on Beaconsfield, north of Grahamstown

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The Grahamstown clay deposits occur below the Grahamstown Formation silcrete, which forms a remnant of an extensive peneplain that developed on the African erosion surface during the Cretaceous–Tertiary period. This paper provides new data on the distribution of the kaolinitic clay deposits in the Beaconsfield area north of Grahamstown. These data include 23 borehole profiles through the deposits, and the chemistry and mineralogy of the clays. Relatively little information is available on this part of the peneplain. It was found that the thickness of the kaolin horizon varies considerably, but reaches 35 m in places. It generally occurs under a silcrete cover, which attains a thickness of 8 m in places. Lithological logs enable direct comparison across the Beaconsfield area. The clays are developed in both the Witteberg Group shale and Dwyka Group tillite. The contact between the clay and underlying bedrock is gradational and relatively uneven. Major-element X-ray fluorescence analyses revealed that there is chemical variation, both vertically and laterally. Al_2O_3 content is generally near 20%, but may reach 29%. SiO_2 content varies between 55 and 70+%. SiO_2 contents are highest in the silcretes occurring just below soil level. Fe_2O_3 is high locally in the top part of the profile. K_2O and Na_2O are generally low, but increase towards the unweathered bedrock as the primary feldspar content increases.

concentrations of kaolinitic clays through deep weathering below the former African erosion surface.

Introduction

The Grahamstown area is situated in the eastern part of the Cape Fold Belt and is underlain by folded rocks of the Cape and Karoo supergroups (Fig. 1). The clay deposits are related to the Grahamstown Formation silcrete, an ancient pedogenic horizon which developed across the folded rock sequences on a broad, slightly concave, peneplain. Remnants of this peneplain owe their preservation to the resistant layer of silcrete, which hinders erosional destruction.[1,2] Clay deposits underlie the peneplain and represent mainly the deeply weathered profile that developed during Cretaceous to Tertiary times.[3–5]

This paper is concerned with the geology and mineralogy of the Beaconsfield area on the northern part of the peneplain. Recent mining and exploration activity has provided a number of vertical profiles through the deposits, and clay material for chemical and mineralogical analyses. No such data are presently available for this area.

Location and geology

The clay deposits described here are located about 7 km north of Grahamstown on Beaconsfield (33°51′S, 26°33′E), a subdivision of the farm Brakkefontein 243 (Fig. 2). The pit from which the clay is presently extracted lies at the northern edge of the Grahamstown Formation silcrete (also the edge of the peneplain).

The region is underlain mainly by rocks of the Witteberg Group of the Cape Supergroup, and the Dwyka and Ecca groups of the Karoo Supergroup (Fig. 1). In the general area, the oldest rocks of the Cape Supergroup are the shales and sandstones of the Weltevrede Formation, overlain by resistant quartz arenites of the Witpoort Formation. These quartzites are overlain by fine-grained shales and thin sandstones of the Lake Mentz and Kommadagga subgroups.[4] The published geological map of the

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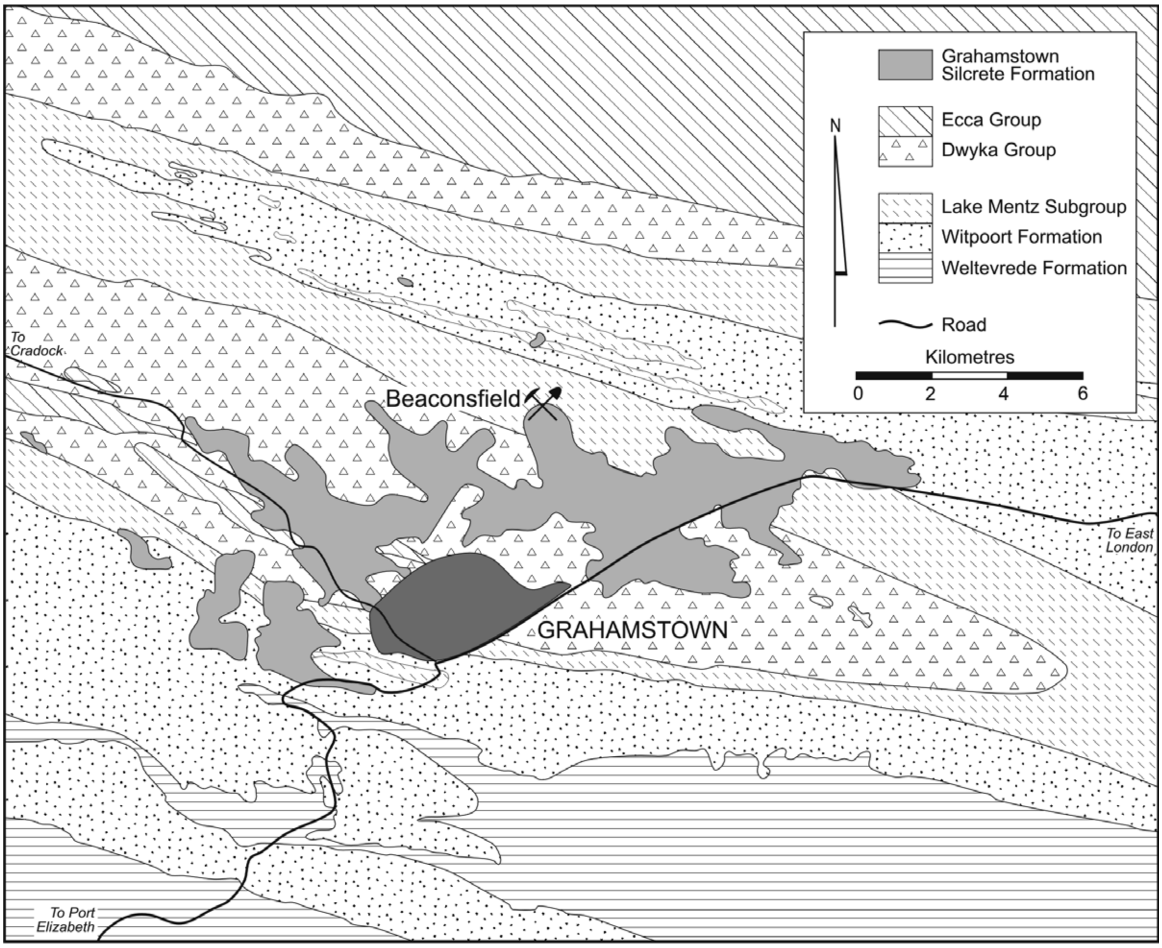

Fig. 1. Simplified geological map of the area around Grahamstown showing the location of the Beaconsfield clay deposit. Adapted from 1:250 000 scale sheet 3326 Grahamstown.[6]

Grahamstown region[6] does not indicate the presence of the Kommadagga Subgroup in the Grahamstown area (Fig. 1). However, the Miller, Swartwaterspoort and Soutkloof formations of the Kommadagga Subgroup crop out west of Grahamstown, as well as the lowermost Dirkskraal Formation, immediately below the Dwyka Group. The rocks in the Kommadagga Subgroup are mainly shales, with minor greywacke and arenite sandstone units. Feldspar content increases upward in these rocks near the base of the Dwyka Group, reflecting cooler and drier conditions at the onset of glaciation.[5,10]

The Witteberg Group rocks are overlain by rocks of the Dwyka Group, the basal unit of the Karoo Supergroup. The contact generally is poorly exposed but probably is paraconformable.[4] The Dwyka consists mainly of glacial diamictite[1] and is composed of a variety of angular to rounded clasts of various igneous and sedimentary rocks set in a fine-grained, dark, massive argillaceous matrix. The overlying argillaceous and arenaceous rocks of the Ecca Group occur mainly to the north of the area.

In the area around Grahamstown, the Dwyka Group forms a syncline whose fold axial trace trends ESE[1,4] (Fig. 1). This syncline plunges at a low angle to the WNW. To the north and south of the syncline, quartzite ridges of the Witpoort Formation form the higher-lying hills that enclose the area where the Grahamstown peneplain was developed.

The peneplain varies in altitude from 620 to 660 m above sea level. The original peneplain extended more than 300 km^2. However, only a remnant, about 34 km^2, remains.[2]

Geology of Beaconsfield

The surface geology of part of Beaconsfield is shown in Fig. 2. The northern part is underlain by grey, fine-grained Witteberg Group shale, characterized by distinct bedding laminations. Further north, towards Botha's River (beyond the limit of Fig. 2),

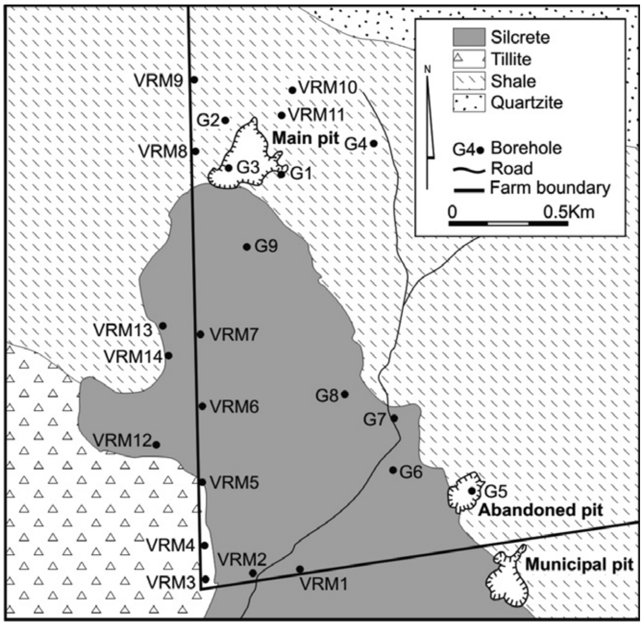

Fig. 2. Simplified geological map of the southern part of Beaconsfield farm, showing borehole and open-pit positions.

the shale is very fine-grained and structurally folded and thrusted with quartzites of the Witpoort Formation. The Dwyka Group crops out poorly and its contact with the underlying shale is not evident on Beaconsfield because of the silcrete cover. This contact should be close to the southern Municipal Pit at Mayfield (Fig. 2), which contains kaolinized Witteberg Group shale.

The limit of the area on Beaconsfield underlain by the Grahamstown Formation silcrete (Fig. 2) marks the extent of the ancient Grahamstown peneplain. To the east, north and west, the peneplain has been destroyed by erosion. To the south, silcrete is not exposed everywhere because of a superficial soil cover. It crops out best along the eroded margins of the peneplain. The silcrete passes downwards through a rather nodular zone into highly kaolinized material. This, in turn, grades downwards into partly weathered shale or tillite, then into fresh bedrock. Profiles through the silcrete and underlying weathered kaolinite zones are well displayed in the open-pit excavations and exploration boreholes (Fig. 2). Borehole logs are presented in Fig. 3. The typical detailed profile from the peneplain surface downwards is that of a thin soil grading down into a ferruginous zone containing small limonite concretions, followed by rubbly, commonly iron-stained silcrete and massive pale silcrete. The silcrete usually is present as a single unit, with variable thickness up to 9 m (e.g. VRM 2, Fig. 3). In places, two silcrete layers may be present, separated by up to a metre of clay (e.g. VRM 1). Where the borehole collar elevations are below that of the peneplain, silcrete is absent (e.g. VRM 3, 8, 11; G1, 2, 3, 4). Open-pit exposures indicate that the silcrete is blocky and has a rather undulating contact with the underlying kaolinitic clay. The open pits clearly show relict bedding in the kaolinized shale, and depositional foresets are also evident in places (e.g. Municipal Pit). In parts, small fold structures are still preserved in the kaolinized shale. To the south of Beaconsfield, where the original rock was tillite, kaolinized 'ghost' clasts are evident.

Table 1. XRD mineralogy of selected Beaconsfield kaolinitic clays.

Borehole no.	Sample depth below collar (m)	Borehole collar elevation (m a.m.s.l.)	Minerals
VRM 2	30	650	Kaolinite, quartz
VRM 4	15	645	Kaolinite, quartz
VRM 5	15	645	Kaolinite, quartz
VRM 6	10	648	Kaolinite-1Md, quartz, muscovite-2M1
	15	648	Kaolinite-1Md, quartz, muscovite, illite-2M1
	20	648	Kaolinite-1Md, quartz, muscovite
	25	648	Kaolinite-1Md, quartz, muscovite
VRM 7	20	644	Kaolinite-1Md, quartz, illite-2M1, muscovite-2M1
VRM 8	15	628	Kaolinite, quartz
VRM 11	5	618	Kaolinite-1Md, quartz, muscovite-2M1, illite-2M1, montmorillonite-14A
VRM 14	10	643	Kaolinite, quartz
G 8	3	643	Kaolinite, quartz, illite, haematite
	30	643	Kaolinite, quartz, illite
	43	643	Kaolinite, quartz, illite
	46	643	Kaolinite, quartz, illite
G 9	20	640	Kaolinite, quartz, illite
	30	640	Kaolinite, quartz, illite
	35	640	Quartz, illite, low temperature albite

The profiles in Fig. 3 show that the thickness of the kaolin varies across the area, from very little, if any, in the valleys (e.g. VRM 9, 10, G4), to 30 m under the peneplain (G8). Thickness is commonly between 15 and 30 m, averaging between 15 and 20 m. The kaolinitic clay is commonly white to cream but where iron and manganese staining is present, the colour ranges from pale pink to yellowish brown, to red and purple, in the latter case particularly where weathered quartz veins containing limonite are present. The clay grades downward into fresh bedrock over a vertical distance of a few metres, through which the colour changes from yellowish brown to grey and dark grey.

Mineralogy and chemistry of the clay

In this study, the Beaconsfield clays, derived largely from the Witteberg Group shales, were identified by X-ray diffraction (XRD). The analyses were carried out on Philips PW 1050/25, Philips PW 1830/00 and Bruker AXS ADVANCE instruments (at Rhodes University, and at the universities of Cape Town and of Port Elizabeth, respectively), using Cu tubes.[7,8] Major- and trace-element distributions were obtained from a number of borehole samples (Table 2) by standard X-ray fluorescence analysis (XRF)[7–9] using fusion discs and pressed pellets on a Philips PW 1480 instrument at Rhodes University.

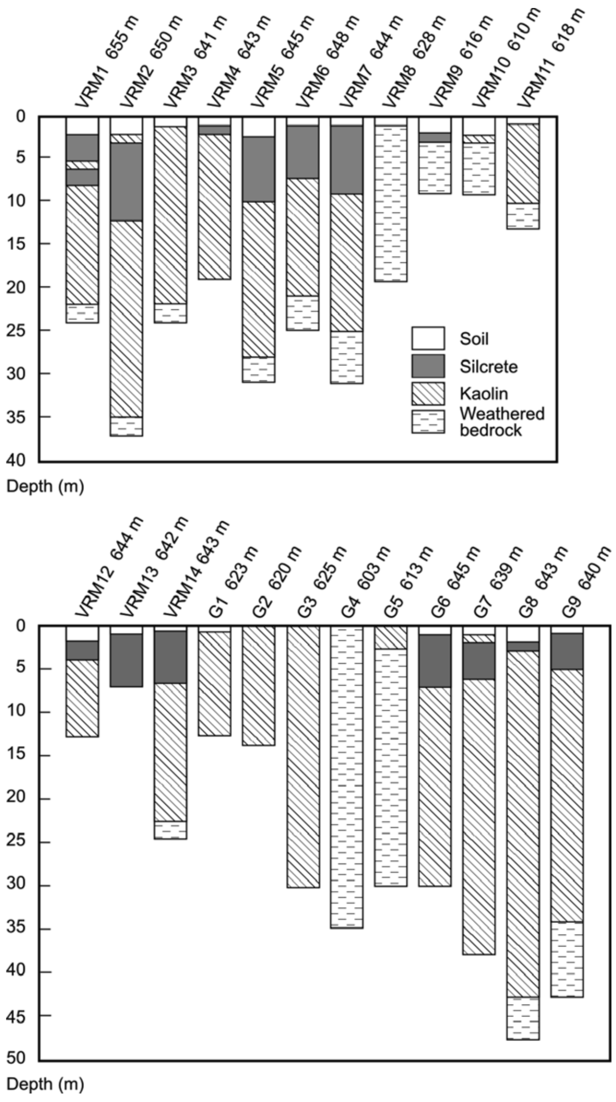

Fig. 3. Lithological logs for VRM series and G series boreholes. Collar elevations (in metres above mean sea level) are indicated. The profiles extend down from surface soil to bedrock. Use in conjunction with Fig. 4 and Tables 1 and 2.

Table 2. Major-element XRF geochemical analyses of Beaconsfield kaolinitic clays. Sample depths are those below collar elevations of boreholes. VRM 15 was collected 11 m below surface in the Municipal Pit (Fig. 2).

	VRM1 10 m	VRM2 30 m	VRM3 15 m	VRM4 15 m	VRM5 15 m	VRM6 10 m	VRM6 15 m	VRM6 20 m	VRM6 25 m	VRM7 20 m	VRM8 15 m	VRM11 5 m	VRM12 5 m	VRM14 10 m	VRM15
SiO_2	56.93	70.03	64.6	61.6	68.21	67.11	65.17	65.63	67.78	55.54	71.05	60.21	74.98	64.56	69.82
TiO_2	0.65	0.79	0.69	0.84	0.72	0.65	0.81	0.84	0.77	0.69	0.84	0.92	1.14	0.75	0.69
$Al2O_3$	20.24	19.24	22.45	21.7	20.74	20.76	22.02	20.73	20.43	28.91	17.71	19.06	11.35	23.73	19.87
Fe_2O_3	12.53	1.04	1.24	5.39	0.76	0.83	0.99	1.58	0.88	1.07	0.72	6.7	5.63	0.74	0.35
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0.05	0.01	0.01	0
MgO	0.2	0.3	0.27	0.28	0.17	0.47	0.6	0.57	0.6	0.6	0.63	0.02	0.09	0.36	0.39
CaO	0.21	0.05	0.05	0.04	0.03	0.05	0.07	0.15	0.06	0.1	0.05	0.34	0.04	0.03	0.01
Na_2O	0.16	0.07	0.11	0.02	0.06	0.07	0.1	0.12	0.12	0.26	0.43	0.52	0.09	0.19	0.13
K_2O	0.11	0.78	0.66	0.63	0.41	2.29	3.54	3.69	3.54	4.91	3.24	3.9	0.08	2.38	2.95
P_2O_5	0.06	0.04	0.15	0.13	0.08	0.12	0.06	0.06	0.05	0.19	0.04	0.16	0.05	0.03	0.02
LOI	8.53	7.13	8.61	9.14	7.89	6.17	5.69	5.49	5.52	6.77	4.96	5.84	5.39	6.89	5.25
H_2O^-	0.39	0.27	0.4	0.52	0.33	0.4	0.35	0.3	0.33	0.38	0.49	1.16	26	0.32	29
Total	100.02	99.76	99.23	100.28	99.39	98.91	99.39	99.15	100.07	99.42	100.15	100.85	99.09	99.98	99.77

	G8 3 m	G8 7 m	G8 12 m	G8 20 m	G8 30 m	G8 35 m	G8 43 m	G8 46 m	G9 3 m	G9 7 m	G9 12 m	G9 20 m	G9 24 m	G9 30 m	G9 35 m	G9 43 m
SiO_2	39.64	68.07	82.00	70.37	70.07	73.95	69.03	62.69	88.89	67.32	66.40	67.59	70.97	74.72	72.39	73.91
TiO_2	0.67	0.79	0.34	0.87	0.82	0.75	0.71	0.83	1.17	0.65	0.73	0.83	0.80	0.65	0.71	0.58
Al_2O_3	16.60	14.21	12.34	19.06	19.49	17.00	18.63	17.25	1.88	15.86	20.01	20.77	17.59	14.63	15.08	14.54
Fe_2O_3	27.90	5.00	0.45	0.85	0.77	1.02	2.63	4.23	5.61	5.87	1.56	1.11	1.80	1.53	2.66	2.25
MnO	0.05	0.02	0.01	0.01	0.01	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01
MgO	0.69	0.55	0.16	0.44	0.48	0.39	0.48	1.02	0.09	0.54	0.67	0.65	0.61	0.40	0.58	0.44
CaO	0.20	0.51	0.04	0.05	0.05	0.02	0.05	0.22	0.04	0.22	0.10	0.03	0.04	0.13	0.17	0.17
Na_2O	0.17	0.15	0.05	0.07	0.07	0.05	0.13	0.85	0.03	0.16	0.08	0.04	0.12	2.49	1.88	2.63
K_2O	0.76	1.24	1.26	3.67	3.19	2.58	3.50	4.28	0.08	1.10	2.71	3.10	3.84	3.31	3.63	3.62
P_2O_5	0.08	0.05	0.01	0.03	0.05	0.02	0.04	0.39	0.04	0.06	0.03	0.02	0.03	0.08	0.12	0.09
LOI	11.24	7.82	4.23	5.12	5.63	4.95	5.19	6.18	2.26	7.70	7.44	6.38	4.82	2.66	3.17	2.35
H_2O^-	3.05	2.24	0.47	0.62	0.59	0.36	0.51	2.19	0.46	1.56	0.97	0.42	0.30	0.26	0.46	0.20
Total	101.05	100.65	101.36	101.16	101.22	101.12	100.92	100.16	100.57	101.06	100.71	100.95	100.93	100.87	100.87	100.79

The samples were selected in order to determine the lateral and vertical compositions of the clays. Samples were collected from the upper, central and lower parts of the boreholes, and VRM 6, G8 and G9 were sampled more closely in order to track variation in the vertical dimension (Tables 1 and 2).

The main minerals found are kaolinite and quartz (Table 1). Illite is present in several samples, and muscovite and low-temperature albite are found more commonly towards the base of the clay.

Major-element distributions were obtained by XRF from the borehole samples (Table 2). Figure 4 shows the variation of SiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O and K_2O with depth for a select number of boreholes. SiO_2, Fe_2O_3 (and MnO, not shown in Fig. 4) contents increase towards the surface, whereas Al_2O_3 concentrations are highest in the kaolin zones and generally decrease upwards towards the surface silcrete and limonitic soil. TiO_2 shows very little variation (Table 2), K_2O and Na_2O contents are low near surface and in the clay, but increase in the concentration downwards towards bedrock. CaO is present only in small amounts and is generally highest near the surface, associated with the silcrete. In those samples, small amounts of calcite are found (boreholes VRM 1, 2, 7, G8) and VRM 9 (in the valley).

Discussion

The Beaconsfield clay deposits are related to the distribution of the Grahamstown Formation silcrete, an erosional remnant of a former, extensive peneplain. The deep weathering of the underlying rocks indicates that the peneplain formed over an extended period of time. This led Partridge and Maud[3] to conclude that the peneplain formed during the major African cycle of erosion and so represents a portion of the African Land Surface. They showed by means of both onshore erosion rates and offshore sedimentation rates that the African cycle of erosion probably lasted from the late Jurassic to the early Miocene. To the southeast of Grahamstown, the occurrence of silcrete clasts in the Bathurst Formation at Birbury indicates that silcrete had formed by early Eocene times.[3,4]

The association of the peneplain, silcrete and kaolinitic clay, and vertical zonation of lithologies and chemical variations in the boreholes (Table 2, Figs 3 and 4), suggest that the Beaconsfield clay is a product of deep bedrock weathering.[1,2,10] Smuts,[5] Heckroodt and Bühmann,[11] and Heckroodt[10] show that the mineralogy of the clays in the Grahamstown region varies from one place to another and is related to

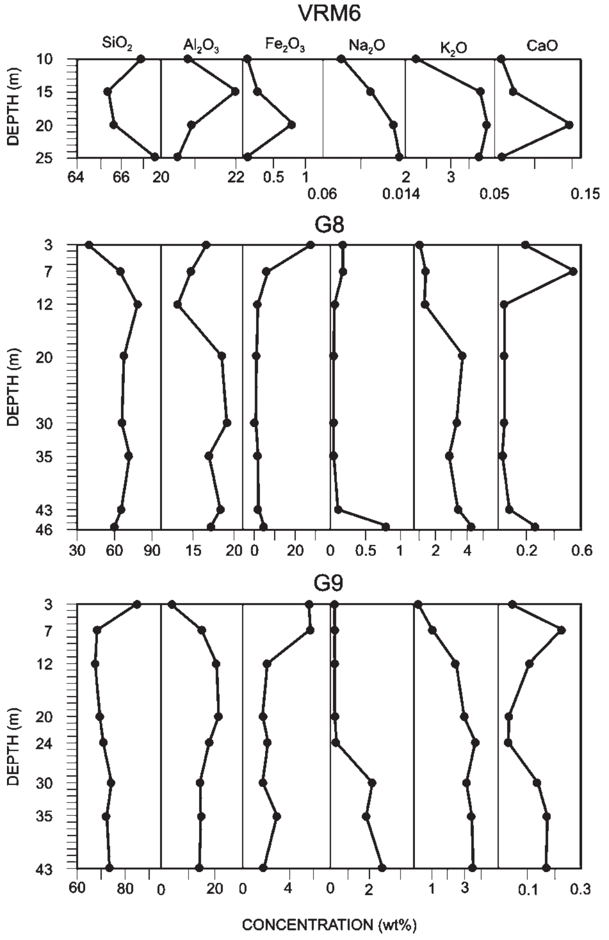

Fig. 4. Variation of selected major-element oxides with depth for samples from boreholes VRM6, G8 and G9.

the particular bedrock type. Most of the analyses reported here are from clays overlying the Witteberg Group, but the above authors[10,11] do report some differences between those and clays overlying the Dwyka Group. Such differences are not apparent from our limited set of data.

SiO_2 content at the surface is extremely high because of the silcrete and may even be more than 90%.[12] The increase in Fe and Mn oxide contents upwards reflects the increase in Fe and Mn hydroxide and oxide minerals associated with the silcrete, for example, the limonite pisolitic concretions making up the ferricrete layers under the soil cover. The increase in CaO content upwards is attributable to an increase in calcite in the upper parts of the clay, commonly just below the silcrete. In places around Grahamstown, calcrete is weakly developed in the upper parts of the weathered profiles, both near the top of the clay and in some of the valleys that post-date the African Surface.

Na_2O and K_2O generally were leached from the clay profile during weathering of the shale and tillite. These oxides increase downwards towards the base of the weathered zone and fresh bedrock, where shale or tillite, containing feldspar and muscovite, are present. K_2O also is retained in illite, a constituent of the kaolinitic clays, particularly in the clays derived from the Witteberg shales.

Concentrations of oxides in the clays reported by Smuts[5] and Heckroodt[10] (generally SiO_2 58–74%, Al_2O_3 21–28%, combined CaO + MgO < 1%, Na_2O < 1%, K_2O < 3%) compare well with those from Beaconsfield (generally SiO_2 55–75%, Al_2O_3 19–29%, combined CaO + Mg < 1%, Na_2O < 1%, K_2O < 4%). Variation in composition reflects in some way the variability in composition of the underlying lithologies.[5,10]

The observed lithological sequence from fresh to weathered bedrock at depth, upward into clays and limonitic ferricrete-type surface soil, is typical of weathering in fairly warm, humid climates.[13] Those conditions have been proposed for much of the Cretaceous period, when the Grahamstown peneplain and its weathered profile developed.[1,2,5,10,12,14,15] At that time, poor drainage allowed a seasonally fluctuating water table to leach soluble constituents from considerable depths,[2] particularly when the climate changed to drier conditions at the end of the Cretaceous period.[3,14] The silica was precipitated in the upper parts of the soil profile,[2] and possibly also in playa lakes or pans, eventually to harden and form silcrete.[14,15]

Conclusion

Well-developed weathering profiles are present on the Grahamstown peneplain at Beaconsfield. Downwards from surface, the soil becomes ferruginous, followed by the Grahamstown Formation silcrete, then kaolinitic clay into weathered bedrock. The kaolinitic zones are very thin in the valleys surrounding the peneplain, but up to 30 m thick below the silcrete cover.

The clay comprises mainly kaolinite and quartz, with muscovite and illite. During the weathering process, amounts of SiO_2, Fe oxides, Na_2O and K_2O were removed, and Al_2O_3 was enriched through residual concentration. The Beaconsfield clays exhibit similar compositions to clays from elsewhere in the Grahamstown area.

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