CHARACTERIZATION OF LOESS-PALAEOSOL SEQUENCES IN KASHMIR (INDIA) VALLEY USING MULTI-ELEMENT CONCENTRATION DATA

G S LODHA, K J S SAWHNEY and H RAZDAN

Bhabha Atomic Research Centre, Nuclear Research Laboratory, Srinagar, India

and

D P AGRAWAL and N JUYAL

Physical Research Laboratory, Navrangpura, Ahmedabad-380 009, India

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Major and trace element concentrations of a few representative loess profiles in Kashmir valley are studied using EDXRF spectroscopy. Principal component analysis for pattern recognition has been employed to study association between elemental concentration variations in various horizons. The present study reveals that elements related to clay illuviation (K, Rb, Fe, Ti, Mn) and plant activity (Cu, Zn) are generally higher in ‘B’ horizon of the palaeosols whereas Ca and Sr have a high concentration in the loess layers. Such an elemental concentration variation study provides us with an objective index for identification and confirmation of palaeosols. Further there is a close association in the movement of (i) K, Rb; (ii) Fe, Ti, Mn; (iii) Cu, Zn; and (iv) Ca, Sr. These clusters of elements are also present in modern soils, suggesting that the soil characteristics in palaeosols have been preserved. Concentration of iron and titanium is also observed to be higher in loess profiles on Pir Panjal mountain flank which is dominated by basic rocks, compared to profiles on Himalayan flank, suggesting that the loess in Kashmir might have been derived from the nearby rocks in a very localized way. The high concentration of K, Fe and Ti in Kashmir loess compared to concentration values for loess in other parts of the world suggests that the loess might not have been transported from far-off distances.

Key Words: Loess; Palaeosols; EDXRF; Principal Component; Component Analysis

INTRODUCTION

In Kashmir Valley (India) the Karewa terrace deposits are capped by a blanket of windborne loess deposits. These loess sequences are of great value in palaeoenvironmental reconstruction because they are essentially continuous and can be directly correlated with deep sea sediments. The palaeosols develop within the loess sections during various stages of weathering in the periods of climatic amelioration, e.g., from cold arid to temperate humid. They generally contain a humus rich ‘A’ horizon followed by a clay rich compact ‘B’ horizon with low
CaCO$_3$ content and a carbonate illuvial horizon with high CaCO$_3$ content. We see this sequence in most of the loess profiles, but there are instances when some of these horizons are missing, apparently due to some perturbations.

A variety of techniques have been attempted to study the loess deposits in the valley with a view to deduce the past climatic history of the region. Due to the absence of vertebrates$^3$ and preserved pollen$^4$ palaeontological and palaeobotanical studies of Kashmir loess have not provided any worthwhile information about the past climatic history during the periods of loess deposition. Loess chronological studies using radiocarbon and TL (see pp. 380–385) techniques, have met with some success.

Thus the sub-division of loess in the valley for climatic reconstruction has to rely heavily upon the investigation of the depositional environment of loess and its weathering and diagenetic developments. Surface texture and particle shape analyses of loess in Kashmir have been carried out by Pant et al.$^5$ using scanning electron microscopy. However, particle shape and surface texture are not clear diagnostics of the mode of the origin of loess.$^7$ Hence, more powerful methods like mineralogical and geochemical characteristics and isotopic ratios need to be used to identify the source and mode of deposition of loess.$^8$ The isotopic ratio studies on some of the sections of Kashmir loess have been carried out by Krishnamurthy.$^9$ The multi-element concentration studies have been reported in this paper.

**AIMS OF STUDYING THE LOESS GEOCHEMISTRY**

We have undertaken the study of loess geochemistry with the following specific aims:—

1. To generate geochemical data which will aid in the investigation of the source of loess deposits and to make possible the intercomparison with the deposits in the other parts of the world. For this purpose geochemical analyses of many loess sections on Pir Panjal and Himalayan ranges have been undertaken.

2. Traditionally, a vertical repetition of morphological features such as colour, structure and compaction have been used to identify the palaeosols buried in loesses. We have instead attempted to use the major and minor element concentration variation to recognize loess palaeosol horizons, an approach that has been used to identify the New Zealand$^{10}$ and the Chinese loess.$^{11}$

3. A special feature of the study has been the application of principal component (PC) analysis technique to the multielement data which helps us to identify a set of elements with similar collective behaviour. The technique makes identification of loess palaeosol horizons easier than was possible with individual elemental concentration in isolation.

The locations of seven loess sections of Kashmir valley geochemically studied by us are shown in Fig. 1. In this paper we report multielement data studies on four representative loess sections.
The elemental analyses was carried out with our EDXRF spectrometer using $^{238}$Pu and $^{241}$Am radioisotope excitations and the laboratory built transmissions anode molybdenum X-ray tube. For the quantitative estimation we have used the MICRO-2200 based on line data processing system. The quantitative estimation was done using fundamental parameter approach after proper estimation of the peak intensity.

For the interpretation of multielement data at various sections, principal components analysis technique has been adopted by us. The reliability of the technique is apparent from its capability to characterize loess palaeosol sequences from the multielement data inspite of the fact that the sections have undergone post-depositional changes. The technique involves reduction of the elemental data set with a large number of variables (which are often correlated and sometimes redundant) to smaller number of independent variables. Furthermore, the analysis provides a graphical representation of objects and variables in a vector subspace with reduced number of dimensions. In our analysis we have used concentration values of K, Ca, Ti, Mn, Fe, Cu, Zn, Rb and Sr obtained from EDXRF analysis. The concentration of Ni and Br have not been included in the analysis due to high estimated errors in their concentration. The two major principal components account for 75 per cent to 80 per cent of the features in all the sections which is adequate for the interpretation of geochemical data on loess palaeosols.
MAIN RESULTS OF VARIOUS LOESS SECTIONS IN KASHMIR VALLEY

1. Burzahom Loess Profile

The section is \( \sim 6 \) m thick and is \( \sim 2 \) km northeast of Srinagar of the Himalayan flank, resting on Upper Karewa laminated silt members. The stratigraphy, the concentration profile of various elements and the first principal component are shown in Fig. 2. The main results are summarized below:

1. The B horizon of the palaeosols are generally marked by high concentration of K, Rb, Fe, Ti, and Mn, compared to the A horizon and the loess.

2. The low values of K, Rb, Fe and Ti in the bottom-most ‘B’ horizon (tag No. 2) could be due to the B horizon getting mixed with the laminated silt members and the consequent removal of these elements in the lacustrine activity.

3. The top A horizon (tag No 24) has high concentration of K, Rb, Fe, Ti, Mn, Cu and Zn because it is a part of archaeological soil and must have got perturbed by man-made activity.

4. Calcium is high in loess layers and low in palaeosols.

5. The average Fe concentration is \( \sim 4.5 \) per cent and average Ti concentration is \( \sim 0.9 \) per cent.

6. The first principal component accounts for 60 per cent of the total variability in the concentration of the elemental data set. It is high for B horizons of the palaeosols and low for loess and A horizons. The maximum contribution to the variation in the first principal component for this section is from K, Rb, Fe, and Ti. Thus instead of seeing the variation of individual elemental concentration in isolation, the variation of the first principal component provides a better identification of the various horizons.

![Fig 2 Field stratigraphy, tag numbers, concentration profiles and first principal component variation for Butzahom loess section.](image)
7. The principal component analysis identifies the clusters of elements with similar variability in concentration for this section. The three clusters for the Burzahom section are (Fig. 3):

(i) K, Rb, Fe, Ti
(ii) Cu, Mn, Zn
(iii) Ca, Sr

These clusters show that the movement of elemental concentration within these groups follows a similar pattern. The associated movement of elements mentioned in the above groups occur in modern soils because of similar chemical changes they undergo under various stages of weathering. However, this clustering is not well discernible by seeing the individual elemental concentration in isolation for the loess palaeosols but has been well brought out by principal component analyses.

2. Wagahoma Loess Profile

Wagahoma loess section near Brijbihara on Jammu Srinagar highway is ~21m thick on the Himalayan mountain flank. The section rests on Upper Karewa laminated silt members. Fig. 4 shows the field stratigraphy of the loess section, the variation of various elemental concentrations and the variation of the first principal component in the various horizons. The main results are summarized below:

1. The concentration of K, Rb, Fe, Ti, Mn, Cu, and Zn are generally higher in B horizon of the palaeosol compared to the A horizon. However, elemental
concentrations in the A horizon at 13m is not appreciably low compared to the thick B horizon below it. It could be that the A horizon was leached to a much greater extent but post-depositional mixing with the B horizon above it, at 13.25m (tag No. 9), has led to the smoothening of the leaching parameters. Further, the B horizon at 13.25m has distinctly very high concentration values of K, Rb, Fe, Ti and Mn which probably suggests that this horizon is from altogether a different source.

2. Palaeosols are observed to have generally low values of Ca and Sr. Accumulation of these elements takes place below the B horizon of the palaeosols forming a calcium carbonate horizon, or in the loess layer itself.
3. The loess layer between 10–11.25 m was marked as a doubtful B horizon during our field observation. However, both major and trace elemental concentrations as also the values of the first principal component for this horizon, are similar to the loess horizon above and below it. Thus the elemental data helps in identifying it correctly as a part of the loess.

4. The average value of Fe is \( \sim 3.8 \) per cent and Ti is \( \sim 0.8 \) per cent.

5. For this section, the first principal component (PC) is high for the B horizons of the palaeosols and low for the loess. The first PC accounts for 46 per cent of the variance and the second PC accounts for 28 per cent of the variance. The variation in the concentration of K, Rb, Fe, Ti and Mn dominates in the first PC while Ca and Sr variations dominate in the second PC.

6. The clusters of elements with similar variability in concentration are (Fig. 5).

   (i) K, Rb
   (ii) Fe, Ti, Mn
   (iii) Ca, Sr
   (iv) Cu, Zn

3. Khanchikhol II Loess Profile

   This plateau loess section is \( \sim 22 \) m thick and is located on the Pir Panjal mountain flank. The field stratigraphy, the concentration profile and the first principal component for this section, are shown in Fig. 6. The main results are summarised below:

1. The B horizons between 0.75–2.5 m, 6.25–6.75 m and 15.5–19.0 m are accumulation horizons for K, Rb, Fe, Ti.

![Fig 5 Plot of latent vector 1 vs. latent vector 2 for Wagahoma loess section.](image-url)
2. The horizon marked loess on the basis of field observation at 9.5–10.0m has accumulated Ca, Sr, Fe, Ti, Mn. High Ca, Sr is due to thick CaCO₃ nodular horizon below the B horizon, but the high concentration of Fe, Ti and Mn suggests secondary accumulation of these elements from the A and B horizons above it.

3. The horizon marked B at 13–14m is not acting as an accumulation zone for K, Rb, Fe, Ti and Mn. Rather the accumulation is taking place in the horizon marked loess at 14–15m. It appears that the A horizon at 13m extends down to 14m and the loess at 14–15m is the B horizon. These observational inferences are supported by the mineral magnetic data.¹⁴

4. The first and the second principal component for this section account for 56 per cent and 25 per cent of variance respectively, in contrast to the Khanchikhol I loess section where the first PC itself accounts for 75 per cent of the variance.
5. The principal component analyses for association among elements shows the following groupings (Fig. 7):

(i) K, Rb;
(ii) Fe, Ti, Mn;
(iii) Cu, Zn;
(iv) Ca, Sr.

6. The average value of iron is \( \sim 5.5 \) per cent and that for titanium is \( \sim 1.2 \) per cent.

4. Dilpur Loess Profile

Dilpur is situated near Nagum village, about 22km south of Srinagar on the Pir Panjal mountain flank. The section rests on fluvial sand beds. The stratigraphy and concentration profiles are shown in Fig. 8. For this section very dense sampling at 0.25m interval was done. The samples for this section were run with \(^{238}\text{Pu}\) radioisotope excitation and the concentration values were computed for K, Fe, Ti and Ca. The results for this section are summarized below:

1. The B horizons have generally high concentration of K, Fe and Ti and low concentration of Ca.

2. The top portion of the A horizon between 1.5–2m appears to be part of the B horizon with high concentration of K, Fe, Ti and the A horizon is extending downwards in the loess horizon upto 2.25m.

![Fig 7 Plot of latent vector 1 vs. latent vector 2 for Khanchikhol II loess section.](image-url)
3. The loess horizon between 2–4.5m has two Ca peaks at 2.5m and 3.25m. At 3.25m soil formation process appears to have started which is reflected in slightly high concentration of K, Fe and Ti but secondary CaCO₃ leaching appears to have suppressed its characteristics. This is also reflected in a slightly higher magnetic susceptibility in this horizon.¹⁵

4. The B horizon at 4.75m has higher concentration of K, Fe and Ti.

5. For the thick B horizon between 5.25–7.5m, K, Fe, Ti, accumulation has taken place but data clearly shows that the maximum K accumulation is slightly above the maximum accumulation zone for Fe and Ti.

6. Just below the above B horizon is a Cₑa horizon with very high Ca concentration, but Fe, Ti concentration is also high in this horizon. This could be due to secondary weathering contribution from the top palaeosol and the CaCO₃ horizon is acting as an impermeable zone.

7. The multiple peaking of calcium concentration between 7.5–10.5m, which is also reflected in high concentration of K, Fe and Ti, shows that some post-depositional weathering has taken in this loess layer. This fact is also reflected in the high concentrations of K, Fe and Ti in A horizon at 10.25m.

8. The top portion of the B horizon at 11m has high concentrations of K, Fe, Ti and low concentration of Ca. However, the lower portion has higher concentrations of K, Fe, Ti and a higher concentration of Ca. So it appears that the lower portion of the B horizon should be included in the loess.

9. The horizon marked loess between 11.75–12.75m has a palaeosol embedded in between it at 12.5m, as is reflected by the high concentration of K, Fe and Ti and two Ca peaks in between the loess.

10. The horizon marked B at 13.25m has higher concentration of K, Fe and Ti but the maximum accumulation zone of Fe and Ti is slightly below the K accumulation zone. It appears that there are two more soils embedded in this thick B horizon at 14 and 16 m as is indicated by higher concentrations of K, Fe and Ti at these depths.

11. The top portion of the horizon marked loess between 16.5–18.5m should be included in the B horizon above it in view of the high concentration of K, Fe, and Ti and low concentration of Ca.

Thus with the help of elemental data at a close sampling interval we are able to draw a more precise stratigraphy of this section (Fig. 8).

**DISCUSSION**

The main conclusions drawn from the present study are the following:

1. The analyses of loess palaeosol sequences presented reveal that elements related to clay illuviation (K, Rb, Fe, Ti and Mn) and plant activity (Cu and Zn) are generally higher in B horizons of the palaeosols. The concentration distribution of these elements in palaeosols is closely related to the process of soil formation.
Fig 8 Field stratigraphy, tag numbers, elemental concentration profiles and the elemental data stratigraphy for Dilpur loess section.

2. The principal component analyses for the association among elements reveal that in spite of post-depositional perturbation there is a close association in the movement of

(i) K, Rb
(ii) Fe, Ti, Mn
(iii) Cu, Zn
(iv) Ca, Sr

These associations are not obvious from the individual concentration data seen in isolation. However, as these associations are also observed in modern soils
due to their similar chemistry. The result suggests that the loess sections have preserved the elemental concentration signatures to some extent and thus have not been reworked to a great extent.

3. Calcium has a very high leaching rate and generally gets deposited below the B horizon in the top portion of the loess layers.

4. The variation in the concentrations of K, Rb, Fe, Ti, Cu and Zn and Ca and Sr helps in the proper identification and confirmation of loess palaeosol horizons. With the variation in concentration we can predict with some degree of confidence the extent of post-depositional perturbations in various horizons.

5. Concentration of iron and titanium is generally high in loess profiles on the Pir Panjal mountain flank compared to the Himalayan side. The average titanium value on Pir Panjal flank is $\sim 1.2$ per cent which is higher than on the Himalayan side (Ti $\sim 0.9$ per cent). Likewise, the average Fe value for loess profiles on the Pir Panjal flank (Fe $\sim 5.5$ per cent) is higher than the value for the Himalayan flank (Fe $\sim 4.5$ per cent). The movement of iron and titanium is further closely related in our data suggesting the presence of ilmenite (Fe Ti O$_3$). The Pir Panjals are dominated by the basic igneous rocks and have high concentration of ilmenite. On the other hand, the Himalayan flank is made up of limestones which generally have lower concentration of titanium. Thus it appears that the source material for loess deposits at various sections were derived from the nearby rocks in a periglacial environment.

6. In Kashmir loess palaeosol sequences, the average value of K ($\sim 3$ per cent). Ti ($\sim 1$ per cent) and Fe ($\sim 5$ per cent) are higher than the concentration of these elements in other parts of the world e.g. China, USA, Europe and New Zealand. The values reported for K$_2$O, Fe$_2$O$_3$ and TiO$_2$ are generally lower than 2 per cent, 3 per cent, and .7 per cent respectively. The concentration values of these elements for Kashmir loess correlates well with the rock mineralogy of the region. This observation suggests that the Kashmir loess deposition was controlled to a great extent by the local climatic changes and the loess sediment load was not transported from very far of distances.

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