The clay mineralogy of sediments in the Vaal Dam and in the rivers supplying and draining the dam upstream of the barrage

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Abstract

Clays in the sediments from the Vaal Dam and from the Vaal and Wilge Rivers are mainly illitic (av. 81%), with smaller quantities of smectite (av. 16%) and kaolinite (av. 4%). Chloritic clays are absent. A distinctive clay mineral distribution pattern can be related to the geology of the drainage basin. The drainage area is underlain by rocks predominantly of the Karoo Supergroup which, when eroded, liberate mainly illitic clay minerals. The breakdown of volcanic and feldspathic rocks of the Ventersdorp and Witwatersrand Supergroups in the north western part of the basin produce expandable smectitic clay minerals and kaolinite, respectively. The Vaal Dam and Vaal River downstream of the latter areas contain sediments which are enriched in smectite and kaolinite. Sediments in the lower reaches of the submerged Wilge River tributary are also enriched in kaolinite and smectite, probably due to mixing and diffusion of Vaal River water which is rich in these minerals. Although some of the rocks of the drainage basin contain chloritic clays, this mineral is not present in young sediments of the region, probably because it is unstable in the present-day environment. Vertical trends in the clay mineral abundance may represent an incomplete sedimentation cycle governed by differential settling rates of clay minerals.

Introduction

The Geological Survey of South Africa was requested to undertake geophysical and sedimentological investigations at three sites in the submerged tributaries of the Vaal Dam. It is proposed that earthen dams be built at these sites to assist in flood control and give flexibility in drawing water from the dam. The Vaal and Wilge Rivers which supply the dam and also the Vaal River downstream of the dam wall to the Vaal Barrage were included in the study in order to understand more fully the overall sedimentation system of the region.

Results of the above investigation will be published in three separate articles, i.e. sediment texture and the sedimentation pattern; geochemistry of the sediments; and the present report which deals with the clay mineralogy of the sediments.

In the present work an attempt is made to relate the clay mineralogy of sediments of the Vaal Dam and of the rivers supplying and draining the dam to the geology of the drainage basin.

Methods

The methods used in the present work are the same as those described by Birch (1978). A brief summary of these methods are given below. The <2 μm fraction of the sediment was concentrated by sedimentation and the calcium carbonate and organic matter content was removed by glacial acetic acid and hydrogen peroxide, respectively. The clay was homo-ionically saturated with a Mg-solution to ensure uniform expansion on hydration: untreated slides were run from 3 to 30° 2∅ and heated and glycolated slides were scanned from 3 to 14° 2∅. A Philips X-ray diffractometer was used with a Geiger detector and Ni-filtered CuKa radiation.

Smectite was detected by its 14Å reflection which expands to 17Å on glycolation and which collapses to 10Å on heating to 555 °C for one hour. Illite was identified by its 10 and 2,3Å reflections.

Kaolinite was identified by the disappearance of a reflection at 7,2Å on the diffractogram of heated slides (550 °C). Chlorite is not detected in any of the samples examined.

Semi-quantitative mineralogical determinations were made by weighing the integrated peak areas on the diffractograms of glycolated slides. The precision of the analytical technique is better than 3% (Birch, 1981).

Clay Mineral Distribution

The 29 clay mineral samples (Fig. 1) contained predominantly illite (av. 81%; range, 58-98%) with subordinate smectite (av. 14%; range 0-32%) and minor kaolinite (av. 4%, range 0-11%). The regional distribution of the three minerals is described below.

Illite

Samples collected from sites upstream of the Vaal Dam on the Klip, Vaal and Wilge Rivers contained the highest abundance illite (>95%). The sediments in the submerged Wilge River tributary are richer in illite than the sediments in the submerged tributary of the Vaal River (Fig. 2 and Table 1). Illite abundances in both rivers diminish towards the dam wall and remain low (<65%) downstream to the barrage.

Kaolinite

The distribution of kaolinite (Fig. 3 and Table 1) is the reverse of that of illite, i.e. kaolinite is most abundant (>6%) in the submerged sections of the Wilge and Vaal tributaries and in the river sediments below the wall of the Vaal Dam. Minor quantities (<3%) or no kaolinite is contained in sediments in the upper reaches of the inundated tributaries or the rivers upstream of the dam.

Smectite

The distribution of smectite displays a complex, but well defined pattern (Fig. 4 and Table 1). Sediments in the submerged por-

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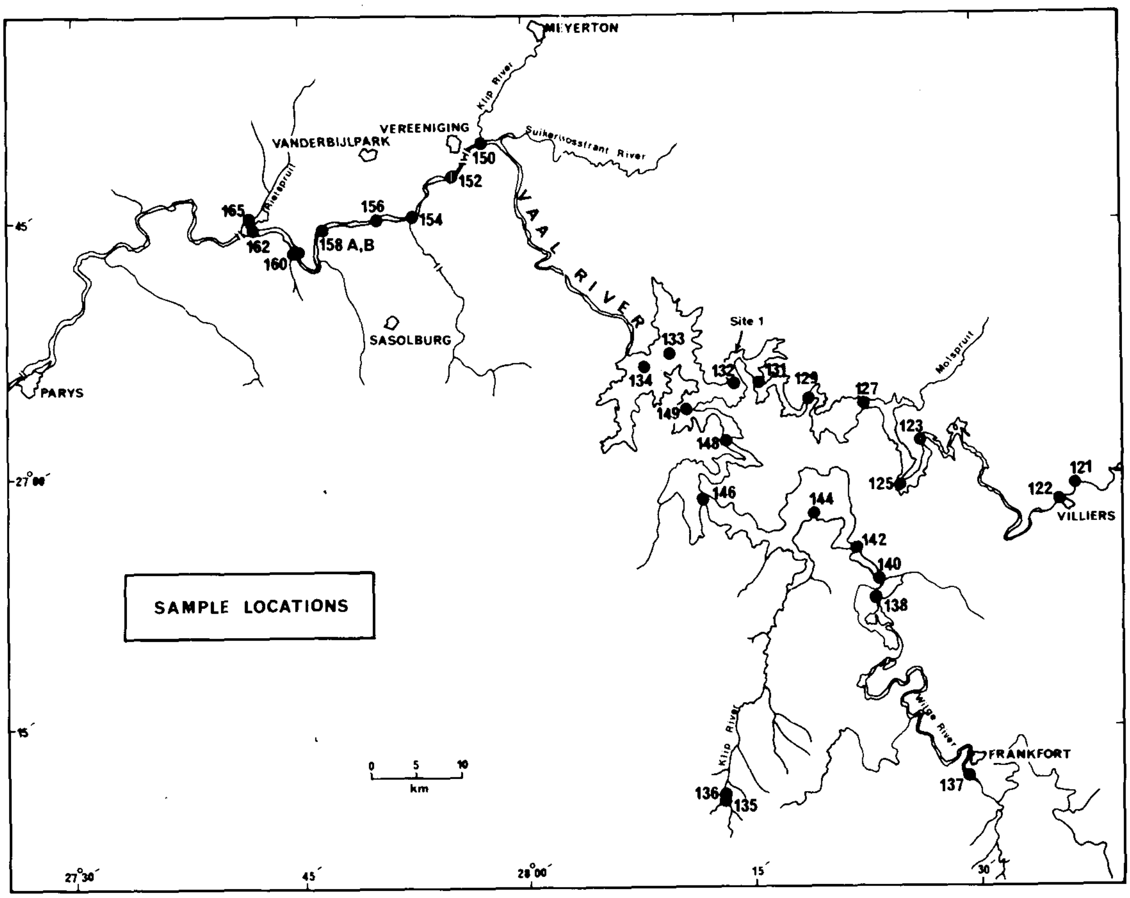

Figure 1
Sample distribution.

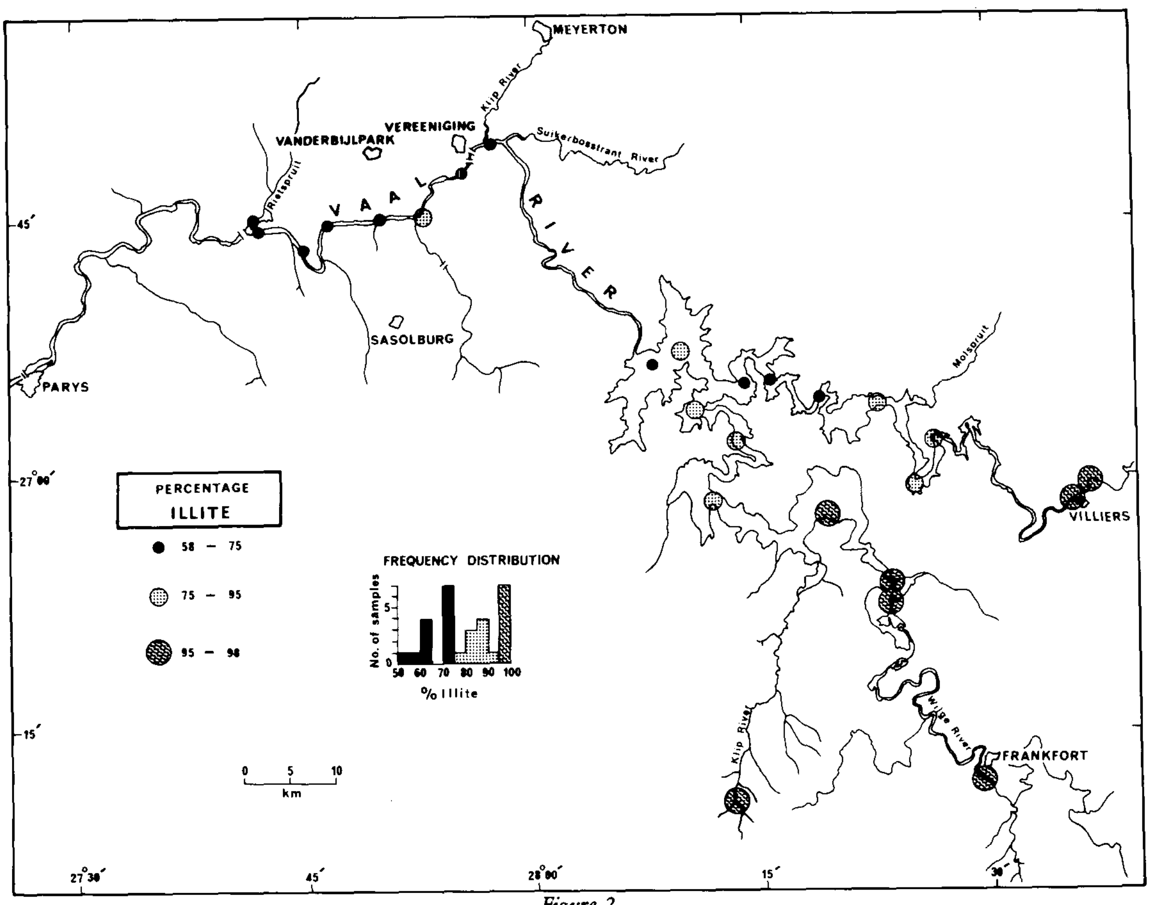

Figure 2
Distribution of Illite.

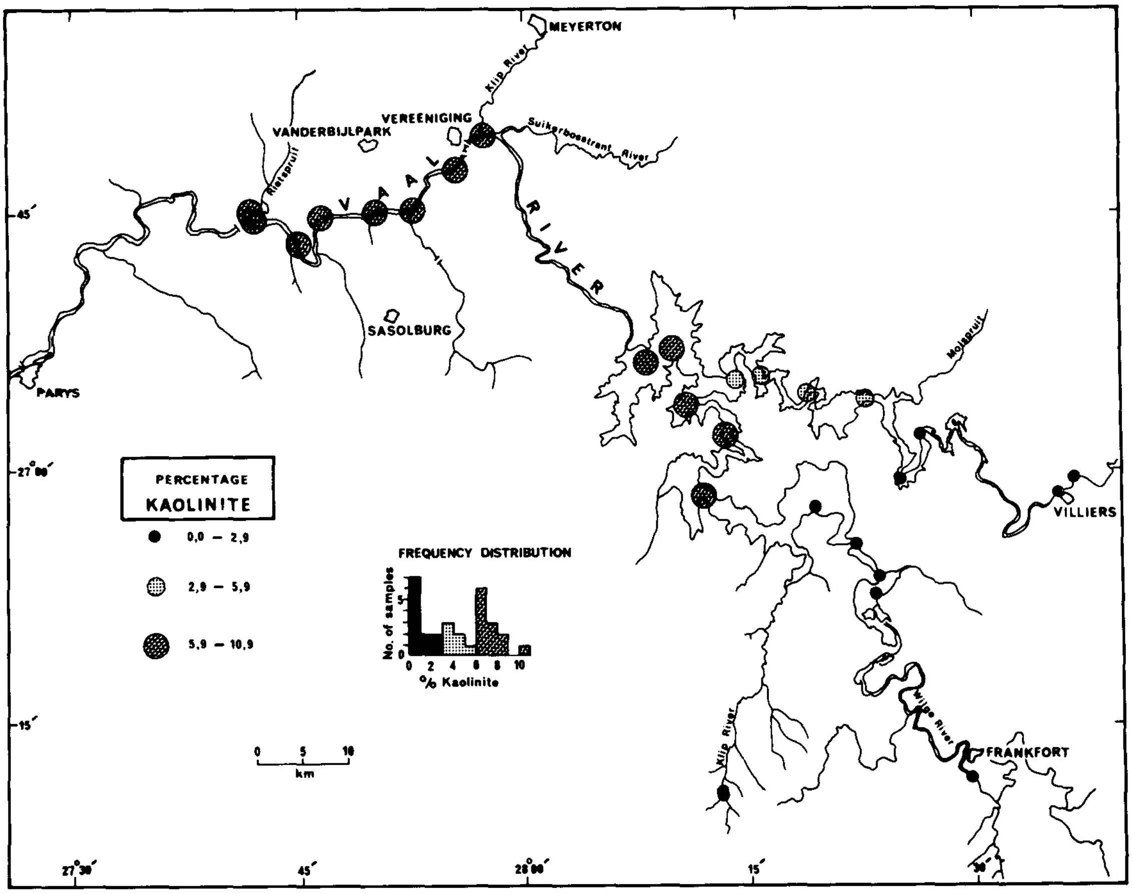

Figure 3
Distribution of Kaolinite.

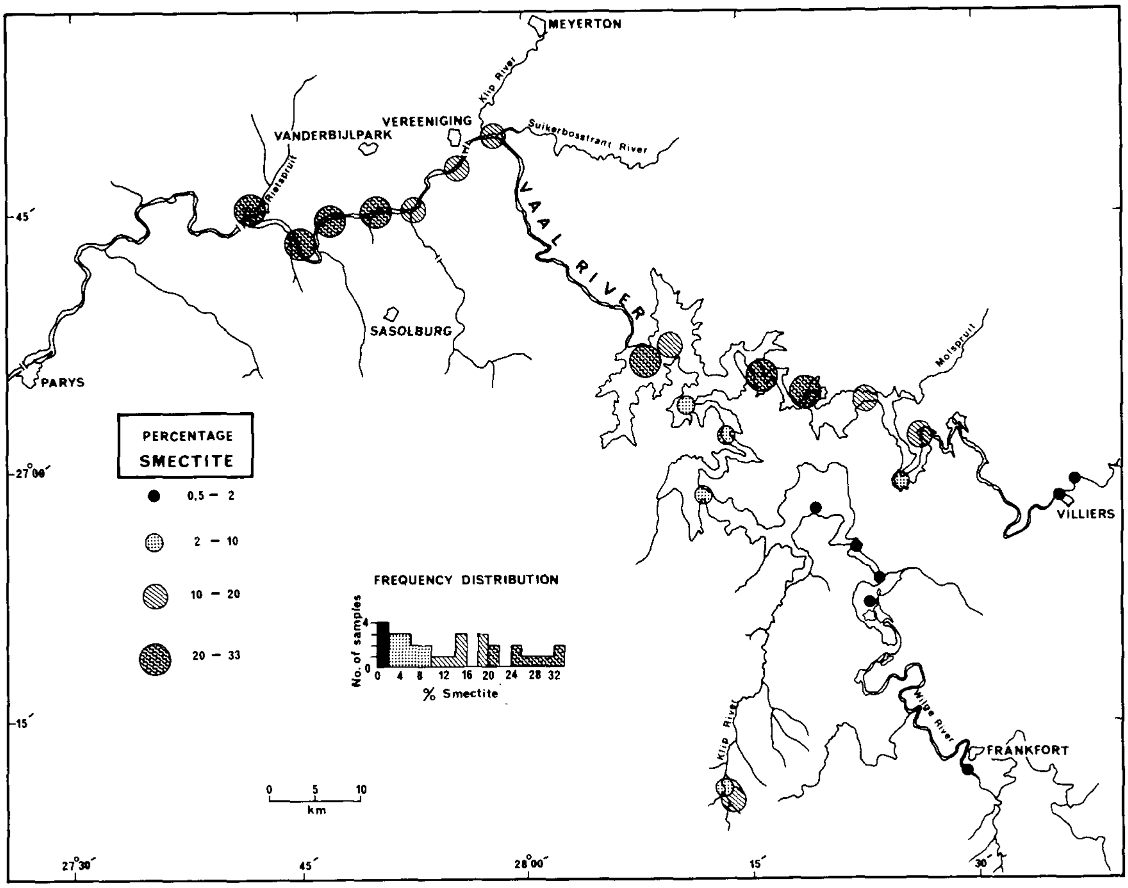

Figure 4
Distribution of Smectite.

TABLE 1
CLAY MINERAL ABUNDANCE IN VAAL DAM AND IN THE RIVERS SUPPLYING AND DRAINING THE DAM

Sample No	% Smectite	% Illite	% Kaolinite
MGR-121	2	96	2
-122	2	98	0
-123	11	87	2
-125	9	91	0
-127	14	83	3
-129	26	70	4
-131	31	65	4
-132	25	72	3
-133	13	80	7
-134	33	60	7
-135	18	82	0
-136	5	95	0
-137	2	97	1
-138	1	98	1
-140	2	97	1
-142	2	95	3
-144	2	97	1
-146	5	88	7
-148	6	87	7
-149	8	85	7
-150	16	73	11
-152	19	75	6
-154	14	79	7
-156	21	73	6
-158A	27	64	9
-158B	20	72	8
-160	29	64	7
-162	21	73	6
-165	34	58	8

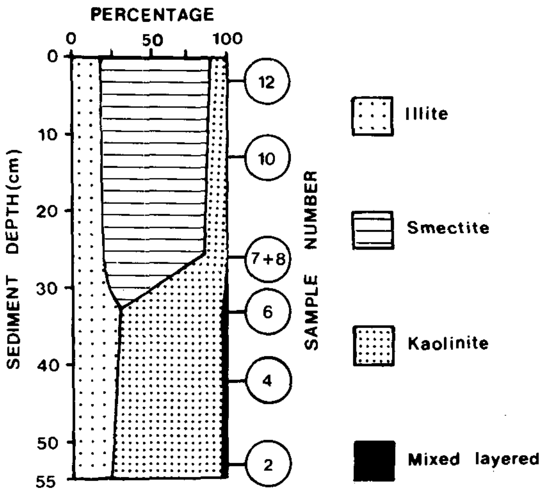

Figure 5
Vertical distribution of clay minerals in core from Site 1.

tion of the Vaal River have a distinctly higher (>10%) concentration of smectitic minerals than the sediment from the Vaal and Wilge Rivers (<10%) upstream of the dam. The smectite concentration of sediment from below the dam wall remains high (>10%), but is lower than that of the submerged Vaal tributary. A well-consolidated light-grey clay taken from a terrace of the Klip River (MGR-135) contained an anomalously high smectite content (18%).

Vertical distribution of clay minerals

The abundance of clay minerals was determined on six samples taken down a 0,55 m-long core recovered from site 1 (Fig. 1).

The concentration of illite remains fairly constant (16-25%) down the length of the core (Fig. 5 and Table 2), whereas the abundance of smectite increases radically (3 to 69%) at the expense of kaolinite at a sediment depth of 30 cm. Minor (<2%) mix-mineral clays are detectable at the lower end of the core (>30 cm) at 12-16Å.

TABLE 2
CLAY MINERALOGY OF VAAL DAM CORE – SITE 1

Sample No.	Core depth (cm)	Illite (%)	Smectite (%)	Kaolinite (%)	Chlorite (%)	mixed-layer mineral (%)
12	0 – 5	16	74	10	0	
10	10 – 15	17	72	11	0	0
7 & 8	22 – 30	17	69	14	0	0
6	30 – 35	25	3	71	0	1
4	40 – 45	22	0	77	0	1
2	50 – 55	22	0	76	0	2

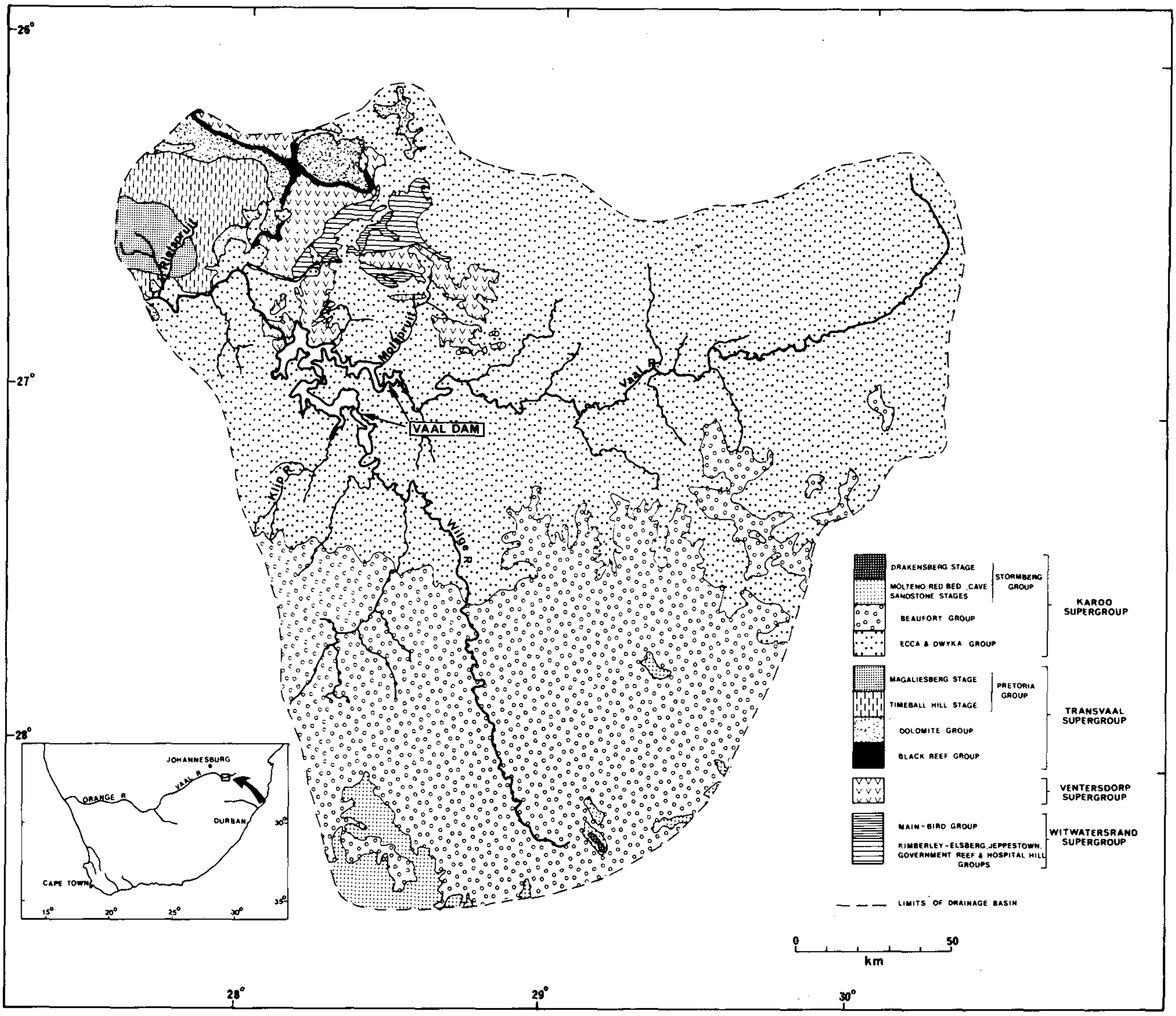

Figure 6
Geology of the drainage basin.

The Geology of the Drainage Basin

The drainage basin comprises predominantly (>90%) rocks of the Karoo Supergroup (Truswell, 1970). Rocks of the Transvaal, Ventersdorp and Witwatersrand Supergroups are located in a small area in the north west corner of the drainage basin (Fig. 6). Of the Karoo Supergroup, rocks of the Beaufort, Dwyka and Stormberg Groups are exposed over most of the drainage basin, whereas the Stormberg Group is restricted to the south west corner of the area. The four lithological subdivisions of the Stormberg are the Molteno sandstones and shales; the argillaceous Red Beds; the Cave Sandstone; and the basaltic Drakensberg volcanics. Only an extremely small exposure of the latter volcanics are present in the drainage area. Rocks of the Ecca and Dwyka Group are exposed over approximately 90% of the northern half of the basin, whereas 95% of the southern section is composed of rocks of the Beaufort Group. Tillite is the dominant rock of the Dwyka Group. It contains angular fragments of rock set in a dense argillaceous matrix. The northern facies of the Ecca Group is composed of bluish-black shale, coarse arkose, conglomerate and coal seams.

The Witwatersrand Supergroup is a thick sequence of shales, quartzites and conglomerates. The Lower Witwatersrand (Hospital Hill, Government Reef and Jeppestown Groups) is predominantly argillaceous, whereas the Upper Witwatersrand (Main - Bird and Kimberley - Elsburg Groups) is composed almost entirely of quartzites and conglomerates.

Five of the six groups of the Ventersdorp Supergroup contain andesitic volcanic material, but only in three of these groups is this the main mineral constituent. Conglomerates, quartzites, tuffaceous and calcareous shales, limestones and cherts are commonly intercalated between lavas.

The Transvaal Supergroup comprises the Pretoria, Dolomite and Black Reef Groups. The Black Reef Group is made up primarily of shales with interbedded quartzites and dolómites. Dolomite and ironstone comprise the Dolomite Group. The former contains minor chert, shale and quartzite and in places the latter is ferruginous. Three of the four stages of the Pretoria Group are composed of shales and quartzites, and the fourth stage (the Daspoort stage) is made up of glacial tillites and volcanics. Localized pyroclastic and colcanic rocks are also present in the Magaliesberg stage.

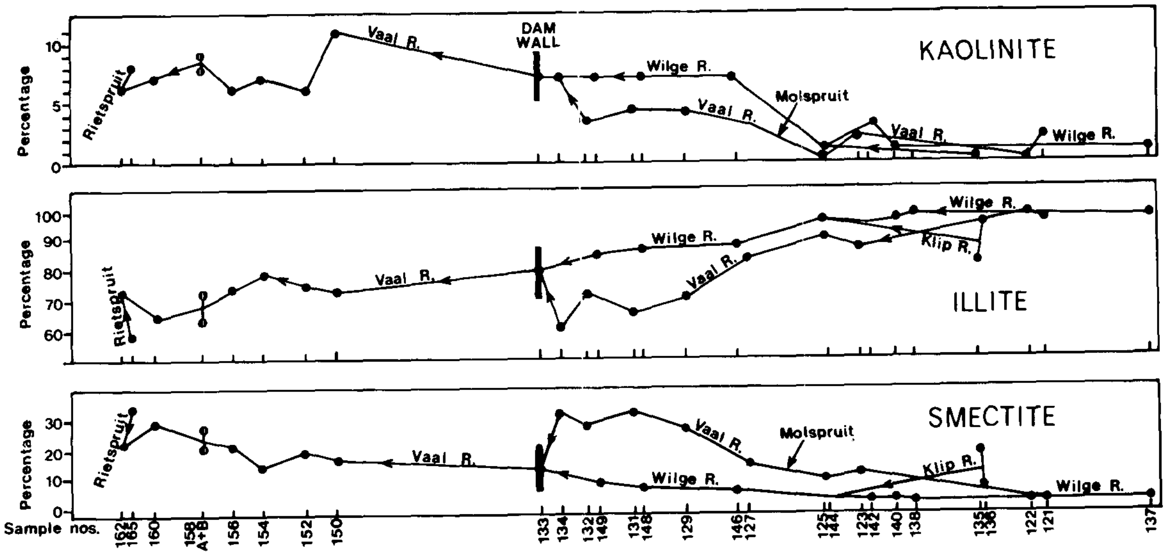

Figure 7
Downstream trends in clay mineral abundance.

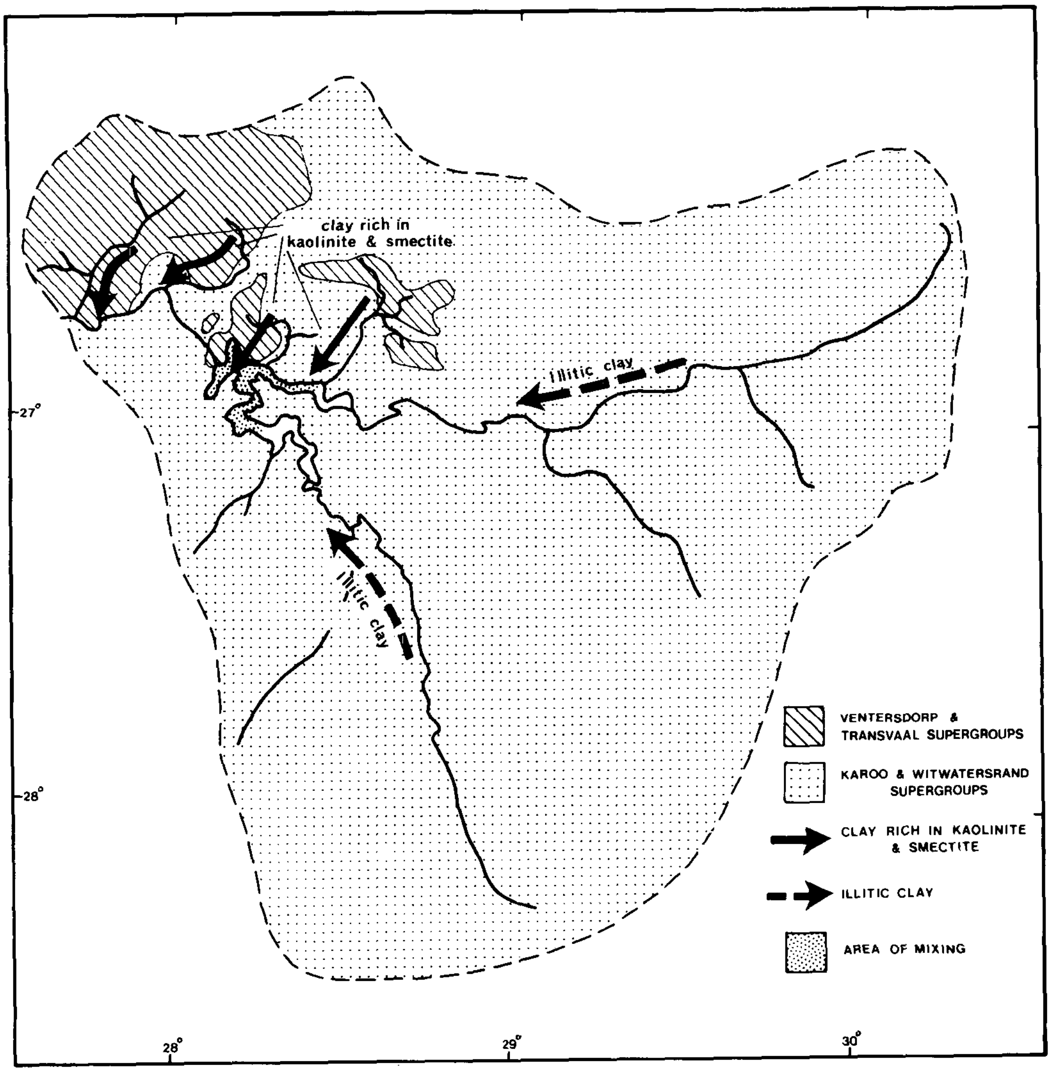

Figure 8
Possible provenance of clay minerals within the drainage basin.

Discussion

A number of clear trends (Fig. 7) in the distribution of clay minerals have been revealed by the present mineralogical study. These are –

- The Vaal River upstream of the dam is enriched in smectite relative to the Wilge River. Conversely, the Wilge River is enriched in kaolinite and illite with regard to the Vaal River.
- The relative abundance of kaolinite and smectite increases in the Vaal River only after the confluence of the Molspruit and concentrations of these minerals continue to increase downstream of the Vaal Dam.
- The kaolinite and smectite concentrations upstream of the submerged sections of the dam are low (<3%).
- The illite concentration declines steadily downstream. Upstream from the Molspruit confluence, the Vaal and Wilge River sediments contain approximately the same smectite content (<20%), but with the former displaying slightly higher values. The coincident increase in abundance of this mineral with the input of sediments from the Molspruit can probably be ascribed to weathering of the Ventersdorp Volcanics (Fig. 8). The continued relative increase in concentration of smectite downstream of this confluence and of the dam is probably due to the additional influx of breakdown products of volcanics of the Ventersdorp and Transvaal Supergroups. Clearly, the decrease in smectite concentration at the confluence of the Wilge and Vaal Rivers is due to dilution of illite-rich sediment carried by the former river (Fig. 7).

The distribution trend of kaolinite in the sediments is contrary to that of illite. The relative abundance of kaolinite increases (<3% to >10%) steadily downstream, whereas that of illite declines. In addition, kaolinite becomes markedly enriched in the submerged parts of the Vaal and Wilge Rivers and even more so downstream of the dam wall. This enrichment could result from weathering of the feldspar-rich mafic minerals of the Transvaal and Ventersdorp Supergroups (Fig. 8).

Increased dilution by kaolinitic and smectite clay minerals, liberated from rocks of the Ventersdorp and Transvaal Supergroups (Fig. 8), is the major cause of the progressive downstream decline in the illite content of the sediments.

Shales of the Lower Witwatersrand Supergroup, especially those that have undergone low grade metamorphism are known to contain chlorite and chloritoids. The tillites, because they originated in the cold, higher latitudes, are likely to contain chlorite as well. Therefore, the total absence of this mineral in the dam and river sediments is unexpected. It is apparent that the chlorite that is available in the rocks of the drainage basin is unstable and is rapidly transformed into a more stable clay mineral group, probably kaolinite.

The marked change in clay mineralogy with sediment depth may relate to a rapid and major change in environmental conditions, or a change in supply. The latter is difficult to comprehend as the rocks likely to liberate these two minerals are regionally closely associated in the drainage basin. A rapid change in environmental conditions is also not possible during the recent past. However, the settling rate would also affect the downcore concentration of clay minerals. This rate is determined by particle size and shape as well as by flocculation characteristics. Differential settling velocities of illite, kaolinite and smectite has been determined as 15,8; 11,8 and 1,3 m/day, respectively (Whitehouse, *et al.*, 1960). Moreover, this separation is known to be accentuated by the formation of floccules (Whitehouse and Jeffrey, 1955; Siegel *et al.*, 1968). The smectite concentration may increase towards the top of the core because it has the slowest settling rate and, being the finest clay, it is the first mineral to be remobilized and removed when the water is disturbed.

If settling velocity is the only mechanism governing the vertical concentration of clay minerals, then there would be a consistent down-core clay mineral trend. Instead, the illite concentration remains fairly consistent (22-16%) and the smectite/kaolinite reversal is abrupt. Water drawn off the Vaal Dam during dry seasons may remobilize the finer smectitic clay particles, thereby concentrating the coarser illite and kaolinite minerals in the bottom sediment. Also less smectite would be available for deposition as the overlying water would be considerably shallower during this period. As the dam again filled and the water column stabilized the relative smectite contribution would increase.

The minor and declining up-core illite content (22-16%) is difficult to explain, especially as the surficial sediment collected with a small grab from the Vaal River in the vicinity of the core site contains >80% illite (Figs. 2 and 7). If differential settling is operative in the dam, then the illite concentration should increase progressively downcore. An absence of such enrichment may indicate that the start of the sedimentation cycle lies below the level of penetration of the core, i.e. >0,55 m. Conversely the high illite content of the surficial sediment obtained in grab samples from the area may herald the onset of a new sedimentation cycle. The absence of such enrichment in the core samples could be due to a loss of the uppermost sediment from the core barrel on impaction. Such losses are common with the gravity device used in this survey.

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