A Comparison of the Geochemical Features of Some Loess Sections in New Zealand and China

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Abstract

A comparison of the geochemical features of loesses of New Zealand and China indicates that the distributions of the elements and their variations reflect the fluctuations of climate which can be compared with the oxygen isotope stages and glacial periods.

New Zealand loess is different in source from Chinese loess. Therefore, some differences are also noticed in their chemical compositions. Loess accumulation in New Zealand is later than that in China. Because of more rainfall in New Zealand and different distributions of loess the elements in loess have suffered stronger leaching than in China.

Introduction

Loess is widespread in New Zealand with soils containing a loess component, covering about $100000 \, km^2$. The main deposits occur in the southern half of North Island south of latitude 39 ʾS on both sides of the axial ranges and over a large part of South Island east of the Southern Alps. The loess deposits generally occur near major rivers where dust has been blown from aggrading river floodplains and deposited on river terraces and downlands downwind. Most of the loess is quartzo-feldspathic, having been derived· from Mesozoic greywacke rocks, but North Island loess also contains tephric material. Up to six or seven layers have been identified in the thickest sections, e.g. Rangitikei Valley, southern North Island (Milne and Smalley, 1979) and Awatere Valley, northern South Island (Eden, 1987). These layers have accumulated over the last 300000 years or so. Tephrae dated at c. 23000 a B.P. and c. 250000 a B.P. provide important time data within North Island and northern South Island loess. Together with Argentina, New Zealand has the most significant loess deposits in the Southern Hemisphere.

Loess is also widespread in northern China, covering $440000 \, km^2$ with thicknesses known to reach 300 m. In the middle reaches of the Yellow River, it forms the famous Loess Plateau. China's loess deposits are the thickest and most extensive in the world. Because New Zealand and China are located in different hemispheres, there is much interest in comparing and contrasting the loess deposits of both countries.

Under the agreement between DSIR of New Zealand and SSTC of China,

scientists of both countries have carried out cooperative research on the mineralogy and geochemistry of loess between China and New Zealand during 1990. This paper concentrates on the major element chemistry of the Kimbolton loess column (North Island) together with the Muritai and Claremont loess columns (South Island) to understand the geochemical characteristics of the loess, and to compare with the Luochuan loess section from North China. The distributions and variations of elements are studied to interpret climatic fluctuations. This study has provided useful background data for learning global environmental changes.

New Zealand Loess Sections

Description of the main sections of loess in New Zealand

Several loess columns in New Zealand have been previously studied in detail, e. g. Mount Curl, Craigs Flat, Kimbolton and Table Flat columns in North Island; Muritai, Claremont, Darling and Stewarts Claim columns in South Island. This paper describes the major element chemistry of a new loess core from Kimbolton and compares and contrasts its chemistry with that of the previously described Muritai and Claremont loess columns.

1. Kimbolton loess column   The Kimbolton loess column is located in southern North Island about 30 km north of Palmerston North at grid ref. T23 478269. Here loess has accumulated on an old terrace of the Oroua River at an altitude of 540 m above sea level. The thickness of the drilled core was 11.21 m. The core consists of five loess layers and five paleosol layers in which two tephra interbeds are recognized in loess Layer No.1 and between loess layer Nos.4 and 5 (Fig.1). In the lower part of the column are clayey sediments, which may be lacustrine in origin. The clayey sediments are distinguished from the loess by their light olive-grey colour, distinct horizontal veins and very sticky and plastic nature. The five loess layers are similar to those defined by Milne and Smalley (1979).

Top soil, 0-22 cm: Dark yellowish-brown; silt loam; very weak ped strength.

Loess Layer No. 1 (Ohakea), 22-121 cm: Dark yellowish-brown to yellowish-brown; silt loam to silty clay loam; slightly sticky; very weak ped strength, moderate angular blocky fracture; manganese and iron mottles from 34-76 cm depth, 20% yellowish-red mottles and black Mn flecks in bottom 10cm.

Aokautere Ash, 121-138 cm: Yellowish-brown to brownish-yellow; very fine sandy ash; brittle fracture; weak to moderate sub-angular blocky fracture; common (5%) fine (4 mm) faint strong brown mottles.

Loess Layer No.1 (Ohakea), 138-161 cm: Yellowish-brown; silty clay loam; moderately weak ped strength; moderate fine angular blocky fracture; 1% small distinct black Mn flecks; diffuse boundary.

Paleosol, 161-195 cm: Dark yellowish-brown; silty clay loam; moderately weak ped strength; fine angular blocky fracture; small (2mm) distinct black Mn flecks.

Loess Layer No. 2 (Rata), 195-258 cm: Yellowish-brown; silty clay loam; slightly sticky; moderately weak ped strength; fine angular blocky fracture.

Paleosol, 258-399 cm: Dark yellowish-brown to dark brown; silty clay

loam ; moderately weak ped strength ; moderate to strongly developed fine angular blocky fracture ; prominent medium (10 mm) Mn mottles in lower 24 cm.

Loess Layer No. 3 (Porewa), 399-554 cm : Dark yellowish-brown to yellowish-brown ; silty clay loam or silty clay ; very weak ped strength ; moderately developed fine angular blocky fracture ; dark reddish-brown Mn mottles and faint brown Fe oxide mottles in lower part.

Paleosol , 554-678 cm : Dark brown to strongly brown ; silty clay or silty clay loam ; very weak to moderate ped strength ; strongly developed fine angular blocky fracture ; distinct Mn mottles.

Loess Layer No. 4 (Marton), 678-770 cm : Dark yellowish-brown to yellowish brown, silty clay loam ; very weak ped strength ; 3% fine (2mm) distinct black Mn flecks.

Paleosol , 770-834 cm : Dark brown to dark yellowish-brown ; silt clay to clay ; moderately weak ped strength ; 3% fine (2mm) distinct black Mn flecks.

Mount Curl Tephra , 834-883 cm : Yellowish-brown to strongly brown ; clay loam or clay ; moderately firm ped strength to 862 cm , then moderately or very weak ped strength ; weak fine angular or sub-angular fracture ; 2% fine (3mm) black Mn flecks.

Loess Layer No.5, 883-983 cm : Yellowish-brown to brown ; silty clay loam or silty clay ; moderately weak ped strength ; weak fine angular blocky fracture ; up to 3% strongly brown Fe mottles ; up to 10% black Mn mottles.

Paleosol? , 983-1013 cm : Light yellowish-brown to strongly brown ; clay ; very firm ped strength ; massive ; up to 50% brown Fe mottles and up to 3% black Mn flecks , as well as dark reddish-brown Mn and Fe nodules.

Clayey sediments , 1013-1121 cm : Light olive-grey with yellowish-brown , strongly brown and light grey mottles ; clay ; massive ; very firm ped strength ; characterized by distinct veins containing some black Mn-Fe nodules.

The upper part of the Kimbolton loess column is a typical yellow-brown earth-yellowish-brown loam intergrade soil in the New Zealand genetic classification (New Zealand Soil Bureau, 1968) or Ochrept using Soil Taxonomy (Soil Survey Staff , 1975). The soil is characterized by moderate dry bulk density , permeable yellowish-brown coloured B and C horizons and lack of hard pans or gley fea - tures. It has developed under about 1200 mm mean annual rainfall , which is evenly distributed throughout the year without extended periods of moisture deficit. However, the lower part of the column below the Mount Curl Tephra has mottled grey and yellowish-brown colouring similar to yellow-grey earths in the New Zealand genetic classification (Aqualfs), suggesting it has been gleyed.

2. Muritai core   The Muritai core was drilled near the mouth of the Awatere River (grid ref. P28 063507) in the northeastern part of South Island, New Zealand at an altitude of 90 m. The thickness of the core is 15.24 m. The stratigraphy of the loess column is given by Eden (1987). The seven members, in order of increasing age , are Starborough , Downs , Upton , Clifford , Grassmere, Station and Muritai loesses (Fig.1). The lower part of each member consists of relatively unweathered loess and the upper part of relatively weathered paleosol. The paleosol is distinguished from the underlying loess by having : (1) a finer soil texture and a higher clay content (generally > 25%), which are reflected in increased

plasticity and stickiness; and (2) moderately to strongly developed soil features, including oxide concretions, mottles and structures. The present soil developed in the loess is a typical yellow-grey earth of the New Zealand genetic classification or an Aqualf using Soil Taxonomy. It is characterized by its high bulk density and hard pan in the subsoil which has low porosity. The soil has developed under 600 mm mean annual rainfall in which there are pronounced summer moisture deficits and in winter excess rainfall may result in waterlogging due to impeded drainage caused by the low porosity of the hard pan. The Muritai loess core below the top soil is generally a uniform, yellowish-brown, massive, fine sandy loam or silt loam with dry bulk densities $1.6\text{-}1.8\,g\,cm^{-3}$ and water contents mostly between 10-15% (Eden, 1983). The morphology features several hard pans, which are present in the relatively unweathered loesses and protrude as shoulders in outcrop. The most prominent hard pans occur in Loess Layer No.1 (Starborough) and Loess Layer No.3 (Upton). In Loess Layer No.3 the hard pan is overlain by a fossil gleyed horizon marking the boundary between the paleosol and the loess beneath. The presence of occasional pebbles in this paleosol at Muritai suggests a break in the loess record at this section.

Close to this section, a thin, pale-coloured, fine ash layer was recognized in the uppermost loess. The tephra is in a similar stratigraphic position to Kawakawa Tephra (Aokautere Ash) in North Canterbury (Kohn, 1979) and to
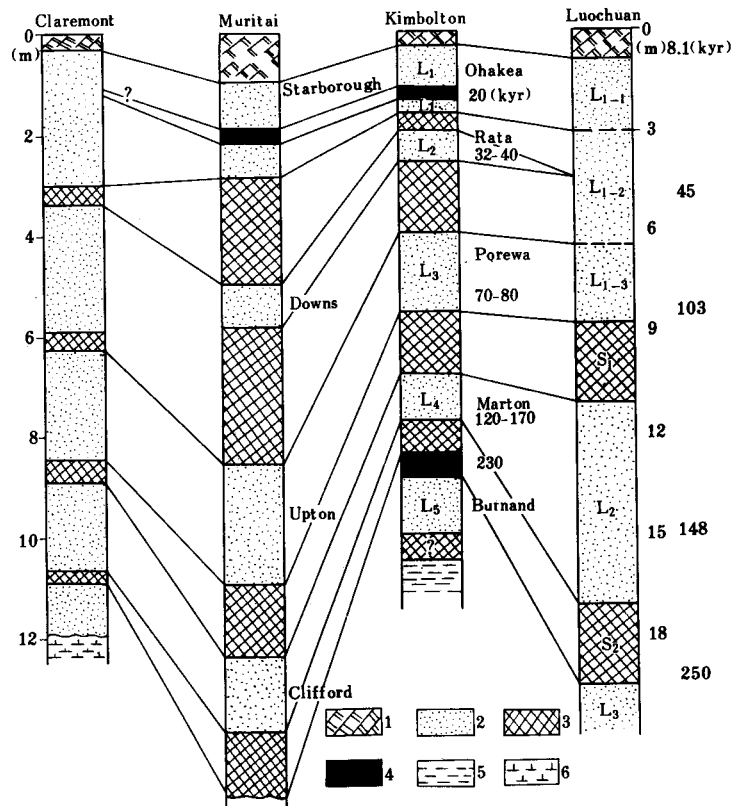

Fig.1. Comparison of some loess sections in N.Z. with the Luochuan loess section in China.
1. Top soil; 2. loess; 3. paleosol; 4. tephra; 5. clayey sediment; 6. basalt.

Aokautere Ash in southern North Island (Cowie, 1964). Therefore, it is correlated with Aokautere Ash. The tephra has a radiocarbon age of c.23000 a B.P. (Wilson, 1988). It is the most important stratigraphic marker in Awatere Valley loess.

3. Claremont column   The Claremont core was drilled in the middle part of South Island, 10 km west of Timaru (grid ref. J39 614422) at an altitude of 140m.

The core studied represents the Claremont No. 1 column of the South Canterbury loess deposits. The stratigraphy of this loess column is given by Bruce et al. (1973). Four morphologically similar loess layers were recognized, containing three paleosol layers. Below the loess deposits are mixed loess and weathered basalt, named Timaru Basalt. The surface layer of the column containing the present soil is classified as a yellow-grey earth under the New Zealand genetic classification or an Aqualf using Soil Taxonomy. The soil occurs under a mean annual rainfall of 600 mm. Each soil within the column is or has been, weakly gleyed, and iron-manganese concretions and iron mottles, indicative of reducing conditions in some parts of the soil, are evident. The morphology of the core is similar to that of Muritai (Fig.1).

Method of Analysis for Major Element Chemistry

The Kimbolton loess core was channel-sampled at 10 cm intervals along the core face. No sampling was done across horizon boundaries. Samples were air-dried for 48 hours at 30 ℃. Dried samples were then ground in a 100-ml tungsten carbide ring mill for one minute. Following grinding, samples were split into two. Analyses were done on the two samples. Ignition loss determinations (LOI) were carried out at 1000 ℃ for 1 hour on 2−3 g of sample material dried overnight at 105 ℃. Fused glass discs for X-ray fluorescence analysis were prepared from 0.55 g of ignited material incorporated into a lithium tetraborate flux using the method of Kennedy et al. (1983). The major element analyses were carried out by X-ray fluorescence (XRF) spectrometry on a Siemens SRS-1 sequential spectrometer, using the method of Kennedy et al. (1983). The XRF data presented in this paper represent the averages of single measurements on each of two subsamples. Eight subsamples of four reference soils from the Canadian

Table 1. Chemical compositions of loess and paleosol in the Kimbolton loess column

Component			SiO₂	Al₂O₃	Fe₂O₃	TiO₂	CaO	MgO	K₂O	Na₂O	MnO	P₂O₅
Loess	Range		51.63−67.48	16.02−26.31	4.6−9.78	0.66−1.09	0.09−1.78	0.5−1.35	0.78−1.69	0.68−2.45	0.05−0.17	0.01−0.26
	Average	1)	59.87	20.32	8.16	0.89	0.37	0.79	1.29	1.54	0.10	0.02
		2)	59.76	20.18	7.24	0.89	0.27	0.77	1.28	1.46	0.09	0.01
Paleosol	Range		43.3−61.31	15.78−26.89	5.25−11.57	0.66−1.38	0.05−1.94	0.4−1.44	0.55−1.43	0.51−2.33	0.1−0.37	0.01−0.30
	Average	1)	52.22	22.92	8.82	1.05	0.56	0.84	0.89	1.16	0.22	0.13
		2)	51.99	22.67	8.62	1.04	0.25	0.77	0.87	1.04	0.20	0.06

1) Arithmetic mean; 2) geometric mean.

Certified Reference Materials Programme were prepared and analysed at regular intervals along with the core samples. Mean values, standard deviations (at the 99.7% confidence level) for replicated determination of elements in these standards are presented with currently preferred international concensus values (Govindaraji, 1989) in the Appendix.

Results and Discussion

Kimbolton loess column

The analytical results for the Kimbolton loess core are listed in Table 1. It is clear from the frequency distribution histograms of these major elements that Si, Al, Fe, Ti, Mg, K, and Na display a normal distribution or approximately normal distribution. Therefore, their average values should be expressed as arithmetic mean values. But Ca and P show no normal distribution or log normal distribution, and thus their average values should be expressed as geometric mean values.

Element distributions for this loess column are shown in Fig.2(a) and (b). From this figure it can be seen that three elements Fe, Mn, and Ti show distinct variations in concentrations. The maximum concentrations generally appear in paleosols and the present soil, while the minimum concentrations appear in loess layers. There are clear peaks in paleosols developed on loess layers Nos. 3,4 and 5. Moreover, the peaks for Fe, Mn and Ti are synchronous. The high titanium contents in these paleosols may be due to weathering of andesitic ash, which contains large amounts of titanomagnetite (Palmer, 1982).

In addition, at the boundary between the loess and the clayey sediments there is also a marked peak for Fe and Mn, and a lower concentration of Ti [Fig.2(a)].

The concentrations of Al in paleosols are relatively higher than those of adjacent loesses whereas the concentrations of Si in paleosols are low relative to adjacent loesses. In addition, at the boundary between the loess and the clayey sediments the concentration of Al is low.

The concentrations of K and Na are very similar to each other with lower concentrations in the paleosols and relatively higher concentrations in the loess layers. The distribution patterns for K and Na may be attributed to weathering during paleosol formation, causing leaching of the elements. The concentrations of Ca in the upper part of the core are similar to those of K and Na with relatively low concentrations in the paleosols. But the concentrations of Ca are highest in the present soil, Aokautere Ash and Mount Curl Tephra layers. The high Ca content in the topsoil is probably due to addition of lime while the other peaks are probably due to Ca-feldspars.

The highest concentrations of P and Mg occur in the present soil as well as in the paleosol developed on loess Layer No.3. The high contents in the present soil are probably related to fertiliser additions while the pattern in the paleosol may be attributed to weathering during soil formation, including transport of P by plants from the rooting zone to the top of the paleosol (Childs and Searle, 1975). In addition, below 7.8 m the concentrations of P are all < 0.02%, i.e.,
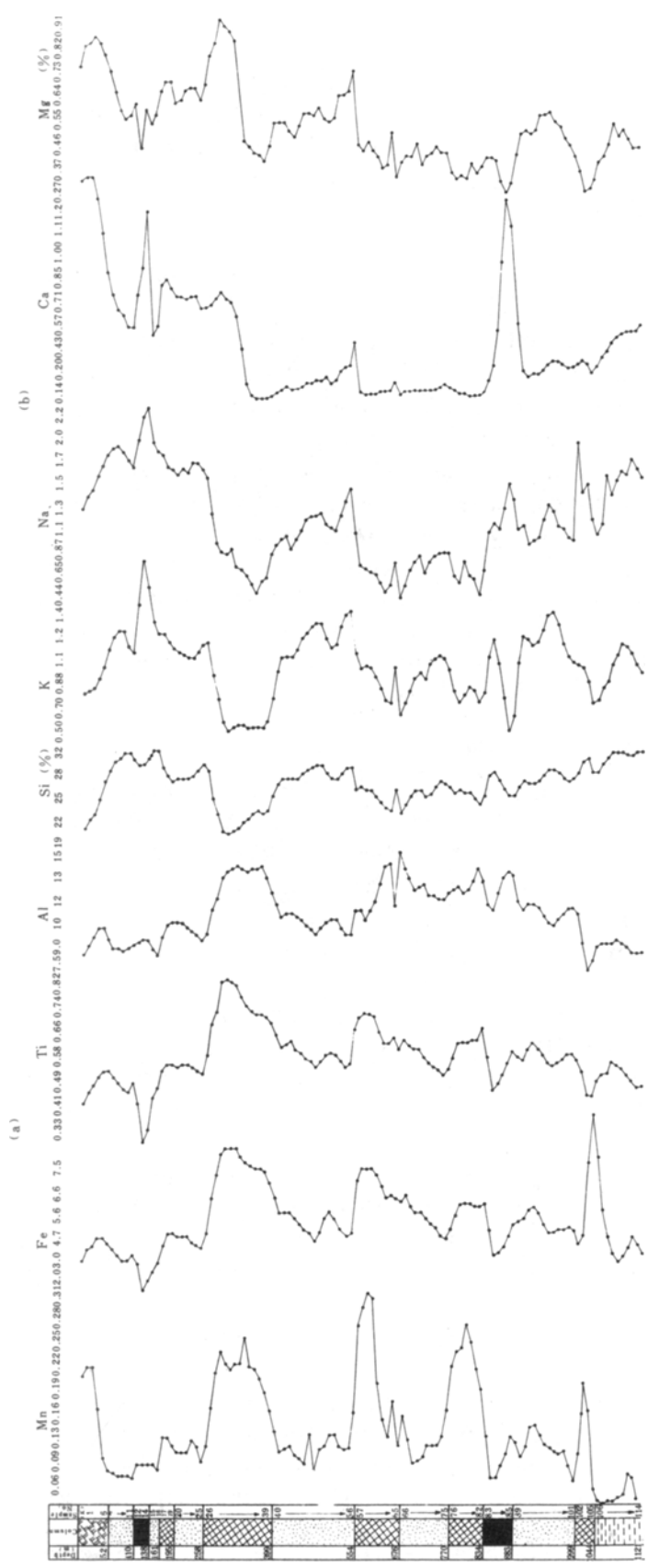
Fig .2. The distribution of major elements in the Kimbolton loess column.

below the detection limits for the instrument.

During paleosol formation from loess some elements were redistributed or lost from the column. For example, Fe, Mn, Ti and Al increase in the paleosols while K, Na, Ca and Si decrease.

In addition, the major element distributions of the clayey (lacustrine) sediments beneath the loess differ from those of the loess. The concentrations of Fe, Mn and Ti in the clayey sediments are slightly lower, and the concentrations of Si, Na and Ca are slightly higher than those in the loess. It may reflect the different material sources and origins. There are considerable variations at the boundary between the loess and the clayey sediments in which K, Na, Mg and Al decrease, and Fe and Mn increase. It is possible that after deposition of the clayey sediments there was a hiatus in which the clayey sediments were strongly weathered, causing migration of many elements. Only Fe and Mn accumulated. Moreover, Ti is usually considered to resist translocation by weathering processes, but its content at the boundary is also lower, which needs to be studied further.

The contents of P, Mn, Ca and Mg in the top soil are relatively higher than those of the underlying loess materials while the contents of Na and K are lower. Evidently, it is related to weathering during soil formation, though the increase of Ca, Mg and P at the top of the top soil is probably due to fertiliser addition.

Muritai and Claremont loess columns

Muritai   In the Muritai core, the loess layers are characterized by generally high Si and K contents relative to paleosols. But the paleosols are characterized by generally high Ti, Fe, and Al contents relative to loess, reflecting a higher clay mineral content in the paleosols. For example, it was found that as the clay content increases, the titanium percentage increases progressively (Eden, 1983).

The lowermost part of paleosol Layer No.2 (Upton) has very low contents of Ca, Mg, Mn and K, confirming the particle-size heavy mineral data, which indicate it is the most weathered part of the paleosol. Loess Layer No.3 contrasts greatly with its paleosol (2) in morphology and chemistry by markedly higher Si and K contents, and markedly lower Ti, Fe and Al contents.

In paleosol Layer No.3 developed on loess Layer No.4 (Clifford) very low Si, low K, high Ti, Fe, and moderately high Al contents indicate considerable weathering, despite the high pyroxene and basaltic hornblende contents. High Ca and Mg contents are probably due to the secondary carbonates noted in the outcrop section (Eden, 1983).

High Fe contents within paleosol Layer No.4 developed on loess Layer No.5 correspond to iron pans.

The top soil has relatively high contents of P, Mg, and K (horizon A only). The high P content is very probably due to organic phosphorus and fertiliser. The high Mn content may be due to the upwards relocation of manganese from the reducing environment of the underlying Btg horizon. The relatively high K content of the top soil (horizon A) is probably due to fertiliser addition.

Claremont   The distributions of elements in the Claremont loess column are similar to those in Muritai. The distributions of Si and Al show little variation

down the column, indicating probably they are uniformly distributed in the parent material and that weathering processes have not redistributed the elements (Childs and Searle , 1975). The distributions of Ti and Fe are similar. Both show higher concentrations in paleosols than in the loess. These high concentrations in paleosols may be related to clay illuviation (Childs and Searle, 1975). Lower concentrations of K , Ca, Mn and P occur in paleosols and higher concentrations in the loess. The pattern for K is particularly smooth, indicating an even distribution of K in the loess. The distribution patterns for K , Ca, and P may be due to weathering processes during soil formation, causing mobilization of the ele-ments, and hence their relocation in or loss from the column (Childs and Searle, 1975). Although Na and Mg display only small variations in concentration, they are also lower in the paleosols than in adjacent samples of loess. So it can be seen that the distributions of P , K , Ca , Mn and to a lesser extent Ti, Fe, and Mg follow the patterns which reflect soil development in each loess layer. In the Claremont column these elements provide useful evidence for the identification or confirmation of paleosols.

From the above description it is clear that the distributions of major elements in the South Island loess columns are similar to those in the North Island. Only Mn is an exception. The content of Mn in paleosols in the North Island is higher than that in loess, whereas the contents of Mn in the lower part of paleosols in the South Island are lower than in adjacent loesses. The Mn contents in the lower part of the Claremont and Muritai paleosols are low due probably to the upwards relocation of Mn. It is envisaged that under the reducing environ-ment of the lower B horizons, caused by seasonal waterlogging as described earlier, Mn is reduced to relatively soluble Mn^{2+} and it moves upwards to be reprecipitated as Mn^{4+} oxides in the oxidising environment of the A and AB horizons above the water table (Childs and Searle, 1975). This pattern does not occur in the Kimbolton core where the loess is permeable and waterlogging does not occur.

Comparison with Chinese Luochuan loess section

Loess is bast developed in the middle reaches of the Yellow River in North China. There is a lot o good natural loess sections, of which the Luochuan loess section is the most complete and typical section. This section is located at Potou Village, 4km from Luochuan City, Shaanxi Province. It has a thickness of 130 m. This section is divided into Malan loess, Upper Lishi loess, Lower Lishi loess and Wucheng loess in descending order. Loess deposition began about 2.4 Ma B.P. This section is composed of a series of loesses and paleosols. The individual loess-paleosol layers are named from top to bottom as: S0 , L1, S1, L2, S2, L14, S14, L15, WS-1, WL-1, WS-2, WL-2, WS-3, and WL-3 (Liu Dongsheng et al., 1985).

The major chemical compositions of loess are SiO_2 , Al_2O_3 , CaO, Fe_2O_3 , MgO, K_2O, Na_2O and FeO . The average contents of them are SiO_2 54.66%, Al_2O_3 11.45% , CaO 7.87%, Fe_2O_3 4.36%, MgO 3.44%, K_2O 1.96%, Na_2O 1.70%, and FeO 1.07%, respectively. In loess strata of different ages, variations in element distribution are described as follows: the contents of Ca and Fe^{2+} in

the upper part of Malan loess are higher than those in Lower Lishi and Wucheng loesses, whereas the contents of Fe^{3+}, K and Mn show an opposite tendency.

Table 2. The relationship between the contents of K for paleosol and minerals

Fraction	Mineral*	Porewa paleosol (Kimbolton)			S_1 (Luochuan)		
		K % mineral	Mineral % sample	K% fraction	K% mineral	Mineral % sample	K % fraction
Coarse silt 60-20 m	A. f.	12	10	1.2	12	8	1.0
	M.	9	4	0.4	9	10	0.9
Fine silt 20-2 m	A .f.	12	8	1.0	12	8	1.0
	M.	9	4	0.4	9	25	2.3
Clay 2 m	A .f.	6	3	0.2	6	0	0
	M.	4	3	0.1	4	60	2.4
Total				3.3			7.6

* A. f.: alkali feldspar; M.: mica.

Paleosols of different types and ages are found in the Luochuan section. The elements have undergone differentiation and reassignment during the change from loess into paleosol. In paleosols, the contents of Al, Fe^{3+}, K, Ti and Mn have increased to some extent compared with the parent loess, whereas Ca, Si, Fe^{2+}, etc. are lower than those in the loess. Relevant ratios of oxides (SiO_2 / Al_2O_3, FeO / Fe_2O_3, $CaO + K_2O + Na_2O / Al_2O_3$) are lower than those in loess too (except K_2O / Na_2O). Moreover, the values of oxide ratios have progressively decreased as a result of strong pedogenesis (Wen Qizhong et al., 1984). By means of "t test analysis" it has been found that paleosols were formed from loess through weathering, and Ca, Al, Fe^{3+}, K, Si, Ti, etc. are more variable than in the loess, This shows that Fe_2O_3, Al_2O_3 and K_2O accumulated while CaO and Na_2O were leached during loess weathering. At the same time a large amount of Fe^{2+} was oxidized into Fe^{3+}.

Frequent loess-paleosol alternation in the section reflects frequent climatic fluctuations from arid to humid throughout the Quaternary. At the same time the oxide values, degree of leaching and accumulation also reflect the differences in amplitudes of each climatic fluctuation.

It can be seen that some of the main chemical elements in loess from New Zealand are similar to those of loess in North China, while some of them are different. The most striking features are less Ca and Mg in New Zealand loess. Ca content is much lower than that in Chinese loess, resulting from a lack of carbonate minerals. In contrast, the Chinese loess is rich in carbonates. In addi-tion, the Al content of New Zealand loess is twice as much as that of China's loess. This may be related to a higher content of clay in New Zealand loess. The content of clay in loess from Muritai, for example, ranges from 18 to 38% (Eden, 1983), whereas the clay content of Chinese loess ranges from 7 to 30% (Liu, 1965).

Compared to Chinese loess, New Zealand loess has higher Al, Fe (Fe_2O_3)

and Mn contents in the paleosols, while Ca and Na contents in the paleosol are lower.

Also New Zealand loess has lower K and Si contents in paleosols, compared to Chinese loess where K and Si are higher in the loess than in the paleosol. This may be due to leaching of Si during weathering, whereas in China Si accumulates in paleosols as a result of leaching of $CaCO_3$. The contents of K in paleosols from Kimbolton and Luochuan are related to micas and alkali feldspars (Table 2). In paleosols between Kimbolton and Luochuan the contributions of K from alkali feldspars are similar to each other in content; .while the contributions of K from micas show striking differences (Table 2). So the lower K content of paleosols in New Zealand may be due to a lower mica content than in China. Since mica contains up to 11% K (Deer et al., 1966), its content can considerably affect the K content. Mica of silt and clay sizes in New Zealand paleosols is always lower (2 − 8%) than that in China (22 − 27%). Therefore, the concentration of K in paleosols in New Zealand is also lower (0. 48 − 1. 12) than that in China (1. 74 − 2.12%)(Fig .3).
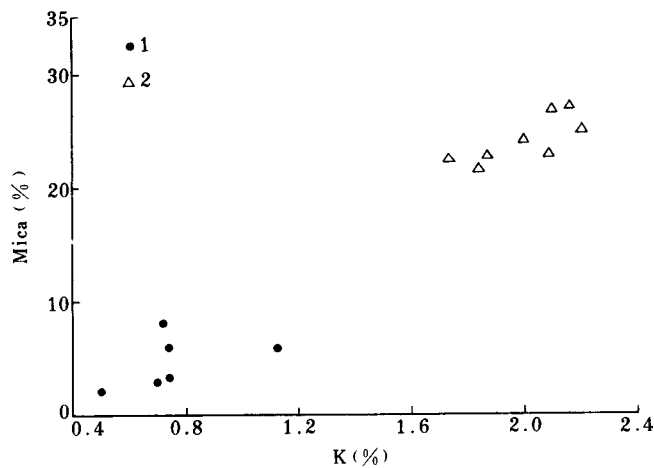

Fig .3 .   Relationship between K content in paleosol and mica content.
1. Kimbolton paleosol ;   2 . Luochuan paleosol .

Another factor may result from climatic differences in which the precipitation in New Zealand is higher than and distributed more differently than that in the Loess Plateau of China. The annual precipitation at Kimbolton is about 1200 mm and is fairly evenly distributed the year round while at Muritai and Claremont the annual precipitation is about 600 mm and there is a marked summer moisture deficit. At Luochuan the precipitation is less than 600 mm , but most of it falls during the summer months with no extended summer moisture deficits. At Muritai and Claremont the alternating, oxidizing and reducing conditions which have occurred as a result of annual summer moisture deficits and winter waterlogging of the soil above the hard pans have led to weathering and redistribution of elements .

Conclusions

From the geochemical comparison of New Zealand and Chinese loesses the

following conclusions can be drawn :

1. Although New Zealand and China are located in different hemispheres, the mechanisms of transport (by wind) and deposition are the same in both coun - tries.

2. In both countries loess columns are found containing loess-paleosol alterna - tions. The distributions and variations of the elements reflect the fluctuations of climate and can be compared both with oxygen isotope (δ ^{18}O) stages and with glacial periods. Loess was deposited during glacial periods (corresponding to the even numbered δ ^{18}O stages) while the deposition of paleosols is generally consis- tent with interglacials (corresponding to the odd numbered δ ^{18}O stages) (Liu, 1985; Eden, 1987). Among them, the main loess accumulation phase (from 25000 − 10000 a B.P.) in New Zealand corresponds to the Upper Malan loess in China and matches well with the cold climate conditions at δ ^{18}O stage 2, and coincides with the last glaciation maximum (LGM).

3. The source of loess in New Zealand is different from that in China. Therefore, the chemical composition also displays some differences, as indicated by very low Ca contents, which would have resulted from a lack of carbonate, and a high content of Al_2O_3.

4. Because of more rainfall in New Zealand and its different distributions, the leaching of elements in loess is stronger than that in China, so that not only Ca, Na, Mg and K migrated, but also Si was mobilized to a certain extent during weathering from loess into paleosol.

5. Loess accumulation (c.300000 a) in New Zealand started much later than in China (c.2.4 Ma). During the interval from 230000 − 10000 a B.P. at least four phases of paleosol were developed in New Zealand loess, but in the loess of China there were only three phases of paleosol during the same period of time (Wen and Zheng, 1988).

Possibly New Zealand was completely surrounded by the ocean, hence re- sulting in a greater sensitivity to slight climate changes, which were not recog- nized in continental land masses such as the Loess Plateau of North China. Since 10000 a B.P., in New Zealand Holocene loess is not widely recognized, although it has been dominant in the Awatere River Valley (Eden, 1987) and near Barrhill in Canterbury (Cox et al., 1973). But in China Holocene loess is widespread (Zheng, 1985). It may reflect an arid to semi-arid steppe environment on the Loess Plateau, which allowed loess to continue accumulating during the Holocene. By contrast, in New Zealand the widespread forest vegetation of the Holocene did not favour loess accumulation until the last 1000 years when man- and animal-induced vegetation removal has increased erosion in some areas (e.g. Awatere Valley), thus leading to loess accumulation.

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