The geochemistry of surface soils from the Garhwal region, NW Lesser Himalaya: an evidence for neotectonic activity in the area

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The soil samples collected from the Garhwal region, Uttarakhand, NW Lesser Himalaya are characterised by fine to medium grained textures with brown and black as major colours. The soil samples have variable silica contents ranging from 55–72 wt% with moderate SiO$_2$/Al$_2$O$_3$, K$_2$O/Na$_2$O ratios but relatively high Fe$_2$O$_3$+MgO (5–6 wt%) and moderate CaO contents. Relative to the post–Archean North American Shale Composite (NASC) and Post Archean Average Shales from Australia (PAAS), the Garhwal samples have lower large ion lithophile elements (LILE) and high field strength elements (HFSE) abundances and exhibit negative anomalies in a NASC--normalised spider diagram. The wide spectrum of SiO$_2$ contents, large variation in ratios like Cr/Zr (0.3–3.5), Sc/Th (0.6–2.43), Th/U (> 2), Th/Co and Zr/Y indicate that the weathering of mostly felsic rocks with minor inputs of mafic rocks might have played an important role in producing these soils. In the discrimination functions (Fl–F2) diagram, the Garhwal samples exhibit scattered pattern and plot in the fields of Quartzose sedimentary provenance, intermediate igneous provenance and mafic igneous provenance thus substantiating the above inference. The relationship among alkali and alkaline earth elements, the chemical index of alteration (CIA) suggests that the source rocks have undergone moderate chemical weathering. The weathering conditions of any source region can also be depicted from Al$_2$O$_3$(A)–CaO+Na$_2$O(CN)–K$_2$O(K) diagram. The soil samples plot near idealized average shale composition and between shale and granodiorite in A–CN–K diagram pointing towards moderate weathering history of the source region.

Despite the fact that the study area is more favourable for physical, chemical and biological weathering, striking similarities were observed between the composition of soils and source/bed rocks without much loss of elements. This inference has led to the conclusion that the area is undergoing periodic neotectonic activity.

Keywords: Geochemistry, Garhwal Soils, Lesser Himalaya, Neotectonic activity

INTRODUCTION

Soil, next to air and water, is generally considered as the third main environmental component that supports many forms of life. The increasing rate at which the soil degradation (by extracting nutrients) is taking place, particularly in India, large population is going to face a self-created problem very soon. In this respect, an understanding of soil geochemistry in any region becomes significant. The geochemistry of soils apart from providing information about source rock weathering processes in a particular environment also gives essential information about their nutrient values. For the last many decades, the geologists from all over the world have extensively carried out the geochemical studies of different rock types and river waters in the Himalaya. More recently, several papers have begun to deal specifically with the elemental composition of sediments and sedimentary rocks of the Himalayas (Ahmad et al., 1998; Bhat and Ghosh, 2001; Rashid, 2002). The soil geochemistry in the Himalaya is almost unattended. In this context, the present study may be considered as an important contribution towards understanding the in-situ weathering processes in high altitude regions. The surface soils of any region are considered to be representative of first cycle sediments and thus provide useful information about the source region.

The main objective of the paper is to deal with the geochemical characteristics of surface soils from the Garhwal region, NW Lesser Himalaya. The elemental concentrations of soils are compared with the source/bed rock chemistry mainly to put constraints on the weathering of source rocks vis-à-vis tectonic activity in the region.
GEOLOGY OF THE AREA

The geology of the area is complex, consisting of Precambrian and Cambrian lithological units of the Garhwal region of the NW Lesser Himalaya. The area under investigation is sandwiched between important thrust faults of the Lesser Himalaya such as Alaknanda thrust (in north) and North Almora thrust (in south) (Fig. 1). Because of the presence of these faults, this area is tectonically active and experiences moderate- to high magnitude earthquakes. Valdiya (1980) divided the inner Lesser Himalaya into four lithotectonic groups on the basis of lithological composition, stratigraphic succession, structural pattern and magmatic history. These are (1) The Damta and Tejam groups; (2) The Krol Nappe of the outer (southern) Lesser Himalaya consisting of the Chandpur, Naghat-Berinag formations; (3) The Ramgarh Group and (4) The Almora Group (Fig. 1). Of these units, the Damta and Tejam groups occur at the lowermost levels of the four units and are considered to be the autochthonous units consisting of Precambrian sedimentary rocks exposed in the inner (northern) belt of the Lesser Himalaya (Valdiya, 1980).

The Damta Group at the base consists of the Chakrata Formation having a pelite-dominated sequence overlain by the Rautgara Formation, which includes siliciclastic rocks with considerable amounts of intrusive dolerites and basalts. The Tejam Group, comprising the Deoban (dolomite) Fm and Mandhali (carbonaceous slates and marbles) Fm, conformably succeeds the Damta Group. Another lithotectonic unit in this region is the Garhwal volcanics, which is composed of alternating sequences of psamites-mafic volcanics (Ahmad and Tarney, 1991). The bedrock or basal lithologies on which the soils were developed are chiefly pelites, quartzites (belonging to Rautgara Fm) and mafic volcanics (Garhwal...
### Table 1. Major and trace element concentrations of Garhwal soils, Lesser Himalaya

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<tr>
<th>Sample Locations</th>
<th>Tilwara</th>
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<th>Tilwara</th>
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<th>Th</th>
<th>U</th>
<th>Rb</th>
<th>Ba</th>
<th>Sr</th>
<th>Y</th>
<th>Zr</th>
<th>Nb</th>
<th>SiO₂/Al₂O₃</th>
<th>K₂O/Na₂O</th>
<th>K₂O/O₂Al₂O₃</th>
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<td>14</td>
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<td>3.7</td>
<td>129</td>
<td>430</td>
<td>91</td>
<td>40.7</td>
<td>203</td>
<td>10.1</td>
<td>4.84</td>
<td>1.63</td>
<td>0.21</td>
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<tr>
<td>ppm</td>
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<td>44</td>
<td>88</td>
<td>14</td>
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<td>4.7</td>
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<td>411</td>
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<tr>
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Major oxides in wt%, trace elements in ppm, total iron as Fe₂O₃.


Average volcanics and pelite compositions from Ahmad and Tarney (1991) and Rashid (2004), respectively. R Prayag, Radraprayag. Numbers 1, 5, 7 etc. refers to sample locations on the map.
volcanics) (Fig. 1). The samples were collected mainly from these two formations in and around Rudraprayag, Tilwara, Dewal and Adibadri areas along Mandakini and Alaknanda valleys. One of the main difficulties in soil chemistry studies is the selection of suitable sites. To avoid any kind of contamination, the samples were collected in the vertically exposed fresh sections on the road cuttings. Special care was taken to exclude sites, which showed evidence of agricultural activity.

**ANALYTICAL TECHNIQUES**

After appropriate crushing, splitting, pulverization and homogenization procedures, each sample was analysed in duplicate for all the major and trace elements by X-ray fluorescence (XRF) spectrophotometer (SIEMENS SRS 3000) on pressed pellets at the Wadia Institute of Himalayan Geology, Dehradun. The element concentrations of Na and K were, however, determined by Flame photometer. The quality of the analysis was monitored, by the simultaneous analysis of some in-house and international standards.

The analytical precision, obtained on the basis of replicate analysis, is well within 5-10% for trace elements and ~5% for major oxides. Accuracy for most of the elements that are analysed is good. The Qualitative mineral analyses of the clay fraction (< 2 μm) of the soils were determined by X-ray diffraction (XRD) at the Wadia Institute of Himalayan Geology, Dehradun. The XRD analyses were performed for untreated; ethylene glycol treated and heated (at 500 °C) samples of the clay fraction.

**RESULTS AND DISCUSSION**

**Geochemical characteristics of Soil**

The major and trace element analytical data of the Garhwal soils are given in Table 1. For the purpose of comparison the average composition of NASC, PAAS, and analyses of potential source rocks to these soils are also given in Table 1. In terms of major element composition, the soils of the study area are on the whole characterised by intermediate SiO<sub>2</sub> contents, variable Al<sub>2</sub>O<sub>3</sub> concentrations (8.7-15.6 wt%) and relatively high Fe<sub>2</sub>O<sub>3</sub> + MgO contents (usually 5-10 wt%). Two samples (SL-11, SL-15), however, show higher concentrations of Fe<sub>2</sub>O<sub>3</sub> + MgO (15-16 wt%) along with abundant Cr(556-628 ppm) and Ni(45-186 ppm) contents suggesting an input from the weathering of mafic rocks. The Al<sub>2</sub>O<sub>3</sub>/SiO<sub>2</sub> and K<sub>2</sub>O/Na<sub>2</sub>O ratios of the soils are intermediate with a range of 0.14 to 0.27, (mostly 0.2) and 1.63 to 10 (mostly > 2), respectively. These variations in the elemental ratios may be accounted for by variation in Quartz and clay minerals-muscovite. This is also consistent with the K<sub>2</sub>O and SiO<sub>2</sub> contents of the samples wherein soils having high Al<sub>2</sub>O<sub>3</sub> contents show high K<sub>2</sub>O concentrations and low Al<sub>2</sub>O<sub>3</sub> samples have relatively low K<sub>2</sub>O contents (Table 1), probably suggesting the role of clay minerals control on the soil chemistry.

It is significant to note from the chemistry of the soils that the samples have seem to be enriched in Ni, Cr, Mg and Fe that in turn may suggest a mafic rock-dominated source. However, the other element concentrations as well as source lithologies do not support this inference. Nesbitt and others (1996) have observed that the finer fraction of the sediments show a mafic bias chemistry because of sediment sorting, but even high SiO<sub>2</sub> soil samples have high concentrations of mafic components such as Fe, Mg, Ni and Cr. This suggests that weathering of source rock lithology, apart from sorting, is an important factor in controlling the soil chemistry. The samples show high Rb and Ba contents relative to Sr resulting in high Rb/Sr ratios (0.83-3.0). Th/U ratios are variable (2-4), but are generally less than or equal to average upper crustal values (= 3.8; Taylor and McLennan, 1985). The soil samples have Sc/Th ratios ranging from 0.6 to 2.43, (mostly around 1) which are similar to upper crustal values of 1 (Taylor and McLennan, 1985). The V concentrations are highly variable (Table 1). The sample number SL-15 has anomalously high values of V (225 ppm) when compared to other samples, but this sample is also enriched in Fe<sub>2</sub>O<sub>3</sub>(12.42 wt%), TiO<sub>2</sub>(1.25 wt%) and Cr(556 ppm), indicating that probably Fe-Ti oxides such as ilmenite or titanomagnetite were present in the source. In addition to the above characteristics, this sample plot in a mafic igneous provenance field in F1–F2 diagram (Fig. 6), thus pointing towards mafic source. It has been observed that most of the soil samples have similar Cr and Ni con-
tents with that of post-Archean pelitic rocks and plot very close to NASC field in the Ni-Cr diagram (Fig. 2). Having slightly higher concentrations of Cr and Ni, some samples however show affinity towards late Archaen sediments.

It is evident from the Harker diagram (Fig. 3) that the soil samples show variable degrees of negative correlations for SiO$_2$ vs. A$_2$O$_3$, Fe$_2$O$_3$, MgO, K$_2$O and TiO$_2$, suggesting a decrease in unstable components with an increase in mineralogical maturity. A strong positive correlation between K and Rb ($r = 0.87$) suggest that K-bearing clay minerals (e.g., illite and sericite) might have controlled the abundances of these elements (McLennan et al., 1983; Feng and Kerrich, 1990; Cullers and Podkovyrov, 2000; Gu et al., 2002). The scatter between SiO$_2$...
vs. Na₂O and CaO in the samples may be attributed to the extensive secondary alteration of feldspar and also indicates that the feldspars are not fractionated out selectively from the sediments (Singh and Rajamani, 2001). From Figure 4, it can be clearly observed that the Garhwal soils have more or less similar compositions with that of post-Archean shales.

**Mineralogy**

In order to correlate the mineralogy and chemistry of the soils, the samples were analysed for mineralogical abundances. The XRD studies reveal the occurrence of kaolinite, illite-muscovite, quartz, feldspar and chlorite as major components in the soils. The presence of clay mineral such as kaolinite and absence of smectite (indicates lower degree of weathering) and Gibbsite (indicates extensive weathering) in the soil samples strongly suggests that the source rocks of the soils have undergone moderate chemical weathering (Nesbitt et al., 1996; Fedo et al., 1997).

**Source rocks**

For source rock evaluation, it is always better to rely on least mobile and refractory elements such as HFSE, REEs, Th, Sc, Hf, Co, and Cr (Taylor and McLennan, 1985), because concentration of these elements are not significantly affected during weathering, transportation and sedimentation. The Garhwal Himalayan region under study consists of mainly two rock sequences i.e., metamorphosed successions of sedimentary and volcanic rocks (Fig. 1). The sedimentary rocks (dominantly pelites with interbedded quartzites) are felsic in nature and are most probably derived from granite to granodiorite source rocks (Rashid, 2004). Whereas the volcanic rocks and associated dykes are tholeiitic in nature and are distinctly enriched in incompatible elements (Ahmad and Tarney, 1991). The average composition of soils is plotted against average pelites and volcanic rocks to determine the relative contributions of two major rock types in the formation of soils (Fig. 5). It is evident from this major and trace element diagram that the soil composition is very close to the equiline for the pelites source rocks than to the mafic volcanic rocks. This in turn suggest that the weathering of pelites has produced the majority of the soils in the region with less input from mafic rocks and the source rocks were not subjected to prolonged chemical weathering.

Using other trace element concentrations and their ratios also tests the more readily weathering of pelites when compared to mafic volcanic rocks in this part of Himalayan region. The samples fall in three different fields when they were plotted in a F1–F2 (discriminant functions) diagram (after Roser and Korch, 1988). It can be observed from Figure 6 that most of the samples plot in the quartzose sedimentary provenance field with three samples plotting in the intermediate and mafic igneous

![Figure 4](image4.png)  
**Figure 4.** NASC normalised spider diagram for the soils. See text for explanation.

![Figure 5](image5.png)  
**Figure 5.** Comparison diagram for the average composition of the soils and the average of source rocks. A) Garhwal volcanics B) Rautgara pelites. Most elements plot closer to the equiline for pelites than volcanics.
The geochemistry of surface soils from the Garhwal region

provenance, which is consistent with the above inference. This is further examined below. Wronkiewicz and Condie (1990) demonstrate that Cr/Zr ratio serves as an excellent provenance indicator, which monitors relative contributions of mafic/felsic source contents, because these two elements represent chromite and zircon contents, respectively. Most of the Garhwal samples have Cr/Zr ratios less than or equal to 1 (0.3–1.5), however two samples show Cr/Zr ratios greater than 2.5, thus substantiating the previous interpretation. Further, a large variation in K2O/Na2O ratios (1.6–10) in the soils probably resulted because of differential Na leaching from the samples due to weathering. The important constituents of fine-grained sediments or soils such as K and Al and their ratios are helpful in depicting the source rock composition. Cox and others (1995) have observed that the K2O/Al2O3 ratios of Garhwal soils vary from 0.17 to 0.23 with an average of 0.20, suggesting minimal alkali feldspar relative to other minerals.

This further suggests that the weathering of pelitic rocks rather than mafic rocks is dominant in the region; because of these reasons the mafic rocks make up most of the high hills in the region.

Weather of Source rocks

The extent of weathering undergone by source area can be evaluated by using molecular proportions of alkali and alkaline earth elements (Nesbitt and Young, 1982), known as chemical index of alteration (CIA). The CIA is calculated as CIA = [Al2O3/(Al2O3 + CaO + Na2O + K2O)] × 100 where CaO* is the concentration of CaO in silicates only. The samples were treated with 1M cold dilute HCl acid before digestion and were analysed separately for determination of CaO in silicate phases (Gale and Hoare, 1991). The Garhwal soils have CIA values ranging from 61–76 with an average of 66.4, implying that the source rocks of the soils have undergone moderate chemical weathering. The CIA values also suggest that the effects of weathering had not produced to the stage where alkali and alkaline earth elements are substantially removed from the clay minerals (Taylor and McLennan, 1985). The weathering condition of any source region can also be depicted from A–CN–K diagram of Nesbitt and Young (1984). This diagram is very much useful because it provides valuable information not only about the source rock composition but also about the weathering intensity and metasomatic effects undergone by the samples (Fedo et al., 1997). The background information of this diagram is...
that during initial stages of weathering, Na, Ca are removed from the earlier dissolved plagioclase and those samples which have undergone weak weathering will plot close to A-CN line. Whereas advanced weathering results in the dissolution of K-feldspar to release K in preference to Al so that the bulk composition trends of the residues are redirected to the Al$_2$O$_3$ apex. The soil samples data plot around average idealized shale and between shale and granodiorite in A-CN-K diagram (Fig. 7), indicating that the weathering in provenance was moderate. It can also be observed from the Figure 7 that the soil samples are shifted slightly towards A-K line, suggesting the role of different extents of K-metasomatism undergone by the samples.

**Implications of weathering in the region**

Along with other factors such as temperature, relief etc., water is essential for most chemical weathering and therefore an increase in rainfall leads to greater weathering (Ollier, 1969). Whereas temperature mainly affects the rate of chemical reactions and so warmer climates in general are expected to give rise to stronger weathering than cold climates. Thus weathering, particularly chemical weathering is greatest in hot wet climates and becomes less as rainfall or temperature decreases. The Garhwal region of the Lesser Himalaya is located at high altitudes and experiences moderate to heavy rainfall > 100 cm with fluctuating annual temperatures from 0 ° to 30 °C. Thus according to the above discussion, in this type of regions both the physical and chemical weathering rates along with biological activity will be high (Ollier, 1969). In contrary to this, when the composition of Rudraprayag (Garhwal) soil samples were compared with the source rocks occurring in the region (Fig. 8), surprisingly striking similarities were observed without much loss of the elemental abundance. This reveals that the chemical weathering is less dominant than physical weathering in this area. The soil cover is also not thick. These characters however suggest that the area have recently been uplifted for weathering and erosion.

All these factors which are discussed above including thin soil cover despite high rainfall, dominance of physical weathering over chemical weathering, striking similarities of the compositions of sediments and source rocks clearly suggest that the region is probably undergoing neotectonic activity periodically in the area and helping to remove weathered products and so enhancing future weathering.

**CONCLUSION**

The major and trace element chemistry of the Garhwal soils is controlled by the weathering condition of bed rocks/source, which seems to be greatly influenced by the tectonic set up of the area and also the nature of source rocks. Their geochemistry suggests that the soils are dominantly derived from metamorphosed sedimentary (pelitic) rocks with less input from mafic source rocks exposed in the area. The source rocks were affected by moderate chemical weathering, which is recorded in the chemical index of alteration values. When the soil chemistry was compared with the source/bed rock chemistry, interesting results were found. These results have led to the conclusion that the area is undergoing neotectonic activity. This work also suggests that the first cycle sediments or surface soils can often be used to evaluate the tectonic upliftment of any region.

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