Clay Research, Vol. 31, No. 1, pp. 12-26 (2012)

Elemental Composition and Mineralogy of Silt and Clay Fractions of Cracking Clay Soils of Semi Arid and Arid Parts of Gujarat, India

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Abstract: *Elemental composition and mineralogy of silt and clay fractions in two basaltic Vertisols viz Semla series: Aridic Haplusterts and Sokhda series: Calcic Haplusterts from semi-arid and arid tracts respectively of Gujarat were studied to characterize the nature and composition of clay minerals in relation to elemental composition and to derive geochemical climofunctions. The most reactive fine clay had smectite with traces of quartz and mica whereas concentrations of CaO and Na_2O contents in silt fractions indicating intensive weathering of calcium and sodium minerals. The chemical data further supported the formation of montmorillonite-beidellite group(molar ratio of Al/Al+Fe >0.5 in fine clay fracion). The high degree of salinisation (CaO/K_2O) in Sokhda series indicated the prevalence of high evapotranspiration and prolonged dry seasons in the region. The CALMAG index supported the formation smecite under past humid climate but preserved even in existing alternate wet and dry seasons.*

Key words : *Geochemistry, vertisols, mineralogy, weathering indices*

The geochemistry and mineralogy of Vertisols is of considerable interest because of their wide distribution (72 million hectares) and agricultural use in India. The Deccan basaltic clay soils have dominant smectite clay mineral (Pal and Desphande, 1987; Satyavathi *et al.,* 2010) but later found that the clays contained predominant amounts of the intermediate montmorillonite-beidellite group (Bhattacharyya *et al.,* 1993). These soils under alkaline conditions have high iron in their crystal lattice (Krishnamurthi and Satyanarayana, 1969) where as under anoxic conditions, iron is replaced by magnesium(Van Breemen, 1980). Pedogenic smectite forms in poorly drained soils characterized by high pH with high chemical activity of silica and basic cations (Borchardt, 1989). Minerals of intermediate weathering may be used as indicators of climate change in Southern and Central peninsular India (Pal *et al.*, 1989 and Srivastava *et al.*, 1998). The slow dissolution of Ca zeolites (<1me Ca L^{-1} in distilled water, Pal *et al*., 2006) provide sufficient bases to prevent compete transformation of smectite in vertisols of humid tropics of western India (Bhattacharyya *et al.*, 2005). The soils in arid climates shows a progressive formation of pedogenic carbonates with concomitant increase in Na ions in soil solution (Pal *et al.,* 2009). Larger differences in octahedral cation composition and in the proportion of aluminum in tetrahedral position of smectites have attributed to weathering environments under which they occur(Mermut *et al.*, 1984). It was further reported that the octahedral cation occupancy together with the number of Mg and Fe atoms per cell decreases with decrease in particle size of soil fractions (Curtin and Smillie, 1981). Therefore, an attempt is made to explore major elemental distribution in silt and clay fractions of smectite dominated basaltic vertisols to discuss changes in chemical composition during pedogenesis and to infer geochemical climofunctions.

Materials and Methods

The two dominant soil series *viz.,* Semla (P1) from semi-arid dry (MAR ≥635mm, mean air temperature (MAT) of 26.7^{o}C, Aridic Haplusterts) and Sokhda (P2) from arid (MARe≥533mm and MAT 26.7^{o}C, Calcic Haplusterts) regions of Gujarat were selected for elemental composition and mineralogical investigations in relation to particle size. These soils were developed over basalt with dark greyish brown to brown, clay textured, moderate, medium, subangular blocky structures in Ap horizons and very dark brown (P1) to dark reddish brown (P2) strong medium angular blocky structures in slickensided Bss horizons enriched with fine common lime nodules (Table 1). The morphological, physical and chemical properties of these soils were described earlier (Satyavathi *et al*., 2005).

The particle size distribution was determined as per International Pipette method after removal of organic matter, calcium carbonate and iron oxides. Sand (2000-50µm), coarse silt (50-20µm), medium silt (20-6µm), fine silt (6-2µm), coarse plus medium clay (2 to 0.2 µm) and fine clay (<0.2µm) fractions were separated according to size segregation procedure (Jackson, 1979). The elemental composition in different silt and clay fractions was determined using HF and aqua regia acid digestion (Page *et al.,* 1982). Mineralogy of silt and clay fractions was carried out by X-ray diffraction analyses of oriented aggregates saturated with either Ca or K using Philips diffractometer with Ni filtered CuKá at a scanning speed of 2^{0}2è/min. The minerals were identified using the diagnostic methods of Jackson (1979) and Brown (1984). Semi-quantitative estimates of minerals in the clay and silt size fractions were carried out as per the method of Gjems (1967).

Table 1. *Morphology of soils*

Depth (cm)	Horizon	Colour(moist)	Texture	Structure	consistence	Lime nodules	Other features
P1.Semla –Aridic Haplusterts(22^{0}01'59" N -70^{0}48'22"E, mean annual rain fall-635mm, mean annual temperature-26.7^{0}C							
0-17	Ap	10YR2/2	Clay loam	2msbk	sh, fr, s,p	Few, medium	
17-42	Bw1	10YR2/2	Silty clay	2msbk	fr, s,p	Fine-many, few-medium	Shiny pressure faces on ped surfaces
42-57	Bw2	10YR2/2	clay	2mabk	fr, s,p	Fine, very fine-many, few-medium	Shiny pressure faces on ped surfaces
57-86	Bss1	10YR2/2	Silty clay	3cabk	fr, s, p	Very fine –many, few-medium	Wedge shaped aggregates, presence of slickensides
86-115	Bss2	10YR2/2	Silty clay	3cabk	fr, s, p	Very fine-many, few-fine/medium	Wedge shaped aggregates, presence of slickensides
115-144	Bss3	10YR2/2	Silty clay	3cabk	fr, vs,vp	Very fine-many, few-medium	Wedge shaped aggregates, presence of slickensides
144-155	BC	10YR4/2	Clay loam	1msbk	fr, s,p	Very fine-many, few-medium	Powdery lime present in patches
P2.Sokhda- Calcic Haplusterts (23^{o}02'19" N – 70^{04}7'30"E, , mean annual rain fall-533mm, mean annual temperature, 26.7^{0}C							
0-11	Ap	10YR4/2	Clay loam	1msbk	sh, fr, s,p	Few, medium	
11-37	Bw1	10YR3/2	clay loam	2msbk	fr, s,p	Fine-common, few-medium	Shiny pressure faces on ped surfaces
37-63	Bw2	10YR3/3	clay	3msbk	fr, s,p	Fine, very fine-common, few-medium	Shiny pressure faces on ped surfaces, wedge shaped, slickensides
63-98	Bss1	10YR3/3	clay	3mabk	fr, s, p	Very fine –common, few-medium	Wedge shaped aggregates, presence of slickensides
98-145	Bss2	10YR3/3	clay	3mabk	fr, s, p	Very fine-common, few-fine/medium	Wedge shaped aggregates, presence of slickensides
145-160	BC	5YR3/4	clay	2msbk	fr, s, p	Very fine, fine -common, few-medium	

Results and Discussion

Particle size distribution

The sand content is 7.3 to 23.7% in Semla series (P1) and 8.5 to 37.3% in Sokhda series (P2) with depthwise decreasing trends (Table 2). The sand content in cambic and slickensided zones of Semla series (P1, 7.3 to 9.5%) is three times less than in Sokhda aeries (P2). Semla soil (P1) has 26 to 33% silt and 37 to 67% clay with irregular depth trends whereas Sokhda series (P2) has 20 to 43% silt and 41 to 55 % clay. Among silt fractions, medium silt is 9.2 to 15.8 % in P1 and 9.6 to 16.7% in P2 with erratic distribution. The clay content in control section (25 to 100 cm) has more than 60 per cent in Semla (P1) but 45 to 55 per cent in Sokhdal (P2). The fine clay is 70 to 80 per cent of total clay with irregular distribution in P1 and increasing trends in P2. Both soils have 2 to 9 per cent of coarse clay (2 to 0.6µm) and 4.3 to 14.6 per cent of medium clay (0.6 to 0.2µm). These soils are interpreted as vertic palesols based on high clay content (>40% to 60%), most of which is smectite accompanied by intersecting slickensides and mukkara structure(Soil Survey Staff 1999). These basaltic clay soils have coefficient of linear extensibility (COLE) values >0.10, supporting the presence of slickensides(designated as Bss), pedogenic carbonates (k) and seasonal wetness(g). The low matrix chroma(<2) is commonly linked with seasonal saturation and represent the environmentally controlled differences in iron bearing minerals. The estimated hydraulic conductivity is 2.3 cm/h in Ap horizons but reduced to 0.9cm/h in slickensided B horizons at 115 to 144 cm in P1 but decreased from 3.2 (Ap horizons) to 0.2cm/h in P2 at 98 to 145cm (Table 2).

The Semla soil (P1) is mildly alkaline (pH 7.8 to 8.0) with decreasing organic carbon (0.83 to 0.23%), erratic distribution of calcium carbonate (14.5 to 23.3 %), exchangeable Ca/Mg ratio of 1.1 to 2.3, CEC of 37.5 to 53.2 cmol(+)kg^{-1} and exchangeable magnesium per cent of 30 to 45 per cent. On the other hand, Sokhda (P2) is strongly alkaline with exchangeable magnesium per cent of 32 to 51 per cent, CEC of 27 to 32 cmol(+)kg^{-1} and shows slight inflections in organic carbon (0.21 to 0.48%) and calcium carbonate contents (11.6 to 22%). The presence of calcium carbonate nodules are common due to seasonal climates yielding mean annaual precipitation (MAP) between 760mm and 1000mm. The calcitic rhizoliths are common in arid regions where evapotranspiration is greater than effective precipitatio (Srivastava *et al.,* 2002) due to episodic rains that easily solubilise calcium carbonate and micrite precipitates when soil dries (Pal *et al.,* 2009).

Elemental composition and mineralogy

Semla series:

The data shows that Al_2O_3 and Fe_2O_3 are dominant in silt–clay fractions with erratic distribution. The content of Al_2O_3 is

Table 2. *Particle size distribution, available water holding capacity (AWC), hydraulic conductivity (HC) and chemical properties of soils*

Depth (cm)	Particle size distribution (%)							HC (cm/h)	AWC (%)	pH water (1:2)	OC (%)	$CaCO_3$ (%)	EX Ca/Mg	CEC cmol (+)kg-1	EMP
	Sand	Silt			Clay										
	(2000-50µ)	Coarse (50-20µ)	Medium (20-6µ)	Fine (6-2µ)	Coarse (2-0.6µ)	Medium (0.6-0.2µ)	Fine (<0.2µ)								
							P1.Semla								
0-17	23.7	9.3	11.2	12.6	2.6	13.1	27.5	2.3	15.6	7.8	0.83	15.4	2.3	49.5	30
17-42	11.8	5.2	13.8	9.1	5.4	7.2	47.5	4.2	15.5	7.8	0.66	18.2	2.1	50.1	34
42-57	9.5	7.8	9.2	9.8	9.8	2.4	51.5	2.1	13.3	7.9	0.68	18.6	1.4	53.2	41
57-86	7.5	6.4	15.8	9.8	6.2	7.8	46.5	1.7	16.3	7.9	0.48	14.5	2.2	48.3	32
86-115	7.8	2.6	13.2	9.8	5.2	6.7	54.7	3.2	12.5	7.9	0.61	17.2	1.4	52.5	41
115-144	7.3	5.6	14.9	10.4	6.4	6.9	48.5	0.9	14.9	7.9	0.54	17.7	1.7	47.0	35
144-155	21.5	10.9	12.1	18.5	9.2	14.6	13.2	1.2	13.5	8.0	0.23	23.3	1.1	37.5	45
							P2.Sokhda								
0-11	37.3	4.7	10	7.1	5.5	9.4	26	3.2	6.8	8.2	0.48	21.9	2.2	27.6	35.0
11-37	34.6	1.9	11.3	6.8	5.4	5.9	34.1	3.0	12.5	8.4	0.46	21.4	2.3	27.5	32.0
37-63	29.4	3.1	10.5	7.4	4.5	5.4	39.7	1.5	12.7	8.7	0.45	21.5	1.4	28.5	46
63-98	27.3	3.9	9.6	8.5	4.5	6.9	39.3	0.4	14.0	8.8	0.43	22.0	1.0	29.0	47
98-145	23.9	4.2	9.6	7.5	8.0	4.3	42.5	0.2	13.9	8.6	0.25	21.6	0.8	30.3	51
145-160	8.5	9.0	16.7	16.9	7.4	7.1	34.4	2.1	14.0	8.5	0.21	11.6	0.8	32.3	43

10 to 26.4% in coarse silt, 10.6 to 14.9% in medium silt, 13.1 to 16.9 % in fine silt, 15.8 to 20.1 % in coarse plus medium clay and 15.2 to 19.5% in fine clay fractions (Table 3). Similarly, Fe_2O_3 contents vary between 11.4 to 19.8 % in coarse silt and 12.1 to 17.9% in coarse and medium clay fractions showing relatively higher Fe_2O_3 contents in clay fractions. Among bases, CaO is dominant in coarse (4.1 to 16.1%) and medium silt (2.6 to 3.7%) but substantially decreased in coarse plus medium (0.1 to 2.4%) and fine clay fractions (0.1 to 0.7 %). The CaO decreases with particle size due to the less-resistant nature of Ca-rich plagioclase and slow release of Ca from Ca Zeolites that prevents transformation of smectite (Pal *et al.,* 2006). Next to CaO, MgO shows slight variations with depth (2 to 7.7 %) except in coarse silt fractions of Ap horizons (> 10%). The Na_2O contents are relatively high in silt fractions (1.2 to 4.4 %) but decreased to less than 1 per cent in coarse plus medium and fine clay fractions. This leads us to conclude that calcic plagioclases disappear in soil more rapidly than sodic plagioclases, as Ca-rich plagioclase is less resistant to weathering than Na-rich plagioclase. Depletion of CaO and K_2O in clay reflects the greater alteration rate of plagioclase compared to K-feldspar and the formation of illite from plagioclase and micas (Nesbitt *et al*., 1980). It was reported that silt and clay fractions have close relation with Al_2O_3, Fe_2O_3 and K_2O contents whereas MgO and CaO contents with silt fractions in these basaltic clay soils. Similar kind of relations were reported in basaltic clay soils of Sudan (Blokhuis *et al.,* 1968).

The fine clay contains 99 per cent of smectite with 1 per cent of mica (Table 3) whereas coarse plus medium together contains 58 to 71.5 clay % of smectite whereas coarse silt has 50 to 70% of Na/Ca feldspars, 8 to 16.0 % of K feldspars, 5 to 15% of quartz and 3 to 11% of smectite and fine silt with 28 to 40 % of smectite and 22 to 42 % of Na/Ca feldspars. In general, clay fractions have more smectite whereas silt fractions have high content of feldspars and quartz.

Sokhda series

The Sokhda series shows the dominance of Al_2O_3 in coarse plus medium clay fractions (22.6 % in surface to 28.2 %, Table 4) where as 5.6 to 7.8 % in coarse silt. In coarse plus medium clay fractions, Fe_2O_3 vary from 12.4 to15.8% as against fine silt fraction(8.7 to 13.7%) whereas MgO contents vary 5.3 to 7 % to 4.2 to 4.9%. The CaO in coarse silt contains 0.8 to 2.2 % but decreases with particle size from medium silt (0.5 to 1.3 %) to fine silt (0.2 to 1.1%) and less than 0.1 % in coarse plus medium clay. Na_2O contents in silt fractions is more than 1% but decreased to 0.1 % in fine clay. The K_2O contents are more than 2% in coarse plus medium clay, >1.5 % in fine and medium silt and <1% in coarse silt and fine clay. The more K_2O contents indicate the presence of weathering products of biotite

Table 3. *Elemental and mineral composition in selected fractions of silt and clay in semla series (Please explore a meaning in the fairly uniform depth distribution of Na_2O and CaO in the silt and clay fractions)*

Depth (cm)	Elemental composition (%)						Minerals (%)				feldspars		
	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	smectite	chlorite	mica	quartz	K	Na/Ca	zeolites
P1.Semla series –Aridic Haplusterts													
Coarse silt													
0-17	26.4	19.8	16.1	11.3	3.3	0.8	11	tr	3	6	8	54	15
17-42	13	13.4	5.6	5	1.9	0.5	7	tr	tr	5	13	70	4
42-57	10.9	12.6	5.1	4.7	1.7	0.4	3	1	tr	15	16	56	8
57-86	10	11.4	4.1	2.8	1.8	0.5	8	0	1	13	13	55	8
86-115	11	16.3	4.7	4.9	2	0.5	7	2	2	9	16	50	11
115-144	10.9	11.9	4.1	2.7	1.7	0.6	6	1	1	13	14	52	10
144-155	14	12.2	4.4	4.6	1.9	0.6	4	1	1	10	12	67	2
Medium silt													
0-17	14.9	9	3.4	3.3	2.6	0.7	15	tr	1	4	9	57	11
17-42	13.8	12.9	3.7	3.4	2.5	0.8	19	7	tr	5	8	58	3
42-57	14.4	13.6	3.7	3.2	2.7	0.8	14	5	tr	11	10	51	8
57-86	11.6	9.7	2.6	2	2.3	0.9	13	3	2	10	12	52	5
86-115	14.1	13.3	3.5	3.4	2.7	0.8	16	6	tr	12	9	48	7
115-144	10.6	10.9	3.1	2.7	2.2	1	18	3	4	10	8	47	1
144-155	14	11.9	2.8	3.9	2.3	0.9	15	1	2	8	7	60	3
Fine silt													
0-17	14.5	10.7	0.6	4.3	2	0.9	40	9	2	5	0	35	7
17-42	16.9	14.5	2	4.4	4.4	1.2	30	12	4	5	0	42	4
42-57	14.7	15.6	2.2	4.8	2.3	1	37	15	tr	9	0	31	3
57-86	13.2	12.5	1.3	3.5	1.8	1.3	37	11	4	11	0	22	4
86-115	15	14.8	4.3	6.3	2.4	1	34	11	1	8	0	33	2
115-144	13.1	11.5	1	3.4	2	1.3	28	5	3	11	3	35	2
144-155	15	13.6	0.9	5.1	1.2	0.8	38	4	1	4	0	42	3
Coarse +medium clay													
0-17	16.8	12.1	0	5.6	0.6	0.5	71.5	12	0.5	0	0	7.0	4.5
17-42	20.1	17.9	0.8	6.3	0.7	0.8	60.5	19	1.5	4.0	0	13.5	1.5

Table 3. *Continued ....*

Depth (cm)	Elemental composition (%)						Minerals (%)						
	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	smectite	chlorite	mica	quartz	feldspars K	feldspars Na/Ca	zeolites
42-57	16.9	16.7	1.1	6.6	0.8	0.5	61	14.5	tr	5.0	0	14.0	2.0
57-86	18.2	16.2	0.5	5.8	0.6	1.4	58	9	4.5	5.0	0	8.5	4.0
86-115	17.6	17.7	1.4	7.7	0.8	0.6	64.5	13.0	1.0	3.0	0	6.5	2.0
115-144	17.6	17.1	2.4	7.5	0.6	1.3	62.5	9.0	5.0	2.5	0	11.5	1.5
144-155	15.8	13.6	0.1	4.6	0.2	0.3	72.5	1.0	tr	0	0	18.0	1.0
Fine clay													
0-17	15.6	10.9	0	3.6	0	0.3	99	0	1	0	0	0	tr
17-42	19.5	14.1	0	4.2	0.1	0.3	99	0	1	0	0	0	0
42-57	17.5	13.6	0.7	4.4	0.2	0.2	99	0	1	0	0	0	tr
57-86	16.4	13.9	0.1	3.9	0.2	0.5	99	0	1	0	0	0	0
86-115	16.5	13.7	0.4	4.8	0.4	0.1	99	0	1	0	0	0	0
115-144	16.2	15	0.6	4.4	0.2	0.5	99	tr	1	0	0	0	0
144-155	15.2	12	0.3	4.4	0.1	0.2	99	tr	1	0	0	0	0

and its strong association with silt plus clay fractions (Abdel Ghani, 1964).

The CIW(Maynard, 1992) in coarse and medium silt fractions showed high values 63 to 80 per cent in P2 as against P1 (50 to 68%) indicating more feldspar weathering in Sokhda series(P2). The bases to Al ratio and Ca to Al ratio's are generally high silt and clay fractions of Semla series (P1,Table 5) but relatively low K+Na to Al ratio(2.8 to 6.8 per cent). The salinization ratio(K+Na/Al*100) in silt fractions of Sokhda series (P2) is varied from 6.2 to 11.1 and is related with mean annual temperature. However, salinization is not reliable pedogenic process indicators because of differences in behaviour of K and Na and also Na less subject to diagenetic redistribution (Retallack, 1991). Using the regression equatons of Sheldon *et al.,* (2002) between mean annual temperature (MAT) and salinization of a Bw or Bss horizon: MAT(^{0}C) = " 18.5S + 17.3 where the standard error (SE) is ±4.4°C, S is salinization. The underlying principle is that alkali elements (K and Na) are typically accumulated in desert settings, which usually have relatively low MAT (even if they are seasonally or daily high). Thus, high salinization ratios should have low MAT values. As per this equation , the differences in mean annual temperature of sokhada and semla series is almost 15±4.4. Further using CALMAG index (MAR=22.69*

Table 4. *Elemental composition and mineralogy of silt and clay fractions in sokhda series*

Depth(cm)	Elemental composition (%)						Minerals(%)				feldspars		
	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	smectite	chlorite	mica	quartz	K	Na/Ca	zeolites
P2.Sokhda series- Calcic Haplusterts													
Coarse silt													
0-11	7.8	8.2	1.7	1.9	1.3	0.7	tr	2	6	19	8	56	3
11-37	9.1	8.8	2.2	2.5	1.6	0.9	3	4	9	35	10	26	5
37-63	8.3	9.7	1.9	2	1.4	0.8	tr	0	9	25	33	23	5
63-98	9.5	10.3	1.9	2	1.7	1	3	2	2	17	25	45	4
98-145	8.6	10.8	1.8	2.1	1.4	0.9	0	2	5	14	18	53	5
145-160	5.6	1.7	0.8	0.2	1.2	0.9	0	2	13	19	30	32	2
Medium silt													
0-11	12.3	10.4	1.2	2.9	1.6	1.3	6	7	6	19	10	46	2
11-37	10.8	9.5	0.7	2.4	1.6	1.1	12	8	8	29	0	30	2
37-63	11.3	10.1	1	2.7	1.7	1.2	7	7	8	29	19	18	1
63-98	14.4	12	1.3	3.2	1.8	1.4	5	8	6	19	19	35	4
98-145	10.1	10.3	0.7	2.8	1.7	1.2	tr	8	9	20	15	38	4
145-160	9.7	3.7	0.5	1.1	1.5	1.5	0	7	13	21	22	27	3
Fine silt													
0-11	15.9	12.2	1.1	4.9	1.2	1.7	20	20	12	17	0	19	2
11-37	15.5	12.1	0.2	4.2	1.1	1.7	24	18	18	13	0	15	1
37-63	16	13.5	0.3	4.6	1	1.8	11	15	6	30	0	8	2
63-98	16.1	13.4	0.7	4.8	1.2	1.8	13	20	17	18	0	15	2
98-145	15.8	13.7	0.9	4.9	1.3	1.7	11	20	14	16	0	13	2
145-160	17.7	8.7	0.3	4.8	0.8	2.4	tr	22	24	16	14	14	4
Coarse +medium clay													
0-11	22.6	13.1	0	5.3	0.4	2	42.0	9.5	11.5	4.5	0	11.0	3.0
11-37	23.7	14.2	0.1	5.9	0.5	2.1	43.5	11.5	11.0	4	0	4.5	3.0
37-63	23.6	13.7	0.7	6.4	0.5	2.2	50.0	11.5	11.0	5	0	3.0	1.0
63-98	25.1	14.9	0	6.4	0.4	2.3	39.0	25.0	10.0	4	0	5.5	2.0
98-145	26.8	15.8	0.1	6.5	0.4	2.3	45.0	13.0	11.0	6	0	6.0	0.5
145-160	28.2	12.4	0.1	7	0.4	3.1	38.5	26.0	23.0	5	0	0	2.0

Table 4. *Continued ...*

Depth(cm)	Elemental composition (%)						Minerals(%)						
	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	smectite	chlorite	mica	quartz	feldspars		zeolites
											K	Na/Ca	
					Fine clay								
0-11	20.4	12.5	0	4.5	0	0.9	97	0	2	0	0	0	1
11-37	19.3	13	0	5	0.1	0.8	97	0	3	0	0	0	tr
37-63	18.1	12.4	0	4.6	0.1	0.7	95	0	5	0	0	0	tr
63-98	19.2	13.2	0	5.1	0.1	0.7	95	0	5	0	0	0	0
98-145	18.3	13.2	0	5.3	0.1	0.7	96	0	4	0	0	0	0
145-160	22.8	12.4	0	3.5	0.1	1.3	95	4	1	0	0	0	0

CALMAG-435.8, Nordt and Driesse, 2010) the mean annual rainfall (MAR) is estimated to be varying from 880mm to 960mm per year which slightly higher than the current rainfall in the region supporting the formation of smectite under humid past climate.

The smectite is more than 95 per cent in fine clay but only 3 per cent if coarse silt. The predominance of smectite over other mineral phases in the fine clay is the cause of shrink-swell properties in these soils. The CIA in coarse plus medium clay fractions of Sokhdad series(P2) is about 60 to 85 per cent as compared to Semla series (P1) with values of 45 to 59 per cent (Table 6). due to clay-rich in the first place with CIA values of 60 and above (Sheldon and Tabor , 2009). The weathering indices such as CIA is a measurement of the weathering of feldspar minerals and their hydration to form clay minerals. As clay content increases Al should also increase, whereas Ca, K, and Na contents should decrease, leading to higher CIA values. Further , the elemental composition of fine clay has a trend line of Al/Al+Fe versus Al/Al+Mg exceeding 0.5 suggesting a trend of in the direction of an iron analog of montmorillonite (Mermut, 1984, Table 6). The occurrence of iron rich smectites (propably iron rich bedillite) from basaltic parent rock (Krishnamurthi and Satyanarayana, 1969). The Fe-content of the smectite is a function of the chemical composition of the circulating water: nontronite is favoured by “dilute”neutral

Table 5. Molar ratios oxide concentrations of silt fractions

Soilseries	Coarse silt					Medium silt					Fine silt				
	CIA	CIW	Bases /Al	Ca/Al *100	K+Na/ Al*100	CIA	CIW	Bases/ Al	Ca/Al *100	K+Na/ Al*100	CIA	CIW	Bases/ Al	Ca/ *100	K+Na/ Al*100
P1. Semla series															
0-17	50.3	50.8	0.94	82.1	2.16	64.7	66.1	0.28	30.7	3.3	79.3	82.1	0.24	5.6	4.3
17-42	56.2	57.1	0.38	57.9	2.69	61.9	63.5	0.29	36.0	4.1	66.0	68.2	0.33	15.9	4.9
42-57	54.4	55.2	0.35	62.9	2.56	62.3	63.8	0.28	34.6	3.9	69.8	72.1	0.30	20.1	4.7
57-86	55.6	56.7	0.26	55.2	3.48	62.9	65.1	0.19	30.1	5.4	73.4	77.3	0.22	13.3	6.8
86-115	54.9	55.9	0.36	57.5	3.18	62.5	64.1	0.28	33.4	3.9	61.7	63.5	0.42	38.5	4.6
115-144	57.8	59.2	0.25	50.6	3.83	58.7	61.0	0.24	39.3	6.6	74.1	78.0	0.21	10.3	6.8
144-155	62.0	63.2	0.34	42.3	2.99	66.3	68.3	0.28	26.9	4.5	82.5	85.1	0.26	8.07	3.7
P2.Sokhda series															
0-11	64.5	67.2	0.15	29.3	6.2	73.6	77.8	0.18	13.1	7.3	79.6	84.6	0.26	9.3	7.4
11-37	62.5	65.3	0.19	32.5	6.8	75.1	79.2	0.15	8.7	7.0	85.0	90.8	0.20	1.7	7.6
37-63	63.6	66.4	0.16	30.8	6.6	73.0	77.1	0.17	11.9	7.3	85.0	91.0	0.22	2.5	7.8
63-98	64.4	67.6	0.16	26.9	7.3	74.8	78.8	0.20	12.1	6.7	81.7	87.2	0.24	5.8	7.7
98-145	64.7	67.8	0.16	28.1	7.2	72.8	77.4	0.17	9.3	8.2	80.1	85.2	0.25	7.6	7.5
145-160	64.3	69.2	0.05	19.2	11.1	73.6	79.9	0.09	6.9	10.7	85.5	92.9	0.22	2.2	9.4

systems and Mg-montmorillonite by concentrated, alkaline systems(Ghosh and Kapoor, 1982).

The first weathering products of plagioclase rich Deccan basalt is a dioctahedral smectite in arid to humid climate. Weathering of primary minerals contributes very little towards the formation of smectite. It is thus difficult to resolve the formation of large amounts of smectite clay in vertisols with the current semi arid climates. Therefore, smectites were formed in earlier humid climate and preserved in the nonleaching environment of arid and semiarid climate (Bhattacharyya *et al.*, 1993 and Pal *et al.*, 2009). At the high pH prevailing in the upper 54 cm of this soil (8.8-9), silica becomes most soluble and is free to recombine with soil cations such as Mg, Fe and Al to form secondary clay minerals.

Conclusions

Elemental composition and mineralogy of silt and clay fractions of typical moderately alkaline basaltic vertisols in semiarid (Semla series) and arid (Sokhada series) parts of Gujarat showed increase of clay content with concomitant increase of Al and decrease of Ca, K and Na contents. These vertic palesols have 45 to 60% clay, out of which 70 to 80 per cent is fine clay dominated by smectite and traces of mica. Elemental composition of these basaltic clay soils are rich in Mg and Fe with a significant differences in the ratio of bases

Table 6. *Molar ratios of geochemical elements in clay fractions*

Depth(cm)	Coarse plus medium clay					Fine clay	
	CIA	CIW	Bases/Al	Ca/Al *100	K+Na/ Al *100	Al/ Al+Fe	Al/Al+ Mg
				P1. Semla series			
0-17	55.5	95.9	0.80	0	2.11	0.87	0.77
17-42	55.0	91.4	0.82	5.35	2.76	0.87	0.78
42-57	49.3	87.5	1.03	8.76	2.06	0.87	0.76
57-86	54.5	92.9	0.84	3.69	5.32	0.86	0.77
86-115	46.4	86.2	1.15	10.71	2.36	0.87	0.74
115-144	45.0	81.7	1.22	18.36	5.11	0.86	0.76
144-155	59.4	97.7	0.68	0.85	1.31	0.87	0.74
				P2.Sokhda series			
0-11	62.4	97.9	0.60	0	6.11	0.82	0.67
11-37	60.8	97.0	0.64	0.57	6.12	0.81	0.63
37-63	57.8	93.9	0.73	3.99	6.44	0.81	0.64
63-98	60.7	98.2	0.65	0	6.33	0.81	0.63
98-145	61.7	97.8	0.62	0.50	5.93	0.80	0.61
145-160	60.7	97.9	0.65	0.48	7.59	0.84	0.75

to Al ratio, Ca to Al ratio and K+Na to Al ratio in both silt and clay fractions. Formation of smectites under humid past climate further confirmed with CALMAG index and molar ratio's of Na_2O and K_2O to Al_2O_3. The study of vertisols in semiarid and arid regions of Gujara suggested that geochemical records in relation to mineralogy is important to reconstruct climatic interpretation and the existence of iron rich smectites.

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(Received 15th July, 2012; Accepted 30 July, 2012)