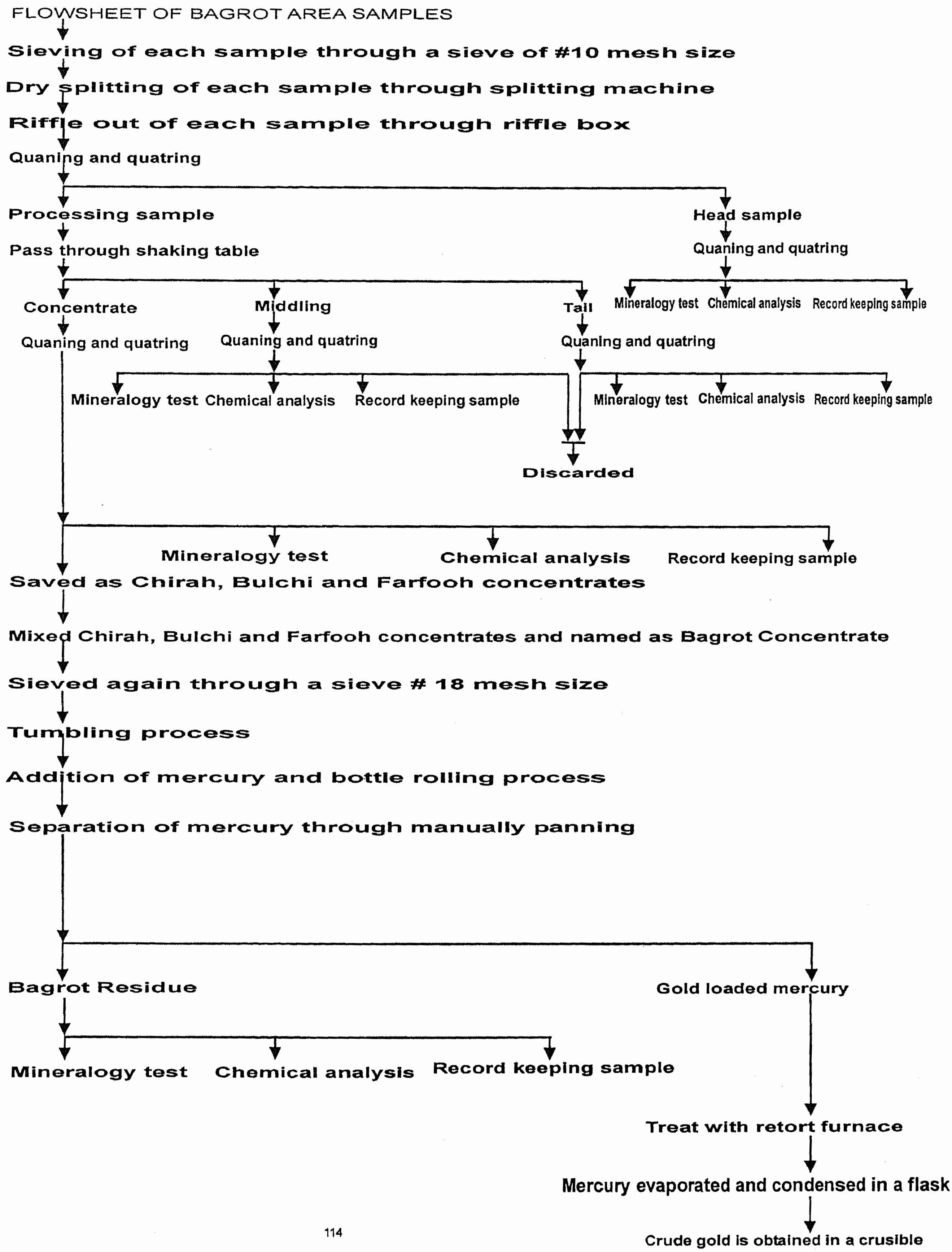
ANNEXURES

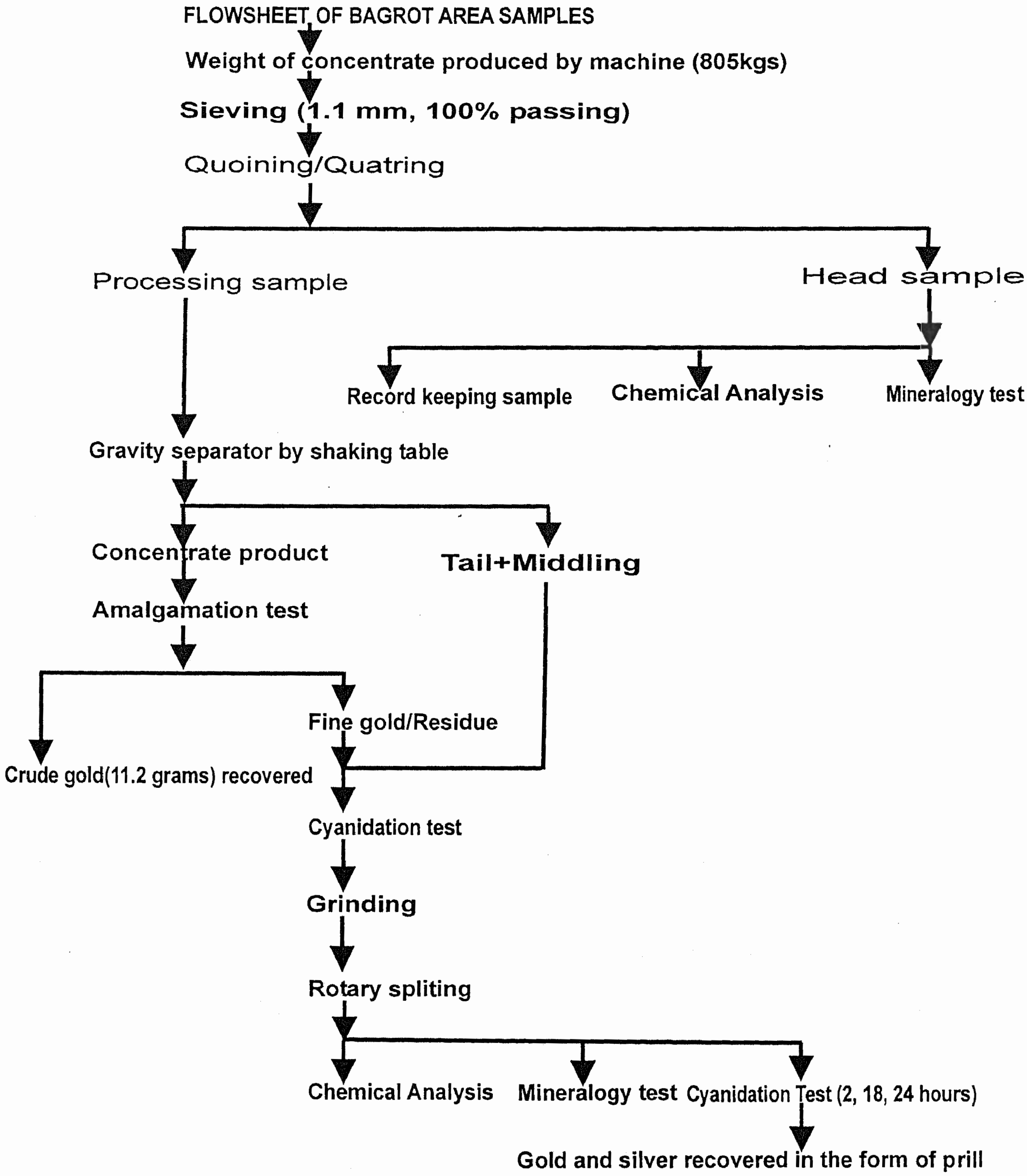
Annexure - i

Flowsheet showing the step by step procedure adopted during the present study.



Annexure - ii

Flowsheet showing the step by step precedure during the PMDC- SDA joint venture



FLOWSHEET OF AMALGAMATION PROCEE

↓

Concentrate product of shaking table test

↓

Thumbling (Time 30 minutes)

↓

Mercury amalgamation (by Bottle Rolling Machine Time I hour)

↓

Separation of Mercury through panning

↓

- Mercury reside
- Loaded Gold in Mercury
  - ↓ Separation of Mercury from gold

↓

Farnace Temprature 500c for 30 minutes and 650c for 15 minutes

↓

- Crude gold
  - ↓ 15 grams i.e 16gms/tone of pneumatic M/C concentrate
- Mercury recovered

ANNEXURE - iv

FLOWSHEET OF CIL PROCESS(CARBON IN LEACH PROCESS)

↓

Residue of Mercury

↓

Riffle out

↓

Grinding (size 100% passing 45 micron)

↓

Cyanidation (period 2, 18 and 24 hours at pH-10.5 addition of NaCN .1% of the solid solution))

↓

Filtration

↓

- **Pregnant solution(Au 10.24 g/t Ag 22g/t)**
  - ↓
  - **Addition of ativated carbon 15gms/kg**
  - ↓
  - Agitation for loading of Au and Ag (Time 24 hours, in the activated carbon)
  - ↓
  - **Filtration**
  - ↓
    - **Gold and silver loaded carbon**
    - **Barren solution**
- **Residue**
  - ↓
  - Fire Assay for gold and silver determination

ANNEXURE - V

FLOWSHEET OF SMELTING PROCESS

↓

Gold and silver loaded Carbon

↓

Carbon Firing (1000c for 1 hour)

↓

Ash products

↓

Addition of general flux Heating Temp 950c for 30 minutes)

↓

Lead Button (Heating Temp 930c at open Air for 1 hour)

↓

Prill products

↓

Refining of prill

↓

Prill (Bullion gold +silver)