BACKGROUND CONCENTRATIONS OF ELEMENTS IN SOILS OF CHINA

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ABSTRACT. Mean concentrations of 62 elements, pH, organic matter and grain size have been computed for soil samples from 4,095 locations throughout mainland China. The compositions of geochemical data between mainland China and the conterminous United States and between Tibet and Alaska show a close correspondence for most elements determined. These geochemical data may reveal evidence of regional variations in the abundance of elements in soils. In general, the sequence for metal content in samples of soil orders was: Lithosol>Cold-highland soils>Inceptisol> Aridisol = Mollisol>Ultisol>Alfisol>Oxisol. This trend was apparently a result of climatic influence on soil genesis, with the Oxisols (high rainfall areas with highly weathered and highly leached soils) yielding the lowest elemental mean values. However, the highest mean values of most trace elements in the Lithosols were a result of its relatively high indigenous elemental contents as well as chemical properties of the bedrock from which the soils were formed.

1. Introduction

Until 1950, there was only meager information on the chemical analysis of soils in China. Most of the reports on soil composition published in the 1950's and 1960's discussed only the major elemental composition of soils (Institute of Pedology, Chinese Academy of Sciences, 1959; Kovda, 1960; Institute of Pedology and Soil Conservation

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Chinese Academy of Sciences, 1961; Wen et al., 1965). Some of the works in the 1970's considered elements that were only of importance to geochemical exploration, agriculture or human health (Nanjing Institute of Pedology, 1978; Institute of Forestry and Pedology, 1980). These limited data can not be used to determine certain statistical parameters for undisturbed soils because they were primarily based on samples from cultivated fields, or were based on samples of deposits expected to have anomalous amounts of certain elements. Therefore, calculation of background data based on these studies, especially on a national scale, was deemed inappropriate.

In the 1980's, in response to the need for background data for concentrations of certain elements, particularly those of environmental and health concerns, several regional geochemical studies were initiated. They have been largely directed to the establishment of baseline abundance of elements in soils and other surficial materials (Joint Group for Background Data of Certain Elements in soils, 1982; Wu, 1986). This culminated in 1986 on a national extensive program "Investigations on Background Data for Concentrations of Elements in Soils of mainland China." This multi-institutional and disciplinary program had the following objectives: 1) estimate the range of elemental abundance in soils throughout mainland China; 2) compile the serial maps on elemental contents in soils of China, and; 3) study regional variations in abundance of elements in soils and the relationships of elemental levels with parent rocks, climate and soil formation. This paper deals with the comparison of the mean concentrations of elements in samples of soils from mainland China to those from the conterminous United States, the comparison of the means in soil samples from Tibet to those from Alaska; and the regional variation in abundance of elements of soils in China. This paper reflects only a small part of the program.

2. Methods and Materials

2.1 SAMPLE COLLECTION

Sampling locations were selected based on four criteria: distribution of soil types; distribution of parent rock types; province-level administrative divisions; and road network in China. Twenty-six groups of samplers, consisting of pedologists, geographers and geochemists, were involved. One group was assigned to each administrative division. Sampling intensity varied according to region: one location every 40x40 km^2 in the eastern coastal provinces; every 50x50 km^2 in most of the central provinces; and every 80x80 km^2 in western provinces. In the Tibetan Highland and the desert basins of Xinjiang Province, sampling locations were arranged along vehicular routes. The number of sampling locations in the administrative provinces of mainland China are given in Figure 1.

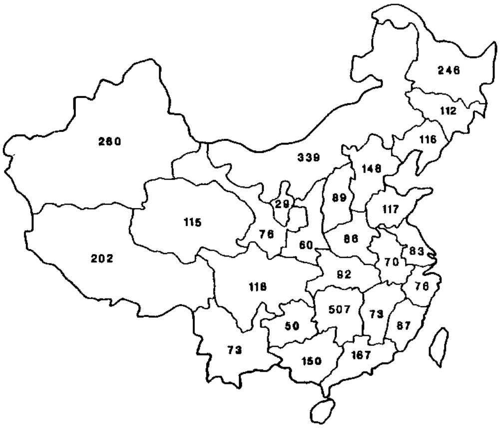

Figure 1. Number of soil and surficial matter sampling locations in the "administrative" provinces of mainland China.

The samples for the most part could be termed "soil." Some of the samples, however, were not soil, but other kinds of geologic matter, such as regolith. The regolith included desert sands, desert dunes, loess deposits, and beach and alluvial deposits A total of 4,095 locations were sampled. We requested the samplers to collect three samples from three horizons (upper, middle and lower layers) of every profile at every location. A total of 12,400 samples were collected. Collection was accomplished using conventional soil samplers such as shovel, spade and augers.

Sampling locations that were obviously affected by pollution or mining activity, or those within 200 m of roadways, were avoided. The samplers were asked to make notes on geology, pedology, physiography, and vegetation at each location, to mark the latitude and longitude, and to give a physical description of the soils sampled In some critical areas, sampling intensity and sampling depth were more frequent than the one outlined above.

2.2 CHEMICAL ANALYSIS

Sample analysis was conducted in 34 laboratories scattered among the National Environmental Monitoring Network, and national institutes and universities. These laboratories have passed the "Unified analysis quality examination" organized by a specific group of Chinese analytical chemists.

The samples were dried at ambient temperature in the laboratory. The material was then crushed and sieved through a 2-mm screen. The less than 2mm fraction was used for pH, organic matter determination and grain-size differentiation; the remaining material was pulverized to pass a 200-mesh sieve to be analyzed for 62 elements. All samples were analyzed for pH, organic matter, grain-size and 13 elements: Cu, Cd, Pb, Zn, Hg, As, Cr, Ni, Co, V, Mn, F and Se. These 13 elements were considered more important for environmental and health concerns. Approximately 10% of the total samples was analyzed for the other elements. The analytical methods used are given in Table I.

Table I. Analytical methodology for soil analysis.

Parameter*					Methods**
K (20)	Na (20)	Ca (70)	Mg (20)	Al (20)	ICP-AES (Digestion, HNO_3-HF-$HClO_4$)
Fe (40)	Ti (6)	Li (2.4)	Be (0.1)	Sr (2.1)	
Ba (6.0)	Ga (2.0)	V (5.0)			
La (.02)	Ce (1.0)	Pr (0.3)	Nd (0.1)		ICP-AES (Melt,Na_2CO_3-Na_2O_2)
Sm (0.06)	Eu (0.02)	Cd (0.09)	Tb (0.07)		
Dy (0.06)	Ho (0.06)	Er (0.08)	Tm (0.08)		
Yb (0.06)	Lu (0.02)	Y (0.023)			
Co (2.0)	Ni(2.0)	Cu (1.0)	Mn (5.0)		F-AAS (Digestion, HNO_3-HF-$HClO_4$)
Zn (1.0					
Cd (0.002)	Pb (1.0)	Ag (0.002)	In (0.002)		G-AAS (Digestion, HNO_3-HF-$HClO_4$)
Tl (0.003)					
Bi (0.003)	Te (0.009)	Se (0.002)			HG-AFS (Digestion, HNO_3-HF-$HClO_4$)
Mo (0.15)	W (0.15)	Sn (0.2)			Catalyst Polarography (Melt,Na_2CO_3-Na_2O_2)
As (0.5)	Ge (0.2)				Spectrophotometry
Cs (0.2)	Br (0.5)	Hf (0.2)	Zr (50)		INNA
Rb (8)	Sb (0.2)	Se (0.02)	Ta (0.1)		
Th (0.09)	U (0.2)				
Hg (0.002)					C-AAS (Digestion, HNO_3-V_2O_5)
I (0.03)					I-GC
F (5.0)					Selective ion electrode
pH					pH · meter
grain size					micro photo size
organic matter					chromic acid method

* Values in parentheses are detection limits in ug/g

** ICP-AES - Inductively Coupled Argon - Plasma Optical Spectrometry

F-AAS - Flame Atomic Absorption Spectrometry

G-AAS - Graphite Atomic Absorption Spectrometry

HG-AFS - Hydrogenate Atomic Fluorescence Spectrographic

I-NAA - Neutron Activation Analysis

C-AAS - Flameless Atomic Absorption - Spectrometry

I-GC - Gas Chromatography

2.3 DATA PRESENTATION

In this paper, we present only the geometric and primary arithmetic means. These data are more simply comparable with data generally reported in the literature. The arithmetic means may be best used as estimates of geochemical abundance (Miesch, 1967). Geometric means, however, are better "maximum likelihood estimators" for most geochemical data because of the tendency for concentration of elements in natural materials, particularly the trace elements, to have positively skewed frequency distribution (Miesch, 1967). Therefore, the analytical data for soils, as received from the laboratory, were logarithmically transformed. The geometric mean is reported as our best estimator of central tendency. Summary data for 65 elements, organic matter, and grain-size values of soil samples from mainland China are reported in Table II, in which the elemental concentrations found in samples from conterminous United States (Shacklette and Boerngen, 1984) are also provided for comparison. The same geochemical data of soil samples from Tibet are given in Table III, in which data of soil samples from Alaska (Gough et al., 1988) are also provided to make comparison.

Table II. Mean concentrations of elements in soils and other surficial materials from mainland China and the conterminous United States (Means are in μg g^{-1}, except as indicated).

	Mainland China			Conterminous United States*		
Element	Sample number	Geometric mean	Primary arithmetic mean	Detection ratio**	Geometric mean	Estimated arithmetic mean
Ag	825	0.11	0.13			
Al (%)	833	6.4	6.6	1092:1247	4.7	7.2
As	2982	9.2	11	1249:1257	5.2	7.2
B	834	39	68	931:1319	26	33
Ba	795	450	469	1219:1319	440	580
Be	842	1.8	2.0	479:1319	0.6	0.92
Bi	833	0.32	0.37			
Br	849	3.4	5.3			
C (%)	3887	1.2	1.8	412:413	1.6	2.5
Ca (%)	811	0.71	1.5	1291:1291	0.92	2.4
Cd	3947	0.074	0.097			
Ce	839	65	68	151:1171	63	75
Co	3923	11	13	1101:1311	6.7	9.1
Cr	3981	54	61	1319:1319	37	54
Cs	832	7.2	8.2			
Cu	3938	20	23	1301:1311	17	25
Dy	831	3.9	4.1			
Er	830	2.4	2.5			
Eu	824	0.98	1.0			

Table II.---Continued

	Mainland China			Conterminous United States*		
Element	Sample number	Geometric mean	Primary arithmetic mean	Detection ratio**	Geometric mean	Estimated arithmetic mean
F	3987	440	478	990:1015	210	430
Fe (%)	828	2.8	3.0	1315:1317	1.8	2.6
Ga	853	16	18	1198:1316	13	17
Gd	827	4.4	4.6			
Ge	827	1.7	1.7			
Hf	836	7.3	7.7			
Hg	4041	0.040	0.065	1263:1267	0.058	0.089
Ho	828	0.83	0.87			
I	852	2.3	3.7	259:399	0.75	1.2
In	846	0.060	0.068			
K (%)	819	1.8	1.9	1314:1314		1.5
La	844	37	40	756:1293	30	37
Li	846	29	33	1210:1258	20	24
Lu	820	0.35	0.36			
Mg (%)	829	0.64	0.78	1305:1306	0.44	0.90
Mn	3990	432	582	1314:1317	333	600
Mo	850	1.2	2.0	89:298	0.59	0.98
Na (%)	849	0.70	1.0	1107:1193	0.59	1.20
Nb				740:1296	9.3	11
Nd	820	25	26	339:870	40	46
Ni	3951	23	27	1190:1318	13	19
P (%)				904:906	0.026	0.04
Pb	3989	24	27	1134:1319	16	19
Pr	824	6.7	7.2			
Rb	810	107	111			
Sb	823	1.1	1.2			
Sc	818	10.5	11.1	1074:1304	7.5	8.9
Se	2904	0.22	0.29	1039:1307	0.26	0.39
Si (%)				406:406		31
Sm	833	4.9	5.2			
Sn	814	2.3	2.6	341:355	0.89	1.3
Sr	846	120	166	1279:1318	120	240
Ta	813	1.1	1.0			
Tb	818	0.58	0.63			
Te	842	0.021	0.035			

Table II.---Continued

	Mainland China			Conterminous United States*		
Element	Sample number	Geometric mean	Primary arithmetic mean	Detection ratio**	Geometric mean	Estimated arithmetic mean
Th	823	13	14	297:297	8.6	9.4
Ti (%)	826	0.36	0.38	1313:1317	0.24	0.29
Tl	838	0.58	0.62			
Tm	830	0.35	0.37			
U	827	2.8	3.0	354:354	2.3	2.7
V	3874	77	82	1294:1319	58	80
W	823	2.2	2.5			
Y	837	22	23	1236:1319	21	25
Yb	836	2.3	2.4	206:1250	2.6	3.1
Zn	3939	67	74	1239:1248	48	60
Zr	834	237	256			
pH	4087	6.5	6.7			
Organic Matter (%)	3887	2.0	3.1			
M1 (%)#	3884	58	61			
M2 (%)	3874	20	23			
M3 (%)	3833	14	18			

* Data taken from Shacklette and Boerngen (1984).

** Detection ratio refers to the number of samples in which the element was detected in measurable amount to the number of samples analyzed.

\# M1 - Particle size (.01 - 1.0 mm)

M2 - Particle size (.001 - .01 mm)

M3 - Particle size (<.001 mm)

Table III. Mean concentrations of elements in samples of soils and other surficial materials from Tibet, China and Alaska, USA (Means are reported in $\mu g\, g^{-1}$, except as indicated).

	Tibet, China			Alaska, USA*		
Element	Sample number	Geometric mean	Primary arithmetic mean	Detection ratio**	Geometric mean	Estimated arithmetic mean
Ag	75	0.10	0.11			
Al (%)	76	6.2	6.4	416:416	6.2	6.5
As	202	17	20	154:437	6.7	9.6
B	76	61	77			
Ba	75	370	380	437:437	595	678
Be	75	2.6	2.7	245:437	1.5	1.35
Bi	76	0.49	0.54			
Br	76	3.6	4.5			
Ca (%)	76	1.2	1.8	416:416	1.3	2.3
Cd	193	0.080	0.080			
Ce	76	67	71	427:437	28	33
Co	201	11	12	436:437	13	14
Cr	202	70	79	437:437	50	64
Cs	76	17	19			
Cu	200	20	22	437:437	24	29
Dy	76	3.2	3.9	322:437	2.5	6.8
Er	76	2.2	2.3			
Eu	76	0.90	1.0			
F	202	525	564			
Fe (%)	76	2.0	3.0	416:416	3.5	3.8
Fa	76	18	19	430:437	15	16
Gd	76	4.4	4.7			
Ge	72	1.8	1.8			
Hf	76	6.6	7.0			
Hg	199	0.021	0.024			
Ho	76	0.83	0.88			
I	75	1.3	1.4			
In	73	0.049	0.052			
K (%)	76	1.9	2.0	416:416	1.2	1.3
La	76	40	42	434:437	19	21
Li	76	38	42	436:437	26	30
Lu	76	0.31	0.33			

Table III. -- Continued

	Tibet, China			Alaska, USA*		
Element	Sample number	Geometric mean	Primary arithmetic mean	Detection ratio**	Geometric mean	Estimated arithmetic mean
Mg (%)	73	0.64	0.70	416:416	0.98	1.2
Mn	201	566	627	384:416	510	670
Mo	75	1.1	1.1	78:437	0.86	1.3
Na (%)	75	1.1	1.2	415:416	1.2	1.5
Nb				393:437	8.0	9.0
Nd	76	26	27	411:437	23	27
Ni	196	29	32	437:437	24	33
P (%)				411;416	0.078	0.086
Pb	193	28	29	417:437	12	14
Pr	76	6.2	6.7			
Rb	76	134	139			
Sb	76	1.4	1.6			
Sc	75	9.3	10	431:437	13	14
Se	201	0.14	0.16			
Si (%)				416:416	28	28
Sm	76	5.0	5.4			
Sn	74	3.1	3.3	111:437	2.6	3.1
Sr	75	135	150	437:437	159	198
Ta	76	1.1	1.2			
Tb	76	0.50	0.63			
Te	75	0.037	0.049			
Th	76	16	18	418:437	6.1	7.6
Ti (%)	75	0.32	0.34	416:416	0.48	0.52
Tl	76	0.66	0.70			
Tm	75	0.34	0.36			
U	76	3.2	3.4	436:437	2.3	2.8
V	202	73	77	437:437	112	129
W	75	2.8	3.0			
Y	76	20	21	434:437	14	15
Yb	76	2.1	2.2	362:437	1.4	1.6
Zn	201	71	74	427:437	70	79
Zr	76	229	241			

Table III. -- Continued

	Tibet, China			Alaska, USA*		
Element	Sample number	Geometric mean	Primary arithmetic mean	Detection ratio**	Geometric mean	Estimated arithmetic mean
pH	202	7.5	7.98	437:437	5.5	5.6
HM (%)	205	2.9	4.6			
M1 (%)	205	81	82			
M2 (%)	205	11	13			
M3 (%)	205	5.9	7.4			

* Data taken from Gough et al. (1988).

** Detection ratio refers to the number of samples in which the element was detected in measurable amount to the number of samples analyzed.

3. Results and Discussion

3.1 COMPARISON OF GEOCHEMICAL DATA BETWEEN MAINLAND CHINA AND THE CONTERMINOUS UNITED STATES

China is often compared to the United States since both are about equal in area and both occupy similar latitudes. Therefore, we suspected that geochemical data of soils in mainland China are comparable to those of the conterminous United States since the climate and soil distribution in the two countries are fairly alike. Both countries are characterized by extreme climatic conditions, i.e. desert in the western regions to a warmer more humid climate in the southeastern regions.

A comparison of the geometric and arithmetic means of elemental concentrations in soils between mainland China and the conterminous United States shows a close correspondence for most of the elements determined (Table II). This occurs in spite of differences in sampling intensity and analytical methods adopted by the two countries.

Only four elements (i.e. Be, I, Mo, and Sn) showed as much as two- to three-fold higher mean values for China. Most of the elements, notably As, B, Co, Cr, Li, Ni, Pb and Zn, showed slightly higher values in Chinese soils. However, C, Ca, Nd, and Yb showed similar or lower values than for the U.S. soils. Although it is premature to infer, these differences might have partly arisen from sampling and analytical variations between the two countries.

3.2 COMPARISON OF GEOCHEMICAL DATA BETWEEN TIBET AND ALASKA

Despite the great differences in geomorphology and latitudes between Tibet and Alaska and the variations in sampling intensity and analytical methods between the two studies, results between these two places can be compared because of their resemblance in climate and soil formation. In the Tibetan Highland and in Alaska, the same cold climate reduces the rate of chemical weathering and elemental loss by leaching. But, the action of the freeze-thaw cycle increases the rate of physical weathering. Although the growth of vegetation in the Tibetan Highland and in the Alaskan high-latitude regions is generally slow, the rate of decomposition is even slower, resulting in large deposits of organic materials in which many elements may be immobilized. Table III shows that the geochemical data in Tibet are fairly similar to that of Alaska. In general, there is close agreement for the mean values between the two areas, except for As, Ce, La, Pb, and Th, where Tibetan soils showed a two-to-three-fold increase in these values.

3.3 REGIONAL VARIATION IN ABUNDANCE OF ELEMENTS IN SOILS OF CHINA

In an initial effort to discern regional variation in elemental occurrence, 13 elements (Cu, Cd, Pb, Zn, Hg, As, Cr, Ni, Co, V, Mn, F and Se) considered of more environmental concern in China, were closely examined. These elements were analyzed in all soil and surficial samples (i.e. more than 12,000 samples). The data obtained in this study may reveal evidence of regional variations in abundance of elements in soils and other surficial materials in China. We devoted the effort especially to some members of the Fe family since this information might indicate some obvious geographical and geochemical patterns of the soil orders, suborders and great groups that might be expected to relate to differences in parent materials and temperature-precipitation regimes under which the soils developed.

Distribution of soil orders in China is displayed in Figure 2. The geometric means of the elements of various soil orders are given in Table IV and indicate that the means of most of the 13 elements in Oxisols are the lowest, except for Hg, Pb, and Se. The means of most elements in Alfisols or Ultisols are the next lowest; while Lithosols (terra rossa and purplish soils) have the highest mean values for most of elements, except Se. The Cold Highland soils (Gelic Inceptisol and Rock Land) have the second highest mean values for most elements. The mean values of these 13 elements (not including Hg) in Mollisols and Aridisols are about equal and are somewhat intermediate among the soil orders; all the 13 element values for Inceptisols are slightly higher than those for Mollisols and Aridisols. In general, the sequence of elemental mean values by soil order is: Lithosol>Cold-highland soils>Inceptisol>Aridisol = Mollisol>Alfisol>Oxisol (Table IV). Correspondingly, the sequence for the regional division is: Southwest China>Tibetan Highland>Xinjiang-Mongolia>Northern China>Northeast China>Southeast China (Figure 2).

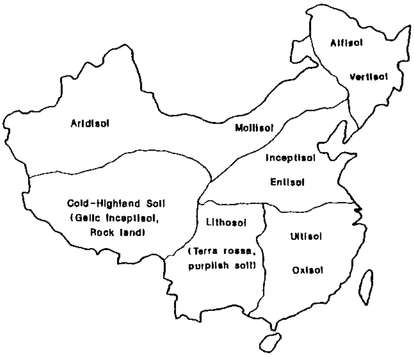

Figure 2. Distribution of soil orders in mainland China.

Table IV. Geometric means of elements in soils of mainland China by soil order (means are in μg g^{-1}).

Soil Order	Number of Samples	Cu	Pb	Zn	Cd	Ni	Cr	Hg	As	Co	Mn	F	Se	V
Lithosol	205	26.5	29.8	94.6	0.24	35.9	76.4	0.084	16.2	16.8	577	589	0.05	114
Cold-Highland soils	196	23.8	26.0	78.9	0.098	31.4	69.6	0.021	16.9	12.0	619	490	0.19	78.5
Mollisol	240	10.0	18.3	60.0	0.070	21.9	46.2	0.022	9.00	11.3	563	378	0.14	67.7
Aridisol	108	21.7	18.6	59.3	0.087	23.6	48.0	0.011	8.63	12.0	582	394	0.11	69.0
Inceptisol	508	21.8	20.0	71.4	0.080	27.6	56.4	0.009	10.1	13.8	613	446	0.18	82.1
Alfisol	186	15.1	19.8	75.3	0.090	17.7	46.8	0.055	4.95	11.2	1127	366	0.16	69.0
Ultisol	796	17.8	26.8	71.9	0.055	20.6	49.8	0.077	9.50	9.50	323	483	0.38	86.2
Oxisol	262	10.9	26.0	33.6	0.030	10.2	34.2	0.040	5.70	5.55	197	281	0.33	57.0
Vertisol	223	19.6	24.2	64.4	0.070	23.3	53.2	0.030	8.60	11.8	586	447	0.20	77.5
Entisol	265	22.2	21.4	69.7	0.090	28.9	63.0	0.032	9.40	11.4	604	517	0.15	82.9

We attribute the apparent geochemical and geographical patterns in elemental composition of soil orders in China mainly to the effect of climate on soil development. The highest values of the Lithosols are caused by the high indigenous elemental contents of the parent rock from which the soil originated. For example, the purplish soils in the Sichuan Basin were developed from the purple shales characterized by high elemental contents, including the trace metals. The "terra rossa" soil's characteristically high mean values for most trace elements may have been caused by certain properties and weathering processes of its parent limestone. We speculate that as the alkali metals and alkaline-earth metals were dissolved and leached during the weathering of limestone, the residual clay could accumulate some of the trace elements thereby acting as a sink. Certain elements, such as Hg and Pb, are difficult to relate to any climatic or soil formation factors, since these elements are widely introduced into the environment through agricultural and industrial input.

In summary, a massive effort undertaken in China in 1986 to establish a national bank for soil samples and soil characterization is aimed to provide information that are necessary to properly manage China's soil resources with regard to production of food and fiber and for environmental and health protection of livestock and humans. This paper deals primarily with elemental contents of soils and surficial materials in mainland China and how they are interrelated to climatic and geological factors.

4. ACKNOWLEDGMENT

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