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Evaluation of mineral exploration potential based on the multi-element analysis of stream sediments and mineral deposit modelling, Central Nepal

Shrestha, Rajendra Bahadur, Ph.D.

University of Hawaii, 1991
EVALUATION OF MINERAL EXPLORATION POTENTIAL BASED ON
THE MULTI-ELEMENT ANALYSIS OF STREAM SEDIMENTS
AND MINERAL DEPOSIT MODELLING, CENTRAL NEPAL

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
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DECEMBER 1991

By
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Charles J. Johnson
Dedicated to my

Parents
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Last, but not least, I express my heartfelt thanks to my former advisor the late Dr. William T. Coulbourn.
ABSTRACT

Evaluation of mineral exploration potential in Central Nepal between coordinates 27° 15' to 28° 00'N and 84° 15' to 86° 00'E, an area of approximately 2610 kilometers², was accomplished based on the multi-element analytical data of stream sediment samples and geological information. Inter-element relationship and relationship between geology and geochemistry were established by factor analysis of a database consisting of stream sediment samples derived by weathering of time-petrographic units. Factor-1 (Mg, Ba, La, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn) is the group of mafic elements related mainly to basic intrusives. Factor-2 (Li, Na, K, Be, Al), is the group of felsic elements, related to the felsic intrusives. Factor-3 (As, Sb, Bi, Pb) is inferred to be related to sulfide mineralization. Factor-4 (Ca, Mg, Sr, Pb) is an association of elements related to carbonates and associated Pb-Zn mineralization. Factor-5 (Ag, Sn, Cd) is inferred to be related to tin-bearing granites. Factor-6 (Mo, W) is interpreted to be related to contact metasomatic deposits associated with granitic intrusives.

Using the mean ± 2 standard deviation and factor analysis, meaningful geochemical anomalies were identified. Descriptive mineral deposit models were developed using
mineral deposits occurring in the study area and models of deposits occurring elsewhere in the world. The multivariate technique of Characteristic analysis was successfully applied to the integrated data base for every cell consisting of information on presence or absence of weighted variables defining rock-types, structures and geochemical anomalies to find degree of match or similarity with attributes of each mineral deposit model developed. The degree of match was expressed quantitatively in terms of the index of favorability for each cell.

Results obtained showed that the most favorable area is around the cell 1142 with high favorability for 6 out of 7 mineral deposit models applied. Area around cells 1144, 1146, 1148 and 1149 are found to be favorable for 4 out of 7 mineral deposit models applied. Cells 1099 and 1141 showed high favorability only for 3 and cells 1091, 1093, 1133, 1145, 1147, 5071, 5074 and 5077 only for 2 out of 7 deposit models applied. Area around cells 1095, 1136, 1139, 5021, 5022, 5023, 5025, 5026, 5019, 5029 and 5068 showed high favorability for only one deposit model.
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Plate-1 Geological map of Kathmandu area and the Central Mahabharat Range (from Stocklin and Bhattarai, 1980)
CHAPTER I
INTRODUCTION

The Himalayan mountain belt bordered by the Indian shield or peninsular India on the south and China on the north is the world's highest mountain belt. The Himalayan belt extends NW-SE from Burma in the east to the Afghanistan-Pakistan border in the west (Fig. 1.1). The Himalayan mountain range was created by the collision between continental plates (Gansser, 1964). The Himalayan belt has been subdivided (Burrard and Hayden, 1934 and Bordet, 1961) into the following geographic and tectonic units (fig. 1.1):

Also, the Himalayan range had been divided into the following six longitudinal tectonic units across the Himalayan belt in a N-S direction (figs. 1.2 and 1.3, after Windley, 1983):

Fig. 1.1. The general subdivisions in the Himalayas (from Gansser, 1964).
1. The Karakorum Range in Pakistan lies along the southern border of the western part of the Tibetan Plateau and north of the 'Northern Suture' of Bard et al. (1980) and Coward et al. (1982) (fig. 1.2) and contains the calc-alkaline Karakorum batholith of Late Cretaceous age (Windley, 1984).

2. The Trans-Himalayan unit (fig. 1.3) occurring along the southern border of the Tibetan plateau is mainly comprised of Paleozoic and younger rocks extensively intruded by calc-alkaline batholiths of Cretaceous to Paleocene age. The unit is bounded by the Indus-Zangbo Suture in the south.

3. The Indus-Zangbo Suture Zone also called the 'Main Mantle Thrust' (MMT) separates the Indian plate from the Kohistan (Pakistan)-Ladakh(India) arc on the west and the Tibetan plateau on the east (fig. 1.3). This zone is a complex assemblage of ophiolites, glaucophane schists, granulites, basic volcanics, and molasse (Windley, 1984).

4. The Higher Himalayas is bounded on north by the MMT and on south by the Main Central Thrust (MCT) (figs. 1.2 and 1.3). The Higher Himalayas consist of Proterozoic metamorphic basement overlain by a conformable sequence of Cambrian to Eocene Tethyan fossiliferous sedimentary rocks of over 10 km thickness (also called the 'Tethys Himalayas; Gansser 1980). Intruded by Cambrian granites, this unit is characterized by Miocene metamorphism and extensive Miocene leucogranite
Fig. 1.2. Tectonic map of the Himalayas showing the zonation (after Windley, 1983b).
Fig. 1.3. Schematic cross-section through the Central Himalaya (from Windley et. al., 1983b).
intrusives. Ophiolite nappes were thrust southwards onto the Higher Himalayas from the Indus-Zangbo Suture in the early Eocene (Windley, 1984).

5. The lower Himalayan zone is bounded by the MCT on the north and the Main Boundary Thrust (MBT) on the south (figs. 1.2 and 1.3). It is comprised of low grade metamorphic rocks of Proterozoic, Paleozoic and Mesozoic age. These largely unfossiliferous metasedimentary rocks are cut by multiple north-dipping thrusts with progressively older rocks to the north. Thrust slabs of gneiss (the Lower Himalayan Crystallines) and major klippen derived from the Higher Himalayan Zone, of high grade metamorphic rocks termed the 'Outer Crystallines' are present in this zone. A narrow band of discontinuous outcrops of late Mesozoic and early Tertiary sedimentary rocks are also present in the western half of the belt. Miocene granitic intrusions are locally important.

6. The Sub-Himalyan area is bounded on the north by the Main Boundary Thrust (MBT) and comprised of middle Miocene to Pleistocene Siwalik molasse sediments of largely nonmarine origin (figs. 1.2 and 1.3). The southern limit is primarily defined by the Main Frontal Thrust (MFT) but at places by the Quartenary alluvial overlap of the Ganga Basin.
The Ganga Basin (figs. 1.1 and 1.2) lies between the outermost margin of Himalayan deformation, south of the Main Frontal Thrust (MFT) and north of peninsular Indian Shield.

The Nepal Himalaya:

The Nepal Himalayas with a length of approximately 885 km, covers about one third of the total length of the Himalayan mountain system. The Nepal Himalaya lies in the central part of the Himalayan mountain system and extending from the Mahakali River in the west to the Mechi River in the east with roughly 80° to 88° E longitude and roughly 26° to 30° N latitude, comprising an approximately 147,000 sq. km. area is bordered in the north by China and in the south, east and west by India (fig. 1.4). With a length of approximately 885 km, the Nepal Himalaya covers about one third of the total length of the Himalayan mountain system (figs. 1.1 and 1.2). In the Nepal Himalaya, four tectonic units have been recognized. They are as follows:

The southernmost part of Nepal, south of the Main Boundary Thrust (MBT), is covered by Quaternary alluvium of the Ganga Basin.
Location of The Study Area:

The area of the present study lies in the Central Nepal and extended from roughly $84^\circ 25'$ to $86^\circ 00'$ E longitude and $27^\circ 15'$ to $28^\circ 00'$ N latitude, covering an area of approximately 2610 sq.km (fig. 1.4) primarily within the Lower Himalaya and Sub-Himalaya zones (figs. 1.1 and 1.3).
Fig. 1.4. Location map of the present area of study with index map of Nepal in the inset.
CHAPTER II

AREA OF STUDY

General Information:

Mineral exploration in Nepal has been extremely limited and as a result Nepal is one of the least explored countries in the Himalayan mountain belt. Nepal is yet to be systematically explored at even a reconnaissance level and detailed exploration has been conducted on only a very few known mineral occurrences. A brief review of past mineral exploration activities is outlined below:

Initial geologic investigation in Nepal were carried out in the 1930's by Auden (1935), Heim and Gansser (1939) and Gansser (1964). Hagen (1969) prepared the first preliminary geological report of Nepal, based on his geological field work during the years 1951-57. Between 1961-66, additional geologic fieldwork and limited mineral exploration in different parts of the country was carried out by geologists from the Geological Survey of India. Since, the establishment of the Nepal Geological Survey in 1967, detail geological mapping of the country has been conducted at a scale of 1" = 1 mile. The Nepal Geological Survey has also conducted systematic geochemical, geophysical and drilling investigations and exploration of various known metallic and non-metallic deposits.
To date the only systematic and detailed mineral exploration program in Nepal, carried out jointly by the Mineral Exploration and Development Board (MEDB) and the United Nations Development Program (UNDP), was conducted during 1973 to 1978 in the geographically limited area of Central Nepal.

The basic data of this MEDB/UNDP study form the basis for much of the research of this dissertation and as a result the project and its activities are outlined in the following. The MEDB/UNDP program consisted of the following activities:

1) regional geological and photogeological mapping to determine the lithological, structural and metamorphic setting of the study area, 2) regional geochemical survey including geochemical drainage reconnaissance survey and soil sampling, 3) geophysical surveys, 4) economic geologic studies including detailed mapping and trenching and 5) diamond drilling of identified mineral prospects. The exploration program was restricted to metallic minerals and specifically to base metals. For the regional geochemical investigation, approximately 17,000 stream sediment samples were collected in the project area and approximately 4000 samples were analyzed for a broad range of elements. A Regional Geological Map of the project area, at the scale of 1:250,000, has been published by Stocklin and Bhattarai.
Although no commercially exploitable deposits were discovered, approximately 250 prospects and or geochemically anomalous samples were identified. Five were deemed worthy of exploratory drilling.

Additional studies of importance in assessing the mineral potential of Nepal include: (a) the mineral potential assessment of the country prepared by Talalov (1972), (b) the Land Resources Mapping Project, Nepal (1980) which undertook a Photo-geological Mapping investigation of the mineral potential of the country and (c) the Unit Regional Production Value (URPV) resource assessment (Kansakar et.al., 1986) by the Minerals Policy Program of the East-West Center.

Present Study:

The lack of systematic evaluation of the mineral potential of Nepal and the lack of application of new methods of evaluation continues to restrict both an assessment of mineral potential and the possibilities of mineral development for the benefit of the nation.

The present study is undertaken to address these problems by evaluating the mineral potential of Central Nepal, utilizing existing data, but by applying new or
modified mineral evaluation techniques not applied before. The present study therefore is designed to address not only a definition of the mineral potential of known areas of Nepal but to provide a basis for predicting the types and numbers of mineral deposits which may occur in the country. Previous studies in Nepal have been based on traditional geological and geochemical methods or the evaluation of known occurrences. In the present study, the emphasis is on the use of the deposit models in conjunction with geology, structure, and geochemistry to assess the mineral resource potential. This approach relies heavily on multivariate techniques such as factor analysis, characteristic analysis and also basic statistical procedures, in conjunction with characteristic analysis (McCammon, Botbol, Sinding-Larsen, and Bowen, 1983) for the identification of wide variety of deposit types. These techniques together with mineral deposit models, are utilized both to identify exploration targets but also to define the types of deposits which should be the focus of exploration. As such the present study represents a new methodology in identifying mineral exploration targets in Nepal.

Sources of Information:

As stated previously, the present project is based largely on the information collected by the Mineral
Exploration Development Board of the Department of Mines & Geology, Nepal. Access to multi-element geochemical analysis of stream sediments (1131 samples) was made available to the author by the Department of Mines & Geology, Kathmandu, Nepal. Geologic and photo-geologic maps (scales of 1:250,000 and 1:63,360), both published and unpublished, were also made available to the author by the same organization. Available drilling information was also obtained. Basic data on the location of prospects and other attributes such as geologic and tectonic settings, host-rock information, commodities etc. were derived from the geological reports and maps of the Mineral Exploration Development Board. Additional information was obtained from the professional papers and reports of the Department of Mines & Geology, Nepal.

**Purpose or Objective of Study:**

The overall purpose of the present study is to develop an analytical methodology, specific to application in Nepal but with broader application, for assessing the mineral potential of the study area. The specific objectives of the study are:

1. Establish within the study area the relationship between stream sediment geochemistry and lithostratigraphic units,
the results of which can be applied to geologically similar areas within Nepal and to the Himalayan belt.

2. Define anomalous areas or identify areas of interest for mineral exploration.

3. Within the area, classify known mineral occurrences, as well as any anomalous areas defined as part of the present study, into specific types of mineral deposits based on the lithostratigraphy, tectonic history, and local geochemistry.

4. Define a regional geochemical signature for lithostratigraphic units and mineralized areas (exploration model) for use in other parts of the country.

5. Ascertain inter-element relationships and define the 'Exploration Elements' which are significant for further exploration purposes.

6. Establish an analytical basis for interpreting and estimating mineral potential of other parts of the country based on the analytical result of the present study.

7. Establish an exploration model, based on deposits occurring internationally and within the study area, which can be applied to other areas in Nepal with similar geologic attributes.

8. Develop a list of "Mineral Deposit Model Types" which can be used in other parts of Nepal as well and the geochemical signature for each deposit type.

9. Evaluate the specific geochemical signature for selected deposit types defined above against the regional
geochemistry to define new exploration areas for specific type of mineral deposits that may exist in the other parts of the study area.
CHAPTER III
GENERAL OUTLINE OF METHODOLOGY

The Method in General:

The present study combines elements of traditional mineral exploration (mineral inventory and stream sediment geochemistry) with less well known techniques (multi-element analysis of stream sediment samples and deposit models) to define specific exploration targets and the results of the analyses are then utilized as exploration tools for the evaluation of (a) less well known areas within the study area or (b) to evaluate similar areas throughout the Himalayan Mountain Chain.

The basic procedure utilized in the study is shown in fig. 3.1. The initial geochemical evaluation by stream sediment samples is based on the recognition of geochemical anomalies either by graphical methods with the preparation of geochemical maps or by basic statistical analysis to determine threshold and background values. These approaches have been utilised since the development of geochemical stream sediment sampling technique and have proven to be quite successful wherever applied.
Following the geochemical evaluation phase of the program deposit models are developed for the control area based on the resource inventory, geology and geochemistry. The results obtained from these analyses of the control area can be applied to the other parts of the region and based on geological correlation and structural and geochemical similarities, the evaluation of favourable areas for mineral exploration can be made. Thus, small favorable areas within the large tract of land can be delineated which reduces the cost, time and effort required to survey the whole area. The methodology in general, is outlined in fig. 3.1 below and steps involved in this methodology is shown in fig. 3.2.

Statistical Data Analysis:

The first part of the present research is concerned with the interpretation of the multi-element analysis of stream sediment data. Statistical techniques including both simple statistical method such as mean and standard deviations and multi-variate technique of factor analysis are useful techniques which can be utilised to identify the favorable areas in terms of their geochemical signature. Additionally, the results obtained by the use of both techniques can be compared in order to identify the advantage of one technique over the another. Thus, the first step of the application of statistical technique is
a) to identify geochemical anomalies in terms of single
element geochemistry or b) several elements in combination
and c) to determine the relation between geology and
geochemistry. This step is defined as 'Statistical data
analysis' in fig. 3.1 and are described in chapters-5 and 6
in detail.

Stream sediment analysis
\[\text{Statistical Data Analysis}\]
Favorable areas
\[\text{Correlation}\]
Time-petrography/Structural Association
\[\text{Interpretation}\]
Mineral deposit models
\[\text{Interpretation}\]
Favorable areas
\[\text{Analysis and Conclusion}\]

Conclusion

Fig. 3.1. General flow diagram showing the methodology
Fig. 3.2. Flow diagram showing the steps involved in the evaluation of mineral potential in the study area.
Correlation:

Following the geochemical evaluation the next step is to develop the association of geochemistry with lithology (actually time-petrographic units and structures) to evaluate areas with respect to their favorability for the occurrence of a particular type of mineral deposit as discussed in the following. Thus, a data-base is created showing the presence or absence of time-petrographic units, structural features and geochemical anomalies are to be developed for each cell. This data base can be prepared by the binary transformation of geochemical anomaly, time-petrography and structure data for each cell, and weightings shall be given to take into account the importance of one variable over another.

Mineral deposit models:

A resource inventory i.e., a compilation of information on the location, type of deposit, geologic and tectonic setting and commodities is compiled for the study area based on the existing information available in the study area. This resource inventory provide information regarding the type of deposits that occur in the study area. The established mineral deposit models occurring elsewhere in the world is also to be included in the 'resource inventory'
in the present research such that they can also be utilized as mineral deposit models for the evaluation of mineral potential. The selection of mineral deposits to use as models are to be defined based on time-petrographic units, structure and geochemical anomalies. These information could be utilized in together with the technique of characteristic analysis to evaluate the favorability of the study area for the occurrence of particular type of mineral deposit model used. Because the establishment of deposit models involves the integrated synthesis of resource inventory, geochemical signatures, geological correlation and deposit models information. The multivariate technique of characteristic analysis is a useful technique of comparing the characters or attributes of mineral deposit models with similar characters or attributes of each cell. Thus, the application of characteristic analysis in identifying the favorability of certain areas for the occurrence of certain type of mineral deposit is dealt with in the following section and in chapter-7.

Favorable areas:

Thus the mineral potential of the study area can be evaluated by the application of characteristic analysis to the results obtained by the statistical analysis of geochemical data, their association with geology,
quantitative data on time-petrographic units and structure and the mineral deposit models. The possibility of the occurrence of particular type of mineral deposit model, the favorability of occurrence of a certain type of deposit is then expressed by the degree of match, or similarity, between characters or attributes of mineral deposit models being used and characters of each cell. This degree of similarity is expressed as index of favorability as explained in details in chapter-7. These indices of favorability of occurrences for different mineral deposits are then displayed as different cell layout map for each mineral deposit model used.
CHAPTER IV

GEOLOGY OF THE STUDY AREA

General Geology:

In this chapter, a brief summary of the geological attributes of the lithostratigraphic units of the study area is presented with an emphasis on their relation to the present research. More detailed geologic and structural information can be found in the available geological literature previously cited.

The study area lies in Central Nepal mainly within the Lower Himalayan zone and also covers a portion of Sub-Himalayas (fig. 1.2). The area is comprised mostly of metasediments and crystallines in the area north of the Main Boundary Thrust. South of the Main Boundary Thrust, Neogene molassic deposits of the Sub-Himalayan foothills cover the area. The metasediments and crystallines of the Lower Himalaya in the northern part of the area comprise a thick Proterozoic to Paleozoic fold and thrust sequence. The northernmost limit of the Lower Himalayan belt is delimited by the Main Central Thrust, north of which the successions of the Higher Himalaya occurs. The Sub-Himalayan sequence south of the Main Boundary Thrust is believed to range in age from Middle Miocene to Lower Pleistocene. However, the stratigraphy of the area is not well established due to the
structural complexities and lack of stratigraphic controls within the sequence.

**Lithostratigraphic Description:**

The lithostratigraphy of the study area including the lithology, physical relationships between different geological formations and members, and spatial distributions of individual rock units has been described by Stocklin and Bhattarai (1977), (table 4.1).

The Lower Himalayan rocks of the study area have been broadly grouped into two complexes (Stocklin and Bhattarai, 1977, table 4.1). They are the Nawakot Complex and the Kathmandu Complex and are exposed in a major structural feature called the Mahabharat synclinorium. High grade metamorphic rocks of the Kathmandu Complex occur primarily in the core of the Mahabharat synclinorium while lower grade metamorphic rocks of the Nawakot Complex occur mainly around the rim of the synclinorium. The superposition of the high grade metamorphic rocks and crystallines of the Kathmandu complex over the lower grade metasedimentary rocks of the Nawakot Complex is an ongoing subject of dispute in Nepal geology. But, for the purpose of the present investigation the lithostratigraphy and lithological descriptions is largely taken from, as presented by Stocklin and Bhattarai
<table>
<thead>
<tr>
<th>Name of unit</th>
<th>Main Lithology</th>
<th>Approximate Thickness in m</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phulchauki Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Godavari Limestone</td>
<td>Limestone, Dolomite</td>
<td>300</td>
<td>Devonian</td>
</tr>
<tr>
<td>Chitlang Slates</td>
<td>Slate</td>
<td>1000</td>
<td>Silurian</td>
</tr>
<tr>
<td>Chandraigiri Limestone</td>
<td>Limestone</td>
<td>2000</td>
<td>Cambrian-</td>
</tr>
<tr>
<td>Sopyang Formation</td>
<td>Slate, calciphyllite</td>
<td>200</td>
<td>? Ordovician</td>
</tr>
<tr>
<td>Rhimphedi Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tistung Formation</td>
<td>Metasandstone, phyllite</td>
<td>1000</td>
<td>Early Cambrian</td>
</tr>
<tr>
<td>Markhu Formation</td>
<td>Marble, schist</td>
<td>1000</td>
<td>Late Precambrian</td>
</tr>
<tr>
<td>Kulikhani Formation</td>
<td>Quartzite, schist</td>
<td>2000</td>
<td>Precambrian</td>
</tr>
<tr>
<td>Chisapani Quartzite</td>
<td>White quartzite</td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>Kalitar Formation</td>
<td>Schist, Quartzite,</td>
<td>2000</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>partly garnetiferous</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jurikhet Conglomerate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pandrang Quartzite</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shimsen Dolomite</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower schist member</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bhainsedobhan Marble</td>
<td>Marble</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>Raduwa Formation</td>
<td>Garnetiferous schist</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bhainsedobhan Marble</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raduwa Formation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Nawakot Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robang Phyllites</td>
<td>Phyllites, Quartzite</td>
<td>200-1000</td>
<td>? Paleozoic</td>
</tr>
<tr>
<td></td>
<td>with Dunqa Quartzites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malekhu Limestone</td>
<td>Limestone, dolomite</td>
<td>800</td>
<td>? &quot;</td>
</tr>
<tr>
<td>Benighat Slates</td>
<td>Slate, argillaceous dolomite</td>
<td>500-?3000</td>
<td>? &quot;</td>
</tr>
<tr>
<td></td>
<td>with Jhiku calcareous beds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unconformity</td>
</tr>
<tr>
<td>Lower Nawakot Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dhading Dolomite</td>
<td>Stromatolitic dolomite</td>
<td>500-1000</td>
<td>Late Precambrian</td>
</tr>
<tr>
<td>Nourpul Formation</td>
<td>Phyllite, quartzite, dolomite</td>
<td>800</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>Phyllite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dandagaon Phyllites</td>
<td>Phyllite</td>
<td>1000</td>
<td>&quot;</td>
</tr>
<tr>
<td>Fagfog Quartzite</td>
<td>White Quartzite</td>
<td>400</td>
<td>&quot;</td>
</tr>
<tr>
<td>Kuncha Formation</td>
<td>Phyllite, Quartzite</td>
<td>3000+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with grit-stones, conglomerate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labdi Phyllites</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banspani Quartzite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siwalik Group</td>
<td>Main Boundary Thrust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(undifferentiated)</td>
<td>Sandstones, mudstones, several Kms. conglomerates</td>
<td>Neogene</td>
<td></td>
</tr>
</tbody>
</table>

Table-4.1 Stratigraphic Subdivisions (from Stocklin and Bhattarai, 1977)
(1977) as only the lithological characteristics of the individual units and the presence or absence of structural features are the primary attributes utilized in the present study. Clearly however the resolution of this major geologic problem is an issue to be addressed in future studies.

**Siwalik Group:**

The Siwalik Group has commonly been divided into the Lower, Middle and Upper Siwalik Units. The Lower Siwalik is mainly comprised of argillaceous deposits with minor interbeddings of fine grained sandstones. The Middle Siwalik is mainly composed of grey, fine to coarse grained sandstones with intercalations of grey shales and mudstones while the Upper Siwalik is dominantly conglomerates with intercalations of mudstones and pebbly beds. The Siwalik Group had been assigned the age of Middle Miocene to Lower Pleistocene based on the presence of mammalian fossils.

**Nawakot Complex:**

The Nawakot Complex is comprised of low grade metasediments such as phyllites, quartzites and carbonates and ranges in age from Late Precambrian to Late Paleozoic. The Nawakot Complex is further subdivided into two groups -
the Lower Nawakot Group and the Upper Nawakot Group
separated by regional disconformity (Stocklin and Bhattarai, 1977).

Based on the identified stromatolites from the dolomite
units of the Nawakot Group, this group had been assigned a
Late Precambrian-Paleozoic age (Stocklin and Bhattarai, 1977). The Lower Nawakot Group had been subdivided into
five geological formations while the Upper Nawakot Group has
been subdivided into three formations.

**Lower Nawakot Group:**

Kuncha Phyllites:

The Kuncha Formation consists of a rather monotonous
sequence of flysch-like phyllites, phyllitic quartzites, and
phyllitic gritstones resembling greywackes. Carbonate rocks
are rare. The overall color is yellow-green to light blue-
green, generally lighter than the phyllitic rocks in higher
parts of the Nawakot Complex. The phyllites are
argillaceous, more or less silty or quartzitic, and also
extremely fine-grained to dense, laminated and siliceous.

The Kuncha Formation is frequently intercalated with
'gritty phyllites' consisting of detrital quartz, minor
feldspar, tourmaline and other minerals. It is also intercalated with fine quartz-conglomerates and occurrence of basic intrusives had been reported. Sericite and chlorite are usually the metamorphic minerals recognized and strong lineation predominantly in a N or NE direction. For the purpose of establishing the geochemical signatures of the lithostratigraphic units, the Banspani Quartzite Member, occurring a short interval below the top of the Kuncha Phyllite, is dealt with as an individual unit, based on its characteristic lithology. This member of the Kuncha Formation is a medium grained impure quartzite of dirty-green-grey color with a slight carbonate content in the matrix. Quartzite beds are compact but also finely layered with some cross-bedding structures locally. Thus, the Kuncha Phyllites and Banspani Quartzites are two separate units of the Kuncha Formation dealt with as individual time-petrographic units.

Fagfog Quartzite:

The Fagfog Quartzite consists of a series of white quartzite units comprised of colloidal fine grained chert, impure coarse orthoquartzite, and intercalations of green phyllites with occasional reddish to pale orange tints. The Fagfog Quartzite has graded bedding and ripple marks (Arita et.al., 1973, Stocklin and Bhattarai, 1977).
Dandagaon Phyllites:

The Dandagaon Phyllites are dominantly comprised of argillaceous to finely quartzitic phyllites of dark blue-green color with green fine grained sericite or occasional chloritic quartzite intercalations. Thin bands of dense dolomite and calc-phylite have also been reported from this formation.

Nourpul Formation:

The Nourpul Formation consists of a mixed lithology of phyllitic, quartzitic and carbonatic rock types. Stocklin and Bhattarai (1977) made a rough subdivisions of this formation into three subunits. The basal member called the Purebesi Quartzite Member is comprised of cross-bedded and ripple marked white to greenish-white, fine to coarse grained arkosic quartzite. The middle member, above the Purebesi Quartzite, is primarily comprised of dark green- or blue-grey phyllites with a variable amount of quartzite and carbonatic intercalations. The quartzites are reported to be impure, micaceous, green-grey to pinkish in color. Carbonate rocks are multi-colored but predominantly neutral light-grey to yellow and pale-green color, usually dolomitic but often siliceous and fine-grained to almost dense (Stocklin and Bhattarai, 1977). Both quartzites and
carbonate form intercalations with phyllites. The Upper Member of the Nourpul Formation is dominantly dolomite and dolomitic quartzite with a characteristic green/buff or green/orange color banding reported to be caused by a regular alternation of green phyllite and quartzitic dolomite. This upper member of the Nourpul Formation gradually passes into the Dhading Dolomite.

Dhading Dolomite:

As the name implies, the Dhading Dolomite Formation is composed predominantly of dolomites which are reported to be thick bedded to massive in the main portion and thinner bedded and platy in the basal section. The dolomites are finely crystalline to dense, light-blue-grey in color and demonstrate a splintery fracture. According to Stocklin and Bhattarai (1977) chert nodules and lenses occur locally within the formation.

Upper Nawakot Group:

The Upper Nawakot Group had been subdivided into three formations: the lower Benighat Slates, the middle Malekhu Limestone, and the upper Robang Phyllites.
Benighat Slates:

The Benighat Slate formation is comprised of dark, bluish-grey to nearly black and also green-grey color due to the presence of chlorite, soft-weathering slates and phyllites, mainly argillaceous, subordinately siliceous or finely quartzitic. The Benighat Slates are black carbonaceous slates containing 60-65% mica and quartz and 35-40% graphitic matter and fine disseminations and veinlets of pyrite. Characteristic of the dark slates are powdery encrustations of white salt (probably bitter salt), in fresh dried outcrops and locally the occurrence of malachite staining.

The Jhiku carbonate bed mainly constituted of calcphyllites and phyllitic limestones or dolomites forming irregular intercalations are reported to occur as tongues and lenses within the Benighat Slates. The rocks are more argillaceous in nature with sericite and chlorite. These carbonate beds are dark-grey to black, thinly bedded, dense or very fine-grained siliceous dolomites associated with the black carbonaceous Benighat Slates. The thin, platy, yellowish to pale-green, fine grained siliceous limestones and dolomites are reported to be more frequent in the upper part of the Benighat Formation.
Again for the geochemical investigation of the lithostratigraphic unit, the Jhiku carbonate beds are treated separately as individual time-petrographic unit as shall be described in the chapter-5.

Malekhu Limestone:

The Malekhu Limestone is comprised of upper and lower thin platy dolomitic and siliceous limestones and a middle thickly bedded dolomite or dolomitic limestone. The thin limestone beds occurring at the lower and upper part of the formation are of light-yellow color, very fine-grained to dense, with partings and thin intercalations of green sericite-chloritic material while dolomitic limestone of the middle part is dark grey color. Intercalations of black siliceous and carbonaceous slates and bands of black chert occur in the middle part of the formation in association with the middle massive unit.

Malachite staining in quartz-veins cutting through the Malekhu Limestone and the occurrence of disseminated ore grains of hematite and copper sulfides are reported (Stocklin and Bhattarai, 1977).
Robang Phyllites:

The Robang Phyllites consist predominantly of sericitic-chloritic phyllites of green-grey color with beds of quartzites. The unit contains basic rocks such as metadiabase, metagabbro and amphibolites. The 'Dunga Quartzite Beds' of this formation are generally medium grained, white in color and contain minor green phyllite intercalations. Locally, they are fine grained and thin bedded.

Kathmandu Complex:

The Kathmandu Complex had been subdivided into two groups—the Bhimphedi Group and the Phulchauki Group. They are metasedimentary sequences of high- to low-grade schists, quartzites and carbonate rocks with the association of granitic and migmatitic rocks of the Bhimphedi Group.

Bhimphedi Group:

The Bhimphedi Group had been further subdivided into 7 geological formations:
Raduwa Formation:

The Raduwa Formation consists of coarse-crystalline, dark green-grey colored biotite schist with profusion of lenses and nodules of quartz but lighter varieties with sericite or muscovite and chlorite are also present. The schist is dominantly garnetiferous with amphibole and pyroxene occurring locally. In places, subordinate layers of micaceous grey quartzite and zones of pale-green or white pure quartzites had also been reported. Its lower contact with the Upper Nawakot Group had been reported as tectonic contact while the upper contact with the Bhainsedobhan Marble as a transitional one.

Bhainsedobhan Marble:

The Bhainsedobhan Marble, as the name itself implies had been reported to consist of coarse-crystalline, well bedded to massive, white colored marbles with subordinate layers of biotite and occasionally garnetiferous schist. Some mica such as biotite, muscovite and phlogopite and ore grains of pyrite, magnetite, galena, copper sulfides had been reported to occur in the marble. The Bhainsedobhan Marble overlies the underlying Raduwa Formation and underlies the overlying Kalitar Formation with transitional contacts to the schists.
Minor Pb-Zn mineralizations and occasional traces of iron and copper had also been reported from the Bhainsedobhan Marble.

Kalitar Formation:

The Kalitar Formation mainly consist of dark green grey, two-mica and biotite schist with subordinate intercalations or layers of strongly micaceous quartzite. The schist in the lower part of the Kalitar Formation is coarser with garnet usually present than in the upper part where garnet is disappearing altogether. Rare thin amphibolite bands has been reported from the Kalitar Formation. Several lithological members had been recognized in the Kalitar Formation by Stocklin and Bhattarai (1977).

The Pandrang Quartzite member occurring above the Bhainsedobhan Marble is comprised of fine-grained, pale-green to greenish-white, well bedded quartzites containing partings and seams of sericite-chlorite schist.

The schist interval between the Bhainsedobhan Marble and the Pandrang Quartzite had been defined by Stocklin and Bhattarai (1977) as the Lower Schist Member only where the Pandrang Quartzite is present. Garnets are reported to
occur always in the schist while the amphiboles and/or pyroxene minerals occur locally.

Rare layers of brownish marble or calcsilicate forming sporadic lenticular layers had been identified as the Bhainsedobhan Dolomite Member with a thickness of about 100m. Association of green amphibolites with carbonates had been reported.

More massive, unbedded dark-grey biotitic quartzite of blocky appearance of Kalitar type containing large, well-rounded boulders of grey micaceous quartzite and biotite schist reaching 30 cms. in diameter had been defined as the Jurikhet Conglomerate member underlying the Chisapani Quartzite. These lithological members of the Kalitar Formation are not continuous but present locally in certain geographic areas only.

Chisapani Quartzite:

The Chisapani Quartzite overlying the Kalitar Formation consists of white or pale green quartzite containing sericite as fine partings or thin sericitic phyllite seams. The Quartzite is often cross-bedded and occasionally ripple-marked. The Chisapani Quartzite is overlain by the Kulikhani Schist with a rapid transitional contact.

Kulikhani Formation:
The Kulikhani Formation is comprised of alternation of lustrous dark green-grey more or less micaceous quartzite and more or less quartzitic schist. Few small grains of garnet had been reported to occur locally. Quartzites had been reported to show occasional cross-bedding and graded-bedding and the local occurrences of thin dykes and sills of amphibolite had also been reported. Its upper contact with the overlying Markhu Formation is transitional contact.

Markhu Formation:

The Markhu Formation is comprised of schists, quartzites and carbonates with carbonates being the distinctive lithology. The carbonates are mainly medium to coarse-crystalline, white to occasionally pinkish color and massive occurring in the south. Northwards, schists and quartzites are dark, biotitic and fine-grained. Stocklin and Bhattarai (1977) reported a gradational contact with the overlying Tistung Formation. However, Kumar et.al. (1978) reported an unconformable contact with the Tistung Formation based on pebbly bed at the base of the Tistung Formation.

Again in the present research, as shall be explained later in chapter-5, the Markhu Marble and the Markhu Schist constituting the Markhu Formation are treated separately.
Tistung Formation:

The Tistung Formation, mainly comprised of slates, phyllites and metasandstones is mostly dark phyllite with some biotite in the lower part of the formation while in the upper part, sericite and chlorite are dominant. The sandstone often shows a red/green color banding with the interbedded green phyllite. Occasional thin limestone bands were reported to occur within sandstones and phyllites. Sandstones were reported to be current bedded with graded bedding and ripple marks occurring in them while clay cracks were reported to be present in phyllite. The Tistung Formation is overlain by the Sopyang Formation with a transitional contact.

Phulchauki Group:

The Phulchauki Group which had been divided into 5 geologic formations by Stocklin and Bhattarai (1977), is mainly comprised of limestones with subordinate zones of shaly and sandy rocks.

Sopyang Formation:

The Sopyang Formation is essentially reported to be comprised of dark, almost black, soft-weathering phyllitic
slates, argillaceous to marly, thinly bedded, with thin lenticular layers of argillaceous limestone. The Sopyang Formation is reported to underlain by the Tistung Formation and overlain by the Chandragiri Limestone with a gradational contact.

Chandragiri Limestone:

The Chandragiri Limestone mainly consists of light, fine-crystalline, white and yellow to pale-green and pinkish colored, partly siliceous and also dolomitic limestone. The main part is reported to be thick-bedded to massive in appearance but well bedded while lower part being thinly-bedded and more argillaceous with micaceous seams. White quartzites are reported to occur in upper part and impure argillaceous, green and pink colored limestones above the quartzite band are reported to contain abundant crinoid and other echinoderm fragments including cystoids. Based on fossils found Stocklin et.al. (1977) assigned the Late Ordovician age to the Chandragiri Limestone. The Chandragiri Limestone is conformably overlain by the Chitlang Slates with crinoidal limestones passing upwards into slates.
Chitlang Slates:

The Chitlang Slates is reported to form the true core of the Chandragiri syncline (Stocklin et al., 1977) and it consists of dark, violet soft weathered slates. In the lower part of the formation, interbeddings of white quartzites are reported while in the upper part, few thin limestone intercalations are reported to occur.

The Silurian beds of Phulchauki, as defined by Stocklin and Bhattarai (1977) also consisted of violet slates with thick band of white quartzite in the lower part and few limestone beds in the upper part. In the upper part, two ferruginous beds containing trilobites (Silurian) are reported to occur and iron deposits of Phulchauki is reported to occur in one of the ferruginous bed. This formation is underlain by the Chandragiri Limestone and overlain by the crinoidal limestones of the Godavari Limestone.

Godavari Limestone (Devonian Limestone of Phulchauki):

The youngest rock of the Kathmandu Complex, occupying the very core of the Mahabharat synclinorium is reported to consists of well-bedded, green and purple argillaceous crinoidal limestones while massive, coarsely crystalline
dolomite of white to light-brown color occur above the
crinoidal limestones forming the main part of the formation.

**Magmatic and Migmatitic Rocks:**

Granites and gneisses occupying a considerable part of
the study area had all been reported to be confined to the
Kathmandu Complex. Also, small linear basic intrusives
along the major faults or thrust-faults had been reported to
occur too.

**Granites:**

Stocklin and Bhattarai (1977) had mapped several
granitic bodies in the study area and distinguished two
types of granites viz. biotite granites and tourmaline
granites. Biotite granites are reported to be porphyric
with phenocrysts of idiomorphic K-feldspar and biotite being
the common dark mineral with muscovite and tourmaline absent
or occurring in very subordinate amount.

The tourmaline granites are reported to be younger than
biotite granite and either occur within the biotite granites
as irregular portions or as dykes cutting both through the
biotite granites and the country rocks. Aplitic varities
are also reported to occur associated with the tourmaline granites.

Stocklin and Bhattarai (1977) noted that the granitic intrusives affect all formations of the Bhimphedi Group including the Tistung Formation developing crosscutting contacts. The contact aureoles of a few tens of m up to maximum 200-300 m in width of the granite intrusions upon the country rocks were reported. Skarn minerals such as tremolite-actinolite, diopside etc. had been reported to develop in the carbonatic zones near granitic contacts and also granitisation of the country rock had been reported to be observed as the most conspicuous effect.

The Himalayan granites were considered as very young based on few radiometric dating of different granites. However, Talalov (1972) gave an apparent age of 165 m.y. (Mid Jurassic) for the Agra intrusion based on K/Ar whole rock determination of a biotite granite. Similarly, Krummenacher (in Bordet et. al., 1965) gave an age of 48 m.y. based on K/Ar dating of a biotite from the Palung Granite and Khan and Tater (1970) gave an age of 51 m.y. (Eocene) to the Palung Granite based on K/Ar dating of a muscovite concentrate.
Gneisses:

Large gneiss masses were reported to occur in the crystalline zones of the Sheopuri Lekh in the north of Sindhuli Garhi in the east and in the small granite-and-gneiss complex of Timaldanda in the eastern-central part of the study area (Stocklin and Bhattarai, 1977) and associated with biotite and tourmaline granites. The gneisses are reported to have a granitic or pegmatitic composition, with both muscovite and biotite, much tourmaline and porphyroblasts of or augen of feldspar. Stocklin and Bhattarai (1977) also reported a different kind of gneiss and gneissic schist in a narrow zone immediately above the main tectonic separation between the Nawakot and Kathmandu Complexes.

Basic Rocks:

Basic intrusives of "meta-gabbros, diabases, amphibolites" along the Mahabharat Thrust-fault or other thrust faults have been reported to occur in association mostly with green chloritic phyllites of the Robang Formation or with pale green Dunga Quartzites. Stocklin and Bhattarai (1977) reported that these basic intrusives display distinctly intrusive nature showing cross-cutting contacts with the phyllites and quartzites. These basic
rocks are reported to be medium-grained, dark-green color with clearly distinguishable feldspar and amphibole or pyroxene minerals while some of them are reported to be of lighter green-grey color, chloritic, showing clear schistocity.

Stocklin and Bhattarai also reported occurrences of minor basic rocks of similar petrographic character in the Kuncha Formation and also associated with quartzites of the Nourpul Formation.
CHAPTER V
STATISTICAL ANALYSIS OF GEOCHEMICAL DATA
AND ITS RELATION TO GEOLOGY

This chapter deals with the establishment of the relation between the geology and geochemistry of the study area. Also, how inter-element relationships been defined is explained in this chapter. Central to the success of the present research is the development of an appropriate data base of both basic and derived data for use in the following analyses. Therefore, this chapter discusses and defines the procedures used in constructing the basic data and provides a discussion of results from the analyses. Specifically, the discussion focusses on the following: (1) the definition of the geological and geochemical variables used to create the analytical data base, (2) the determination of time-petrographic units for the lithostratigraphy of the study area, (3) the definition of geochemical signatures for time-petrographic units, (4) procedures for statistical analyses of multi-element stream sediment sample data, and (5) results obtained and their interpretation. Special emphasis is placed on the statistical analysis utilized in this study in particular how inter-element relationships and elemental associations were established by multivariate technique of factor analysis. Finally, contour maps of the factor analysis of the geochemical data are combined with the geology of the study area to show the relation of
geochemistry to geology. It is important to emphasize here that only the stream sediment samples from areas of individual time-petrographic units were used to create the data base for the present analysis.

Geological and Geochemical Variables:

Geologic and structural variables in the present study, in particular lithologies of differing age within the same formation, were determined by analysis of the photo-geologic maps of the area prepared by Stocklin and Bhattarai (1977). Photo-geologic maps at the scale of 1:63,360 of the study area were utilized to define the geologic variables, rather than the compiled map for the whole area at the scale of 1:250,000, to give a wider range of rock types and more detail structural information. Lithologic data were subsequently used to determine the time-petrographic units of the area and as geologic variables were classified on the basis of age and dominant lithology, they are called time-petrographic units. The determination of both lithology and time-petrographic units is of importance to later phases of the study because of the association of specific types of mineral deposits with specific lithologies of specific ages. For example, the Markhu Formation consists of marble in the south and biotitic schist interbedded with impure marble and quartzite in the north: each a possible host to different types of mineral deposits. Thus, two geological variables,
the Markhu marble and the Markhu schist, were defined for the Markhu Formation. Also, igneous bodies of differing composition and metamorphic units such as different granitic intrusives, metagabbro, metadiabase, and amphibolite are treated individually making it possible to use them as separate variables. In this way their age and structural relationship with the rocks they intrude could also be accounted for in the evaluation.

After the individual time-petrographic units were determined, they were then coded numerically for use in the statistical analysis. A transducer (table 5.1a), as developed by Griffiths et.al. (1973), was used to numerically code the time-petrographic units (table 5.1b) such that the first two digits as in table 5.1(b) denote the time or age and last two digits denote the petrography. For example in table 5.1(b), the code of 2410, means the first two digit of 24 refers to the age of Quaternary in the vertical column of ages and the last two digit of 10 refers to the dominant lithology of alluvium along the horizontal axis of rock-types. Thus, the numerical codes in the data base for time-petrographic units took into account both the dominant rock-type and its age. The total number of time-petrographic units defined from the map symbols of the lithostratigraphic units are 40 as shown in the table 5.1b.
Table 5.1(a). Table showing the transducer as developed by Griffiths et al. (1979) to convert geological map units to time-petrographic units.
Table 5.1(b). Transducer converting the geological map units from the study area into time-petrographic units.
There are six structural variables (table 5.2) defined for the area of study. The first two variables (S1 and S2, table 5.2) are total length of faults per cell and number of faults per cell. There are two major thrust faults in the study area—the Main Boundary Thrust (MBT) and the Mahabharat Thrust (Stocklin and Bhattarai, 1980). The lengths of these major thrust faults are also defined as structural variables and denoted as S3 and S4 (table 5.2). The measure of total length of contacts between metasediments and granitic intrusives is also structural variable (S5) as is the measure of length of contact between the basic rocks and metasedimentary formations (S6). Thus there are 46 geological variables as shown in table 5.1(b) and table 5.2.

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S1 = total length of faults per cell.
S2 = number of faults per cell.
S3 = total length of the Main Boundary Thrust (MBT).
S4 = total length of the Mahabharat Thrust.
S5 = total length of contacts between metasedimentary formations and granite.
S6 = total length of contact between basic rocks and metasedimentary formations.

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Table 5.2. Table showing the list of structural variables.
Geochemical Data:

For the study area, the results of multi-element analysis (28 elements) of 1131 stream sediment samples were obtained. The multi-element analysis of these samples were performed using the coupled-plasma spectrometry at the Geochemical Research Group, Imperial College, London. These 28-elemental analysis of stream sediment samples are the geochemical variables that are utilized in the present study.

Gridded Data:

The study area falls in the toposheet nos. 72 A/5, A/9, A/13, A/14, E/1, E/2, E/3, E/6, E/7, E/10, E/11, and E/15 of Survey of India. For analysis the whole area is subdivided into five-minutes of latitude and longitude squares (29 sq.km. area) cells using 15' quadrangles mentioned above of the scale 1:63,360 (fig. 5.2). Cells of this size were choosen as the cells (a) represent several time-petrographic units (b) consist of a reasonable number of stream sediment samples for most of the cells (c) are large enough in area to contain mineral deposits of economic significance and show the relationship of geology and geochemistry. Moreover, the divisions of the cells were simple in nature as they coincide with the grids of the topographic maps.
Fig. 5.1. Grid cell layout. Four digit numbers on the top of each cell represent identification of each cell. Numbers on the bottom of each cell is the number of samples available for that grid.
The subdivisions of cells were given an identification following the procedure as described below. First, each cell was given an identification of four digits, the first numeral of 1 or 5 corresponding to either A-series or E-series toposheets, followed by next two digits denoting the toposheet numbers which can range from 1 to 16 in general and the last digit, which ranges from 1 to 9 as each toposheet was divided into 9 grids of five-minutes square each in the present case. For example, toposheet no. 72 E/2 of 15 minutes quadrangle is divided into 9-grids or cells of 5-minutes squares. Each grid was numbered 1 to 9 vertically with 3 columns. Thus, grid I.D. of 5029 e.g., corresponds to toposheet no. 72E/2, as all the toposheets in the study area are numbered 72, with the first digit of 5 corresponding to E-series toposheet, 02 corresponding to toposheet no. 2 and last digit 9 corresponding to 9th grid or cell. Following this procedure, the grid or cell layout for the study area is derived which is shown in figure 5.2. Thus in figure 5.2, the four digits on the top of each cell is the identification number corresponding to a 5-minutes square cell within the toposheet of the study area. Numbers on the bottom of each cell are the total number of geochemical stream sediment samples available for that grid or cell.
The data for geological, structural and geochemical variables were stored on magnetic tape using the mainframe computer IBM 3081 at the computing center of the University of Hawaii Computing Center, Hawaii.

The primary data base was prepared with the information on sample number of stream sediment samples, the grid on which the sample occurs, the content of 28-elements for that sample, and the rock-type. A separate data base was prepared for the sample numbers of stream sediment samples and their coordinates. A third data base was created which, as described in geochemical signatures and anomalies section of chapter III, contained only the results of those stream sediment analyses of samples from individual time-petrographic unit. Another data base was built which consisted of grid identification, and coefficients such as 1s and 0s indicating presence or absence respectively of geological, structural, and geochemical variables in grids.

Time-petrographic Units and Their Geochemical Signature:

As described in the Geological and Geochemical Variables section of this chapter, the lithostratigraphic units of Stocklin and Bhattarai (1977) are further subdivided into time-petrographic units (table-5.1) utilizing a transducer (Griffiths et.al., 1979) designed to
yield a consistent set of classes (rock-types or time-petrographic units) which are, as far as possible, mutually exclusive and exhaustive (Griffiths, 1968b, 1972?). This transducing process makes it possible to classify the individual geological formation or lithostratigraphic units into units which account for both time and lithology. Thus, they are called time-petrographic units by Griffiths (1977). As discussed earlier, this classification into time-petrographic units is helpful in associating rock-types of different ages with mineral deposits which will be described in later section.

In the present study, the geochemical signature of a time-petrographic unit is defined as the average elemental concentration, of different elements individually or in associations, which is diagnostic or unique to that unit. The geochemical signature for the individual time-petrographic unit was based on a selection of specific stream sediment samples which could reasonably be shown to have been derived from an individual time-petrographic unit. As stream sediment sampling relies on the fact that products of rock weathering are channeled into surface drainage systems, either in solution or as clastic sediments, samples were choosen that represented drainage from only one time-petrographic unit: thereby avoiding contamination from other units normally lower in the drainage system. One important
point which needs to be borne in mind is that the geochemical signatures could not be defined for all time-petrographic units as the stream sediment samples derived from the drainage of individual time-petrographic units could not be defined for all units from the data-base available. Thus, based on an analysis of data of selected stream sediment samples, a comparative study was made to define the geochemical signature of individual time-petrographic units.

Statistically, the primary criteria used to define the geochemical signatures of the time-petrographic units are the mean concentrations of different elements. Thus, the mean concentrations of elements and the standard deviations for the individual time-petrographic units are calculated first. The mean concentrations obtained for the individual time-petrographic units of the study area are presented in the table-5.3.

The geochemical signatures for first two units in table-5.3 are for the Kuncha Phyllites and the Banspani Quartzite Member of the lithostratigraphic unit-Kuncha Formation. In terms of lithostratigraphy, these two units are grouped into one geological formation (table-4.1), (Stocklin and Bhattarai, 1977), however, for the present purpose of study, the Kuncha Formation is divided into two
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Table-5.3. Mean concentrations of elements for individual time-petrographic units.
### Time-petrographic units

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<th>NAGR</th>
<th>MSC</th>
<th>MGN</th>
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Table-5.3 (continued)
time-petrographic units which takes into account both time and lithology. In other words, although, this unit is considered as a single geological formation with the same age, using the transducing method, for this study it is considered as two units with the same age but with differing lithology. This concept is applied to all the geological formations defined by Stocklin and Bhattarai (1977). Thus, the Benighat Slates with the Jhiku Carbonate Beds are defined as two time-petrographic units, so was the Markhu Formation which was subdivided into the Markhu Marble and the Markhu Schist time-petrographic units. Similarly, different granite bodies are treated as individual time-petrographic units.

Although, geochemical signatures have been established for 26 time-petrographic units (table-5.3), it must be noted that for the Banspani Quartzite Member (KNQ), Dhading Dolomite (DHD), Malekhu Limestone (MLL), Kalitar Quartzite (KAQ) and Sopyang Slates, the signatures are based only on 2 or 3 available samples. Thus, caution is practiced when using geochemical signatures of these time-petrographic units.

In order to establish the confidence level for the individual geochemical signatures, the 95% confidence interval was chosen and the standard deviation was used to
define the ranges of variation. Samples lying outside the range defined by mean ± 2 standard deviations were considered as outliers. Subsequently, mean values of different elements were recalculated, removing outliers, for all time-petrographic units. The results obtained are presented in table 5.4.

A comparison of tables 5.3 and 5.4 show that for most elements, signatures obtained are more or less the same. This similarity is due to the fact that in the first method, although outliers were included in the computation, those outliers lying at the two sides of the distribution i.e., the low value outlier and the high value outlier compensate each other. Thus, the two procedures give similar results. However, for certain elements there are some discrepancies in the geochemical signatures obtained. Specifically the Markhu Marble unit, which shows substantially lower geochemical signatures for elements such as As, Sb, Ca, Sr, Ba, Zn, and Pb when computed using the 95% confidence level. As will be shown later, this occurs because the unit contains Pb and Zn deposits and as a result, stream sediments derived from this unit have a larger number of highly anomalous samples producing an anomalous signatures when computed without any confidence interval.
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Table-5.4. The geochemical signatures for selected time-petrographic units with 95% confidence level.
Transformation of Geochemical Variables:

The logarithmic transformations on raw geochemical variables were performed in order that they nearly satisfy the requirement for normally distributed variables before performing statistical analysis. A basic assumption needed for most multivariate statistical analyses is that the variables under study follow a multivariate normal distribution. So, before proceeding to the multivariate statistical analysis of the geochemical variable, tests on normality (skewness and kurtosis) were performed by plotting histograms (fig. 5.2a and fig. 5.2b) and computing skewness and kurtosis for each geochemical variables. Miesch (1976) defined skewness and kurtosis as follows:

"The skewness and kurtosis of a frequency distribution curve are, respectively, measures of the assymetry and peakedness of the curve.....and can be made by both mathematical and graphical procedures. All of the conventional methods for measuring skewness yield a value of zero for a distribution that is symmetrical about its mean value, a positive value for a distribution that has a tail extended towards the higher values, and a negative value for a distribution with a tail extended towards the lower values. Some commonly used methods for measuring kurtosis yield a value greater than three for a distribution that is more peaked than a normal distribution curve and a value less than three for a distribution that is less peaked."
Thus for a normal distribution, the skewness (alpha3) and kurtosis (alpha4) should be equal to 0.0 and 3.0 respectively. Table-5.5 shows the skewness and kurtosis obtained for the variables in its raw state as well as after their natural logarithmic transformations. Skewness and kurtosis are calculated using formulas:

Skewness = \[ \frac{n}{(n-1)(n-2)} \sum_{i=1}^{n} (x_i - x)^3 / s^3 \]

Kurtosis = \[ \frac{n(n+1)(n-2)(n-3)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n} (x_i - x)^4 / s^4 - 3(n-1)(n-2)(n-3). \]

Similarly, figs. 5.1(a) and 5.1(b) show histogram for As and Li respectively before and after logarithmic transformations. It is obvious also from the illustrations that the geochemical variables showed remarkably marked improvement approaching the normal distribution after the logarithmic transformations.

As can be seen from table 5.5 for most of the geochemical variables, measures of skewness and kurtosis are greater than zero and 3.0 respectively. Especially, for the elements like As, Ca, Sr, La, Cu, Zn, and Pb, the measures of kurtosis are from 45.32 to 237.45. The measures of skewness for these variables also ranges in magnitudes from 5.4 to 13.1. The only geochemical variable that seems to approximate closely to the normal distribution is potassium.
Fig. 5.2(a). Histogram plot for arsenic (As) before log transformation (upper diagram) and after log transformation (lower diagram).
Fig. 5.2(b). Histogram plot for lithium (Li) before log transformation (upper diagram) and after log transformation (lower diagram).
### Table 5.5. Skewness and kurtosis of data before and after logarithmic transformation.

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<tr>
<th>Variable</th>
<th>Skewness (1)</th>
<th>Kurtosis (1)</th>
<th>Skewness (2)</th>
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Note:
1. For original variables
2. Log transformed variables with 0 as missing values
3. For log transformed variables with 0 equal to detection limit
As the geochemical variables in general did not follow a normal distribution, it was necessary to perform a logarithmic transformations in order to approximate a normal distribution. So, before proceeding to the factor analysis, the logarithmic transformations were made on each variable using the equation \( y_i = \ln x_i \), where \( x_i \) is the raw geochemical variable and \( y_i \) the corresponding logarithmically transformed variable for \( x_i \).

**Factor Analysis:**

Joreskog et.al. (1976) defined factor analysis as below:

"Factor analysis is a term which we use to describe a number of methods designed to analyze inter-relationships within a set of variables or objects. Although the various techniques differ greatly in their objectives, and in the mathematical model underlying them, they all have one feature in common, to which, the construction of a few hypothetical variables (or objects), called factors, that are supposed to contain the essential information in a larger set of observed variables or objects. The factors are constructed in a way that reduces the overall complexity of the data by taking advantage of inherent inter-dependencies. As a result, a small number of factors will usually account for approximately the same amount of information as do the much larger set of original observations. Thus, factor analysis is, in this one sense, a multivariate method of data reduction."
Rose et.al. (1981) briefly defined the R-mode and Q-mode factor analyses as follows:

"Statistical correlations between elements are commonly found when a set of samples is analyzed for many elements. In many instances, a group of elements may correlate with each other and reflect the operation of a single process, geochemical characteristic or master variable. The information contained in such sets of data can be expressed by a smaller number of variables that combine elements into groups with close correlation. R-mode factor analysis is a method of resolving large number of elements into a smaller number of new combinations. These combinations may then be examined for significance in terms of process, types of samples or other geological geochemical information. Q-mode factor analysis is a method of recognizing different population in a group of samples based on multi-element similarity."

In summary therefore, factor analysis creates a minimum number of new variables or objects which are linear combinations of the original variables such that the new variables or objects show inter-relations between the original variables without loosing the original amount of information.

One chief aim of the present study is to relate the geochemistry of the study area with its geology. As the relationship has to deal with multi-element (28 elements) variables instead of just a single variable or element, that
are statistically dependent to a greater or lesser extent, it is required to process the data such that statistically independent parameters can be generated. Thus, R-mode factor analysis was performed for the data set consisting of stream sediment samples chosen to reflect individual time-petrographic units, utilizing the SAS (Statistical Analysis System) program. This analysis was useful to establish the association of elements and to ascertain the inter-element relationships.

The ever increasing availability of computer programs and facilities leaves no question that a geologist can perform a factor analysis with little difficulty. Because of this ease, there is often a tendency to apply methods without fully understanding either the logic of the method or the more subtle question of what actually happens to the data at various stages during computation (Joreskog et.al., 1976). Thus the various stages that I went through are described below:

1. The geochemical variables were logarithmically transformed as they tend to be lognormally distributed as mentioned in the 'Transformation of Geochemical Variables' section. Based on the statistical parameters (skewness and kurtosis, table 5.5) computed, it can be seen that the data, after logarithmic transformation, showed a close
approximation to a normal distribution, although none of the transformed variables are perfectly normally distributed. Nevertheless, many of the variables showed a marked improvement in approximating a normal distribution.

2. The raw data matrix denoted by 'X' were standardized for individual observations and variables by subtracting the mean and dividing by their standard deviations using the equation $z_i = (x_i - x)/s_i$ before computing the similarity matrix, where,

- $z_i$ = standardized score for raw data,
- $x_i$ = the value for the $i$th variable,
- $x$ = the mean for the $i$th variable,
- $s_i$ = standard deviation for the $i$th variable.

3. Following standardization of the data set, a similarity matrix (Pearson's correlation coefficient matrix, PCCM) was used to establish the degree of the interrelation between the geochemical variables for each pair of variables. This matrix denoted by 'Z' is calculated from the standardized raw data matrix which makes the values for each observations unit free for the comparisons so that the intercorrelations between variables is not influenced by measurement units. Also, this matrix is sensitive to trends in abundances and thus is appropriate in the present case. The equation used
for obtaining the matrix of Pearson’s correlation coefficient is given below:

\[ r_{ij} = \frac{\text{COV}_{ij}}{s_i s_j} \]

where,
\[ r_{ij} \] = the correlation between the \( i \)th and \( j \)th variables,
\[ \text{COV}_{ij} \] = the covariance between the \( i \)th and \( j \)th variables,
\[ s_i \] = the standard deviation of the \( i \)th variable, and
\[ s_j \] = the standard deviation of the \( j \)th variable.

Theoretically, the correlation coefficient ranges from +1 to -1 with a correlation coefficient of +1 indicating a perfect direct relationship between two variables and a correlation of -1 indicating that one variable changes inversely in relation to the another. Between these two extreme relationships, there is a wide range of less-than perfect relationships. A correlation coefficient of zero indicates the lack of any linear relationship. The matrix of correlation coefficients is denoted by ‘\( R \)’.

4. The next step followed was the selection of the number of factors. In the practical application of factor analysis, one of the problem is to determine the correct number of factors to be used. In the present case, mainly based on the grouping of elements, a 6-factor model was selected. The appropriateness of the 6-factor model is described below in the section ‘Results and discussion’.
5. Next, the principle (unrotated) factor-patterns matrix was derived for the 6-factor model. This matrix expresses the contribution (or loading) of each element into each factor in a quantitative way and these loadings are derived from the eigenvectors which are computed in together with eigenvalues. The matrix of factor patterns or loadings 'A' is computed by using the relationship \( A = U \lambda^{0.5} \), where,

- \( A \) = the matrix of factor patterns or loadings,
- \( U \) = the matrix of eigenvectors for the similarity matrix \( R \),
- \( \lambda \) = the diagonal matrix of eigenvalues.

6. One of the chief aim of factor analysis is to display a clearer grouping of the raw variables into factors making them a tighter individual group, thus facilitating interpretation. Davis (1986) pointed out that:

"Although factor analysis may reduce the dimensionality of a problem to manageable size, the meaning of the factors may be difficult to deduce. Under factor theory, this may be the result of the fact that positions of the \( p \) orthogonal factor axes in \( m \) space are constrained by \( m-p \) unnecessary axes, which also must be placed orthogonally through the sample space. However, we need only \( p \) factor axes to explain our data. If we "chop off" the extraneous orthogonal axes, it seems possible to further rotate the factors and perhaps find a better position for them. This we can do by a variety of rotational procedures. The particular technique called Kaiser's varimax scheme, has as its objective the moving of each factor
axis to positions so that projections from each variable onto the factor axes are either near the extremities or near the origin. The method operates by adjusting the factor loadings so they are either near ± 1 or near zero. For each factor, there will be a few significantly high loadings and many insignificant loadings. Interpretation, in terms of original variables, is thus made easier. However, in certain instances rigid rotation of the factor axes will not improve the analysis, and may even confuse the results further. This may indicate that the factors are oblique, or intercorrelated, or it may imply that the factor model is inappropriate."

Thus, the rotation method known as the 'Varimax Rotation' is carried out which causes the rotation of orthogonal axes about the origin so that variance of loadings between each factor is a maximum and the varimax factor pattern is computed again.

7. The next step followed was the computation of factor scores for each sample. The log transformed original data were used in the computation of factor scores. In this R-mode factor analysis, the factors derived may be looked upon as a function of the original variables but as "new" variables created from the old ones. However, it is also important to find out the "amount" of this new variable or factor in each sample or object. Thus, the matrix of factor score is obtained by the following mathematical operation:

\[ Z = AF' \]
where,

\[ Z = \text{the similarity matrix, in the present case, the Pearson's correlation coefficient matrix,} \]

\[ A = \text{the matrix of factor patterns or loadings, and} \]

\[ F' = \text{the transpose of } F', \text{ and } F' \text{ is the matrix of factor scores.} \]

"The usefulness of factor scores can be appreciated by bearing in mind that there will, in general, be fewer factors than original variables. Hence, if the variables are mappable quantities, for example, mapping the derived factor scores will provide the same amount of information with fewer maps." (Joreskog et.al., 1976).

"Hence, in summary, a factor-score matrix, in the R-mode, is a condensed data matrix, the columns of which are linear combinations of the original variables and the rows are the original objects in the analysis (Joreskog et.al., 1976).

Results and Discussion:

The results obtained from the factor analysis of stream sediment analyses, for individual time-petrographic units is discussed in the following:

In the practical application of factor analysis, one of the problem is to determine the correct number of factors to be used to account for the data variability. This problem
is somewhat subjective and many suggestions for choosing the optimal number of factors have been suggested in interpreting the results of factor analysis. It has been suggested that while factoring a correlation matrix, only factors associated with eigenvalues greater than unity should be used. Some workers have recommended that the number of factors should be determined based on the proportion of the total variance explained. Using this procedure one of the useful way to start is to compute the cumulative percentage of total variance contribution by successive number of factors and to stop when this is sufficiently large, for example, larger than 75%, 90%, or 95%. The percentage selected usually depends on the nature of the data, i.e. the degree of collinearity and redundancy etc. Other researchers have used the pattern of the eigenvalues associated with the factors. For example, if there is a distinct break in the pattern of decreasing eigenvalues, only the factors associated with eigenvalues above the break would be used. As described above, the similarity matrix derived for the factoring of the geochemical variables is the Pearson’s correlation coefficient matrix (table 5.6). The lower half of the matrix contains the coefficients of correlation between the pairs of variables. The elemental associations are to be established based on the principal that any pair of elements in an association or coherent group should have a
significant high correlation coefficient. However, although most of the pair of elements in the elemental association show correlation coefficients greater than 0.50, some of the pairs have weaker correlation coefficients. It is to be noted that the possible elemental association of a group of elements as a factor can also be deduced from the factor loadings or patterns as the possible association of a group of elements should show the coherence of these elements in a p-dimensional space of the factors 1 to p. Thus the factor loadings (pattern) matrix derived by the method of varimax rotation, is presented in the table 5.7. And the plots of extracted factor pattern (figures 5.3, 5.4, and 5.5) were constructed.

Thus, in the present context, it appears desirable to employ a 6-factor model based on the criterion of using only factors associated with eigenvalues greater than unity and the criterion of a coherent group of elements, although the cumulative variance explained by a 6-factor model is only 66.57% (table 5.8).

Even the 7-factor model explains only 70% of the total cumulative variance in data space. However, when the 7-factor model was developed the only element that loads high on factor-7 was cadmium (table 5.10). So, 6-factor model is preferred here compared to the higher number factor model as
Table 5.6 Pearson’s correlation coefficient matrix showing correlation between geochemical variables.
### 6-factor model

<table>
<thead>
<tr>
<th>Variable</th>
<th>FACTOR1</th>
<th>FACTOR2</th>
<th>FACTOR3</th>
<th>FACTOR4</th>
<th>FACTOR5</th>
<th>FACTOR6</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>0.028</td>
<td>0.006</td>
<td>0.854</td>
<td>-0.066</td>
<td>0.039</td>
<td>-0.043</td>
</tr>
<tr>
<td>Sb</td>
<td>0.210</td>
<td>-0.183</td>
<td>0.762</td>
<td>0.195</td>
<td>-0.089</td>
<td>0.125</td>
</tr>
<tr>
<td>Bi</td>
<td>-0.202</td>
<td>0.520</td>
<td>0.486</td>
<td>-0.090</td>
<td>0.162</td>
<td>-0.022</td>
</tr>
<tr>
<td>Li</td>
<td>0.042</td>
<td>0.859</td>
<td>0.055</td>
<td>0.006</td>
<td>0.115</td>
<td>0.090</td>
</tr>
<tr>
<td>Na</td>
<td>0.020</td>
<td>0.733</td>
<td>-0.286</td>
<td>0.346</td>
<td>-0.082</td>
<td>0.061</td>
</tr>
<tr>
<td>Be</td>
<td>0.371</td>
<td>0.589</td>
<td>-0.077</td>
<td>0.207</td>
<td>0.280</td>
<td>0.078</td>
</tr>
<tr>
<td>Mg</td>
<td>0.678</td>
<td>0.010</td>
<td>0.233</td>
<td>0.387</td>
<td>-0.094</td>
<td>0.173</td>
</tr>
<tr>
<td>Ca</td>
<td>0.069</td>
<td>0.094</td>
<td>0.161</td>
<td>0.841</td>
<td>-0.022</td>
<td>0.216</td>
</tr>
<tr>
<td>Sr</td>
<td>0.268</td>
<td>0.300</td>
<td>-0.285</td>
<td>0.709</td>
<td>0.112</td>
<td>-0.007</td>
</tr>
<tr>
<td>Ba</td>
<td>0.695</td>
<td>-0.119</td>
<td>-0.047</td>
<td>0.220</td>
<td>0.074</td>
<td>-0.165</td>
</tr>
<tr>
<td>La</td>
<td>0.583</td>
<td>0.222</td>
<td>-0.397</td>
<td>0.351</td>
<td>0.180</td>
<td>-0.071</td>
</tr>
<tr>
<td>Ti</td>
<td>0.773</td>
<td>0.276</td>
<td>-0.217</td>
<td>-0.082</td>
<td>-0.005</td>
<td>0.065</td>
</tr>
<tr>
<td>V</td>
<td>0.865</td>
<td>0.201</td>
<td>0.170</td>
<td>0.072</td>
<td>-0.031</td>
<td>0.156</td>
</tr>
<tr>
<td>Cr</td>
<td>0.661</td>
<td>0.030</td>
<td>-0.057</td>
<td>0.111</td>
<td>0.061</td>
<td>0.035</td>
</tr>
<tr>
<td>Mo</td>
<td>0.147</td>
<td>0.076</td>
<td>0.052</td>
<td>0.157</td>
<td>0.296</td>
<td>0.752</td>
</tr>
<tr>
<td>W</td>
<td>0.125</td>
<td>0.015</td>
<td>0.033</td>
<td>0.082</td>
<td>-0.042</td>
<td>0.797</td>
</tr>
<tr>
<td>Mn</td>
<td>0.481</td>
<td>0.262</td>
<td>0.416</td>
<td>0.162</td>
<td>0.054</td>
<td>0.156</td>
</tr>
<tr>
<td>Fe</td>
<td>0.900</td>
<td>0.144</td>
<td>0.093</td>
<td>-0.052</td>
<td>-0.019</td>
<td>0.141</td>
</tr>
<tr>
<td>Co</td>
<td>0.526</td>
<td>0.163</td>
<td>-0.033</td>
<td>-0.031</td>
<td>0.391</td>
<td>0.094</td>
</tr>
<tr>
<td>Ni</td>
<td>0.666</td>
<td>0.109</td>
<td>0.035</td>
<td>-0.138</td>
<td>0.211</td>
<td>0.096</td>
</tr>
<tr>
<td>Cu</td>
<td>0.661</td>
<td>0.139</td>
<td>0.382</td>
<td>0.198</td>
<td>0.045</td>
<td>0.252</td>
</tr>
<tr>
<td>Ag</td>
<td>0.046</td>
<td>-0.034</td>
<td>-0.034</td>
<td>-0.044</td>
<td>0.858</td>
<td>0.077</td>
</tr>
<tr>
<td>Zn</td>
<td>0.517</td>
<td>0.271</td>
<td>0.297</td>
<td>0.155</td>
<td>-0.036</td>
<td>-0.121</td>
</tr>
<tr>
<td>Cd</td>
<td>0.077</td>
<td>0.056</td>
<td>0.026</td>
<td>0.223</td>
<td>0.582</td>
<td>-0.093</td>
</tr>
<tr>
<td>Al</td>
<td>0.397</td>
<td>0.797</td>
<td>0.019</td>
<td>0.078</td>
<td>0.096</td>
<td>0.056</td>
</tr>
<tr>
<td>Sn</td>
<td>0.042</td>
<td>0.235</td>
<td>0.056</td>
<td>-0.102</td>
<td>0.764</td>
<td>0.214</td>
</tr>
<tr>
<td>K</td>
<td>0.307</td>
<td>0.671</td>
<td>0.060</td>
<td>0.062</td>
<td>0.018</td>
<td>-0.088</td>
</tr>
<tr>
<td>Pb</td>
<td>0.013</td>
<td>0.069</td>
<td>0.536</td>
<td>0.650</td>
<td>0.077</td>
<td>0.094</td>
</tr>
</tbody>
</table>

Table-5.7 The factor loadings (patterns) derived by the method of varimax rotation.
Fig. 5.3. Plot of factor-1 versus factor-2 for multi-element stream sediment data for individual time-petrographic units.
Fig. 5.4. Plot of factor-3 versus factor-4 for multi-element stream sediment data for individual time-petrographic units.
Fig. 5.5. Plot of factor-5 versus factor-6 for multi-element stream sediment data for individual time-petrographic units.
the 6-factor model seems to be consistent with major lithological control, Pb-Zn mineralizations, probably Ag-Sn mineralizations.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Eigenvalue</th>
<th>Eigenvalue as percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.07</td>
<td>0.29</td>
</tr>
<tr>
<td>2</td>
<td>2.93</td>
<td>0.39</td>
</tr>
<tr>
<td>3</td>
<td>2.62</td>
<td>0.49</td>
</tr>
<tr>
<td>4</td>
<td>2.02</td>
<td>0.56</td>
</tr>
<tr>
<td>5</td>
<td>1.80</td>
<td>0.62</td>
</tr>
<tr>
<td>6</td>
<td>1.20</td>
<td>0.67</td>
</tr>
<tr>
<td>7</td>
<td>0.98</td>
<td>0.70</td>
</tr>
<tr>
<td>8</td>
<td>0.88</td>
<td>0.73</td>
</tr>
<tr>
<td>9</td>
<td>0.80</td>
<td>0.76</td>
</tr>
<tr>
<td>10</td>
<td>0.67</td>
<td>0.78</td>
</tr>
<tr>
<td>11</td>
<td>0.66</td>
<td>0.81</td>
</tr>
<tr>
<td>12</td>
<td>0.60</td>
<td>0.83</td>
</tr>
<tr>
<td>13</td>
<td>0.50</td>
<td>0.85</td>
</tr>
<tr>
<td>14</td>
<td>0.47</td>
<td>0.86</td>
</tr>
<tr>
<td>15</td>
<td>0.44</td>
<td>0.88</td>
</tr>
<tr>
<td>16</td>
<td>0.42</td>
<td>0.90</td>
</tr>
<tr>
<td>17</td>
<td>0.38</td>
<td>0.91</td>
</tr>
<tr>
<td>18</td>
<td>0.36</td>
<td>0.92</td>
</tr>
<tr>
<td>19</td>
<td>0.33</td>
<td>0.93</td>
</tr>
<tr>
<td>20</td>
<td>0.32</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Table-5.8. Eigenvalues for the individual factors
Hence, based on the rotated factor loadings matrix (table 5.7) and the correlation coefficients between the elements (table 5.6), the 6-factor model is chosen, and elemental associations (table 5.9) for the area of study established as below:

<table>
<thead>
<tr>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1: Mg, Ba, La, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn</td>
</tr>
<tr>
<td>- 2: Li, Na, K, Be, Al</td>
</tr>
<tr>
<td>- 3: As, Sb, Bi, Pb</td>
</tr>
<tr>
<td>- 4: Ca, Mg, Sr, Pb</td>
</tr>
<tr>
<td>- 5: Ag, Sn, Cd</td>
</tr>
<tr>
<td>- 6: Mo, W</td>
</tr>
</tbody>
</table>

Table 5.9. Elemental Association
### 7-factor model

<table>
<thead>
<tr>
<th>Variable</th>
<th>FACTOR1</th>
<th>FACTOR2</th>
<th>FACTOR3</th>
<th>FACTOR4</th>
<th>FACTOR5</th>
<th>FACTOR6</th>
<th>FACTOR7</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>0.028</td>
<td>0.006</td>
<td>0.054</td>
<td>-0.066</td>
<td>0.039</td>
<td>-0.043</td>
<td>0.010</td>
</tr>
<tr>
<td>Sb</td>
<td>0.208</td>
<td>-0.174</td>
<td>0.758</td>
<td>0.213</td>
<td>-0.077</td>
<td>0.123</td>
<td>-0.080</td>
</tr>
<tr>
<td>Bi</td>
<td>-0.194</td>
<td>0.491</td>
<td>0.491</td>
<td>-0.094</td>
<td>0.105</td>
<td>-0.019</td>
<td>0.326</td>
</tr>
<tr>
<td>Li</td>
<td>0.025</td>
<td>0.866</td>
<td>0.054</td>
<td>0.012</td>
<td>0.124</td>
<td>0.084</td>
<td>-0.012</td>
</tr>
<tr>
<td>Na</td>
<td>0.026</td>
<td>0.716</td>
<td>-0.291</td>
<td>0.312</td>
<td>-0.144</td>
<td>0.096</td>
<td>0.239</td>
</tr>
<tr>
<td>Be</td>
<td>0.358</td>
<td>0.604</td>
<td>-0.082</td>
<td>0.219</td>
<td>0.279</td>
<td>0.057</td>
<td>-0.010</td>
</tr>
<tr>
<td>Mg</td>
<td>0.678</td>
<td>0.026</td>
<td>0.227</td>
<td>0.387</td>
<td>-0.096</td>
<td>0.169</td>
<td>-0.055</td>
</tr>
<tr>
<td>Ca</td>
<td>0.076</td>
<td>0.094</td>
<td>0.143</td>
<td>0.835</td>
<td>-0.075</td>
<td>0.217</td>
<td>0.106</td>
</tr>
<tr>
<td>Sr</td>
<td>0.273</td>
<td>0.303</td>
<td>-0.299</td>
<td>0.697</td>
<td>0.050</td>
<td>-0.013</td>
<td>0.131</td>
</tr>
<tr>
<td>Ba</td>
<td>0.686</td>
<td>-0.092</td>
<td>-0.052</td>
<td>0.231</td>
<td>0.082</td>
<td>-0.182</td>
<td>-0.155</td>
</tr>
<tr>
<td>La</td>
<td>0.578</td>
<td>0.240</td>
<td>-0.404</td>
<td>0.350</td>
<td>0.162</td>
<td>-0.088</td>
<td>-0.018</td>
</tr>
<tr>
<td>Ti</td>
<td>0.787</td>
<td>0.284</td>
<td>-0.208</td>
<td>-0.113</td>
<td>-0.046</td>
<td>0.068</td>
<td>0.238</td>
</tr>
<tr>
<td>v</td>
<td>0.866</td>
<td>0.210</td>
<td>0.173</td>
<td>0.066</td>
<td>-0.033</td>
<td>0.151</td>
<td>0.027</td>
</tr>
<tr>
<td>Cr</td>
<td>0.663</td>
<td>0.040</td>
<td>-0.057</td>
<td>0.108</td>
<td>0.054</td>
<td>0.025</td>
<td>0.011</td>
</tr>
<tr>
<td>Mo</td>
<td>0.138</td>
<td>0.099</td>
<td>0.046</td>
<td>0.195</td>
<td>0.374</td>
<td>0.723</td>
<td>-0.183</td>
</tr>
<tr>
<td>W</td>
<td>0.138</td>
<td>0.007</td>
<td>0.035</td>
<td>0.078</td>
<td>-0.011</td>
<td>0.799</td>
<td>0.065</td>
</tr>
<tr>
<td>Mn</td>
<td>0.497</td>
<td>0.243</td>
<td>0.419</td>
<td>0.147</td>
<td>-0.005</td>
<td>0.157</td>
<td>0.304</td>
</tr>
<tr>
<td>Fe</td>
<td>0.906</td>
<td>0.146</td>
<td>0.100</td>
<td>-0.065</td>
<td>-0.028</td>
<td>0.137</td>
<td>0.092</td>
</tr>
<tr>
<td>Co</td>
<td>0.521</td>
<td>0.178</td>
<td>-0.032</td>
<td>-0.009</td>
<td>0.403</td>
<td>0.064</td>
<td>-0.003</td>
</tr>
<tr>
<td>Ni</td>
<td>0.651</td>
<td>0.138</td>
<td>0.037</td>
<td>-0.113</td>
<td>0.264</td>
<td>0.070</td>
<td>-0.193</td>
</tr>
<tr>
<td>Cu</td>
<td>0.668</td>
<td>0.140</td>
<td>0.382</td>
<td>0.198</td>
<td>0.029</td>
<td>0.246</td>
<td>-0.100</td>
</tr>
<tr>
<td>Ag</td>
<td>0.042</td>
<td>-0.024</td>
<td>-0.036</td>
<td>0.007</td>
<td>0.867</td>
<td>0.021</td>
<td>0.060</td>
</tr>
<tr>
<td>Zn</td>
<td>0.487</td>
<td>0.314</td>
<td>0.289</td>
<td>0.183</td>
<td>0.019</td>
<td>-0.135</td>
<td>-0.365</td>
</tr>
<tr>
<td>Cd</td>
<td>0.111</td>
<td>0.013</td>
<td>0.026</td>
<td>0.211</td>
<td>0.451</td>
<td>-0.112</td>
<td>0.624</td>
</tr>
<tr>
<td>Al</td>
<td>0.385</td>
<td>0.805</td>
<td>0.019</td>
<td>0.076</td>
<td>0.089</td>
<td>0.050</td>
<td>0.034</td>
</tr>
<tr>
<td>Sn</td>
<td>0.037</td>
<td>0.239</td>
<td>0.056</td>
<td>-0.058</td>
<td>0.775</td>
<td>0.167</td>
<td>0.098</td>
</tr>
<tr>
<td>K</td>
<td>0.282</td>
<td>0.697</td>
<td>0.056</td>
<td>0.073</td>
<td>0.045</td>
<td>-0.096</td>
<td>-0.184</td>
</tr>
<tr>
<td>Pb</td>
<td>0.002</td>
<td>0.111</td>
<td>0.516</td>
<td>0.679</td>
<td>0.078</td>
<td>0.081</td>
<td>-0.141</td>
</tr>
</tbody>
</table>

Table 5.10 The factor loadings (patterns) derived by the method of varimax rotation.
The 6-factor model thus defined elemental associations or inter-element relationships based on the geochemistry of individual time-petrographic units. The grouping of 28 elements into 6 groups or associations is a very useful phenomena in both the interpretation of the multi-element geochemical data and to show the relation between the geology and geochemistry of the study area, which will be described in the next section.

For the purpose of reference and comparison in the present study, some common geochemical associations of elements as described by Rose et al. (1977) are presented in the table 5.11.

<table>
<thead>
<tr>
<th>Group</th>
<th>Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally associated</td>
<td>K-Rb</td>
</tr>
<tr>
<td>elements</td>
<td>Ca-Sr</td>
</tr>
<tr>
<td></td>
<td>Al-Ga</td>
</tr>
<tr>
<td></td>
<td>Si-Ge</td>
</tr>
<tr>
<td></td>
<td>Zr-Hf</td>
</tr>
<tr>
<td></td>
<td>Nb-Ta</td>
</tr>
<tr>
<td></td>
<td>Rare earths, La, Y</td>
</tr>
<tr>
<td></td>
<td>Pt-Ru-Rh-Pd-Os-Ir</td>
</tr>
</tbody>
</table>

Table 5.11. Some common geochemical associations of elements (after Rose, Hawkes and Webb, 1977)
(table 5.11. contd.)

<table>
<thead>
<tr>
<th>Plutonic rocks</th>
<th>General association</th>
<th>Specific associations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Si-Al-Fe-Mg-Ca-Na-K-Ti-Mn-Zr</td>
<td>Felsic igneous rocks: Si-K-Na</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alkaline igneous rocks: Al-Na-Zr-Ti-Nb-Ta-F-P-rare earths</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mafic igneous rocks: Fe-Mg-Ti-V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ultramafic rocks: Mg-Fe-Cr-Ni-Co</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some pegmatitic differentiates: Li-Be-B-Rb-Cs-rare earths-Nb-Ta-U-Th</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some contact metasomatic deposits: Mo-W-Sn</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Potash feldspars: K-Ba-Pb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Many other potash minerals: K-Na-Rb-Cs-Tl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ferromagnesian minerals: Fe-Mg-Mn-Cu-Zn-Co-Ni</td>
</tr>
<tr>
<td>Sedimentary rocks</td>
<td>Fe-oxides: Fe-As-Co-Ni-Se</td>
<td>Mn-oxides: Mn-As-Ba-Co-Mo-Ni-V-Zn</td>
</tr>
<tr>
<td></td>
<td>Phosphorite: P-Ag-Mo-Pb-F-U</td>
<td>Black shales: Al-Ag-As-Au-Bi-Cd-Mo-Ni-Pb-Sb-V-Zn</td>
</tr>
</tbody>
</table>
Thus, the 6-major elemental associations (table-5.9) established above, based on the correlation coefficients (table-5.6) and varimax factor loadings (table-5.7 and figs. 5.3, 5.4, and 5.5), can be broadly related to following geological phenomenon:

(1) Factor-1 which is the association of Mg, Ba, La, Ti, V, Mn, Cr, Fe, Co, Ni, Cu, and Zn seems to be related to mafic and ultramafic units such as basic intrusives of metagabbro, metadiabase and amphibolite, and to other certain mixed lithologies of metasediments. Most of the elements associated with each other, constituting the factor-1, are mafic elements with some chalcophile affinity and may be derived from ferromagnesian minerals like olivine, chromite, ilmenite etc. (2) Factor-2 consists of the elements Li, Na, K, Be, and Al. This elemental association is mainly an association of felsic and alkaline elements, with a lithophile affinity, related to acidic intrusives such as granitic bodies and pegmatites. (3) Factor-3 consists of As, Sb, Bi and Pb indicative of a sulfide mineralization and probably derived from arsenopyrite, galena and possibly sphalerite. (4) Factor-4 is composed of the elements Ca, Mg, Sr, and Pb. This elemental association is basically an association of elements derived from limestones and dolomites with an association of element Sr with Ca being a common phenomena as they have very similar ionic radii. The association of the element Pb could be due to Pb-Zn
mineralization in the carbonatic rocks, although Zn does not show its relation to the factor-4, plot of anomalous samples of Pb and Zn occur together. Thus, this elemental association can be related to the carbonate group associated with Pb-Zn mineralization. (5) Factor-5 defined as an elemental association of Ag, Sn, and Cd. Although if the 7-factor model is chosen, Cd will constitute a separate factor by itself, however, Cd almost always appear to occur with Ag in the present area of study. Thus Cd is included in this association with Ag and Sn although known Ag and Sn mineralizations are generally low in Cd. This association could be related to Ag and Sn mineralizations in black shales or Sn placers. It is to be mentioned that the geochemical behavior of Cd is not very well understood. (6) The factor-6 association of Mo and W is a grouping known to occur together and is interpreted to be related to the contact metasomatic deposits associated with granitic intrusives as concentrations of W are unambiguously linked to igneous process and most major ore deposits are associated with granitic rocks (Wedepohl et.al., 1977). Moreover, these two elements also have similar ionic radii of 0.42 Å and 0.41 Å respectively resulting into similar geochemical behavior.

Since the primary purpose of the factor analysis in this section is to demonstrate the relationship of
geochemistry and geology in the study area, contour maps of factor scores for each elemental associations are shown in figures 5.6 to 5.39. The contour maps are prepared in a series of 15'-quadrangles at the scale of 1:250,000 in order that it can be directly compared with the geological map of the area on that scale.

Factor-1 (Mg, Ba, La, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn)

Factor-1 is basically a mixed group with lithophile, siderophile and some chalcophile elements. However, the associated elements show that they are predominantly a mafic elements grouping. High positive scores for this factor occur over the areas underlain with basic rocks such as metagabbro, metadiabase, and amphibolites and show a high positive scores with phyllites of the Kuncha Formation, other phyllitic time-petrographic units containing amphibolite layers and the Fagfog Quartzites. Factor-1 has negative scores over the granitic area.

As a general rule therefore this factor is related to mafic rocks in association with metasediments especially lowgrade phyllites.

For example, in toposheet no. 72A/9 (fig. 5.6 and plate-1), grids 1092, 1095, and 1098, which are dominantly
Fig. 5.6. Contour plot of factor scores of factor-1 for the area in toposheet no. 72A/9.
comprised of the Kuncha Phyllites and Fagfog Quartzites, show a very high positive score of factor-1. Also, the grid 1099 shows a high positive value which may be related to the basic intrusives of the area. This kind of relation between the factor-1 and the lithology described is valid for grids 1112 and 1135 (fig. 5.7 and plate-1). However, grids 1133, 1136, and 1139 with very mixed lithology show high negative scores.

The factor-1 shows high negative scores at the center of the Palung and Agra granitic bodies in toposheet no.72A/14 with scores increasing outward from the center of the granitic body (fig. 5.8 and plate-1). Conversely, factor-1 shows a marked positive value in this area with basic intrusives as well as positive score in the grid 1142 which is dominantly carbonates of the Jhiku Beds and Malekhu Limestone but also consisted of Benighat Slates, Raduwa Schist and Kalitar Schist. It also shows a slightly high positive scores in the grid 1144 area covered by schists of the Kulikhani Formation and Tistung Phyllites.

Similar results for Factor-1 are obtained in the toposheet no.72 E/1, E/6 and E/7. In toposheet no.72E/1 (fig. 5.9), the high positive score for the factor-1 occur over the area overlain by mainly the Kuncha Phyllites and basic intrusive rocks. For example, in the grid 5012, the
Fig. 5.7. Contour plot of factor scores of factor-1 for the area in toposheet no. 72A/13.
Fig. 5.8. Contour plot of factor scores of factor-1 for the area in toposheet no. 72A/14.
Fig. 5.9. Contour plot of factor scores of factor-1 for the area in toposheet no. 72E/1.
occurrence of positive score for the factor-1 coincides with the area underlain by the Kuncha Phyllites, other metasediments and some basic intrusives. Negative score occurs over the area underlain by granitic gneisses, augen gneisses and undifferentiated schist with granitic and pegmatitic dyke-swarms. Sample density in the toposheet no.72E/6 is low. However based on the few available samples, it still shows positive values for the factor-1 scores related to the phyllites of the Tistung Formation (fig. 5.10). Negative scores are obtained in the area around the Narayanthan granite, while positive scores occur in the area covered with schists of the Kulikhani Formation. In toposheet no.72 E/7, the positive scores for the factor-1 occur over the area underlain dominantly by metasediments such as the Markhu Formation, Kulikhani Schist, Bhainsedobhan Marble, Benighat Slates with the Jhiku Beds, Raduwa Schist and a very minor portion of Arkhaule Granite as shown in the grid 5071 (fig. 5.11). In the grid 5077, the negative score occurs around the Narayanthan Granite, whereas positive factor score occurs over the area underlain by the metasediments. Additionally a small zone of positive score, occurring over the granitic area in the grid 5077, seems to be misleading as it is part of the high positive score related to the metasediments (fig. 5.11).
Fig. 5.10. Contour plot of factor scores of factor-1 for the area in toposheet no.72E/6.
Fig. 5.11. Contour plot of factor scores for factor-1 for the area in toposheet no. 72E/7.
Thus in general, it can be inferred that this factor is positively correlated with argillaceous metasediments and basic or mafic intrusives and shows a negative correlation with felsic intrusives.

**Factor-2 (Li,Na,K,Al,Be,Bi)**

Factor-2 essentially shows a negative relationship to factor-1 and is related to felsic and alkaline igneous rocks such as granitic intrusives and pegmatites.

The contour maps of factor-2 (fig. 5.12) scores show a very strong affinity with granitic bodies and to a lesser extent with phyllites of the Nourpul Formation. As can be seen from the contour map of the factor-2 scores for the toposheet no. 72A/9, negative scores occur over most of the area occupied by the green phyllites of the Kuncha Formation except for two small areas of positive values which occur over the area covered with Nourpul and Dandagaon Phyllites. The relation of factor-2 to felsic rocks is also demonstrated in toposheet no. 72A/13. For example, the low positive score occurring in the southern part of grid 1133, 1136 and 1139 seems to be related to the granitic gneisses in these grids and also to the Agra Granitic body occurring just at the southern border of this area (fig. 5.13). The negative factor score in the northern part of the area in
Fig. 5.12. Contour plot of factor scores of factor-2 for the area in toposheet no. 72A/9.
Fig. 5.13. Contour plot of factor scores of factor-2 for the area in toposheet no.72A/13.
toposheet no. 72 A/13 occur over the area mainly overlain by metasediments such as the Kuncha Phyllites, Fagfog Quartzites, Dandagaon Phyllites, Nourpul Formation and Dhading Dolomites. The high positive scores of factor-2 more or less follow the outline of the Agra and Palung Granites in toposheet no. 72A/14 (fig. 5.14). Scores decrease outward from the center of these granitic intrusives.

In toposheet no. 72E/1, similar high positive scores occur over the area covered with augen gneiss and schistose areas with pegmatite veins (fig. 5.15). The sample density in toposheet no. 72E/6 is very low and not much inference can be deduced except for the grid 5069, where a positive score occurs near the Narayanthan Granite and over the area with phyllites of the Tistung Formation (fig. 5.16). It shows negative scores in the area overlain by Chandragiri Limestone which is more closely related to the factor-3 which shall be shown later.

The clear association of Factor-2 with felsic rocks (granitic rocks) is also well demonstrated in the grid 5071 of toposheet no. 72E/7 where a small portion of Arkhaule Granite occurs and in grids 5074 and 5077, where much of the area is underlain by the Narayanthan Granite (fig. 5.17). For example, in the grid 5071, a high positive score occurs
Fig. 5.14. Contour plot of factor scores of factor-2
for the area in toposheet no. 72A/14.
Fig. 5.15. Contour plot of factor scores of factor-2 for the area in toposheet no. 72E/1.
Fig. 5.16. Contour plot of factor scores of factor-2 for the area in toposheet no.72E/6.
Fig. 5.17. Contour plot of factor scores of factor-2 for the area in toposheet no.72E/7.
following the outline of the Arkhaule Granite and a negative score occurs away from the granitic area in areas underlain by other time-petrographic units such as Kulikhani Schist, Markhu Schist and Markhu Marble. Similarly, high positive scores occur over the area of the Narayanthan Granite in grids 5074 and 5077 but the score is low in the area overlain by the Kulikhani Schist and Markhu Marble between the Arkhaule and Narayanthan granitic bodies as can be observed in the grid 5074.

Hence it can be concluded that the factor-2 is clearly related to the granitic intrusives and pegmatites.

Factor-3 (As, Sb, Bi, Pb)

Factor-3 is comprised mainly of chalcophile elements such as As, Sb, Pb, and Zn. The correlation coefficient between the elements As-Sb is 0.57 and that between Pb-Sb is 0.48. However, Zn shows very low correlation with the elements like As and Sb. So this factor is mainly constituted of As, Sb, and Pb and as shown in the following paragraphs, mainly related to base-metal mineralization.

In the toposheet no.72A/9, factor-3 scores show a positive values in the areas underlain by the Benighat Slates, its Jhiku Carbonate Beds and a small band of the
Malekhu Limestone. Generally negative values occur in the area underlain by the Kuncha Phyllites (fig. 5.18).

In toposheet no. 72A/13, the sample density is low and the result obtained showed negative scores over much of the area except for a low positive score in grids 1132 and 1135. The positive score in the grid 1135 roughly follows the Dhading Dolomite while the rest of the area with negative scores is mainly underlain with schists, quartzites, and basic intrusives with minor carbonates (fig. 5.19).

In the toposheet area 72 A/14, factor-3 occurs mainly with Pb-Zn bearing carbonate beds and to a lesser extent with areas underlain by schistose rocks (fig. 5.20). Areas of high factor-3 scores coincide with the known Pb-Zn mineralized areas, for example as in Labang-Khairang area in the grid 1144, proving that this factor is related to the base-metal mineralization. Factor-3 scores are negative around the Agra Granite body but show positive value around the Palung Granite body.

Factor-3 has a high positive score along the marble band of the Markhu Formation in the toposheet no.72A/14 and this marble band is associated with proven carbonate hosted Pb-Zn mineralization. High positive scores also occur along a NW-SE general trend in grids 1142, 1145, 1146 and 1149.
Fig. 5.18. Contour plot of factor scores of factor-3 for the area in toposheet no. 72A/9.
Fig. 5.19. Contour plot of factor scores of factor-3 for the area in toposheet no.72A/13.
Fig. 5.20. Contour plot of factor scores of factor-3 for the area in toposheet no. 72A/14.
along the areas covered with the Benighat Slates, Jhiku Carbonate Beds, and the Malekhu Limestone. Low positive scores occur in the area underlain by the Bhainsedobhan Marble (fig. 5.20).

Factor-3 scores for toposheet no.72E/1 show negative scores for the entire area except for a small area between grids 5012 and 5013 underlain by carbonates of the Dhading Dolomite, Malekhu Limestone, and Benighat Slates. Although, there is a small band of the Markhu Formation in the grid 5019, this factor shows a low negative score. High negative scores occur in areas underlain by metamorphic gneisses and schists (fig. 5.21).

There are few samples available in the toposheet no.72E/6. However, based on the limited information available, the relation of factor-3 with the Pb-Zn mineralized carbonates of the Chandragiri Limestone can be deduced. For example, the factor-3 showed high positive scores over the area covered with the Chandragiri Limestone in grid 5069, a slightly high positive score in the area between 5065 and 5066 and also in the grid 5062 (fig. 5.22). In general, the high positive score for factor-3 follows the NW-SE trend of the Chandragiri Limestone and the Chitlang Slates, Silurian Limestone and Quartzite Beds of Phulchauki, and Devonian Limestone of Phulchauki. In the grid 5071 of
Fig. 5.21. Contour plot of factor scores of factor-3 for the area in toposheet no.72E/1.
Fig. 5.22. Contour plot of factor scores of factor-3 for the area in toposheet no. 72E/6.
toposheet no. 72E/7, high positive scores occur as the grid is mainly underlain by the carbonates of the Markhu Formation, Jhiku Carbonate Beds and Bhainsedobhan Marble (fig. 5.23). Similarly, high positive scores occur around the areas of contact of the Markhu Formation and the Narayanthan Granite in grids 5074 and 5077, showing its relation to carbonates with possible Pb-Zn mineralization.

Thus, it can be stated that factor-3 is defined mainly by Pb and Zn mineralized areas hosted by carbonate rocks in the study area and to a lesser extent related with slates or shales.

Factor-4 (Ca, Sr, Mg, Pb)

Factor-4 consists of Ca, Sr, Mg, and Pb and can be related to carbonates such as limestones and dolomites with galena mineralization in the study area. The correlation coefficients between the pairs Ca and Sr, Ca and Mg, and Ca and Pb are 0.53, 0.49 and 0.55 respectively. However, the correlation between the pairs Mg-Sr, Mg-Pb and Sr-Pb all are weak with the coefficients of correlation of 0.33.

In toposheet no. 72A/9, a contour map of factor scores for factor-4 shows positive values in areas underlain dominantly with carbonates such as the Malekhu Limestones,
Fig. 5.23. Contour plot of factor scores of factor-3 for the area in toposheet no.72E/7.
Jhiku Carbonate Beds of the Benighat Slates, and Dhading Dolomites in grids 1093, 1096, and 1099 (fig. 5.24). Phyllites of the Kuncha Formation show mainly negative or low scores throughout other areas except for the grid 1091. Similar results are obtained in toposheet no. 72A/13 (fig. 5.25) where positive scores occur in areas underlain by carbonates and to a lesser extent calcareous schists. Negative scores occur in grids 1132 and 1135, which are underlain by the Kuncha Phyllites and Fagfog Quartzites. Similarly in the grid 1138, a positive value is also obtained over the area underlain by the Dhading Dolomite which is flanked by the Kuncha Phyllites forming a monoclinal structure and negative scores over the Kuncha Phyllite flanks.

The association of this factor-4 with carbonates is well illustrated in the area of toposheet no. 72A/14 (fig. 5.26), where high positive scores coincide with bands of the Markhu Marble, Bhainsedobhan Marble, and Malekhu Limestone. Low or negative scores generally occur over areas underlain with granites, schists or slates. For example, high positive values in grids 1141 and 1142 follow the general NW-SE trend of the Markhu Formation. In toposheet no. 72E/1 (fig. 5.27), high positive scores occur over the calc-schists and metamorphic gneisses and in toposheet no. 72E/6 (fig. 5.28) area, with the Chandragiri Limestone.
Fig. 5.24. Contour plot of factor scores of factor-4 for the area in toposheet no. 72A/9.
Fig. 5.25. Contour plot of factor scores of factor-4 for the area in toposheet no. 72A/13.
Fig. 5.26. Contour plot of factor scores of factor-4 for the area in toposheet no. 72A/14.
Fig. 5.27. Contour plot of factor scores of factor-4 for the area in toposheet no.72E/1.
Fig. 5.28. Contour plot of factor scores of factor-4 for the area in toposheet no.72E/6.
Similarly, in toposheet no. 72E/7 (fig. 5.29), high positive scores for factor-4 occur over areas of the Markhu Marble and Jhiku Carbonate Beds in the grid 5071 and the NW-SE trending Bhainsedobhan Marble. In grids 5074 and 5077, factor-4 shows high positive scores over areas underlain by the marble of the Markhu Formation. Low or negative scores occur in association with the Narayanthan and Arkhaule Granites and over the Siwaliks Group, south of the Main Boundary Thrust.

Hence, it can be concluded that this association of elements is defined by carbonate rocks of different time-petrographic units such as the Jhiku Carbonate Beds, Malekhu Limestone, Bhainsedobhan Marble, Markhu Marble, and Chandragiri Limestone.

Factor-5 (Ag, Sn, Cd)

Factor-5 consists of elements such as Ag and Sn. The correlation coefficient between Ag and Sn is 0.63 whereas Cd shows weak correlation with Ag (0.31) and Sn (0.28) as discussed previously.

Factor-5 does not characteristically exhibit as definite a pattern as other factors. Normally the high positive scores of factor-5 occur in areas underlain by the...
Fig. 5.29. Contour plot of factor scores of factor-4 for the area in toposheet no. 72E/7.
Kuncha Phyllites but low or negative scores are noted within areas of the Kuncha Phyllites as well. In grids 1091, 1094, 1095 and 1097 in toposheet no. 72A/9 (fig. 5.30), for example, high positive scores occur over the Kuncha Phyllites and in the grid 1096, high positive scores occur with areas of Nourpul Phyllite, Dhading Dolomite, and Benighat Slate. Factor-5 again shows positive value with Kuncha Phyllites in grids 1132 and 1135 (fig. 5.31). In toposheet no. 72A/14 (fig. 5.32), factor-5 shows high values in association with the Benighat Slates and Malekhu Limestone in the grid 1142. In grids 1146 and 1149, positive values occur with metasediments such as Benighat Slate, Malekhu Limestone and Raduwa Schist which were intruded by basic intrusives. Factor-5 also shows positive values within the Agra Granite in the grid 1144, and in some portion of the area covered by the Palung Granite and along its contact boundary with the Kulikhani Schist in the grids 1145 and 1148. In toposheet no. 72E/1 (fig. 5.33), high positive scores for factor-5 occur over areas underlain by augen or banded gneisses and also over the undifferentiated schists, quartzite and calcsilicate rocks of Bhimpedi Group and Tistung Formation (with various stages of migmatization) and with pegmatitic dyke-swarms especially in grids 5013 and 5019. In general, factor-5 scores over areas in toposheet no. 72E/6 (fig. 5.34), which is mostly covered by alluvium or underlain by sediments of the Kathmandu Complex are
Fig. 5.30. Contour plot of factor scores of factor-5 for the area in toposheet no. 72A/9.
Fig. 5.31. Contour plot of factor scores of factor-5 for the area in toposheet no. 72A/13.
Fig. 5.32. Contour plot of factor scores of factor-5 for the area in toposheet no. 72A/14.
Fig. 5.33. Contour plot of factor scores of factor-5 for the area in toposheet no.72E/1.
Fig. 5.34. Contour plot of factor scores of factor-5 for the area in toposheet no.72E/6.
negative. However, it is important to note that much of the area in this toposheet lacks sufficient information to infer any firm conclusion. In toposheet no. 72E/7 (fig. 5.35), factor-5 scores are positive over areas covered with Arkhaule and Narayanthan Granites as shown in grids 5071, 5074, and 5077, and also in the grid 5078 over the schist and marble of the lower Bhimphedi Group. A small high positive value is also noted over the Siwaliks Group in the grid 5072.

Factor-5 shows a broad distribution with its association with different time-petrographic units and thus its occurrence in the study area could be related to different phenomenon. For example, the association of factor-5 with the Kuncha Phyllites may be caused by Sn-placers in these reworked sediments. The Arkhaule and Narayanthan Granites could be productive granite with Ag-Sn mineralization as Sn is typically found concentrated in biotites. The same is true for the Agra and Palung Granites in contact with the Kulikhani Schist or it may also be due to Sn-greisen associated with it.
Fig. 5.35. Contour plot of factor scores of factor-5 for the area in toposheet no. 72E/7.
Factor-6 (Mo,W)

The factor-6 is an association of two elements: Mo and W. Most of the samples showed these elements below detection limits or have missing values for these elements. Even with this limited information, based on the factor loadings of Mo and W on the factor-6, it is noted that the grouping or association of these two elements as a separate factor is valid although they have a weak correlation coefficient of 0.43. As shown in the table 5.11, the association of Mo-W may be related to contact metasomatic deposits along the boundaries or margins of granite intrusives. Also, in terms of geochemical behavior the closest relative of W is Mo.

Inspection of the contour maps of the factor-6 scores show that, in general, this factor has high positive scores along the boundaries of the granitic intrusives and over the metasediments of the Nawakot Complex. For example in toposheet no. 72A/9 (fig. 5.36), factor-6 has positive values in grids 1092, 1095, and 1098, areas covered with metasediments such as the Kuncha Phyllites and Fagfog Quartzites while in the grid 1099, high positive scores occur over the areas covered with the Benighat Slates and Jhiku Carbonate Beds. A similar relationship is observed in
Fig. 5.36. Contour plot of factor scores of factor-6 for the area in toposheet no.72A/9.
the grid 1135 (fig. 5.37) over the areas covered by the Runcha Phyllites and Fagfog Quartzites.

Factor-6 also shows positive values over the areas underlain by metasediments like the Tistung Phyllite, Markhu Marble and Kulikhani Schist units occurring in contact with and within the Agra granitic intrusive. In toposheet no. 72A/14 (fig. 5.38), factor-6 is clearly related to both granite intrusives and granitic boundaries. For example, the factor-6 has shown high positive scores along the southern part of the Agra Granitic Body which is in contact with metasediments such as the Tistung Phyllites, Markhu Marble or Markhu Schist. Similarly, it shows high positive values over the Palung Granitic intrusive and along its contact with metasediments of the Kathmandu complex. In grids 1145 and 1148, high positive scores occur both over the Palung granitic body and along its northern and southern contacts with the Kulikhani Schist and the Kalitar Schist respectively. High positive values follow the NW-SE trend in areas covered with the dark Benighat Slates, Jhiku Carbonate Beds and Malekhu Limestone of the Nawakot Complex in grids 1142, 1145 and 1146. In toposheet no. 72E/1 (fig. 5.39), factor-6 shows positive values over the gneissic zone and along its contact with the Kalitar Schist while in toposheet no. 72E/7 (fig. 5.40), in the grid 5077, a high positive score occurs within the Narayanthan Granitic
Fig. 5.37. Contour plot of factor scores of factor-6 for the area in toposheet no. 72A/13.
Fig. 5.38. Contour plot of factor scores of factor-6 for the area in toposheet no. 72A/14.
Fig. 5.39. Contour plot of factor scores of factor-6 for the area in toposheet no. 72E/1.
Fig. 5.40. Contour plot of factor scores of factor-6 for the area in toposheet no. 72E/7.
Intrusive and along its contact with metasediments at its northern and southern boundary. In toposheet no. 72E/6 (fig. 5.41), factor-6's score is generally low or negative as much of the area is covered by alluvium or underlain by sedimentary rocks of the Kathmandu Complex.

Thus, it can be concluded that the factor-6 is developed in association with granitic and or gneissic contact zones with metasediments of the Kathmandu Complex. Also, it has shown some affinity to the black shales or slates of the Benighat Slates with Jhiku Carbonate Beds, Kuncha Phyllites and Fagfog Quartzites.
Fig. 5.41 Contour plot of factor scores of factor-6 for the area in toposheet no. 72E/6.
CHAPTER VI
GEOCHEMICAL ANOMALIES

The main objectives of the present study are to (a) define significant geochemical anomalies which may be related to mineral zones, occurrences and deposits and (b) based on these identified mineralized areas, classify the type of deposits which might occur and (c) develop mineral deposit models for the study area, for use in future exploration. Therefore this chapter focuses on how anomalous samples and areas are identified, whether such areas are geochemically meaningful or not with respect to mineralizations. Subsequently there will be a discussion of how R-mode factor analysis is utilized to delineate the anomalous areas or zones with respect to the association of elements as defined in the previous chapter. The purpose of using the R-mode factor analysis is also to demonstrate advantages of this technique over the basic statistical technique although similar results can be obtained from both techniques.

Geochemical Anomalies with 95% confidence level:

Central to geochemical exploration is the concept of defining an abnormal chemical distribution i.e. a geochemical anomaly, which may be related to mineralization. Different methods have been utilized, with varying success,
by different researchers, however the most common procedure is to statistically define a threshold value above which values are considered anomalous. Different methods have been used to define the threshold value. For example, Nichol et.al. (1969) classified those samples outside the range of the mean ± 2 standard deviations as anomalies whereas Boyle (1971) suggested the use of two times the background value as threshold. Bolviken (1972) and Tennant and White (1959) showed that there is no single threshold value but rather a distribution of background values and a distribution of anomalous values.

In determining threshold values in the present study, the mean and standard deviations of each element for each grid are calculated based on the samples available within each grid. Then, the mean concentrations of the elements and their standard deviations are recalculated at the 95% confidence level for each grid excluding those samples lying outside the range of the mean ± 2 standard deviations as they are outliers. Thus, the threshold level for each element for each grid used was the mean ± 2 standard deviations. For each grid, the elemental concentrations of every element for all samples were compared with the corresponding threshold level for that element and those above the threshold value are defined as geochemical anomalies for that particular element. But the geochemical
anomalies identified as described above may or may not be significant anomalies, i.e. may or may not be related to mineralizations. Because, in stream sediment geochemical exploration, it should be noted that the composition of the stream sediment could be derived by the weathering of rock formations (time-petrographic units) only or there could be possible contribution from other factors to the composition of stream sediments such as mineralized ore bodies, if there are any. Thus, the fundamental question is whether the anomalous composition of any element in the stream sediment sample is directly related or not to a mineralized zone. For example, as Rose et.al. (1981) pointed out that "insofar as barren rocks characterized by a high background metal content may give rise to distinctive anomalous patterns in either the soil or ground water, so may they affect the metal content of stream sediments that are derived by erosion of the metal-rich soil or that come in contact with the metal-rich water." (Rose, Hawkes and Webb, 1981).

Thus in order to determine whether the anomalous value is meaningful or not, in relation to a mineral deposit, it is necessary to compare the composition of the stream
sediment with the geochemical signatures of individual time-petrographic units. Thus the geochemical signatures for different time-petrographic units previously described were computed. The geochemical anomalies computed for each grid were then compared with the geochemical signatures of the time-petrographic units present within that grid. Those samples with elemental concentrations higher than mean ± 2 standard deviations and the geochemical signatures of the time-petrographic units are defined as significant geochemical anomalies in the present study. These significant geochemical anomalies were plotted and compared with the geochemical anomalies as determined by the method of factor analysis described later (figs. 6.2 to 6.37). The anomaly plots are made only for the elements As, Sb, Bi, Li, Be, Pb, Zn, Cu, Mo, W, Ag, Sn and Cd which are elements determined to be not related to the high background source rocks. Thus, it can be said that the plots were generally made for those elemental values which are associated with mineralizations, and not those normally associated with, and shown to be high, for host rocks such as Fe, Mn, V etc associated with mafic rocks or Ca, Mg etc. with carbonate rocks. Because again as Rose et.al. (1981) pointed out that

"many kinds of rocks are characterized by relatively high concentrations of many of the same elements that occur in ore deposits, but that have no genetic
relation to the ore. Surficial dispersion patterns developed from the weathering of these high-background rocks may show many of the features of patterns that are derived from ores" (Rose et al., 1982).

**Factor Analysis as an aid in identifying the anomalies of several elements in combination:**

The method described above to define the geochemical anomalies only considers single element and may thus fail to detect anomalies, if the interaction between several elements is the feature which characterizes the anomalous locality (Sinding-Larsen, 1977). The anomalous elements which are plotted along with different level boundaries of factor scores for different factors show the behavior of only one element at a time. But in multi-element geochemistry, when there are many variables or elements involved and also the data volume is high, graphical presentation, processing and interpretation become time-consuming and tedious as well as expensive. Additionally in terms of geochemical processes, they can't be accounted for at the same time, operating for the geochemically similarly behaving elements. In the present study, the association of elements based on their geochemical behavior and their
relation to the time-petrographic units had been determined by the use of factor analysis using correlation coefficient matrix which had been described in chapter-5. Here for the all sample data base, the samples were processed again by R-mode factor analysis following the procedure performed in chapter-5 i.e., the all sample data base were logarithmically transformed, standardization to deduce the similarity matrix and utilized the Pearson's correlation coefficient matrix (table 6.1) to generate a number of statistically independent factors. It is to be noted that results obtained from analyses of data base with all samples and that with samples specific to individual time-petrographic units are similar. The varimax factor loading matrix obtained is presented in the table 6.2. Again, a 6-factor model is established based on the varimax factor pattern (fig. 6.1 and table 6.2) and correlation coefficient matrix (table 6.1). Taking one factor at a time reduces the redundancy of data processing and the complexity of interpretation while simultaneously taking into account the geochemical process governing the elemental distributions. Therefore the association of elements defined here is treated as a single variable and used to identify areas with anomalous values. Thus the procedure is to detect anomalous areas by calculating a factor score for each sample for each factor
### Table 6.1 Pearson’s correlation coefficient matrix showing correlation between geochemical variables.

(based on all sample data base of the study area)
<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor1</th>
<th>Factor2</th>
<th>Factor3</th>
<th>Factor4</th>
<th>Factor5</th>
<th>Factor6</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>0.035</td>
<td>0.050</td>
<td>0.856</td>
<td>0.012</td>
<td>0.028</td>
<td>-0.002</td>
</tr>
<tr>
<td>Sb</td>
<td>0.187</td>
<td>-0.156</td>
<td>0.771</td>
<td>0.225</td>
<td>-0.029</td>
<td>0.138</td>
</tr>
<tr>
<td>Bi</td>
<td>-0.179</td>
<td>0.560</td>
<td>0.429</td>
<td>-0.086</td>
<td>0.095</td>
<td>0.050</td>
</tr>
<tr>
<td>Li</td>
<td>0.093</td>
<td>0.841</td>
<td>-0.013</td>
<td>-0.035</td>
<td>0.132</td>
<td>0.039</td>
</tr>
<tr>
<td>Na</td>
<td>0.039</td>
<td>0.680</td>
<td>-0.411</td>
<td>0.337</td>
<td>-0.097</td>
<td>0.084</td>
</tr>
<tr>
<td>Be</td>
<td>0.405</td>
<td>0.518</td>
<td>-0.078</td>
<td>0.183</td>
<td>0.254</td>
<td>0.123</td>
</tr>
<tr>
<td>Mg</td>
<td>0.556</td>
<td>-0.089</td>
<td>0.270</td>
<td>0.471</td>
<td>-0.062</td>
<td>0.246</td>
</tr>
<tr>
<td>Ca</td>
<td>0.004</td>
<td>-0.013</td>
<td>0.186</td>
<td>0.864</td>
<td>-0.014</td>
<td>0.186</td>
</tr>
<tr>
<td>Sr</td>
<td>0.193</td>
<td>0.267</td>
<td>-0.365</td>
<td>0.727</td>
<td>0.060</td>
<td>-0.032</td>
</tr>
<tr>
<td>Ba</td>
<td>0.605</td>
<td>-0.111</td>
<td>-0.035</td>
<td>0.261</td>
<td>0.111</td>
<td>-0.282</td>
</tr>
<tr>
<td>La</td>
<td>0.564</td>
<td>0.180</td>
<td>-0.394</td>
<td>0.314</td>
<td>0.168</td>
<td>-0.106</td>
</tr>
<tr>
<td>Ti</td>
<td>0.687</td>
<td>0.289</td>
<td>-0.334</td>
<td>-0.040</td>
<td>-0.050</td>
<td>0.153</td>
</tr>
<tr>
<td>V</td>
<td>0.836</td>
<td>0.155</td>
<td>0.174</td>
<td>0.057</td>
<td>-0.035</td>
<td>0.241</td>
</tr>
<tr>
<td>Cr</td>
<td>0.647</td>
<td>0.048</td>
<td>-0.011</td>
<td>0.128</td>
<td>0.060</td>
<td>0.023</td>
</tr>
<tr>
<td>Mn</td>
<td>0.146</td>
<td>-0.021</td>
<td>0.103</td>
<td>0.141</td>
<td>0.278</td>
<td>0.704</td>
</tr>
<tr>
<td>W</td>
<td>0.109</td>
<td>0.024</td>
<td>0.037</td>
<td>0.065</td>
<td>0.003</td>
<td>0.755</td>
</tr>
<tr>
<td>Mn</td>
<td>0.452</td>
<td>0.229</td>
<td>0.363</td>
<td>0.178</td>
<td>0.026</td>
<td>0.226</td>
</tr>
<tr>
<td>Fe</td>
<td>0.872</td>
<td>0.120</td>
<td>0.057</td>
<td>-0.045</td>
<td>-0.024</td>
<td>0.236</td>
</tr>
<tr>
<td>Co</td>
<td>0.522</td>
<td>0.223</td>
<td>-0.113</td>
<td>-0.075</td>
<td>0.381</td>
<td>-0.016</td>
</tr>
<tr>
<td>Ni</td>
<td>0.663</td>
<td>0.091</td>
<td>0.028</td>
<td>-0.214</td>
<td>0.204</td>
<td>0.073</td>
</tr>
<tr>
<td>Cu</td>
<td>0.616</td>
<td>0.111</td>
<td>0.394</td>
<td>0.158</td>
<td>-0.045</td>
<td>0.337</td>
</tr>
<tr>
<td>Ag</td>
<td>0.037</td>
<td>-0.046</td>
<td>-0.002</td>
<td>-0.060</td>
<td>0.850</td>
<td>0.006</td>
</tr>
<tr>
<td>Zn</td>
<td>0.509</td>
<td>0.244</td>
<td>0.194</td>
<td>0.033</td>
<td>-0.037</td>
<td>-0.180</td>
</tr>
<tr>
<td>Cd</td>
<td>0.059</td>
<td>0.091</td>
<td>0.034</td>
<td>0.158</td>
<td>0.550</td>
<td>0.010</td>
</tr>
<tr>
<td>Al</td>
<td>0.436</td>
<td>0.759</td>
<td>-0.052</td>
<td>0.091</td>
<td>0.109</td>
<td>0.037</td>
</tr>
<tr>
<td>Sn</td>
<td>0.034</td>
<td>0.212</td>
<td>0.006</td>
<td>-0.001</td>
<td>0.758</td>
<td>0.215</td>
</tr>
<tr>
<td>K</td>
<td>0.310</td>
<td>0.590</td>
<td>0.069</td>
<td>0.018</td>
<td>0.059</td>
<td>-0.162</td>
</tr>
<tr>
<td>Pb</td>
<td>-0.025</td>
<td>0.071</td>
<td>0.474</td>
<td>0.660</td>
<td>0.057</td>
<td>0.053</td>
</tr>
</tbody>
</table>

Table 6.2 Varimax factor loadings (patterns) derived based on all sample data base for the study area.
Fig. 6.1. Varimax factor loadings or patterns plot for all elements based on table-6.1 and 6.2 showing the grouping of elements.
(Based on all the sample data base)
utilizing factor loadings. Because a factor score is the quantitative expression of the amount of a factor or new variable in each object, a factor score matrix provide information similar to the raw data matrix but in a condensed form, with factors as a linear combinations of the original variables and cases as the original objects in the analysis. As with the time-petrographic analysis in chapter-5, contour maps of factor scores for all samples were made and significant anomalous samples were plotted and are described in the following.

Data manipulation for plotting factor scores:

The 6-individual R-mode factor analysis scores divided according to each 15'-toposheet of the area were used as input to plot the contour maps. The coordinates for each sample in each toposheet were combined with the factor scores for each sample resulting in a data base consisting of three columns: latitudes, longitudes and factor scores for each sample which are input as \((X,Y,Z)\) to develop contour maps. Plotting software converted the irregularly spaced \((X,Y,Z)\) data to a regularly spaced form in order to create the contour maps and three dimensional surface plots. In the interpolation method for creating a regularly spaced grid from irregularly spaced \((X,Y,Z)\) input data, the kriging method was employed. Thus the contour plots, for individual
factors, are made by kriging the factor scores. A separate
contour plot was made for each toposheet, at the scale of
1:250,000, in order that the geochemical signatures of the
factors could be compared with the available geologic map of
the area at that scale. These contour plots were utilized
further to identify the anomalous areas which were also
compared with the anomalous sample location for different
elements. It was recognized that the kriging technique
interpolates values for non-sampled locations, based on
gridding of samples available in the nearest radius defined.
Thus, anomalous areas can sometimes be distorted in size and
shape or occasionally false. For this reason, the basic
technique of using the mean ± 2 standard deviations was
utilized in order that the results could be double checked.

**Geochemical anomalies as defined by factors:**

The occurrence of ore deposits may be directly
reflected in a recognizable factor as exemplified by the
factor-3, the occurrence of high factor scores of which
coincides with the already proven mineral deposits as
already explained in chapter-5. Thus, in order to identify
anomalous areas with several elements in combination,
contour plot of factor scores are made using all the sample
data base for different factors. In order to make a
comparative study with the basic statistical technique, a
plot of samples which are significantly anomalous are made over the plot of factor scores. The detail is described below.

Factor-1 (Mn, Fe, Co, Ni, Cu, Zn, La, Ti, V, Cr, Mg, Ba)

R-mode factor analysis has shown previously that factor-1 is comprised of 12-elements and related to mafic intrusives and reworked metasediments such as phyllites, quartzites etc. As shown in fig. 6.1 and analysis of table 6.2, it can be seen that the elements Mn, Fe, Co, Ni, Cu, Zn, La, Ti, V, Cr, Mg, and Ba have high loadings on factor-1 at correlation coefficients (table 6.1) higher than 0.50 and even for the pairs which have lower correlation coefficients one of the element normally has a higher correlation coefficient with the element of another pair.

Factor-1 shows a negative relation to the factor-2, normally related to granitic intrusives, gneisses and pegmatites. The factor scores for each sample are plotted in figs. 6.2 to 6.7. For the purpose of interpretation, the range of computed factor scores were grouped into the following levels:
Level I. Factor scores <0.00  
Level II. Factor scores 0.00-0.39  
Level III. Factor scores 0.40-0.79  
Level IV. Factor scores 0.80-1.19  
Level V. Factor scores >2.0

Although subjective these divisions cover a sufficiently large range of values and thereby insure a sufficient level of discrimination. Thus within toposheet no. 72A/9 e.g., a 5th level zone occurs in grid 1092, this zone is surrounded by a 4th level zone and a 3rd level zone (fig. 6.2). The 4th zones occur in grids 1091, 1092, 1093, 1095, 1096, and 1099. These zones of higher levels coincide with a plot of copper and zinc (fig. 6.2) which occur within areas covered by the Kuncha, Dandagaon, and Nourpul phyllites (fig. 6.2 and plate-1). In the toposheet no. 72A/13, again the areas with high factor-1 scores occur in those areas where the anomalous samples for copper and zinc occur (fig. 6.3). These anomalous zones are again occurring over the areas underlain by the phyllites of Kuncha, Dandagaon, Nourpul and Tistung Formations. Areas with negative factor scores (fig. 6.3) are observed in grids 1136, 1137, 1138 and 1139 and occur in areas mostly underlain by rock types other than phyllites. The occurrences of anomalous samples for copper and zinc, as shown in fig. 6.4, coincide with the zones defined by the
Fig. 6.2. Different level boundaries plot of factor-1 score along with plot of samples anomalous in Cu and Zn for toposheet no.72A/9.
Fig. 6.3. Different level boundaries plot of factor-1 score along with plot of samples anomalous in Cu and Zn for toposheet no. 72A/13.
Fig. 6.4. Different level boundaries plot of factor-1 score along with plot of samples anomalous in Cu and Zn for toposheet no. 72A/14.
high level factor-1 scores in the toposheet no. 72A/14. For example, the zone of level-3, noted along the boundary between grids 1144 and 1145, is surrounded by zones of negative factor scores. In the toposheet no. 72A/14, the broad zone of negative factor-1 score, trending in NW-SE direction, which approximately coincide with the boundary of the Palung Granite (fig. 6.4 and plate-1). It is noteworthy to mention that the negative zone of factor-1 value is overlain by positive factor-2 scores which are mainly related to felsic intrusives (fig. 6.10 and plate-1). Also, the area with negative scores north of this zone coincides with the Agra Granitic body.

In the toposheet no. 72E/1, 50% of the area is not covered by samples. Negative factor-1 scores generally occur over the area underlain by gneisses. For example in grids 5013, 5016 and 5019, areas with negative factor-1 score or 2nd level factor-1 scores coincide with areas underlain by gneisses and undifferentiated schist with granitic and pegmatitic dyke-swarms (fig. 6.5 and plate-1). A small area of 3rd level positive factor-1 score surrounded by 2nd level factor-1 score occurs in grid 5018 over an area mainly underlain by Kalitar Schists, Pandrang Quartzites and Benighat Slates with minor gneisses (fig. 6.5 and plate-1). Also, the positive factor-1 score of 1st-level in grids 5012 and 5015 occurs over areas underlain by metasediments of the
Fig. 6.5. Different level boundaries plot of factor-1 score along with plot of samples anomalous in Cu and Zn for toposheet no. 72E/1.
Nawakot Complex including basic intrusives. In grid 5013, the occurrence of a small area of 3rd level factor-1 score can be noted over the area with schists, slates, quartzites limestone and dolomite of the Nawakot Complex which is in contact with the augen gneisses and the Kalitar Schist. Areas of positive factor-1 scores in the toposheet no. 72E/1 coincide with the plot of samples anomalous in Cu and Zn while areas with negative factor-1 do not show the anomalous samples (fig. 6.5 and plate-1). In the toposheet no. 72E/6 (fig. 6.6 and plate-1), areas with the positive 3rd level factor-1 score occur over areas underlain mainly by the Tistung Phyllites and Chandragiri Limestones and most of the negative factor-1 score occur over the alluvium covered area. The 2nd level positive factor-1 score is generally underlain by sediments of the Phulchauki Group such as Sopyang Formation, Chitlang Slates, Silurian Beds of Phulchauki and Devonian Limestone. In the toposheet no. 72E/6, the small area of 3rd level factor-1 score in the grid 5065 coincides with the plot of samples anomalous in Cu and Zn. Also, the wider area of 3rd level factor-1 score in grids 5068 and 5069 coincide with the samples anomalous in Cu and Zn while the area of negative scores generally do not show any anomalous samples. The 3rd level factor-1 scores are noted in grids 5071, 5072, 5074 and 5077 in the toposheet no. 72E/7 (fig. 6.7) and these higher level areas occur over areas underlain by the Markhu Marble and Schist.
Fig. 6.6. Different level boundaries plot of factor-1 score along with plot of samples anomalous in Cu and Zn for toposheet no.72E/6.
Fig. 6.7. Different level boundaries plot of factor-1 score along with plot of samples anomalous in Cu and Zn for toposheet no.72E/7.
Kulikhani Schist, Bhainsedobhan Marble and the Jhiku Carbonate Beds (fig. 6.7 and plate-1). These high level areas of factor-1 score in grids 5071, 5072, 5073 and 5074 also coincide with the plot of samples anomalous in Cu and Zn (fig. 6.7).

The general pattern shown by the factor-1 is that the zones of higher level factor-1 scores as described above, occur in areas of basic intrusives and mainly argillaceous sediments such as phyllites of the Nawakot Complex. Also, the higher level factor-1 scores coincide with the plot of samples anomalous in Cu and Zn proving that similar anomalies can be detected by both techniques of multivariate factor analysis and basic statistical methods of computing outliers with a certain confidence level, in the present case with 95% confidence level.

Factor-2 (Li, Na, K, Be, Al, Bi)

Factor-2 is comprised of alkali elements such as Li, Na, K, Be, Al and also Bi and primarily related to granitic rocks. As shown in the table-6.1, the correlation coefficients between the elements constituting this factor is greater than 0.5 except for the pairs K-Na and K-Be. Even for the pair K-Be, the correlation coefficient is 0.41 and is particularly low with a coefficient of 0.29 only for
the pair K-Na, however all these elements have high factor loadings on factor-2. Also, the correlation coefficient between the element Bi and other elements of factor-2 are low except with the element Li, which is 0.33 but the element Bi has shown high loading on factor-2 with the factor loading of 0.56. Thus based on factor loading (table 6.2), Bi is also in association with other elements of factor-2.

Again for the purpose of interpretation, factor scores computed for factor-2 for each sample are plotted. The factor scores are grouped into the following levels for the ease of interpretation:

Level I. Factor score < 0.00
Level II. Factor score 0.00-1.00
Level III. Factor score 1.01-2.00
Level IV. Factor score 2.01-3.00
Level V. Factor score > 3.00

Analysis of the contour plot of factor scores for this factor-2 (fig. 6.8) for the toposheet no.72A/9, show that the majority of the area is overlain by negative factor scores, except for small zones of level-2 in grids 1091, 1095, 1098 and 1099, and also a small area of 3rd level is noted in the grid 1098. As described previously, factor-2 is related to the felsic and alkaline igneous rocks. A very
Fig. 6.8. Different level boundaries plot of factor-2 score along with plot of samples anomalous in Li and Be for toposheet no. 72A/9.
similar result is obtained for the area in the toposheet no. 72A/13 (fig. 6.9). Again, much of the area in this toposheet is overlain by negative or low positive scores except for small zones of 3rd level factor-2 scores in the grid 1139 (fig. 6.9). These small zones of 3rd level factor scores are related to felsic rock types of the area (plate-1). These positive factor scores may be derived from the gneisses underlying the area or from sediments derived from the Agra granite body in the south. A narrow zone of 3rd level factor-2 scores occur in the grid 1136, surrounded by 2nd level factor scores, could result from sediments derived from the weathering of the Agra granitic body. The area overlain by the negative factor scores is geologically underlain by phyllites, schists, quartzites, dolomites, limestones, and basic intrusives (fig. 6.9 and plate-1).

A very conclusive result supporting the inference that the factor-2 is related to felsic and alkaline granitic rocks, is obtained in the toposheet area 72A/14 where factor-2 shows a zonal pattern with granitic rocks in the toposheet area 72A/14. For example in grids 1145 and 1148 (fig. 6.10), small zones of highest level factor-2 scores occur at the core of the Palung Granite, and these zones of level-5 are surrounded by the zones of lower level factor-2 scores away from the core of the granitic body. As can be seen from the geological map (plate-1) in together with the
Fig. 6.9. Different level boundaries plot of factor-2 score along with plot of samples anomalous in Li and Be for toposheet no. 72A/13.
Fig. 6.10. Different level boundaries plot of factor-2 score along with plot of samples anomalous in Li and Be for toposheet no. 72A/14.
factor-2 score contour plot (fig. 6.10), the outline of 3rd level factor-2 score coincides with the boundary of the Palung Granite in grids 1145 and 1148. The other zones of 3rd level factor scores noted in grids 1141, 1144 and 1147 are also occurring over areas underlain by the granitic rocks of the Agra Granite. Other areas in this toposheet show either negative factor scores or only 1st level factor scores over the area geologically underlain by rock types other than granites such as Benighat Slates, Malekhu Limestones, basic intrusives, Raduwa Schist, Kulikhani Schist which are mainly related to the factor-1 and Markhu marble and schist, and Bhainsedobhan Marble which are related to factor-3.

In the toposheet no. 72E/1 (fig. 6.11), only 50% of the sheet has been sampled. Geologically, the area in this toposheet is mainly underlain by the Kuncha Phyllites, granitic gneiss, augen gneiss, and undifferentiated schist showing various stages of migmatization (plate-1). The positive factor-2 score of 2nd level approximately follows the boundary defined by the granitic gneiss. The area covered by other rock types shows mainly negative or 1st level factor scores. In the toposheet no. 72E/6 (fig. 6.12), two small zones of 3rd level factor scores occur just north of the Narayanthan Granite boundary and seem to be related to the Narayanthan Granite and adjacent sediments.
Fig. 6.11. Different level boundaries plot of factor-2 score along with plot of samples anomalous in Li and Be for toposheet no. 72E/1.
Fig. 6.12. Different level boundaries plot of factor-2 score along with plot of samples anomalous in Li and Be for toposheet no. 72E/6.
A positive 1st level factor score occurs over the Tistung Phyllites. In the toposheet no. 72E/7, a broad zone of 3rd level factor scores is noted in grids 5074 and 5077. The boundary of this zone coincides approximately with the boundary of the Narayanthan Granite (fig. 6.13 and plate-1). Small zones of 4th level factor scores enveloped by a 3rd level zone occur inside the core of the granitic body and are due to the sediments derived by the weathering of this Narayanthan Granitic body. Two small zones of 3rd level factor scores occur in the grid 5071: one of them associated with the small Arkhaule Granite body occurring in the north-east corner. The next zone in this grid, although far removed from the Arkhaule granitic body may reflect sediments contributed by the Arkhaule Granite.

As previously stated, it is to be noted that the plot of anomalous samples are not made for all elements as for the elements like As, Sb, Bi, Mo, W, Cu, Ag, Zn, Cd, Sn, and Pb. Because, the plot of anomalous samples are made only for those elements which are considered for exploration. Thus, the anomalous plot is made for two elements Li and Be for factor-2 so that these two elements could be utilized for mineral potential evaluation and mineral deposit models, which shall be described in the next chapter.
Fig. 6.13. Different level boundaries plot of factor-2 score along with plot of samples anomalous in Li and Be for toposheet no.72E/7.
Factor-3 (As, Sb, Bi, Pb)

Factor-3 is comprised of As, Sb, Bi, and Pb, although correlation coefficients between the pairs of elements comprising this factor are not normally high. For example, the correlation coefficient between the pair As-Bi is only 0.31 and that between As-Pb is 0.36 (table 6.1). However correlation coefficient between the pair As-Sb is 0.61 and Sb-Pb is 0.44 but that between pairs Sb-Bi and Bi-Pb are 0.17, and 0.15 respectively (table 6.1). However when the factor loadings of these elements into the factor-3 is considered, it is concluded that factor-3 is comprised of As, Sb, Bi, and Pb as they have high loadings on this factor.

As previously described, occurrences of high scores of factor-3 coincide with the already proven Pb-Zn mineralized areas, e.g., Labang-Khairang Pb-Zn deposit, and its association mainly with carbonates such as Markhu Marble, Chandragiri Limestone, the Jhiku Carbonate Beds. The contour plots of factor scores for each samples of factor-3 are inspected to identify the anomalous areas for possible mineralizations.
For the purpose of interpretation of contour plots of factor scores of this factor, the factor scores are divided into 5-levels as previously. They are:

Level I. Factor scores < 0.1
Level II. Factor scores 0.1-1
Level III. Factor scores 1.1-2
Level IV. Factor scores 2.1-3
Level V. Factor scores > 3

In toposheet no. 72A/9 (fig. 6.14), the highest level of factor scores is detected in grid 1093 which occurs over the faulted contacts between the Nourpul Phyllites and Dhading Dolomites and between the Nourpul Phyllites and Benighat Slates (plate-1). This zone is surrounded by a broader zone, with 4th level factor scores, occurring over the area underlain by the Nourpul Phyllites, Benighat Slates and Dhading Dolomites. A zone with similar geology, tectonics and factor scores as grid 1093 occurs in grid 1096. A very small zone of 5th level factor-3 occurs over the Benighat Slates in grid 1099 (fig. 6.14). This zone is surrounded by third level factor-3 scores and occur over the area covered by the Benighat Slates with Jhiku Carbonate Beds. In grid 1099, many of the samples are high in As content but their higher concentrations seem to be caused by their high background content in the basic intrusives occurring in this grid. The remainder of the area in this
Fig. 6.14. Different level boundaries plot of factor-3 score along with plot of samples anomalous in As, Sb, Bi and Pb for toposheet no. 72A/9.
toposheet is low in the factor scores for this factor-3 as demonstrated by the few scattered single element anomalous samples (fig. 6.14).

Similar results are observed for the factor-3 in the toposheet no. 72A/13 (fig. 6.15). In the grid 1133, a small zone of 4th level of factor-3 scores is surrounded by a broader zone of 3rd level factor scores and occurs over an area of multiple time-petrographic units (fig 6.15).

High factor scores of this factor may be caused by the high background content of elements of the rock-types in this grid—especially basic intrusives. Another small zone of high value of this factor is noted mainly over the Benighat Slates in the same grid 1133. Again, broad high score value of 4th level of this factor surrounded by 3rd level are noted over grids 1138 and 1139. These zones again occur over the area covered by the Dhading Dolomites with faulted structures. The factor score values decrease away from the Dhading Dolomites. In general, this result is also derived by plotting the anomalous samples for individual elements constituting this factor. Thus in the fig. 6.15, which shows the plot of anomalous sample locations of As, Sb, Bi, and Pb, e.g., grid 1132 with lowest level of factor score does not have any anomalous samples. The occurrence of the zone of 4th level factor score in grid 1133 is also
Fig. 6.15. Different level boundaries plot of factor-3 score along with plot of samples anomalous in As, Sb, Bi and Pb for toposheet no. 72A/13.
demonstrated by the presence of sample anomalous in As, Sb, and Bi. The same is true in grids 1138 and 1139 where again, the 4th level zone of factor score coincides with the samples anomalous in As, Sb, Pb surrounded by the 3rd level zone with anomalous samples in As or As, Sb etc.

In the toposheet no. 72 A/14 (fig. 6.16), zones of high factor scores of factor-3 are scattered throughout the area. Two small zones of 3rd level factor-3 scores occur in association with the Labang-Khairang Pb/Zn mineral deposit in grids 1141 and 1144 (fig. 6.16). These zones follow the highly faulted Markhu Marble trend. Additionally, NW-SE trending anomalous zones of 3rd level are noted in grids 1142, 1146 and 1149 over the area dominantly underlain by the Benighat Slates and Malekhu Limestone. This broad zone overlies several anomalous samples (fig. 6.16). A small narrow zone of 4th level factor score occurs in grid 1146 along the contact of basic intrusives with the Benighat Slates as exemplified by samples anomalous in As, Sb, Bi, and Pb. Small, scattered patches of 3rd level of factor scores are also noted within and along the contact of the western portion of the Palung Granite in grids 1145 and 1148.
Fig. 6.16. Different level boundaries plot of factor-3 score along with plot of samples anomalous in As, Sb, Bi and Pb for toposheet no.72A/14.
In toposheet no. 72E/1 (fig. 6.17), only 50% of the area is covered by the sampling and much of the area is low in factor-3 score, mostly negative except for the two narrow zones of 3rd level noted in grids 5012, 5013 and 5055. The zone of 3rd level factor score of the factor-3 occurs over the area covered by the Dhading Dolomite, Benighat Slates, Malekhu Limestone, Kuncha, Nourpul and Robang Phyllites and Kalitar Schist in grids 5012 and 5013. Anomalous samples in As and Sb, or Sb coincide with this zone (fig. 6.17) which includes a basic intrusive and a major thrust fault contact between the Kalitar and Robang Formations. The zone occurring in grid 5015 occurs over river terraces, the Kuncha Phyllites and the Fagfog Quartzites.

Much of the area in the toposheet no. 72E/6 (fig. 6.18) has low or negative factor scores for the factor-3. Only two narrow zones of 3rd level factor scores are noted in the grid 5069, one of them occurs over the Chandragiri Limestone bounded by faults, and the other zone occurs over the Markhu Formation in contact with the Narayanthan Granite and the Tistung Phyllites (fig. 6.18 and plate-1). The 1st level of factor-3 is noted in grid 5062 underlain by the faulted Chandragiri Limestone and Chitlang Slates. The anomalous samples for the elements constituting the factor-3 in grid 5069 coincide with the zone of 3rd level factor score. The broader zones of 2nd level factor scores are occurring over
Fig. 6.17. Different level boundaries plot of factor-3 score along with plot of samples anomalous in As, Sb, Bi and Pb for toposheet no. 72E/1.
Fig. 6.18. Different level boundaries plot of factor-3 score along with plot of samples anomalous in As, Sb, Bi and Pb for toposheet no. 72E/6.
the few scattered anomalous samples, while much of the negative factor score zone does not show any anomalous samples or rarely few samples (fig. 6.18).

Factor-3 shows several scattered zones with high 3rd level zones over the areas underlain primarily by carbonates, with faulted structures, in the toposheet no. 72E/7 (fig. 6.19). For example, in grid 5071, two small zones of 3rd level of factor-3 occur over the highly faulted Markhu Formation while in grid 5074 a narrow zone of 3rd level occurs over the faulted contact of the Benighat Slates and Bhainsedobhan Marble (fig. 6.19). Another slightly broader zone is noted at the contact of the Narayanthan Granite with the Kulikhani Schist with a faulted structure. In the grid 5077, a small zone of 3rd level factor-3 occurs over the faulted contact zone between the Narayanthan Granite, the Markhu Formation and a small area over the faulted Bhainsedobhan Marble. Here also, two narrow zones of 3rd level factor scores in the grid 5071 are coincident with the samples anomalous in As, Sb, and Pb. The same is true with the other zones as well.

In general, it appears that high scores of the factor-3 are mainly related to carbonates (limestone, dolomite, marble) and their faulted contacts or boundaries with the
Fig. 6.19. Different level boundaries plot of factor-3 score along with plot of samples anomalous in As, Sb, Bi and Pb for toposheet no. 72E/7.
granitic intrusives, and to a lesser extent occur within the schists or slates and their contact with the granitic intrusives.

Factor-4 (Ca, Mg, Sr, Pb)

Factor-4 is composed of Ca, Mg, Sr, and Pb. These elements correlate with each other with correlation coefficients greater than 0.5, except for the element Mg which has correlation coefficient of 0.34 with Pb and only 0.25 with Sr (table 6.1). Looking at the varimax factor loadings (table 6.2), these elements show high loadings on factor-4. Thus, the element Mg although has shown weak correlation with other elements of this factor, and strong correlation with elements of factor-1, based on its factor loadings, the element Mg shows its association to both factor-1 and factor-4.

Again, for the purpose and ease of interpretation, the factor scores computed for factor-4 are grouped into the following 5-levels:
Level I. Factor score < 0.0
Level II. Factor score 0.0-1.0
Level III. Factor score 1.1-2.0
Level IV. Factor score 2.1-3.0
Level V. Factor score > 3.0

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The plot of factor-4 scores, for individual toposheets, are presented in figs. 6.20 to 6.25. Factor-4 is related to carbonate rock types and possibly with Pb-mineralisations. An analysis of contour plots of factor-4 scores for the toposheet no.72A/9 shows that much of the area is covered by negative factor scores (fig. 6.20). In grid 1091, a narrow zone of 5th level factor scores, surrounded by lower level factor scores, is noted (fig. 6.20) and comparing with the plot of anomalous samples of the elements - As, Sb, Bi, and Pb, for grid 1091, it can be inferred that zones of high factor-4 scores coincide with the plot of anomalous samples for Pb. For example, the zone of the 5th level factor scores in grid 1091 (fig. 6.20) coincides with the anomalous sample plot of Pb. Similarly, in grid 1093, 1094, and 1096 the very narrow zone of the 4th level factor scores occurs just over the plot of samples anomalous in Pb. Also, two small zones of the 3rd level factor-4 score in grid 1096 are coincident with the samples anomalous in Pb. It is important here to mention that this factor is comprised of Ca, Mg, and Sr, besides Pb. So, it is expected that it will have an association with both carbonates and Pb anomalies. The latter could be related to Pb-mineralisations in the carbonate host rocks. Except for the anomalous zones occurring in grid 1091, other zones of high level factor scores, occurring in other grids, are in or adjacent to the carbonates such as those of the Jhiku Carbonate Beds,
Fig. 6.20. Different level boundaries plot of factor-4 score along with plot of samples anomalous in Pb for toposheet no. 72A/9.
Dhading Dolomites, or Malekhu Limestone. Most of the area in this toposheet is underlain by the Kuncha Phyllites and as a result has negative factor-4 scores. The results obtained for the toposheet no.72A/13 are based on only a limited number of available samples. The zones of 3rd level factor scores are noted in grids 1133, 1136, and 1139 (fig. 6.21).

In toposheet no. 72A/14, factor-4 clearly shows its relation to the carbonates and to the anomalous plot of the samples for Pb (fig. 6.22). For example in grids 1141, 1142, and 1144, the 3rd level factor-4 score surrounded by the broad zone of 2nd level factor scores occur over the area mainly with carbonates such as the Bhainsedobhan Marble, the Markhu Marble and Schist, the Malekhu Limestone, and the Jhiku Carbonate Beds. The 3rd level factor score zones occurring within these grids coincide with samples anomalous in Pb and also with the already proven Pb-Zn mineral deposit. The other zone of highest level factor score is noted in grid 1149 and this is demonstrated by the occurrence of samples anomalous in Pb (fig. 6.22). This kind of result is also noted in grids 1145, 1146, and 1149 where the narrow zones of 4th level factor-4 scores coincide with the plot of samples anomalous in Pb or Pb-Zn mineralization. And these anomalous zones or zones of high factor scores are also related to the carbonates such as the
Fig. 6.21. Different level boundaries plot of factor-4 score along with plot of samples anomalous in Pb for toposheet no.72A/13.
Fig. 6.22. Different level boundaries plot of factor-4 score along with plot of samples anomalous in Pb for toposheet no.72A/14.
Bhainsedobhan Marble, Malekhu Limestone, the Jhiku Carbonate Beds. Actually, the zone in grid 1149 approximately follows the trend of the Bhainsedobhan Marble which could be due to the sediments shed from this unit as can be noted from the drainage pattern (plate-1). The large area with negative factor scores occur mainly over the granitic rocks in the NE part of this toposheet or over the Siwaliks Group in the southern part.

Half of the area of toposheet no. 72E/1 is not covered by samples and even for the remainder of the area, the number of available samples are few. However, based on available samples, it can be inferred that the occurrence of 3rd level factor score is primarily over areas mostly underlain by undifferentiated shists and calcsilicates (fig. 6.23). In the toposheet no. 72E/6, the two zones of 3rd level factor-4 scores surrounding the 4th level score coincide with the plot of samples anomalous in Pb (fig. 6.24). This zone includes sediments shed from the Markhu Formation. The another small zone of 3rd level factor score also occurs over the Chandragiri Limestone. Much of the area of negative factor scores occur over the area underlain by alluvium (plate-1). In toposheet no. 72E/7, the half of the area covered by the data, shows negative factor scores over the Siwaliks Group (fig. 6.25 and plate-1). The other half of the area is covered by 2nd level and 3rd level
Fig. 6.23. Different level boundaries plot of factor-4 score along with plot of samples anomalous in Pb for toposheet no. 72E/1.
Fig. 6.24. Different level boundaries plot of factor-4 score along with plot of samples anomalous in Pb for toposheet no. 72E/6.
Fig. 6.25. Different level boundaries plot of factor-4 score along with plot of samples anomalous in Pb for toposheet no.72E/7.
factor scores except for the two very small zones of 4th level factor score in grids 5071 and 5077. There are no anomalous samples in the area covered by the negative factor scores. The areas of 3rd level factor scores in grids 5071, 5074, and 5077 are also in coincident with samples anomalous in Pb. These zones again occur over the areas covered by the Markhu Marble and Schist. The boundary between the 2nd level and 3rd level factor scores coincides approximately with the boundary of the granitic bodies (Narayanthan granite and Arkhaule granite) and the other rock types, mainly the Markhu Marble and Schist and the Kulikhani Schist (fig. 6.25 and plate-1).

Hence, it can be concluded that this factor-4 is mainly a factor related to the carbonates such as dolomites, marbles and limestone with Pb included in this factor due to the presence of carbonate hosted Pb-mineralization in these time-petrographic units. Zones of factor scores of 3rd-level or higher than 3rd-level can be considered anomalous for Pb-mineralization as evidenced by the plot of anomalous samples for Pb.
Factor-5 (Ag, Sn, Cd)

Factor-5 of Ag and Sn is still valid, as shown by the R-mode factor analysis of all the sample data base (fig. 6.1). Table 6.2 shows that the loadings of these two variables into the factor-5 are 0.85 and 0.76, respectively and also the correlation coefficients between the variables Ag and Sn is 0.58. Although it has been shown that this factor is constituted of three elements namely Ag, Sn, and Cd in the section 'Association of Elements', the R-mode factor analysis of all the available samples showed that it is constituted of only two elements. It appears that Cd may represent a separate and distinct factor by itself which should be considered as a seventh factor. However, as mentioned already in chapter-5, six factor model was choosen and Cd is included in factor-5 as the plot of anomalous samples showed that Cd is generally associated with Ag.

Again factor scores computed for this factor-5 are grouped into the following levels for the ease of interpretation:
Level I. Factor score < 0.0
Level II. Factor score 0.0 - 1.0
Level III. Factor score 1.1 - 2.0
Level IV. Factor score 2.1 - 3.0
Level V. Factor score > 3.0

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The plot of these factor scores are shown in figs. 6.26 to 6.31. Plot of samples which are anomalous in Sn and also those samples which show the presence of Ag and Cd are made along with the contour plot of factor-5 scores. Since, Ag is absent or below detection limit in most of samples, those samples which show the presence of Ag are plotted so that this information can be utilized for the interpretation of this association. In fig. 6.26, which is the plot of factor scores for the toposheet no.72A/9, a broad zone of 5th level factor score is noted in grid 1094 surrounded by the lower level zones. This broad zone of high factor scores is also in concurrence with the location of most of anomalous samples in Sn and Ag. This zone is surrounded by the broader zones of the lower levels and the plot of anomalous samples lie within this zone falling in the grid 1091, 1094, and 1097. The similar observation is made in grid 1095 where again, plot of anomalous samples lie within higher level zones of factor score-5. Geologically, these areas in grids 1091, 1094, 1095 and 1097 are underlain by the Kuncha Phyllites. In grid 1096, many samples containing Ag and Cd are noted and the occurrence of these samples lie within zones of higher level factor-5 scores. Geologically, the main time-petrographic units in grid 1096 are the Benighat Slate, the Jhiku Carbonate Beds. In toposheet no.72A/13 (fig. 6.27), for grids 1131, 1134 and 1137, not much information is available, but in rest of the other grids,
Fig. 6.26. Different level boundaries plot of factor-5 score along with plot of samples anomalous in Ag, Sn and Cd for toposheet no. 72A/9.
Fig. 6.27. Different level boundaries plot of factor-5 score along with plot of samples anomalous in Ag, Sn and Cd for toposheet no. 72A/13.
the plot of anomalous samples of Sn and plot of samples with Ag content are in concurrence with higher positive level factor-5 scores. The negative factor-5 scores occurring in grids 1133, 1136 and 1139 did not show anomalous samples while most of anomalous samples for Sn and plot of samples with Ag and Cd, or their combination lie in higher level zones of factor-5 scores (fig. 6.27). For example, in grid 1132, anomalous samples of Ag and Sn occur over mainly in zones of 2nd level and 3rd level factor-5 scores while in grid 1135, anomalous samples of Sn coincide with 2nd level zone and those of Ag and Sn with 3rd and 4th level factor-5 score zones. In grid 1138, samples with Ag and Cd occur together with 3rd level zones of factor-5 score and same is true in grid 1139. In general, the areas with Ag and Sn occur over areas underlain by the Kuncha Phyllites (fig. 6.27 and plate-1). The 3rd level zone with plot of anomalous samples in Ag, Sn and Cd in grid 1139 occur over areas underlain by the Kulikhani Schist, gneiss and the Markhu Formation in close with Agra Granite just south of grid 1139. In toposheet no.72A/14, the plot of anomalous samples for Ag, Sn and Cd are noted in grids 1144, 1145, 1146 and 1148 (fig. 6.28). As can be seen from fig 6.28, these plot of samples lie within the higher level factor-5 score zones. For example in grid 1144, where most of samples with Ag, Sn and Cd are concentrated, 3rd and 4th level zones of factor-5 scores coincide with those sample...
Fig. 6.28. Different level boundaries plot of factor-5 score along with plot of samples anomalous in Ag, Sn and Cd for toposheet no.72A/14.
plots. Similarly, plots of Ag, Sn and Cd, and Ag and Sn are shown by very small 3rd level factor-5 score zones in grids 1145 and 1146 respectively. In grid 1148, anomalous samples of Sn are noted over 3rd level factor-5 score zone. The occurrence of high level factor-5 score zones in concurrence with plot of samples anomalous in Sn and those containing Ag and Cd are over the areas underlain mostly by Agra Granite and Palung Granite with some Cd over areas underlain by the Markhu Formation.

In toposheet no.72E/1, the information is available only in the southern half of the area. In grid 5013, plot of samples with Ag and anomalous Sn content are in concurrence mostly with 3rd level factor-5 score zones with few over 2nd level zones (fig. 6.29). These anomalous zones are mainly over areas underlain by granitic gneiss. The other grid where anomalous samples of Sn and with Ag content occurring over higher level of factor-5 score zones is 5019 (fig. 6.29). Here, most of the anomalous samples are within 3rd, 4th and 5th level zones. These anomalous zones are occurring over the area underlain by augen gneisses and schists with pegmatite veins (fig. 6.29 and plate-1). Geologically, the area in toposheet no.72E/6 is mostly covered with Quartenary alluvium (plate-1). Much of the area is covered by negative factor-5 scores and there are not samples anomalous in elements constituting this factor.
Fig. 6.29. Different level boundaries plot of factor-5 score along with plot of samples anomalous in Ag, Sn and Cd for toposheet no. 72E/1.
in this toposheet no.72E/6 (fig. 6.30) except for few samples in grid 5069. In toposheet no.72E/7, the anomalous samples of Ag and Sn are concentrated mainly in grids 5074 and 5077 and their occurrence coincide with higher level factor-5 score zones (fig. 6.31). For example in grid 5074, plot of anomalous samples for Ag and Sn or their combination are mostly within 3rd, 4th and 5th level zones. The same is true for grid 5077, where plot of samples anomalous in Sn and with Ag content are in concurrence with 3rd and 4th level factor-5 score zones (fig. 6.31). The concentration of high factor-5 scores and the plot of samples anomalous in elements constituting factor-5 are over areas underlain mainly by the Narayanthan granite (fig. 6.31 and plate-1). Thus in general, it can be said for factor-5 that the geochemical anomalies derived by basic statistical procedure of mean ± 2 standard deviations are in coincidence with higher level factor-5 scores and these high level factor-5 scores and significant geochemical anomalies are mainly related to the Kuncha Phyllites and different granitic bodies.

Factor-6 (Mo, W)

Factor-6 is a combination of two elements namely Mo and W. This combination is also shown by the R-mode factor analysis of all the available samples (fig. 6.1).
Fig. 6.30. Different level boundaries plot of factor-5 score along with plot of samples anomalous in Ag, Sn and Cd for toposheet no.72E/6.
Fig. 6.31. Different level boundaries plot of factor-5 score along with plot of samples anomalous in Ag, Sn and Cd for toposheet no.72E/7.
varimax factor loadings of Mo and W on factor-6 are 0.704 and 0.755 respectively (table 6.2) and the correlation coefficients between these two elements is 0.43 (table 6.1). The factor scores for factor-6 are plotted and shown in figs 6.32 to 6.37 for different toposheets. For the purpose of investigation, the factor scores are defined into 5-levels:

Level I. Factor score <0.0
Level II. Factor score 0.1-0.40
Level III. Factor score 0.41-0.80
Level IV. Factor score 0.81-1.19
Level V. Factor score >2.0

Inspection of factor score plots for factor-6 for the toposheet no. 72A/9 shows that there are at least two zones of the 5th level of this factor (fig 6.32). In grids 1092 and 1093, the 5th level zone is surrounded by lower zones down to the 1st level. The highest level zones in these grids occur over the phyllitic rocks of the Kuncha Phyllites, Dandagaon Phyllites, and Nourpul Formation. The area is also characterized by large faults (fig 6.32). Another very narrow zone of the 5th level is noted over grid 1099, and this grid is dominantly comprised of the Benighat Slates, the Jhiku Carbonate Beds and basic intrusives. This zone is also surrounded by a zones of lower level factor scores down to the 1st level. Small, narrow zones of 3rd level factor score for this factor are present in grids
Fig. 6.32. Different level boundaries plot of factor-6 score along with plot of samples anomalous in Mo and W for toposheet no.72A/9.
1095, 1096 and 1098 besides a very small zone of 4th level being present in grid 1095 (fig. 6.32 and plate-1). The occurrences of these high level zones of factor scores coincide with the plot of anomalous samples for these two elements as shown in the fig. 6.32. For example in grid 1092, the occurrence of 5th level zone of factor-6 is coincident with the anomalous samples location. But there are no other samples surrounding this zone. The lower level zones surrounding this 5th level zone are developed by the kriging technique and thus this broader zone could be a misleading anomaly. Again, the 5th level zone in grid 1099 coincides with the samples anomalous in Mo and W, the 4th and 3rd level zone coinciding with the samples anomalous in Mo. The narrow zone of 4th level factor score in grid 1095 is also exemplified by a sample anomalous in Mo.

In the toposheet no. 72A/13, a very narrow zone of level-5 occurs in grid 1133 which is surrounded by the zones of the lower levels (fig. 6.33). Two small zones of level-4 occur in grids 1135 and 1136. The 3rd level zones of factor score for this factor occur in grids 1132, 1133, 1135, 1136, and 1139. Once again in this toposheet, occurrences of the anomalous samples coincide with the zones of high factor scores. Zones of negative factor scores for factor-6 do not show any anomalous samples. For example, in grid 1132, the zone of 3rd level factor score coincides with samples
Fig. 6.33. Different level boundaries plot of factor-6 score along with plot of samples anomalous in Mo and W for toposheet no. 72A/13.
anomalous in molybdenum. The zones of higher level factor scores such as those of levels 3, 4, and 5 in grid 1133 are also exemplified by the samples anomalous in molybdenum or tungsten or in both. The same is true in other grids as well such as those in 1135, 1136 and 1139.

The similarity in results of the anomalous areas as derived by these two techniques of factor analysis and basic statistical method using mean ± 2 s.d. with 95% confidence level are well demonstrated in the topopsheet no. 72A/14. In this toposheet, the zones of highest level of factor scores are scattered in all grids except 1143 which is not covered by samples (fig. 6.34). These scattered zones of highest level factor scores for this factor-6 are virtually coincident with the location of the anomalous samples (fig. 6.34). Grid 1141 is predominantly covered by the zone of the lowest factor score except for a small zone of higher scores up to the 5th level. The zone of highest factor score in this grid, which also falls in grid 1134, coincides with samples anomalous in molybdenum or tungsten or both. This is true for all the zones occurring in all grids.

In the toposheet no.72E/1, more than half of the area is not covered by samples. However, for the small portion of the area covered by samples, mainly two zones of highest factor scores for factor-6 are noted, one in grid 5013 and
Fig. 6.34. Different level boundaries plot of factor-6 score along with plot of samples anomalous in Mo and W for toposheet no.72A/14.
another in grid 5019 (fig. 6.35). These two zones are also demonstrated by the anomalous samples as shown by the anomalous samples location or plot (fig. 6.35). These zones are surrounded by the zones of lower level factor scores and the zones of level 3rd and 4th are still demonstrated by the presence of anomalous samples. Again, the 2nd level zone and the 1st level zone with negative scores are not covered by the anomalous samples or only rarely by one or two samples.

Almost the whole area in toposheet no.72E/6 is covered by negative factor scores. This is also shown by the lack of anomalous samples location or plot for the elements constituting this factor (fig. 6.36). There are few samples which show the presence of molybdenum but they are not anomalous as defined above. However, there are two samples anomalous in molybdenum in grid 5062 and one in 5063 but they are displayed as negative scores (fig. 6.36).

In the toposheet no.72E/7, narrow zones of high factor scores such as 4th level in grid 5071 and 5th and 4th levels in grid 5077 are noted (fig. 6.37). These zones again coincide with the anomalous samples location for these elements as shown in the fig. 6.37. Thus, it can be said that similar results are obtained by both these techniques in defining the anomalous areas.

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Fig. 6.35. Different level boundaries plot of factor-6 score along with plot of samples anomalous in Mo and W for toposheet no.72E/1.
Fig. 6.36. Different level boundaries plot of factor-6 score along with plot of samples anomalous in Mo and W for toposheet no.72E/6.
Fig. 6.37. Different level boundaries plot of factor-6 score along with plot of samples anomalous in Mo and W for toposheet no. 72E/7.
CHAPTER VII
MINERAL POTENTIAL EVALUATION

Introduction:

One main objective of the present study is to evaluate favorable areas based on geology, geochemistry, and mineral deposit models for occurrences of specific types of mineral deposits within the study area. The following evaluation is based on the information compiled from the geology of the study area, information compiled on mineral deposits or occurrences within the study area (resource inventory), geochemical conclusions derived from the preceding statistical analysis of geochemical data and established mineral deposit models (Cox and Singer, eds., 1986). The purpose of this analysis is to ultimately present the first ever resource assessment of the study area.

Although there are several methodologies for undertaking a resource assessment, depending upon the objective of study and available data, the present study evaluates the mineral potential of the study area utilizing the techniques of 'geologic diversity analysis' and 'characteristic analysis' as described in the following. Utilizing these techniques, the characteristics of the present study area are evaluated on a cell by cell basis and
Methods of Mineral Potential Evaluation:

As stated previously, the evaluation of mineral exploration potential in the present study area is accomplished by applying techniques of geologic diversity analysis and characteristic analysis.

1) Geologic Diversity Analysis:

Geologic diversity analysis is based on the simple principle that the greater the geologic diversity (or complexity), the greater the likelihood of mineralization (hence the larger the favorability) (Clark et.al., 1989). The index of geologic diversity is measured by summing all the favorable variables for each cell of the study area (figs. 7.1 and 7.2). As shall be explained in the data transformation section, the presence of the variables are indicated by 1s and their absence by 0s in the data matrix prepared for all grids or cells. The total number of variables present is determined by adding all presences (1) and the sum used as an index indicating the geologic diversity and hence the degree of favorability of the area for the occurrence of a mineral deposit. The geologic diversity
diversity analysis is used without respect to specific deposit types and it is only an indication of favorability of the area for mineral occurrences.

2) Characteristic Analysis:

The application of mineral deposit models for the purpose of evaluation of areas for mineral exploration potential is based on the premise that geological and geochemical signatures which characterize known mineral deposits can be used to define areas of high favorability as such areas will have qualitatively and quantitatively similar attributes. Therefore, measured characters of known deposits are translated into an ideal representative of a specific deposit type, and that is utilized to evaluate the favorability of specific areas for similar mineral deposits. Those with a high similarity are regarded as having a high potential for mineral exploration and the discovery of deposits. This approach have been summarized by McCammon, et.al. (1981) as follows:

"In exploration, an observation or measurement of a single variable is rarely sufficient to detect the presence of a concealed deposit. More often, a combination of observations or measurements of several variables is significant in terms of predicting the presence (or absence) of a deposit. In the earlier formulation of characteristic analysis, the favorability \( f \) of a given cell was
Fig. 7.1: General flow diagram showing the steps involved in the evaluation of areas for occurrences of specific deposit types (modified after Clark et al., 1989)
Fig. 7.2-Summary matrix showing geologic diversity evaluation as determined by summing variables by cell. The number on the top of each cell is grid I.d., the ratio in each grid is the number of variables present by the number of variables with values.
defined as a weighted linear combination of the binary-transformed variable, that is
\[ f = a_1x_1 + a_2x_2 + \ldots + a_nx_n \]
where, the \( a_i (i = 1, 2, \ldots, n) \) represented the weights and the \( x_i (i = 1, 2, \ldots, n) \) represented \( n \) transformed variables. In other words, once the variables were transformed, they were combined in an additive expression."

Thus, the favorability of a certain cell for certain type of deposit is measured by an index which is a linear combination of binary transformed favorable variables for that cell. Again, as in geologic diversity analysis, the data matrix utilized in the characteristic analysis consists of the geological, structural and geochemical variables measured for each cell. For each cell, the binary data transformation is performed, as shall be discussed in the data transformation section later, with arbitrary weightings of 1 to 3 given to variables to emphasize their relative importance. These geological, structural and geochemical attributes are compared with attributes defined for the specific deposit types occurring within the study area or from established mineral deposit models, and the degree of match for each cell with the mineral deposit model is indicated by the 'index of favorability'. Thus, each cell is evaluated by the index derived by the following equation:

\[ I.F. = \frac{X}{Y} \]

where, I.F. = the index of favorability,

\[ X = \text{total number of weighted variables} \]
present within cell,
\[ Y = \text{total count of variables within that cell.} \]

The higher value of 'I.F.' is obtained when there are higher number of favorable variables with greater magnitudes in cells similar to the mineral deposit model thus indicating the higher favorability for mineral exploration potential.

Resource Inventory and Mineral Deposit Model:

In order to evaluate an area for mineral exploration potential with respect to a specific type of mineral deposit, it is first required to define the attributes of the known mineral deposit to be used as a model. Thus, the establishment of deposit models first requires information about their attributes from known mineral deposits. In the present study, known mineral deposits to be used as models are of two types: those mineral prospects or deposits which are occurring within the study area and those occurring elsewhere in the world. In order to use mineral deposit as a specific model, attributes for model have to be defined such that they can be compared with attributes in the study area.
Thus a resource inventory of the study area is undertaken in the present study to define geological and geochemical attributes of mineral deposits occurring within the study area in order that they may be used to identify other areas (cells) of similar mineralization in the area. Information regarding the type of deposit, geologic and tectonic setting, host rock, commodities, age and their location is compiled for the prospects or deposits which are known to occur in the study area. This compilation of information is presented in the table 7.1

Mineral deposit models are defined by geological and geochemical characters for the purpose of exploration which are seemed to be related to the area of study and thus these are named as 'exploration deposit models'. "Exploration is commonly defined as the searching for and discovery of heretofore unrecognized mineral deposits. It is within this context that one may design deposit models that are specific to both meeting the objective of being an exploration tool and evaluating the utility of existing models in the exploration effort" (Clark, 1984). Thus, exploration mineral deposit models are defined in terms of their geology and geochemistry such that these models can be utilized in evaluating the mineral exploration potential in the study area. A list of these established mineral deposit models to be utilized, which are known to occur in other parts of the
<table>
<thead>
<tr>
<th>Deposit Name</th>
<th>Location</th>
<th>Type of Deposit</th>
<th>Geologic Setting</th>
<th>Host rock</th>
<th>Commodities</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devrali Cu prospect</td>
<td>27 33 15 N 84 54 02</td>
<td>Chalcopyrite, chalcocite and malachite associated, disseminated mineralisation.</td>
<td>Related to shear zones with disseminated sulfides within silicified phyllites overlain by grey phyllites and underlain by green phyllites of Robang Formation.</td>
<td>Mostly phyllites and quartzites</td>
<td>Cu</td>
<td></td>
</tr>
<tr>
<td>Dhusa Cu prospect</td>
<td>27 46 24 N 84 45 09 E</td>
<td>Epigenetic stratabound or stratigraphically controlled chalcopyrite stringers in ferruginous band within a succession of interbedded dolomite, quartzite and schist.</td>
<td>Related to faulting.</td>
<td>Ferruginous dolomite, quartzite and schist</td>
<td>Cu</td>
<td></td>
</tr>
<tr>
<td>Agra Cu prospect</td>
<td>27 40 13 N 85 00 11</td>
<td>Strong silicification and location of mineralization near the porphyritic granitic contact and micaceous quartzite and schist of Kulikhan Formation suggesting epigenetic mineralisation and magmatic hydrothermal in origin.</td>
<td>N-W trending tourmaline bearing aplitic and pegmatitic dikes, chalcopyrite and pyrite associated with intense jointing.</td>
<td>Micaceous quartzite and schists of the Kulikhan Formation.</td>
<td>Cu</td>
<td></td>
</tr>
<tr>
<td>Khairang Pb-Zn prospect</td>
<td>27 40 30 N 84 52 23</td>
<td>Disseminated galena in the southern part, and also, massive galena in forms of stringers and lenses.</td>
<td>Strike-fault controlled.</td>
<td>Medium to coarse grained massive marble.</td>
<td>Pb and Zn</td>
<td></td>
</tr>
</tbody>
</table>

Table-7.1 Mineral deposits or prospects occurring within the study area used as models in the present study.
world, and which are considered to be applicable or considered that they might occur in the present area of study based on the broad knowledge of geology and tectonic setting is compiled (Cox and Singer, eds., 1986). The list of mineral deposit models is presented below in table 7.2:

A. Mineral deposits occurring in the study area:

1. Devrali copper deposit
2. Labang-Khairang Pb-Zn deposit
3. Agra copper skarn deposit

B. Mineral deposits from other than study area:

1. Appalachian Zinc deposit
2. Sn-Skarns deposit
3. Be-Li pegmatites
4. W veins deposit

Table-7.2: Mineral deposits used as models in the present investigation.

Selection of Variables for Deposit Modelling:

Cox et al. (1986) defined a mineral deposit model as follows:

"A mineral deposit model is the systematically arranged information describing the essential attributes (properties) of a class of mineral deposits. The model may be empirical (descriptive), in which instance the various attributes are recognized as essential even though their relationships are unknown; or it may be theoretical (genetic), in which instance the attributes are interrelated through some fundamental concept."

In order to evaluate the mineral exploration potential of the study area for a particular type of mineral deposit
the exploration mineral deposit model to be used has to be first defined. As previously stated one set of exploration mineral deposit models was defined on the basis of the mineral deposit inventory. A second set of mineral deposit models was determined by utilizing the mineral deposit models of Cox and Singer (1986). For this second set the known and previous defined attributes of lithology, structure, geochemistry and geological associations were utilized to ascertain which mineral deposit types of those defined by Cox and Singer (1986) could occur in the study area base on similar geology. In essence two types of exploration deposit models were determined i.e. those known to occur in the study area and those which could occur in the area based on known mineral deposit occurrences elsewhere in the world. For example, the Labang-Khairang type Pb-Zn deposit model occurring in the study area, is defined by geological variables such as the Markhu Marble host rock, structural variables like the number of faults and length of faults which would reflect the tectonic history of the area and the geochemical signatures related to the deposit such as Pb anomaly or Zn anomaly etc.

After defining the attributes which characterize the mineral deposits which occur in the area of study, the data matrix is defined showing the presence or absence of the similar attributes for each cell, which shall be discussed
in the data transformation section later. The same procedure is repeated for mineral deposit models occurring elsewhere in the world.

**Data Transformations:**

Prior to beginning the characteristic analysis a data matrix consisting of a total of 85 possible variables (36 time-petrographic unit variables, 6 structural variables, 13 chemical element variables and 30 variables of factor scores divided into five levels for each factor) is prepared for each cell. Data matrix columns representing proportions of each time-petrographic units present in each cell were computed by digitizing geological maps at the scale of 1:63,360. The columns representing structural variables are quantitatively expressed as the total length of faults or number of faults in each cell or length of contact between granitic rocks and metasediments etc. Columns representing geochemical variables show numbers of anomalies present and the presence or absence of 3rd level to 5th level factor scores. The variable defining the 1st level factor score is a negative factor score and thus was excluded from the data matrix. The 2nd level factor score was also excluded as this level does not define a specific anomaly. Therefore, only 3rd level to 5th level factor scores are included and although this judgement is somewhat subjective, it reflects
the main purpose of identifying areas based on geochemical signatures, favorable for mineral exploration potential. All entries in the data matrix were transformed into binary form by coding all the variables with 1s and 0s for each cell (fig. 7.1). The 1s indicate that the particular variable is present in that cell while 0s indicate its absence. In some cases, information for certain variables are not available or missing and thus cells or grids having no data are left blank.

The data matrix showing the presence or absence of all variables are given an arbitrary weights from 1 to 3 so that importance of certain variables or their magnitudes can be emphasized. As an example the proportion of time-petrographic units are divided into three classes, weighted from 1 to 3, based on the proportion of each unit in individual cells. Similarly, magnitudes of structural variables were also grouped into three groups and according to their magnitudes (length of faults or geological contacts and number of faults as defined in table 5.2, they are weighted from 1 to 3. For geochemical anomalies, the number of anomalies present in each cell are grouped into 3 groups and weighted from 1 to 3 so that the number of anomalies can be accounted accordingly. Weightings of 1 to 3 are given to the 3rd, 4th and 5th level respectively of the factor
scores. Hence, the final data matrix consisted of weighted binary transformed data for each variables.

Application of mineral deposit model:

The basic procedure here is to compute an index of favorability which expresses the degree of match or similarity between variables present within every cell with variables of specific mineral deposit model thereby quantitatively defining the favorability of an area for a specific type of mineral deposit. In order to define favorable variables for specific deposit types, occurring within the study area, it is necessary to construct training cells for mineral deposit models over mineralized zones so that geological, structural, and geochemical variables can be defined that are specific to the occurrence of mineral deposit. For example, the Labang-Khairang Pb-Zn deposit, occurring in grid 1144 (fig. 7.3) is defined by variables present within a 'training cell' which bounds the Labang-Khairang Pb-Zn deposit. The variables within the training cell thus defines the model for the Labang-Khairang type Pb-Zn deposit occurring in the study area. Then, from the binary transformed data matrix consisting of all possible 85 variables, variables are selected which correspond with those of the Labang-Khairang Pb-Zn deposit model. These variables then become the basic inputs for subsequent
Fig. 7.3. Location of mineral deposits occurring in the study area being used to define mineral deposit models.
characteristic analysis of individual cells to ascertain their similarity to the training cell containing the Labang-Khairang Pb-Zn deposit. Similarly data matrices consisting of variables corresponding to each deposit model are built up. To utilize mineral deposits occurring elsewhere in the world as models to be applied, again characters or attributes are defined for them as well. Once again, geological mainly rock-types, structural and geochemical signatures for mineral deposits occurring elsewhere in the world are attributes or characters used to define them as models in the present study. These geological, structural and geochemical attributes were derived from the description of these mineral deposits (Cox and Singer, eds., 1986). Characteristic analysis was applied using these models following similar procedure as applied for models derived based on mineral deposits occurring in the study area as described above. The degree of match or similarity between individual cells and the mineral deposit model is made on a cell by cell basis for each cell. Ultimately the index of favorability is computed for each cell by summing the total number of weighted variables present in every cell corresponding to the total number of variables of deposit model. Thus, the index of favorability is computed for every cell for each deposit model.
Since the highest weighting used for all variables is three and if a certain cell consisted of all favorable variables with highest number and magnitude corresponding to certain mineral deposit model, the highest value of index of favorability for that cell that can be obtained is 3 indicating the most favorable cell in the study area for the occurrence of the deposit model being used. Thus, the index of favorability is computed for all cells against all mineral deposit models.

Results and Discussion:

The results obtained from the geologic diversity evaluation of the study area are presented in fig. 7.2. In fig. 7.2, the numbers on the bottom of each cell represent the index of the geologic diversity. These indices representing the geologic diversity are ratios between the total number of variables present in a cell to the total number of variables evaluated for that cell for each cell. As mentioned above the total number of possible variables in the present study area is 85 however not all the possible variables had been evaluated for any cell. Thus, in order to be able to compare these indices for different cells with different values for the total number of variables evaluated for cells, ratios are presented as indices instead of an absolute value. For example, for grid 1139, 83 variables
had been evaluated while for grid 1147, only 77 variables
had been evaluated, out of 85 possible variables (fig. 7.2).
But for grid 1139, total number of variables present out of
83 evaluated variables is 40 and that for grid 1147 is 27
out of 77. And thus these numbers are presented as indices
and they can not be compared with each other since the
amount of information is different for different grids.
However, cells can be grouped on the basis of similar number
of variables thereby allowing comparisons within similar
groupings. The results obtained are already presented in
fig. 7.2.

To test the validity of this methodology, the results
of the geologic diversity analysis was compared against
known mineral occurrence in the study area. Specifically an
inspection of fig. 7.2 shows that the most diverse grids are
1099, 1133, 1136, 1141, 1146, 1149 and 5077 in terms of
geology, structure and geochemistry. Thus, it can be
inferred that the likelihood of occurrence of mineralization
in these areas is greater than in the rest of the other
cells. Hence, the favorability for mineral exploration in
these cells is larger as previously discussed.

This inference is validated by the results obtained
from the geologic diversity analysis, as shown in figs. 7.2
and 7.3 and in conformity with the mineral inventory data.
Specifically, the Dhusa copper prospect is reported to occur in grids 1099 and 1133, the Labang-Khairang Pb-Zn deposit occurs in grids 1141 and 1144 and similarly, the Devrali copper prospect is reported to occur in grids 1146 and 1149, thus proving the applicability of the technique of geologic diversity analysis for the evaluation of mineral potential in the present study area.

Based on the positive correlation of geologic diversity and known mineral occurrences, it is postulated that other cells with high geologic diversity such as 1093 and 1096, which have similar geological setting as 1099, and grids 1144, 1142 and 1145, which have similar geologic setting as 1141, can be considered highly favorable for mineral occurrences.

Labang-Khairang Pb-Zn deposit model:

Similarly, characteristic analysis was applied to the whole study area using the Labang-Khairang Pb-Zn deposit as a model. The variables defining Labang-Khairang Pb-Zn deposit model is presented in table 7.3.
<table>
<thead>
<tr>
<th>Type</th>
<th>Variable Code</th>
<th>Time-petrographic unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological</td>
<td>1507</td>
<td>Markhu marble</td>
</tr>
<tr>
<td></td>
<td>1508</td>
<td>Markhu schist</td>
</tr>
<tr>
<td>Structural</td>
<td>S₁</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S₂</td>
<td></td>
</tr>
<tr>
<td>Geochemical</td>
<td>Pb geochemical anomaly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zn geochemical anomaly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Factor-3, 3rd, 4th, and 5th levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Factor-4, 3rd, 4th, and 5th levels</td>
<td></td>
</tr>
</tbody>
</table>

Table-7.3: Favorable Variables for the Labang-Khairang Pb-Zn deposit type.

The results obtained from applying geologic diversity and characteristic analyses are comparable, with grids showing high geologic diversity coinciding with those having a larger number of favorable variables for the Labang-Khairang Pb-Zn deposit (fig. 7.2 and 7.4). For example, highest number of favorable variables are noted in grids 1141 and 1144 (fig. 7.4) while the Labang-Khairang Pb-Zn deposit occurs in grid 1144. Based on these results, the areas identified for the favorability of the occurrence of the Labang-Khairang Pb-Zn type deposit are shown in fig. 7.4. Among the group of cells for which total variables evaluated are 12, cells with higher indices of favorability are 1093, 1141, 1142, 1144, 1146, 1149, 5071 and 5069 with indices of favorability more than 1. Among the second group
Fig. 7.4. Summary matrix showing indices of favorability of each cell for the Labang-Khairang type Pb-Zn deposit occurrence. The number on the top of each cell is grid i.d., and that on the bottom is the index of favorability.
for which total variables evaluated are 6, most favorable cells for the occurrence of the Labang-Khairang type Pb-Zn deposit are 5106 and 5109 with indices of favorability of 1.50 and 1.16 respectively. The last group of cells with total variables evaluated being 4 or 5, the cell with highest index of favorability of 2.20 is 5029. The cell 5026 has an index of favorability of 2.00 thus indicating high favorability for the occurrence of the labang-Khairang type Pb-Zn deposit. The other cell with indices of favorability greater than 1 are 5021, 5022, 5023, 5024, 5025, 5027, 5028 and 5152.

Agra copper deposit model:

The next deposit model used for a deposit occurring within the area of investigation was that of the Agra copper deposit (table 7.1). The Agra copper deposit is occurring along the contact between the Agra granitic intrusive and Kulikhani schist. The variables which describe the attributes of Agra copper deposit as a model are shown in table 7.4.

Indices showing the degree of favorability for the occurrences of copper deposits of the Agra type in the study area is shown in fig. 7.5. The area of highest favorability for the Agra type copper deposit is in the area around the
<table>
<thead>
<tr>
<th>Type</th>
<th>Variable Code</th>
<th>Time-petrographic unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological</td>
<td>1408</td>
<td>Kulikhani schist</td>
</tr>
<tr>
<td></td>
<td>2111</td>
<td>Palung granite</td>
</tr>
<tr>
<td></td>
<td>2112</td>
<td>Agra granite</td>
</tr>
<tr>
<td></td>
<td>2113</td>
<td>Arkhaule granite</td>
</tr>
<tr>
<td></td>
<td>2114</td>
<td>Narayanthan granite</td>
</tr>
<tr>
<td>Structural</td>
<td>S₁</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S₅</td>
<td></td>
</tr>
<tr>
<td>Geochemical</td>
<td>Sb</td>
<td>geochemical anomaly</td>
</tr>
<tr>
<td></td>
<td>Bi</td>
<td>geochemical anomaly</td>
</tr>
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<td></td>
<td>Cu</td>
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</tr>
<tr>
<td></td>
<td>Mo</td>
<td>geochemical anomaly</td>
</tr>
<tr>
<td></td>
<td>Ag</td>
<td>geochemical anomaly</td>
</tr>
</tbody>
</table>

Table-7.4: Favorable variables for the Agra copper prospect

grid 5025 and 5029. For the Agra type copper deposit, there are only two group of cells, one with 10 variables and another with 5 variables. Among cells with numbers of variables evaluated 10, cell with highest favorability is 5077 (fig. 7.5). There are many cells with the index of favorability more than one. For example, cell 1147 has an index of 1.60 while cell 1142 has an index of 1142. Among the second group of cell with total 5 variables evaluated, cell 5063 is the most favorable one with an index of 1.60 (fig. 7.5).
Fig. 7.5. Summary matrix showing indices of favorability of each cell for the Agra type copper deposit occurrence. The number on the top of each cell is grid i.d., and that on the bottom is the index of favorability.
Devrali copper deposit model:

Another type of copper deposit occurring in the study area and used as a model was the Devrali copper prospect (fig. 7.3 and table 7.1). This copper prospect is related to mafic intrusives, in contrast the Agra copper prospect which is a deposit related to felsic intrusives. The variables used to define this deposit as a model are presented in table 7.5.

<table>
<thead>
<tr>
<th>Type</th>
<th>Variable Code</th>
<th>Time-petrographic unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological</td>
<td>0805</td>
<td>Malekhu Limestone</td>
</tr>
<tr>
<td></td>
<td>0901</td>
<td>Robang Formation</td>
</tr>
<tr>
<td></td>
<td>1006</td>
<td>Raduwa Schist</td>
</tr>
<tr>
<td></td>
<td>0917</td>
<td>Basic Rocks</td>
</tr>
<tr>
<td>Structural</td>
<td>S₁</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S₂</td>
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</tr>
<tr>
<td></td>
<td>S₄</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S₆</td>
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</tr>
<tr>
<td>Geochemical</td>
<td>Zn geochemical anomaly</td>
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<td></td>
<td>Cu geochemical anomaly</td>
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</tr>
<tr>
<td></td>
<td>Factor-1, 3rd, 4th, and 5th levels</td>
<td></td>
</tr>
</tbody>
</table>

Table-7.5: Favorable variables for the Devrali copper prospect.

Again as for the previous deposit models used, indices indicating the favorability of the area are defined by characteristic analysis using the Devrali copper deposit as the model is presented in fig. 7.6. Cells 1099 and 1133
Fig. 7.6. Summary matrix showing indices of favorability of each cell for the Devrali type copper deposit occurrence. The number on the top of each cell is grid i.d., and that on the bottom is the index of favorability.
show the highest indices indicating the most favorability for the occurrence of the Devrali copper deposit type. Indeed an analysis of mineral resource inventory indicates that in between cells 1099 and 1133, a similar type of copper deposit the Dhusa copper had been explored. It is noteworthy to mention here that the validity of application of characteristic analysis is supported by this evidence. Among cells with number of total variables evaluated being 13, cell with highest index of favorability is 1099 with an index of 1.76. The other cells with high indices of favorability are 1092, 1133, 1142, 1146 and 1149 with indices higher than 1. Among second group of cells with total variables evaluated being 10 or 11, cells with index of favorability greater than 1 are 1059 and 5109.

As stated above, the second part of the mineral potential evaluation, utilizing characteristic analysis is based on established mineral deposit models occurring elsewhere in the world (table 7.2). Different mineral deposit models listed in the section 'Resource Inventory and Mineral Deposit Models' are utilized for the evaluation of favorability of occurrence of those deposit models in the study area and is discussed below.
Appalachian Pb-Zn deposit model:

The model for the Appalachian type Zn deposit is defined by the variables presented in the table 7.6. The variables defining this model are selected from the description of the Appalachian type Zn deposit model (Cox and Singers, eds., 1986).

<table>
<thead>
<tr>
<th>Type</th>
<th>Variable Code</th>
<th>Time-petrographic unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological</td>
<td>0805</td>
<td>Malekhu Limestone</td>
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<td></td>
<td>0503</td>
<td>Dhading Dolomite</td>
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<td></td>
<td>0705</td>
<td>Jhiku Carbonate Beds</td>
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<tr>
<td></td>
<td>1107</td>
<td>Bhainsedobhan Marble</td>
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<td></td>
<td>1507</td>
<td>Markhu Marble</td>
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<td></td>
<td>1805</td>
<td>Chandragiri Limestone</td>
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<td></td>
<td>Cd geochemical anomaly</td>
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<td></td>
<td>Factor-3, 3rd, 4th, and 5th levels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor-4, 3rd, 4th, and 5th levels</td>
</tr>
</tbody>
</table>

Table-7.6: Favorable variables for the Appalachian type Pb-Zn deposit model.

Utilizing the Appalachian type zinc deposit model, the areas favorable for the occurrence of this type of deposit in the study area are shown in fig. 7.7. Fig. 7.7 shows indices of the degree of favorability for the occurrence of the Appalachian type zinc deposit. With numbers on the top of each cell being the cell identification and those on the bottom the ratios of the total of weighted variables present.
Fig. 7.7. Summary matrix showing indices of favorability of each cell for the Appalachian type Pb-Zn deposit occurrence. The number on the top of each cell is grid i.d., and that on the bottom is the index of favorability.
within cell to the total number of variables evaluated within that cell. It is important to note that the total number of variables available or evaluated for different cells are different. The maximum and minimum number of variables that are evaluated are 15 and 6 respectively and thus these indices are evaluated separately by groupings. Among cells with data available for highest number of variables i.e. 15, cells 1093, 1096, 1141, 1142, 1144, 1146, and 1149 have the highest indices of favorability with values more than 0.80 with the cell 1141 having the highest index of favorability of one. Among cells for which data are evaluated only for 8-9 variables, areas favorable for the occurrence of Appalachian type Pb-Zn deposit are 5024 and 5029 with indices of favorability slightly greater than 0.60. However, this inference is based only on limited information available for these grids.

Tin skarn type deposit model:

The another deposit model used in the study area applying characteristic analysis was skarn type deposit of tin. In the present study, as at least one deposit model is used to take into account such that all six factors are dealt with in the application of mineral deposit models and characteristic analysis for the evaluation of mineral potential, tin skarn deposit model was chosen such that it
will represent factor-5 since tin is an element constituting factor-5. As for the Appalachian type Pb-Zn deposit model, the tin skarn type deposit model is defined by choosing the geological, structural and geochemical characters in reference to descriptive model for this deposit as described by Cox and Singer (Cox and Singer, eds., 1986). The parameters which defined best the tin skarn type deposit model is presented in table-7.7:

<table>
<thead>
<tr>
<th>Type</th>
<th>Variable Code</th>
<th>Time-petrographic unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological</td>
<td>2111</td>
<td>Palung Granite</td>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
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<td>Zn geochemical anomaly</td>
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<tr>
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<tr>
<td></td>
<td>W geochemical anomaly</td>
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</tr>
<tr>
<td></td>
<td>Ag geochemical anomaly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sn geochemical anomaly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Li geochemical anomaly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Be geochemical anomaly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Factor-5, 3rd, 4th, and 5th levels</td>
<td></td>
</tr>
</tbody>
</table>

Table-7.7: Favorable variables for the tin skarn type deposit model.

The results obtained is presented in fig. 7.8. So, fig. 7.8 shows areas favorable for the occurrence of tin skarn deposits with highly favorable areas with higher value.
Fig. 7.8. Summary matrix showing indices of favorability of each cell for the skarn type tin deposit occurrence. The number on the top of each cell is grid i.d., those on the bottom is the index of favorability.
of the index of favorability. Thus, as can be seen from fig. 7.8, the study area is again grouped into 3 groups because of different number of variables evaluated for different cells. Among cells for which total number of variables evaluated are 18, cells with indices of favorability greater than 1 are 1091, 1142, 1148, 5019, 5069, 5074, and 5077. Thus, the area within cells mentioned above are more favorable for the occurrence of tin skarn deposits compared to other areas or cells among this group of cells. Among cells of next group with number of total variables evaluated being between 14-15, cell 5029 is the most favorable one with the highest index of favorability of 1.14. In this group, other cells which are comparatively favorable are 5022, 5023, 5025, 5026, and 5109 with indices equal to or greater than 0.80.

Beryllium-Lithium Pegmatite deposit:

The beryllium-lithium pegmatite model is defined simply by the variables which are presented in table-7.8 such that factor-2 scores can also be used to evaluate the favorability of areas for the occurrence of mineral deposit similar to the model. The selection of variables defining beryllium-lithium deposit related to pegmatites were choosen simply based on geological reasoning that time-petrographic units favorable must be pegmatites or granites obviously and
similarly the geochemical signatures must be lithium and beryllium. The time-petrographic unit metamorphic schist is included in the geological variable as pegmatite veins are occurring in the metamorphic schist unit. Also, structural variables like number of faults and length of faults are included as these structures are favorable for pegmatite veins.

<table>
<thead>
<tr>
<th>Type</th>
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<th>Time-petrographic unit</th>
</tr>
</thead>
<tbody>
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<td>Geological</td>
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<td>Palung Granite</td>
</tr>
<tr>
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</tr>
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<td>2113</td>
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</tr>
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<td></td>
<td>2114</td>
<td>Narayanthan Granite</td>
</tr>
<tr>
<td></td>
<td>2219</td>
<td>Metamorphic Schist</td>
</tr>
<tr>
<td></td>
<td>2220</td>
<td>Metamorphic Gneiss</td>
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<td></td>
<td>$S_2$</td>
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</tr>
<tr>
<td>Geochemical</td>
<td>Li geochemical anomaly</td>
<td></td>
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<tr>
<td></td>
<td>Be geochemical anomaly</td>
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</tr>
<tr>
<td></td>
<td>Factor-2, 3rd, 4th, and 5th levels</td>
<td></td>
</tr>
</tbody>
</table>

Table-7.8: Favorable variables for the beryllium-lithium pegmatite deposit model.

Using the beryllium-lithium deposit model thus defined and applying characteristic analysis to each cell, areas relatively favorable for the occurrence of this type of deposit are identified and is shown in fig. 7.9.
Fig. 7.9. Summary matrix showing indices of favorability of each cell for the beryllium-lithium pegmatite deposit occurrence. The number on the top of each cell is grid i.d., that on the bottom is the index of favorability.
For this beryllium-lithium deposit model, cells are grouped into 4 groups with different numbers of variables (fig. 7.9). Inspection of fig. 7.9 shows that among cells for which number of variables evaluated is 13, the most favorable cell for the occurrence of beryllium-lithium pegmatite deposit is 5077 with the index of favorability of 1.23. Cells 1145 and 1148 have index of favorability of 1.15 showing that these cells are also highly favorable for the occurrence of beryllium-lithium deposit related to pegmatites (fig. 7.9). The other cells with relatively high index of favorability with the value of 0.92 are cells 5069 and 5074 (fig. 7.9). Among cells for which total number of variables evaluated are 10 to 11, cells 5025, 5026 and 5029 have the index of favorability of 1 and thus they are most favorable ones for the occurrence of beryllium-lithium deposit among this group of cells. For the group of cells with least number of variables evaluated which is 8, the index of favorability obtained are low. The maximum index obtained is 0.25 for all cells in this group which means that these cells are not very favorable for the occurrence of beryllium-lithium deposit related to pegmatites.

Tungsten veins deposit model:

One of the mineral deposit model used in the present research is tungsten vein deposit model. This deposit model
is also chosen based on similar geological reason as with other mineral deposit models used. The tungsten vein mineral deposit model is also chosen such that it can be dealt with factor-6 scores. The tungsten vein deposit model is defined by the selected variables which are presented in the following table 7.9.

Applying characteristic analysis using tungsten vein deposit model thus defined above, areas relatively favorable for the occurrence of tungsten vein type deposit are shown in fig. 7.10. As in other deposit models used, cells were grouped into 3 groups according to number of variables evaluated for every cell. Among cells of first group for which total number of variables evaluated available is 24, cell with the highest index of favorability with the value of 1.58 is 5077. Other cells with high indices of favorability with values equal or greater than 1 are 1099, 1141, 1142, 1144, 1145, 1147, 1148, 1149 and 5069. Similarly among cells of second group, cells with high favorability for the occurrence of tungsten vein type deposit are 5023, 5026 and 5029 with indices of favorability greater than 1. For the group of cells for which total variables evaluated are 11, indices of favorability are low with index of favorability less than 0.18. So, cells of this grouping are not very favorable for the tungsten vein type deposit to occur.
<table>
<thead>
<tr>
<th>Type</th>
<th>Variable Code</th>
<th>Time-petrographic unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological</td>
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</tr>
<tr>
<td></td>
<td>1601</td>
<td>Tistung Phyllites</td>
</tr>
<tr>
<td></td>
<td>1206</td>
<td>Kalitar Schist</td>
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<td></td>
<td>1302</td>
<td>Chisapani Quartzite</td>
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<td></td>
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<td>Arkhaule Granite</td>
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<tr>
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<td>S₂</td>
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<td>S₃</td>
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<td></td>
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<tr>
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<td>W</td>
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<td>Factor-6, 3rd, 4th, and 5th levels</td>
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</table>

Table-7.9: Favorable variables for the tungsten vein deposit model.
Fig. 7.10. Summary matrix showing indices of favorability of each cell for the tungsten vein deposit occurrence. The number on the top of each cell is grid i.d., that on the bottom is the index of favorability.
CHAPTER VIII
SUMMARY AND CONCLUSION

The primary objective of the present study was to evaluate the mineral potential of the study area by developing and applying a methodology that utilizes integrated geological, structural and geochemical data to assess mineral potential. The mineral potential is expressed as the quantitative favorability of an area for the occurrence of a specific type of mineral deposit. The results of the quantitative assessment can be used for guiding exploration programs. The quantitative assessment of mineral potential utilizes time-petrographic units, structure and geochemical signatures defined by statistical tools including both basic statistics and multivariate factor analysis. In evaluating the methodology, it was concluded that factor analysis is the best discriminating tool in establishing elemental associations and the relation between geology and geochemistry. The elemental associations obtained consist of six factors, with each factor comprised of a group of related elements related to the geology of the area. They are:

Factor - 1: Mg, Ba, La, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn
Factor - 2: Li, Na, K, Be, Al
Factor - 3: As, Sb, Bi, Pb
Factor - 4: Ca, Mg, Sr, Pb
Factor - 5: Ag, Sn, Cd
Factor - 6: Mo, W
For example, factor-1 showed the association of mostly mafic elements derived from ferro-magnesian minerals. When the relation between geology and geochemistry was defined by a contour plot of factor-1 scores over the geology of the study area, it was shown that factor-1 is mainly related to mafic intrusives and derived from ferro-magnesian minerals present in these mafic rocks. Similarly, elemental associations defined by factor-2 are composed of felsic elements related to mainly granitic intrusions, pegmatites and gneisses and derived from rock forming minerals such as potash feldspars, plagioclase feldspars, muscovites and biotites. The elemental association as defined by the factor-3 is related to sulfide mineralization, especially Pb and Zn deposits, as shown by the coincidence of high factor scores of the factor-3 over the already identified Pb-Zn mineral deposits in the study area. The element Bi falls into both factor-2 and factor-3.

Within the factor-4 elements Ca, Mg and Sr occur together as would be expected and as Sr has a very similar ionic radius to Ca, in association with dolomites. The element Pb in the factor-4 association is primarily derived from galena occurring in the carbonates as sulfide mineralization. The association of factor-3 and factor-4 over the carbonate rocks substantiates the applicability of factor analysis in establishing both elemental associations.
and the relation between geochemistry and geology. This conclusion is further supported by the factor-5, which is related mainly to the reworked sediments forming the Kuncha Phyllites within which the elemental association of Ag, Sn and Cd are inferred to be derived from Ag and Sn mineralizations or from Sn placers. Within factor-5 the behavior of the element Cd is not well understood, and warrants further investigation however the association of Ag and Sn is well established both in the literature and by present research.

The last factor i.e. factor-6 defined by the association of Mo and W is also geochemically valid as these two elements are known to occur together in contact metasomatic deposits and have similar ionic radius. The factor scores of the factor-6, when contoured over the geologic map of the study area, shows a strong relation with granitic intrusives.

Following the definition of factors 1 to 6 and their relation with geology and mineral occurrences, an evaluation and application of factor analysis in identifying geochemical anomalies was tested. The procedure was evaluated by applying the basic statistical method of using mean ± 2 s.d. to ascertain the advantage of factor analysis over the basic method. As shown in chapter-6, areas defined
by high factor scores for all factors, in general, coincide with the plot of meaningful anomalous samples of individual elements. Thus, for example, when anomalous samples of As, Sb and Pb are plotted, they generally occur over areas with high factor scores for factor-3. However, when samples anomalous in Li and Be are plotted, the plot of anomalous samples do not show any particular association with any particular level of factor scores for factor-2. Even the negative factor scores are covered by the plot of anomalous samples as well as the area with highest factor scores. Thus factor analysis together with the basic statistical method of mean + 2 s.d. enhances identification of anomalous areas and is a useful technique in identifying the meaningful geochemical anomalies.

The technique of geologic diversity analysis was applied to identify favorable areas for mineral occurrences. Its applicability in mineral potential evaluation is validated in the study area by application to reported occurrences of mineral deposits in the study area and with areas of high geologic diversity as shown by the results derived in chapter-7.

The applicability of multivariate characteristic analysis was tested and validated by establishing the coincidence of reported occurrences of mineral deposits over
the area characterized by the high indices of favorability. The application of characteristic analysis to the Devrali type copper prospect occurring in the study area was used as one of the deposit model. The technique showed a high index of favorability in the area between cells 1099 and 1133 where the Dhusa copper prospect, similar to Devrali type deposit, had already been reported to occur.

The evaluation of the mineral potential in the study area was accomplished by the application of characteristic analysis and mineral deposit models, utilizing the basic data of time-petrographic units, structural information and geochemically favorable areas identified by both basic statistics and factor analysis. As the number of variables evaluated are different for different cells or different areas, the favorability of individual area could not be expressed in the same scale. Therefore cells were differentiated into specific groups for each individual type of mineral deposit model used. The favorability of a certain cell therefore is compared to another cell within an individual grouping. Results obtained were presented in chapter-7 as summary matrices showing the indices of favorability of individual area for different mineral deposit models. These results define priority exploration areas, for specific types of mineral deposits, according to the mineral deposit model used. In this study it was
concluded that the potential areas of exploration for the Labang-Khairang type Pb-Zn deposit model are cells 1093, 1141, 1142, 1144, 1146, 1149, 5071, and 5069 based on geologic and geochemical similarities of these cells with the geologic and geochemical parameters of the Labang-Khairang type of deposit. These cells also show high geologic diversity supporting the conclusion derived above by the application of characteristic analysis.

Similarly, the potential areas for the Agra type copper prospect can be delineated as those within cells 1059, 1091, 1095, 1099, 1133, 1136, 1139, 1141, 1142, 1144, 1145, 1146, 1147, 1148, 1149, 5021, 5022, 5023, 5025, 5026, 5029, 5068, 5069, 5071, 5074, and 5077. The geologic diversity analysis also shows these cells with high geologic diversity, again supporting the conclusion derived.

The use of the Devrali type copper prospect model led to the conclusion that the potential areas for this type of deposit in the study area are within cells 1099, 1133, 1142, 1146, and 1149, also evidenced by high geologic diversity. The above mineral deposit models used were derived from known occurrences within the study area. However, the study area was also evaluated on the basis of mineral deposit models, known to occur in the other parts of the world, which were judged to be applicable to the geological
attributes of the study area. For this purpose several international models were applied to evaluate for deposits which may occur within the study area. Thus, the study area was evaluated for the Appalachian type Pb-Zn deposit model and led to the conclusion that the potential areas for this type of occurrence are within cells 1093, 1141, 1142, 1144, 1146 and 1149 with both high indices of favorability and high geologic diversity.

Cells 1091, 1142, 1148, 5019, 5069, 5074 and 5077 are comparatively more favorable for the occurrence of skarn type tin deposit as concluded by high indices of favorability and geologic diversity.

Relatively favorable areas for beryllium-lithium deposits, related to felsic rocks, are within cells 1145, 1148, 5069, 5074 and 5077 showing high indices of favorability and geologic diversity compared to other cells in the study area. Similarly, areas more favorable for the occurrence of tungsten veins type deposit model as delineated by the application of characteristic analysis is within cells 1099, 1141, 1142, 1144, 1145, 1147, 1148, 1149 and 5069 as also supported by high geologic diversity except the cell 1147 has a lower ratio of geologic diversity.
It is important to note that the evaluation of areas favorable for certain type of mineral deposit model can be made by the application of characteristic analysis together with the technique of geologic diversity analysis. In certain cases geologic diversity analysis may show a different result than that from the characteristic analysis. This was apparent in the case of the Agra type copper deposit model because two variables primarily defined the Agra type model, as explained above.

Based on the final results of the mineral potential evaluation of the study area, it was concluded that areas most favorable for mineral potential in the present study area is within the cell 1142 as this cell shows high index of favorability for the occurrence of 6 out of 7 mineral deposit model applied. The area in the cell 5069 showed a high index of favorability for the occurrence of 5 out of 7 mineral deposit model applied and thus it can be considered less favorable than the cell 1142 but more favorable than other cells such as those like 1144, 1146, 1148 and 1149 which showed high index of favorability for 4 out of 7 mineral deposit models applied. Cells 1099 and 1141 showed high index of favorability for only 3 out of 7 mineral deposit models while cells 1091, 1093, 1133, 1145, 1147, 5071, 5074 and 5077 showed favorable for only 2 deposit models. The least favorable cells, among the cells
identified as potential areas for mineral deposit occurrences, as they showed favorability for only one mineral deposit model out of 7 mineral deposit models applied are 1095, 1136, 1139, 5019, 5021, 5022, 5023, 5025, 5026, 5029 and 5068. Hence, the characteristic analysis along with geologic diversity analysis was successfully applied in evaluating the area potential for mineral exploration with the utilization of time-petrographic and structural information of the study area, geochemical conclusions derived based on the statistical analysis of multi-element stream sediment samples from the study area and mineral deposit models from the study area as well as those from other areas.

The methodology utilized in this study represents a new technique that has broad application in other parts of the country, as this kind of approach has not been applied for mineral potential evalution before. This new methodology also resulted in the identification of priority exploration areas for specific types of mineral deposits, the majority of which had not been identified in previous exploration programs. In particular previous stream sediment geochemical exploration activities were only able to identify geochemically anomalous zones while the methodology as applied here leads to the definition of both new zones and identification of the type of mineral deposit to be
explored for in the area. When this methodology for evaluating mineral potential is geographically extended to other areas, certainly other exploration areas not previously identified before are expected to be defined.

The structural control on mineralization in the study area and throughout the Himalayas has been a subject of debate in the economic geology of Nepal for long time. The present study has demonstrated that the structural features are a primary control on mineralizations for several types of mineral deposits. For all mineral deposit models used the structural variables S1 and S2 were important attributes which showed a high index of favorability within cells with these structural characters. The major structural controls are predominantly the major thrust faults, especially the Mahabharat Thrust, and intrusive contacts. For example, the application of the Dhusa type copper deposit, which itself is developed along the major thrust fault and intrusive contact, showed a high favorability in cells with the presence of these structural features as already mentioned and exemplified by Devrali copper prospect. Similarly, the application of the tin skarn deposit model and the Agra copper skarn model showed the importance of the structural contact of granitic rocks with the metasediments of the study area for the formation of both types of deposit. It is also noteworthy that the favorable areas for the tungsten
vein type deposit model are characterized by the structural variable S5 which is again an intrusive contact between granitic rocks and metasediments thus, substantiating the critical role of structure in the ore geology of the study area and inference throughout the region.

Finally, one of the most important contribution of the present study is the integration of meaningful geochemical anomalies through mineral deposit modelling and thereby taking into account their geological association together rather than just defining the geochemical anomalies. Additionally, the elemental associations defined and relation of high factor score zones with those elemental associations has also been interpreted in relation to the geology associated with them. Thus, it can be said that results achieved in identifying favorable areas for exploration of particular types of mineral deposits in the present investigation carry significant and meaningful conclusion which far outweigh results which can be obtained by many other conventional methods.
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PLEASE NOTE:

Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

Standard 35mm slides or 17" x 23" black and white photographic prints are available for an additional charge.
EXPLANATORY NOTE

GENERAL REMARKS

This map is a reduced version of an unpublished map at the inch: 1 mile (1:63360) scale, the result of 8 months field work by authors during the period 1972-77. Systematic use was made of aerial photographs, and additional information was drawn from maps of Gandoor et al. (1968-73), Hashimoto et al. (1973), and P. Le Fort (personal communication).

The area represents part of the Lesser Himalaya to the south of the Manaslu-Langtang segment of the High Range. The Lesser Himalaya includes the densely populated Kathmandu Valley. Monsoon rains during the hot June-September season and a dry climate during the rest of the year. Tropical jungle covers the southern foothills and gives way to rhododendron and higher ridges. Extensive cultivations, dominated by rice, occupy large tracts of the intermediate zone, with terraced rice fields spreading over many of the exceedingly steep mountain slopes. Deep weathering and soil erosion are important where conditions are poor except along river banks.

REVIEW OF FORMATIONS

Apart from the Neogene Siwalik Group of molassic deposits forming the foothill zone, the rocks are mainly Precambrian crystalline. They have been grouped into two complexes: the Nawakot Complex and the Kathmandu Complex. Both are part of the Mahabharat synclinorium, the dominant structural feature (Sections A,B,C,D). The Kathmandu Complex occupies the central part of the Mahabharat synclinorium, whereas the underlying Nawakot Complex forms the synclinorial rim and most of the gently folded Midland Zone. The two Complexes are distinguished primarily by their stratigraphy, but they differ also in nature and grade of metamorphism, association with igneous rocks.

The Nawakot Complex is composed almost exclusively of low-grade metasediments. It has been subdivided into two groups, the Upper Nawakot Group and the Lower Nawakot Group, the two being separated by a regional unconformity.

The Lower Nawakot Group, about 8 km thick, is dominated in the lower part by non-carbonaceous clastic deposits such as phyllic meta-sandstones and quartz-conglomerates that make up the flysch-like Kuncha Formation. The lowest unit, the Aryan Formation, is characterised by massive, reef-like marble bodies (stromatolitic bioherms) in the south to biotitic schist with intercalations of quartzite and quartzites that normally overlie the Dhading Dolomite and have been preserved below the Upper Nawakot Group.

The Upper Nawakot Group, of strongly variable thickness reaching a maximum of 5 km, starts with the Binsar quartzites and partly carbonaceous rocks with local boulder beds and irregular tongues and lenses of phyllic carbonates reminiscent of the Upper Palaeozoic Binsar Beds of the Kotbelta (Simla Himalaya). They onlap on different units of the Lower Nawakot Group and form the main thickness in the low-lying Kuncha Formation in the Sun Kosi Valley. The contact appears everywhere as a sharp lithological break and is marked by traces of lateritization. These facts indicate an erosional unconformity and a sedimentary gap between the two formations. The Upper Nawakot Group has a large area of the High Range, with angular discordance, however, can be discerned. The lithology is very distinctive, with the Binsar Quartzites becoming more important in the south. Associated with both phyllicites and quartzites occur chlorite chloritoid forms that show synsedimentary relationships, as well as massive, gabbroic bodies showing intensive tectonic deformation. These rocks are the Late Palaeozoic volcanism of the Himalaya (Panjal Traps, Abor volcanics) is believed to have been deposited spread over many of the exceedingly steep mountain slopes. Deep weathering and soil erosion are important where conditions are poor except along river banks.

The Kathmandu Complex is divided into the Precambrian Bhimphedi Group of relatively high-grade metasediments and the Phulchauki Group of Palaeozoic sediments. In addition, the Complex contains granites and migmatitic gneisses.

The metasediments of the Bhimphedi Group reach about 8 km thickness. They consist of the greater part of pelitic and argillaceous rocks with local boulder beds and irregular tongues and lenses of phyllic carbonates. The Upper Palaeozoic Binsar Beds of the Kotbelta (Simla Himalaya). They onlap on different units of the Lower Nawakot Group and form the main thickness in the low-lying Kuncha Formation in the Sun Kosi Valley. The contact appears everywhere as a sharp lithological break and is marked by traces of lateritization. These facts indicate an erosional unconformity and a sedimentary gap between the two formations. The Upper Nawakot Group has a large area of the High Range, with angular discordance, however, can be discerned. The lithology is very distinctive, with the Binsar Quartzites becoming more important in the south. Associated with both phyllicites and quartzites occur chlorite chloritoid forms that show synsedimentary relationships, as well as massive, gabbroic bodies showing intensive tectonic deformation. These rocks are the Late Palaeozoic volcanism of the Himalaya (Panjal Traps, Abor volcanics) is believed to have been deposited spread over many of the exceedingly steep mountain slopes. Deep weathering and soil erosion are important where conditions are poor except along river banks.

The Phulchauki Group, about 8 km thick, consists of the slightly metamorphosed siliciclastites, sandstones and quartzites of the upper part, and of fossiliferous limestones and shales in the upper part. Fossils range from Late Ordovician to Late Devonian (Bordet et al., 1959; Gupta, 1975; Stocklin et al., 1977). The Devonian limestone of Phulchauki hill is the highest unit of the Phulchauki Group and shows intercalations of quartzites and sandstones.
EXPLANATORY NOTE

GENERAL REMARKS

This map is a reduced version of an unpublished map at the 1 inch: 1 mile (1:63360) scale, the result of 8 months of field work done by the authors during the period 1975-77. Systematic use was made of aerial photographs, and additional information was drawn from unpublished maps of Gandotra et al. (1966-73), Rashotra et al. (1973), and P. Le Fort (personal communication).

The area represents part of the Lesser Himalaya to the south of the Manali-Langtang segment of the High Range. It covers the central sector of the Mahabharat Range and adjoining parts of the Midland zone, including the densely populated Kathmandu Valley, the heartland of Nepal. The area is drained by the Trisuli and Bagmati Rivers in the west, the Bagmati River in the centre, and the Sun Kosi in the east, all joining the Ganges River in northern India. Elevations range from 200 m at the southern mountains to little short of 5000 m in the highest parts of the Mahabharat Range. The area receives monsoon rains in the hot June-September season and is favoured by a mild, dry climate during the rest of the year. Tropical jungle covers the southern foothills and gives way to rhododendron and pine forest on the higher ridges. Extensive cultivations, dominantly rice, occupy large tracts of the intermediate zone, with terraced fields and scattered settlements spreading over many of the exceedingly steep mountain slopes. Deep weathering and soil erosion are intense, and eutrophic conditions are poor except along river banks.

REVIEW OF FORMATIONS

Apart from the Neogene Siwalik Group of molassic deposits forming the foothill zone, the rocks are mainly metamorphosed and crystalline. They have been grouped into two complexes, the Nawakot Complex and the Kathmandu Complex. Both together build up the Mahabharat synclinal, the dominant structural feature (Sections A,B,C,D). The Kathmandu Complex occupies the large core of the synclinorium, whereas the underlying Nawakot Complex forms the synclinal rim and most of the gently folded Midland zone to the north. The two complexes are distinguished primarily by their stratigraphy, but they differ also in nature and grade of metamorphism and in their association with igneous rocks.

The Nawakot Complex is composed almost exclusively of low-grade metamorphosed rocks. It has been subdivided into the Lower and Upper Nawakot Groups, the two being separated by a regional discontinuity.

The Lower Nawakot Group, about 6 km thick, is dominated in the lower part by non-metamorphic clastic deposits such as the phyllites, phyllitic metasandstones and quartz-schists that make up the typical Kucla Formation, the lowest unit exposed. Carbonatic layers make a sporadic appearance in the Bandagaon Phyllite but become more important in the Kaule Formation. The feature-forming stromatolitic Dhuandari Phyllite has yielded the type Brachytes and Nannolites (identified by G. Terres) as well as indeterminable echinoderm fragments. These are the only fossils ever discovered in the Nawakot Complex; they suggest a Late Precambrian age for its pre-Dhuandari and a Paleozoic age for its post-Dhuandari portion. Only in the Rapti Khola area have the dolomitic, quartzitic and phyllite of the Khosar Beds that normally overlie the Dhuandari Phyllite been preserved below the Upper Nawakot discontinuity.

The Upper Nawakot Group, of strongly variable thickness reaching a maximum of 5 km, starts with the Bengaite Series. These dark argillaceous and partly carbonaceous rocks with local boulder beds and irregular tongues and lenses of phyllitic carbonates (Bengaite Beds) are reminiscent of the Upper Paleozoic Blaine Beds of the Kocbel (Sima Himalaya). They split on different units of the Lower Nawakot Group down to the Kocbel Formation in the Sun Kosi Valley. The contact appears everywhere as a sharp lithological break and in the lower Bungo Ganda this is marked by a zone of translation. These facts indicate an erosional unconformity, and a sedimentary, gap between the Lower and Upper Nawakot Groups; no angular discordance, however, can be discerned. The lithologically very distinct Maluhia Limestone, above the Bengaite Series, is an excellent marker. The dolomite-Rhyolite Formation is predominantly phyllitic in the north, but the intercalated Dunga Quartzites become more important in the south. Associated with both the phyllites and quartzites occur chert and amorpholite metablocks that show syndepositional relationships, as well as massive, gabbroic bodies showing intrusive contacts. A relation of these basic rocks with the Late Precambrian volcanism of the Himalaya Panjal Traps, still controversial, is suggested. The Rhyolite Formation, as in places closer units of the Nawakot Complex, is discordantly overlain by highly metamorphosed assemblages that characterize every where the base of the Kathmandu Complex; the discordance is associated with intense shearing and is interpreted as a thrust plate (Mahabharat Thrust).

The Kathmandu Complex is divided into the Precambrian Bhimphedi Group of relatively high-grade metamorphosed rocks and the overlying Phulchoki Group of Paleozoic sediments. In addition, the Complex contains granites and migmatitic gneisses.

The metamorphosed of the Bhimphedi Group reach about 6 km in thickness. They consist of the greater part of pelitic and phyllitic deposits now converted to monotonous mica-schists and impure, strongly micaeous quartzites (Rudawa, Khetu and Kulkhahi Formations), in which biotite is ubiquitous, whereas garnet occurs only in the lower part, intercalated are the purer, white Puningara and Chisapani Quarries and two thick carbonate formations, the Shaliseddhar Marble and the Marbath Formation, all of which form useful markers. The carbonate rocks, in contrast to those of the Nawakot Complex, have all a coarsely crystalline texture. The Marbath Formation changes from massive, reef-like marble bodies (stromatolitic bioherms) in the south to biotite schist with intercalations of quartzite and impure marble in the north.

The Phulchoki Group, 5.6 km thick, consists of the slightly metamorphosed sandstones, shales and sandstones of the Tistung Formation in the lower part, and of fossiliferous limestones and shales in the upper. Fossils range from late Ordovician to Devonian (Borden et al. 1956; Gupta 1973; Sobolev et al. 1973). The Devonian limestones of Phulchoki is the highest unit of the group, forming the summit of the Phulchoki Hill south of Kathmandu and the very core of the Mahabharat synclinorium. Phulchoki et al. in press reported an
GEOL O GICAL MAP OF
KATHMANDU AREA AND
CENTRAL MAHABHARAT RANGE

Scale: 1:250 000

J. Stocklin and K.D. Bhattarai

with contributions by V. Singh-Chhetri and A.N. Bhandari

N A W A K O T C O M P L E X

Robang Formation: blue-green phyllites, chloritic, partly
tuffaceous; du: Dunga Quartzite Beds,
gd: metagabbro, metabasite, amphibolite.
Maikhali Limestone: yellow, fossiliferous, finecrystalline sili-
ceous limestone, in middle part dark dolomitic limestone.

K A T H M A N D U

Devonian Limestone
dolomitic underclay
Chitlang Slates an
slates; white quar-
impure limestones
trilobites (Silurian
MAP OF AREA AND HARAT RANGE

Bhattarai etri and A. N. Bhandari

KATHMANDU COMPLEX

Dolomite underlain by red oolitic limestone.
Chittang slates and Silurian beds of Phulehua: dark slates; white quartzite near base; in upper part few impure limestones and two ferruginous beds containing
The Upper Nawakot Group, of strongly variably argillaceous and partly carbonate rocks with local reminiscence of the Upper Palaeozoic Blaini Beds of the Kandhai Formation in the Sun Kosi Valley, is marked by traces of lateritization. These facies of the Upper Nawakot Groups, with angular discordance, show the Benighat Slates, an excellent marker. The chlorite-Dunga Quartzites become more important in the southern metadiabases that show synsedimentary relationships and in places older units of the Nawakot Complex, are the base of the Kathmandu Complex (the discordance is the Main Central Thrust).

The Kathmandu Complex is divided into the Pre-Phulchauki Group of Palaeozoic sediments. In addition, the Phulchauki Group, 5-6 km thick, consists of:

1. The Phulchauki Group, 5-6 km thick, consists of deposits now converted to monotonous mica-schists, which are biotitic, with garnet and quartzite, and two thick carbonate formations, the Bha-Quartzites and two thick carbonate formations, the Bha-Quartzites and the Upper Nawakot Groups; no angular discordance, however, to that of the Nawakot Complex.

2. The Phulchauki Group shows unmistakable similarities with the Lower Phulchauki Formation in the Sun Kosi Valley, and with the Chatsun Limestone of the Nlympo Group, which is marked by traces of lateritization. These facies of the Upper Nawakot Groups, with angular discordance, show the Benighat Slates, an excellent marker. The chlorite-Dunga Quartzites become more important in the southern metadiabases that show synsedimentary relationships and in places older units of the Nawakot Complex, are the base of the Kathmandu Complex (the discordance is the Main Central Thrust).

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METAMORPHISM AND GRANITIZATION

The metasediments of the Kathmandu Complex, metamorphosed sediments on top to the coarse-grained metamorphic basement, consist of a sequence of meta-schists: the oldest Bhimphedi schists but appearing in the section and are said to become generally more common to the north. The granites are equally confined to the Kathmandu Complex, related to the gneisses, having a similar mineral composition. Granitization is significant: the metamorphic gneisses clearly interfinger with the metasediments; the all possible stratigraphic levels up to the Tistung Formation, which is marked by traces of lateritization. These facies of the Upper Nawakot Groups, with angular discordance, show the Benighat Slates, an excellent marker. The chlorite-Dunga Quartzites become more important in the southern metadiabases that show synsedimentary relationships and in places older units of the Nawakot Complex, are the base of the Kathmandu Complex (the discordance is the Main Central Thrust).

TECTONICS

Large-scale thrusting seems to be the most plausible explanation. (Bhimphedi) rocks on the lower-grade Palaeozoic Nawakot shear-folding, imbrication and partial truncation of the upper, indicated on the map by the distorted structure of the Main Central Thrust, appears as a rigid, competent mass: the map shows parallel bands smoothly around the large synclinal bend Nawakot rocks to southwest. In outcrop, however, the transitional zone of reverse metamorphism, in which chlorite-schist into the coarse garnet-schists at the base of the Range, where Le Fort (1975) related the movements at the SSW "mineral streak" lineation (This lineation appears a suggesting thus rather an old, Precambrian phase of defor-
econoem fragments. These are the only fossil remains discovered in the Nawakot Complex; they suggest a late Precambrian age for its pre-Dhading and a Paleozoic age for its post-Dhading portion. Only in the Rigil Khola area have the dolomitic, quartzitic and phyllitic Hushi Beds that normally overlie the Dhading Dolomite been preserved below the Upper Nawakot disconformity.

The Upper Nawakot Group, of strongly variable thickness reaching a maximum of 5 km, starts with the Benighat Slates. These dark argillaceous and partly carbonate rocks with local boulder beds and irregular lenses and tongues of phylitic carbonates (Jhika Beds) are reminiscent of the Upper Paleozoic Blains Beds of the Krol belt (Simla Himalaya). They onlap on different units of the Lower Nawakot Group down to the Kuncha Formation in the Sun Kosi Valley. The contact appears everywhere as a sharp lithological break and in the lower Burhi Gandaki is marked by traces of lateritization. These facts indicate an erosional disconformity and a sedimentary gap between the Lower and Upper Nawakot Groups; no angular discordance, however, can be discerned. The lithologically very distinctive Malekhu Limestone, above the Benighat Slates, is an excellent marker. The chlorite-rich Robang Formation is predominantly phyllitic in the north, but the intercalated Danga Quartzites become more important in the south. Associated with both the phyllites and quartzites occur chloritic and amphibolitic metadiabases that show symmetrodium relationships, as well as more massive, gabbroid bodies showing intrusive contacts. A relation of these basic rocks with the Late Paleozoic volcanism of the Himalaya (Panjal Traps, Abor volcanics) is suspected. The Robang Formation, and in places older units of the Nawakot Complex, are discordantly overlain by highly metamorphic schists that characterize everywhere the base of the Kathmandu Complex; the discordance is associated with intense shearing and is interpreted as a thrust plane (Mahabharat Thrust).

The Kathmandu Complex is divided into the Precambrian Bhimphedi Group of relatively high-grade metamorphosed and the overlying Phulchauki Group of Paleozoic sediments. In addition, the Complex contains granites and migmatic gneisses.

The metasediments of the Bhimphedi Group reach about 8 km thickness. They consist for the greater part of pelitic and psammitic deposits now converted to monotonous mica-schists and impure, strongly micaceous quartzites (Rudawa, Kalitar and Kuhlkan formations), in which biotite is ubiquitous, whereas garnet occurs only in the lower part. Intercalated are the purer, while Pandang and Chisapani Quartzites and two thick carbonate formations, the Bhainsedobhan Marble and the Markhu Formation, all of which form useful markers. The carbonate rocks, in contrast to those of the Nawakot Complex, have all a coarsely crystalline texture. The Markhu formation passes upward from massive, reef-like marble bodies (stromatolitic bioherms?) in the south to biotitic schist with intercalations of quartzite and impure marble in the north.

The Phulchauki Group, 5-6 km thick, consists of the slightly metamorphosed silstone beds, shales and sandstones of the Tistung Formation in the lower part, and of fossiliferous limestones and shales in the upper. Fossils range from Late Ordovician to Devonian (Bordet et al., 1977). The Devonian limestone of Phulchauki is the highest unit of the Group, forming the summit of the Phulchauki Hill south of Kathmandu and the very core of the Mahabharat synclinorium. Pradhan et al. (in press) reported an unconformity, associated with pebble beds, at or near the base of the Phulchauki Group. This could indicate a significant break in the sedimentary sequence and possibly in the structural evolution, consistent with the lower grade of metamorphism and a seemingly lower intensity of internal deformation in the Phulchauki Group as compared to the underlying Bhimphedi Group. The discordance, however, cannot be strong, as the underlying Markhu Formation has not been truncated but is preserved all around the synclinorium. The Phulchauki Group shows unmistakable similarities with the Lower Paleozoic succession of the Tibetan sedimentary zone in the High Himalaya; in particular, the thick Chandragiri Limestone can be well compared with the Nilgiri Limestone of the Annapurna Range (Bordet et al., 1967), and also with the Chiusats Limestone of the Nyalam-Jolmo Longma (Everest) region (Mu An-Tze et al., 1972).

METAMORPHISM AND GRANITIZATION

The metasediments of the Kathmandu Complex display a steady increase in regional metamorphism down-section, from the barely metamorphosed sediments on top to the coarsely crystalline garnet-schists marking the highest grade at the base. Only in its northern and eastern parts does the Kathmandu Complex include also gneisses, which rather exceptionally contain higher-grade minerals such as kyanite, staurolite and sillimanite. Most common are banded gneisses in which dark bands of biotite-schist alternate with light bands of granitic and tourmaline-rich pegmatitic material, and augen or parapophylic gneissic in which feldspar crystals may attain enormous sizes. These gneisses clearly interfinger with the metasediments; they represent, however, not specific stratigraphic horizons but appear and disappear at various stratigraphic levels up to the Tistung Formation. They seem thus to represent a second, high-temperature phase of metamorphism superimposed on the primary regional one. Almandine seems related mainly to the primary metamorphism, being a most characteristic mineral of the oldest Bhimphedi schists but appearing in appreciable amounts only in those gneisses which develop from the latter.

Granites are equally confined to the Kathmandu Complex. They comprise biotite- and tourmaline-rich varieties and seem genetically related to the gneisses, having a similar mineral composition and being in places closely associated with them. The contact effects of the granite intrusions are insignificant; the metamorphic grade increases in the direction away from the granites wherever "away" means down-section. In some places (Malekhu Khola) the granite contacts are parallel to bedding and schistosity, showing a narrow zone of granitization (banded gneisses), but in most cases the contacts are sharp and discordant, cutting across bedding and schistosity planes and truncating folds and many faults. The granites themselves are little affected by faulting. The field relations thus suggest a very young age for the granites. The few radiometric data available are inconsistent, with K/Ar apparent ages ranging from Permian to Miocene (Talakov, 1972; Kalyanpur and Tater, 1970). More conclusive seems to be recent Rb/Sr determinations that gave 26-22 m.y. for the Fulang Granite, similar to ages obtained for granites of the High Himalaya (Andreux et al., 1977); a carbonatite origin of the granites was concluded from the high initial Sr/Sr ratio.

In contrast to the Kathmandu Complex, the Nawakot Complex of this area is entirely void of granites and gneisses, and the metasediments rarely exceed the chlorite-sericite grade. Fine biotite and small garnets were, however, noticed locally in the deeper parts of the section and are said to become generally more common further north with approach to the Main Central Thrust (Le Fort, 1975).

TECTONICS

Large-scale thrusting seems to be the most plausible explanation for the superposition of the high-grade Precambrian Kathmandu (Bhimphedi) rocks on the low-grade Paleozoic Nawakot sediments (Sections A,B,C). Direct evidence for thrusting is seen in the intense shear-folding, imbrication and partial truncation of the upper Nawakot rocks below and in front (southwest) of the inferred thrust mass, best illustrated on the map by the distorted structure of the Malekhu Limestone. In contrast, the basal part of the Kathmandu Complex, above the thrust, appears as a rigid, competent mass; the map shows how the Rudawa, Bhainsedobhan and lower Kuhlkan Formations turn as strictly parallel beds that become rounded and the related synclinal bend in the "bulldozing" the underlying Nawakot rocks to southwest. In outcrop, however, the inferred thrust-plane does not appear as a clear-cut break but as a narrow (20-100 m) "transitional" zone of reverse metamorphism, in which the chloritic phyllites on top of the Nawakot Complex pass upwards through chlorite-schist into the coarse garnet-schists at the base of the Kathmandu Complex. This recalls the conditions at the south-foot of the High Range, where Le Fort (1975) related the movements at the Main Central Thrust with a zone of reverse metamorphism and with a pronounced SSW "mineral streak lineation." This lineation appears also in the Mahabharat Range but is here conspicuous only in the Kuncha Formation, suggesting thus rather an old, Precambrian phase of deformation. In Le Fort's (1975) view, migmatization and granitization was an anecdotical effect of the subsequent thrusting event as late Oligocene-Early Miocene, the age of the granite.
NAWAKOT COMPLEX

KATHMANDU

Bhimphedi Group (Precambrian)

- Markhu Formation: phyllites with layers of amphibolite and metagabbro.
- Kulikhan Formation: phyllites and quartzites with interbedded limestone, sandy layers, and phyllites.
- Chisapani Quartzite: compact phyllite with thin limestones and dolomites.
- Malakhu Limestone: yellow, flaggy, fine-crystalline siliceous limestone, in middle part dark dolomitic limestone.
- Benighat Slates: dark-grey slates and phyllites, black banded slates; mix: local boulder beds (Hugsi Khola); ltd: Hugsi Beds: calc-phyllices and thin, strongly phyllitic, light- and dark-grey, siliceous, fine-crystalline limestones and dolomites.
- Disconformity
- Hushdi Beds: well-bedded quartzites, dolomites, phyllites.
- Dhading Dolomite: light blue-grey, dense or fine-grained dolomite.
- Nourpul Formation: phyllites and alternations of phyllite/quartzite and phyllite/dolomite showing colour banding; strongly ripplemarked quartzite at base.
- Dandagaon Phyllites: dark green-grey phyllites, subordinated carbonate laminae, rare thin limestones and quartzites.
- Fagfog Quartzite: white quartzite, ripplemarked, some phyllite.

- Kuncha Formation: light green-grey phyllites, phyllitic quartzites and meta-sandstones, fine-grained quartz-conglomerates, rare basic (amphibolitic) volcanic layers; bsd: Banspani Quartzite: compact impure quartzite with faintly calcareous matrix.

with contributions by V. Singh-Chhetri and A.N. Bhandari
KATHMANDU COMPLEX

Devonian Limestone of Phulchauki: light brown sparry dolomite underlain by red crinoidal limestone.

Chhitang Slates and Silurian beds of Phulchauki: dark slates; white quartzite near base; in upper part few impure limestones and two ferruginous beds containing trilobites (Silurian).

Chandragiri Limestone: light, fine-crystalline limestone, partly siliceous, main part thick-bedded to massive; lower part thin-bedded, with micaceous seams; white quartzite in upper part; top part impure argillaceous, coloured, wavy limestone containing Late Ordovician echinoderms.

Sopyang Formation: dark argillaceous and marly slates, thin limestones.

Tistung Formation: limestones, phyllites, limestones; sandy limestones; ripple marks, clay cracks, worm tracks, intense purple weathering colour; pebble beds near base, underlain by finely biotitic schist.

Markhu Formation: in south massive, coarse-to medium-crystalline, highly garnetiferous mica-schist, changing northward to dark, finely biotitic schist interbedded with impure marble and quartzite; ? stromatolites.

Kulikhani Formation: fine-grained, dark green-grey, biotitized and more or less quartzitic mica-schist alternating with light- and dark-grey, impure, strongly micaceous quartzites.

Chisapani Quartzite: white, fine-grained quartzite, cross-bedded, fine sericite partings.

Juříkhé Conglomerate Member.

Kalitar Formation: dark green-grey two-mica and biotite-schist with layers of strongly micaceous quartzite, garnet and amphibole in lower part.

Pandang Quartzite Member: light-green quartzites.

Bhainabobhan Marble: coarse-crystalline marble, well-bedded to massive, with subordinate schist intercalations.

Raduwa Formation: coarse-crystalline, highly garnetiferous mica-schist, locally gneissic schist; some quartzite, abundant segregational quartz; green chlorite-schist at base.

GNEISSES AND GRANITES

Granitic and pegmatite dyke-swarms.

Biotite-and tourmaline-granites.

Granitic gneiss, porphyroblastic gneiss.

Augen-gneiss, banded gneiss.

Undifferentiated schist, quartzite and calc-silicate (cs) rocks of Bhimpedi Group and Tistung Formation in various stages of migmatization, partly with garnet, kyanite, staurolite, sillimanite.

NEOGENE-QUATERNARY DEPOSITS

Quaternary cover in general, including Kathmandu lake deposits.

River terraces.

Shell beds: recent, modern.
GNEISSES AND GRANITES

- o my.
- dark, marble
- -grey, altered mica.
- te, cross.
- biotite-garnet
- es.
- e, well-laminated.
- garnet-.calcite, schist at

Granitic and pegmatitic dyke-swarms.
Biotite- and tourmaline-gneisses.
Granitic gneisses, porphyroblastic gneisses.
Augen-gneisses, banded gneisses.
Undifferentiated schists, quartzite and calcilicate (cs) rocks of Bhimpedi Group and Tistung Formation in various stages of migmatization, partly with garnet, kyanite, staurolite, sillimanite.

STRUCTURES

Formation boundary, observed
Formation boundary, inferred
Strike line
Anticlinal axis with plunge
Synclinal axis
Fault
Major thrust

GENERALIZED

Formation boundary, observed
Formation boundary, inferred
Strike line
Anticlinal axis with plunge
Synclinal axis
Fault
Major thrust
Mahabharat Synclinorium

URES

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<th>Formation boundary, observed</th>
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<tr>
<td>Formation boundary, inferred</td>
<td>9°-19°</td>
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<tr>
<td>Strike line</td>
<td>20°-30°</td>
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<tr>
<td>Anticlinal axis with plunge</td>
<td>40°-60°</td>
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<td>Synclinal axis</td>
<td>70°-80°</td>
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<td>Fault</td>
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Granites are equally confined to the gneisses, having a similar granite intrusions are insignificant: the down-section. In some places (Malekha granitization (banded gneisses), but in many faults. The gr. the granites. The few radiometric data at Khan and Tater, 1976. More conclusive obtained for granites of the High Himalay Sr/Sr ratio.86°00'

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TECTONICS

Large-scale thrusting seems to (Bhimphedi) rocks on the low-grade Ps shear-folding, imbrication and partial illustrated on the map by the distorted st thrust, appears as a rigid, competent m parallel bands smoothly around the far Nawakot rocks to southwest. In outcoring "transitional" zone of reverse metam chlorite-schist into the coarse garnet-sch Range, where Le Fort (1975) related the SSW "mineral streak" lineation. (This li suggesting thus rather an old, Precambrian effect of the underthrusting of continent. Taking all evidence together, one may a frontal klippe of a large thrust mass, c Mahabharat Thrust may accordingly b

The imbrication, shear-folding thrusting event. Large-scale folding see itself, causing its conformable bend at登山的 combined Nawakot-Ka involved the youngest Siwalik rocks, of rapid erosion, the youthful relief, mar Mahabharat Range, with active upheavals

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Talalov V.A., 1972, Geology and ene:
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TECTONICS

Large-scale thrusting seems to be the most plausible explanation for the superposition of the high-grade Precambrian Kathmandu (Bhimpedi) rocks on the lower-grade Palaeozoic Nawkowt sediments (Sections A,B,C). Direct evidence for thrusting is seen in the intense shear-folding, imbrication and partial truncation of the upper Nawkowt rocks below and in front (southwest) of the inferred thrust mass, best illustrated on the map by the distorted structure of the Malekh Limestone. In contrast, the basal part of the Kathmandu Complex, above the thrust, appears as a rigid, competent mass: the map shows how the Raguwa, Bhainsedobhan and lower Kaitar Formations turn as strictly parallel bands smoothly around the large synclinal bend in the west, themselves being little disturbed but "bulldozing" the underlying Nawkowt rocks to southwest. In outcrop, however, the inferred thrust-plane does not appear as a clear-cut break but as a narrow (20-100 m) "transitional" zone of reverse metamorphism, in which the chloritic phyllites on top of the Nawkowt Complex pass upwards through chlorite-schist into the coarse garnet-schists at the base of the Kathmandu Complex. This recalls the conditions at the south-foot of the High Range, where Le Fort (1975) related the movements at the Main Central Thrust with a zone of reverse metamorphism and with a pronounced SSW "mineral streak" lineation. This lineation appears also in the Mahabharat Range but here is conspicuous only in the Kuncha Formation, suggesting thus rather an old, Precambrian phase of deformation. In Le Fort's (1975) view, migmatization and granitization was an anatectic effect of the underthrusted continental crust, dating the main thrusting event as Late Oligocene-Early Miocene, the age of the granites. Taking all evidence together, one may with Hagen (1969), Gansser (1964), Brunel (1975), and others, consider the Kathmandu Complex as a frontal klippe of a large thrust mass, or nappe, which has been thrust towards the Central Crystalline of the High Himalaya; the Mahabharat Thrust may accordingly be regarded as a southern extension of the Main Central Thrust (Section C-D).

The imbrication, shear-folding and much of the faulting observable in the Mahabharat Range can be related directly to the main thrusting event. Large-scale folding such as created the Mahabharat synclinorium, however, was a later event, as it involved the thrust-plane itself, causing its conformable bend around the synclinal closure and its steepening in both flanks. It may have been related to renewed thrusting of the combined Nawkowt-Kathmandu Complexes upon the Siwalik zone in the south, along the Main Boundary Thrust. As this involved the youngest Siwalik rocks, of Early Piocene age, these last thrusting movements must have taken place in Quaternary time. The rapid erosion, the youthful relief, many pre-Cenozoic faults, and recurring earthquakes, all attest to continuing orogenic processes in the Mahabharat Range, with active uplifting being the most likely mechanism at work today.

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NAWAKOT COMPLEX

KATHMANDU

Robang Formation: blue-green phyllites, chlorite, partly tuffaceous; dp: Dunga Quartzite Beds; dp: metagabbro, metabasalt, amphibolite.

Malekhu Limestone: yellow, flaggy, fine-crystalline siliceous limestone, in middle part dark dolomitic limestone.

Benighat Slates: dark-grey slates and phyllites, black carbonaceous slates; db: local boulder beds (Hugli Khol); jk: Jhiku Beds: calc-phyllite and thin, strongly phyllitic, light- and dark-grey, siliceous, fine-crystalline limestones and dolomites.

Diacomformity

Huhsi Beds: well-bedded quartzites, dolomites, phyllites.

Dhading Dolomite: light blue-grey, dense or fine-crystalline stromatolitic dolomite.

Nourpul Formation: phyllites and alternations of phyllite/quartzite and phyllite/dolomite showing colour banding; strongly ripplemarked quartzite at base.

Dandagaon Phyllites: dark grey phyllites, subordinate carbonatic laminae, rare thin limestones and quartzites.

Fungog Quartzite: white quartzite, ripplemarked, some phyllite.

Kuncia Formation: light green-grey phyllites, phyllitic quartzites and meta-sandstones, fine-grained quartz-conglomerates, rare basic (amphibolitic) volcanic layers; bd: Banspani Quartzite: compact impure quartzite with faintly calcareous matrix.

PHULCHAURI GROUP (Cambrian-Dinantian)

Bhimphedi Group (Precambrian)

Devonian Limestone: dolomite underlain.

Chisapani Quartzite beds; compact, fine-grained quartzites a trilobites (Silurian).

Chandragiri Limestone: partly siliceous, ma lower part thin-bedded quartzite in upper; coloured, wavy limy echinoderms.

Sopyang Formation: thin limestones.

Tistung Formation: stonies, sandy limestone beds, intense purple, near base, underlain.

Disconformity

Dandagaon Phyllites: light green-grey phyllites, subordinately carbonatic laminae, rare thin limestones and quartzites.

Unconformity

Kalitar Formation: dium-crystalline ma fine biotite schist and quartzite, sttro

Kulikhani Formation: biotite and more e nating, with light- and dark-grey quartzites.

Chisapani Quartzite: bedded, fine sericite Jurassic Conglomerate:

Kalit'er Formation: schist with layers of s and amphibole in lo-

Banspani Quartzite

Bhainsudhobhan Matt bedded to massive, wi

Raduwa Formation: focus mica-schist, lo abundant segregation base.

KATHMANDU COMPLEX

Devonian Limestone of Phulchauki: light-brown sparry dolomite underlain by red crinoidal limestone.

Chitlang Slates and Silurian beds of Phulchauki: dark slates; white quartzite near base; in upper part few impure limestones and two ferruginous beds containing trilobites (Silurian).

Chandragiri Limestone: light, fine-crystalline limestone, partly siliceous, main part thick-bedded to massive; lower part thin-bedded, with micaceous seams; white quartzite in upper part; top part impure argillaceous, coloured, wavy limestone containing Late Ordovician echinoderms.

Sopyang Formation: dark argillaceous and marly slates, thin limestones.

Tistung Formation: slates, phyllites, siltstones, sandstones, sandy limestones; ripplemarks, clay cracks, worm tracks, intense purple weathering colours; pebble beds near base, underlain by finely biotitic schist.

\[7\] Uneconformity

Markhu Formation: in south massive, coarse- to medium-crystalline marble, changing northward to dark, finely biotitic schist interbedded with impure marble and quartzite; 7 stromatolites.

Kulikhan Formation: fine-grained, dark green-grey, biotitic and more or less quartzitic mica schist alternating with light- and dark-grey, impure, strongly micaceous quartzites.

Chisapani Quartzite: white, fine-grained quartzite, cross-bedded, fine sericite partings.

Jurikhet Conglomerate Member.

Kalitar Formation: dark green-grey two-mica and biotite-porphyroblastic mica schist with layers of strongly micaceous quartzite, garnet and amphibole in lower part.

Pandrung Quartzite Member: light-green quartzites.

Bhainsedobhan Marble: coarse-crystalline marble, well-bedded to massive, with subordinate schist intercalations.

Raduwa Formation: coarse-crystalline, highly garneliferous mica-schist, locally gneissic schist, some quartzite, abundant segregationary quartz; green chlorite-schist at base.

GNEISSES AND GRANITSES

- Granitic and pegmatitic dyke-swarm.
- Biotite- and tourmaline-granites.
- Granitic gneiss, porphyroblastic gneiss.
- Augen-gneiss, banded gneiss.
- Undifferentiated schist, quartzite and calc-silicate (es) rocks of Bhimphedi Group and Tistung Formation in various stages of migmatization, partly with garnet, kyanite, staurolite, sillimanite.

NEOGENE-QUATERNARY DEPOSITS

- Quaternary cover in general, including Kathmandu lake deposits.
- River terraces.
- Siwalik Group: sandstones, mudstones, conglomerates (Neogene).

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QUATERNARY DEPOSITS

Quaternary cover in general, including Kathmandu lake deposits.

River terraces.

Siwalik Group: sandstones, mudstones, conglomerates (Neogene).

STRUCTURES

| Formation boundary, observed | 0° |
| Formation boundary, inferred | 1°-19° |
| Strike line | 20°-30° |
| Anticlinal axis with plunge | 40°-69° |
| Synclinal axis | 70°-89° |
| Fault | 90° |
| Major thrust |
| Trace of section |
Large-scale thrusting seems to be the most plausible explanation for the superposition (Rhimphedi) rocks on the low-grade Paleozoic Nawakot sediments (Sections A,B,C). Direct shear-folding, imbrication and partial truncation of the upper Nawakot rocks below and in front illustrated on the map by the distorted structure of the Malekhu Limestone. In contrast, the bas thrust, appears as a rigid, competent mass: the map shows how the Ruduwa, Bhainsedobhan parallel bands smoothly around the large synclinal bend in the west, themselves being little Nawakot rocks to southwest. In outcrop, however, the inferred thrust-plane does not appear as "transitional" zone of reverse metamorphism, in which the chloritic phyllites on top of the chlorite-schist into the coarse garnet-schists at the base of the Kathmandu Complex. This recalls Le Fort (1975) related the movements at the Main Central Thrust with a zone of SSW "mineral streak" lineation. (This lineation appears also in the Mahabharat Range but here I suggesting thus rather an old, Precambrian phase of deformation.) In Le Fort’s (1975) view, it effect of the underthrusting of continental crust, dating the main thrusting event as Late Oligocene. Taking all evidence together, one may with Hagen (1969), Gansser (1964), Brunei (1975), and a frontal klippe of a large thrust mass, or nappe, the root of which has to be sought in the C Mahabharat Thrust may accordingly be regarded as a southern extension of the Main Central Thrust Range, where Le Fort (1975) related the movements at the Main Central Thrust with a zone of SSW "mineral streak" lineation. (This lineation appears also in the Mahabharat Range but here I suggesting thus rather an old, Precambrian phase of deformation.) In Le Fort’s (1975) view, it effect of the underthrusting of continental crust, dating the main thrusting event as Late Oligocene. Taking all evidence together, one may with Hagen (1969), Gansser (1964), Brunei (1975), and a frontal klippe of a large thrust mass, or nappe, the root of which has to be sought in the C Mahabharat Thrust may accordingly be regarded as a southern extension of the Main Central Thrust Range, with active uplifting being the most likely mechanism at work today.

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