

CLIMATIC ARIDITY OVER INDIA 11,000 YEARS AGO: EVIDENCE FROM FELDSPAR DISTRIBUTION IN SHELF SEDIMENTS

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ABSTRACT

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Feldspars and quartz contents of sand and silt fractions of forty three samples from the western continental shelf of India were determined by the X-ray diffraction method. The results indicate that the feldspar content in the relict (9000–12,000 yrs B.P.) outer continental shelf sediments exceeds the feldspar content in modern inner continental shelf sediments. The types of feldspar are maximum and intermediate microcline, orthoclase and high albite.

The paleoclimatic inferences drawn from these data are that the climate during the late Pleistocene and early Holocene was arid. These findings are in general agreement with the climate of other tropical areas for that period.

INTRODUCTION

Our earlier studies on paleoclimate inferences for the late Pleistocene period (11,000 years ago) had indicated the presence of a semi-arid climate over peninsular India. These inferences were drawn on the basis of the differences in abundance of carbonate sediments and differences in size of quartz grains from the inner and outer continental shelf of western India, an area of about 310,000 km² (Nair and Hashimi, 1980). In order to evaluate the correctness or otherwise of these earlier paleoclimatic inferences we have undertaken the study of the distribution of feldspars in the continental shelf sediments. Since feldspar in continental shelf sediment is an allogenic mineral derived from the weathering of rocks on the adjacent land areas, the variation in its character reflects the variation in weathering rates, which is a function of the present climate. Feldspar is thus a sensitive climatic indicator (Folk, 1961; Van der Plas, 1966; Damuth and Fairbridge, 1970). In a given basin of deposition, increase in feldspar content indicates climatic aridity, either hot and dry or cold and dry. Under tropical conditions, such as over India, an increase in feldspar content in the shelf sediments will obviously indicate that at the time the feldspar-rich sediments were deposited, the

climate on the adjacent land was hot and dry as compared to the present hot and humid (monsoon climate) conditions. We demonstrate here that the distribution of feldspars in the sediment, particularly in the outer shelf sediments, points to the prevalence of a semi-arid climate 11,000 years ago.

METHODS

The sample selection for the study was determined by the following conditions: (1) The coastal rocks adjacent to the shelf must have feldspar-rich rocks such that a constant source of the mineral is present. (2) No major rivers should discharge into the sea so that contribution to the outer shelf by modern-day processes is minimal. (3) The region should be tectonically stable over the time period under consideration, otherwise tectonic arkoses result (Krynine, 1941). These three conditions are met by the continental shelf between Goa and Mangalore. In this region the rivers are short, stratified estuaries during the monsoon when the fresh water discharge is at its peak; they drain the region of the Western Ghats (tectonically stable shield) composed of feldspar-rich Precambrian (Dharwarian) granite and gneisses. Forty-three grab samples (Fig.1) were selected from the collection of the various cruises of *R/V Gaveshani*. They were separated into sand, silt and clay fractions by wet sieving and settling. The sand and silt were combined and their relative proportions of feldspar were determined as described below by X-ray diffraction.

The carbonate free (by 10% HCl digestion) sand and silt fractions were ground to -230 mesh size ($62.5 \mu\text{m}$) in an agate mortar and the powdered samples were packed in aluminium sample holders or sprinkled on glass slides and analysed on a Philips X-ray diffractometer, using nickel filtered $\text{CuK}\alpha$ radiations at half degree per minute from 26 to $30^\circ 2\theta$. The relative abundances of quartz and feldspar were determined by absolute counts per second over the background for the $26.66^\circ 2\theta$ (101) of quartz and the 27.4 – $27.8^\circ 2\theta$ (002) and 27.9 – $28.1^\circ 2\theta$ (002) for potash and sodic feldspars respectively. The structural state of the feldspars were determined by the three peaks (201, 060, 204) method of Wright (1968). The X-ray diffraction method was selected because earlier attempts to determine the feldspar/quartz ratio in these sediments by the conventional selective staining technique yielded unreliable estimates due to the presence of iron-stained quartz.

GEOMORPHOLOGY AND GEOLOGY OF THE HINTERLAND

The coast adjacent to the study area is bordered by the Western Ghats. Radhakrishna (1967) had noted that to the south of Goa (15°N latitude) the horizontally disposed Deccan Traps give place to the steeply dipping gneisses and schists. The coastal plain is narrow in this region varying from 25–75 km in width. Many short rivers flow across the coastal plain. They

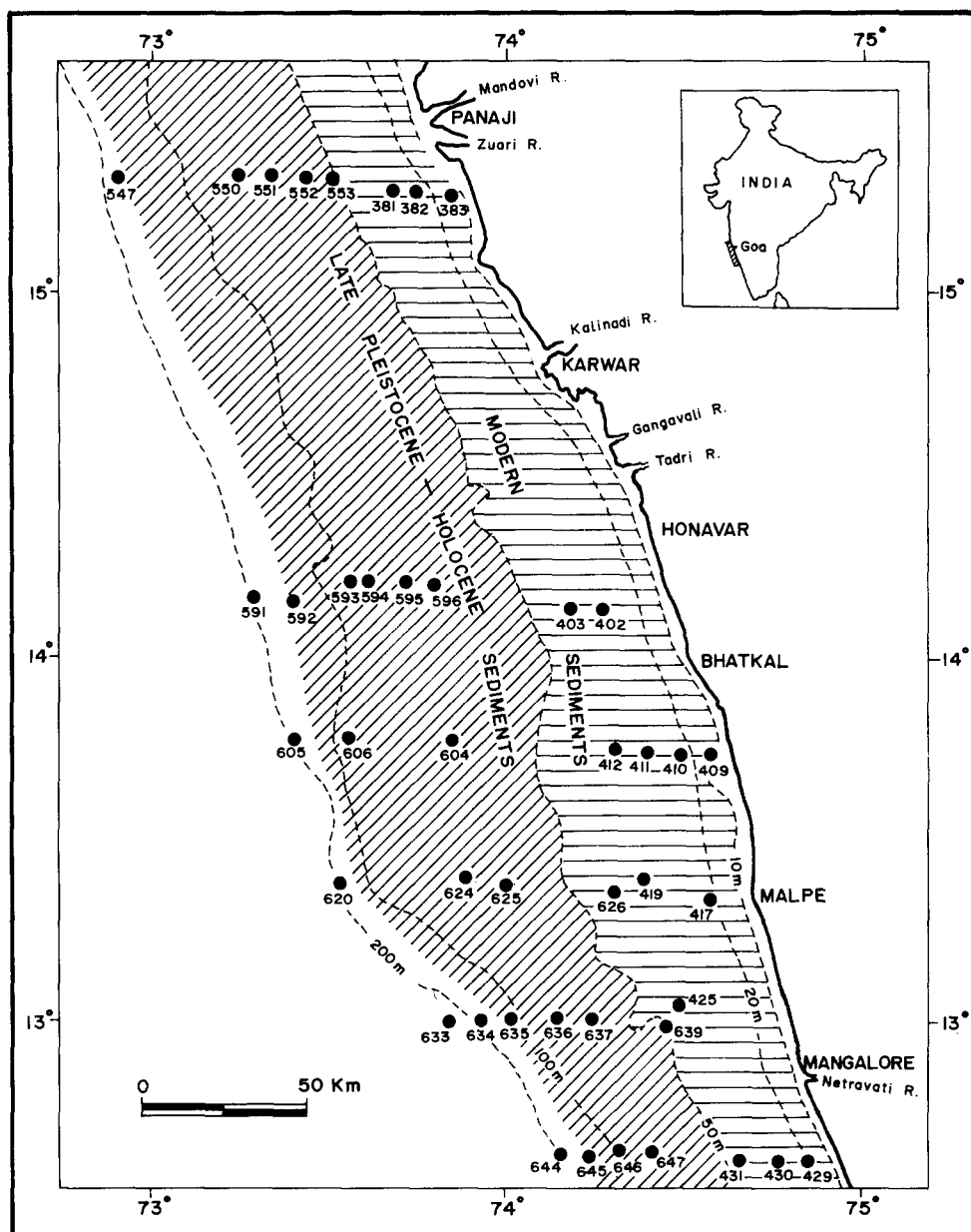


Fig.1. Study area and sample locations, western continental shelf of India.

are Mandovi and Zuari in Goa, Kalinadi and Gangavali near Karwar, Tadri near Honavar and Netravati and Gurpur in Mangalore. However, floods can transport relatively greater sediment loads but these tend to be deposited on the inner shelf (Hashimi et al., 1978). All of these rivers are estuarine in nature.

The following group of formations are present on the land bordering the shelf off the study area (Radhakrishna and Vasudev, 1977).

Chitradurga Group: This group starts with a basal conglomerate giving place to orthoquartzites, phyllites, limestones and dolomites followed by banded ferruginous and manganiferous quartzites and chert.

Bababudan Group: This starts with a basal orthoquartzite conglomerate overlying the gneissic complex and gives place to a thick succession of mafic lava flows which in turn are followed by argillites and massive beds of banded quartz—magnetite rocks.

Older Granite, Gneiss, Migmatite Complex (Peninsular Gneiss), Granulites.

TOPOGRAPHY AND SEDIMENTS OF THE SHELF

The topography and sediments of the western continental margin of India between Vengurla, about 80 km N of Goa, and Mangalore were studied by Nair et al. (1978). The western continental shelf between Vengurla and Mangalore has an average width of about 80 km. The most common shelf break in the region belongs to the gentle break type of Wear et al. (1974) and the depth of the shelf break varies between 90 and 120 m. Surficial sediments consist of silts and clays on the inner shelf (<50 m), sands on the outer shelf (50–100 m) and silty sands on the upper continental slope (>100 m). Carbonate content in the coarse fraction is low in the inner shelf (<30%), intermediate on the outer shelf (30–90%) and high (>90%) on the upper continental slope. Outer shelf sands contain iron-stained quartz (recent and relict) to the extent of 20% whereas the inner shelf sediments contain only unstained quartz. Available ^{14}C dates in the area are shown in Fig. 2.

The number of dates is larger for the northern part and fewer for the study area. We can nevertheless generalise on the basis of these dates that the outer continental shelf sediments and rocks of western India, in common with other continental shelves of the world, are late Pleistocene 12,000–9000 yrs in age. Based on the study of a 65-cm core from the Carlsberg Ridge, Peng et al. (1977, fig. 1, p. 357) report a change in sedimentation rate from 3.46 to 2.26 cm/ 10^3 yrs at about 10,200 yrs B.P. and this date is therefore taken to represent the glacial—post glacial boundary in the Arabian Sea. The climatic inferences that we have drawn from the feldspar data apply to the late Pleistocene and the early Holocene period spanning about 3000 years and represents an averaged picture. Climatic resolution on time scales smaller than this is not possible with these data.

RESULTS

The counts for peak intensities for quartz and feldspars of the study area show their general distribution as follows (Table I). In both the cases the values are low for the inner shelf i.e. ranging from 13×10^3 — 40×10^3 counts

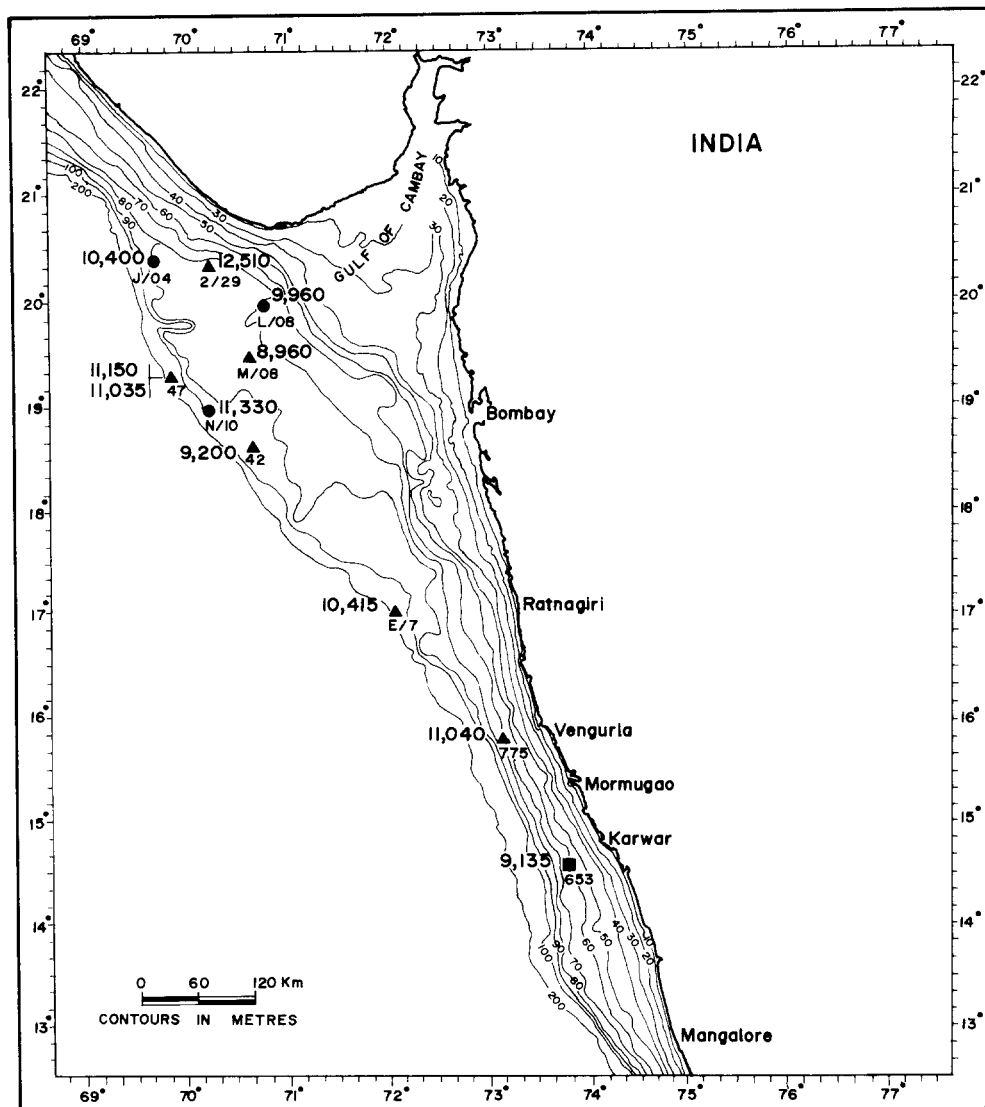


Fig.2. Radiocarbon dates and bathymetry. ● = Ooid concentrate; ▲ = Limestones; ■ = Shells.

for quartz and 6×10^3 – 15×10^3 counts for feldspars. Relative low values are found on the upper continental slope and range from 9×10^3 – 36×10^3 counts for quartz and from 5×10^3 – 13×10^3 counts for feldspars (beyond shelf break). However, the values are higher for the outer shelf and range from 12×10^3 – 86×10^3 counts for quartz and from 5×10^3 – 23×10^3 counts for feldspars. Quartz content is higher on the outer continental shelf than on the inner continental shelf and slope. This is clearly evident from

TABLE I

Absolute counts of quartz and feldspar in the continental margin sediments

Sample no.	Depth (m)	Absolute counts		Feldspars/quartz ratio
		Quartz	Feldspars	
383	18	52090	8289	0.16
382	38	15574	6499	0.42
381	38	13382	8434	0.63
553	51	63437	23120	0.36
552	57	55397	11466	0.21
551	65	44307	12821	0.29
550	80	29284	18333	0.63
547	186	10366	6531	0.63
402	32	23622	10440	0.44
403	44	37367	13710	0.37
596	61	59636	8212	0.14
595	71	58570	7077	0.12
594	67	63341	9034	0.14
593	85	36306	11774	0.32
592	109	36393	16805	0.46
591	210	18598	7140	0.38
409	24	27083	11641	0.43
410	38	25818	9693	0.38
411	45	39855	31047	0.78
412	49	30038	12793	0.43
609	61	63464	17049	0.27
606	84	48004	10852	0.23
605	150	32873	13983	0.43
417	20	32109	9288	0.29
419	42	34061	15146	0.44
626	44	34614	11089	0.32
625	51	57384	12423	0.22
624	63	50636	14615	0.29
620	172	12240	5401	0.44
425	48	59672	9158	0.15
639	48	35647	12024	0.34
637	62	46678	5221	0.11
636	71	66582	5627	0.08
635	102	41604	14651	0.35
634	150	9963	6260	0.63
633	390	15273	9098	0.69
429	18	16844	5836	0.35
430	31	20176	6620	0.33
431	46	23611	13883	0.59
647	65	65933	9130	0.14
646	84	86326	6961	0.08
645	116	17628	13212	0.75
644	184	9442	9293	0.98

the feldspars and quartz ratio as the range of these ratios on the inner shelf and slope are 1:0.15–1:0.77 (average 1:0.42) and 1:0.38–1:0.98 (average 1:0.62) respectively whereas on the outer shelf the range is between 1:0.08 and 1:0.63 (average 1:0.23).

Sodic feldspar is comparatively higher in comparison to potash feldspar in the study area. Three representative sample transects one each on the northern and southern ends of the study area and the third in the central part are shown in Fig.3 and diffractograms in Fig.4. The purpose of determining the structural state of the feldspar in the present instance was to evaluate whether changes in the structural state take place under arid and humid conditions. The data based on three peak method when plotted on the Wright (1968) diagram (figure not shown here) do not display any discernible pattern in that the feldspars in the modern muds and those in the outer shelf relict sands do not group themselves into distinct clusters. One possible reason may be that no significant change in the structure of the feldspar had taken place over the time period under consideration (about 11,000 years) and that the scatter of data points simply is a reflection of the different types of feldspars originating in various source rocks. The types of feldspars present in the samples are maximum and intermediate microcline, orthoclase, and high albite.

DISCUSSION

Nair and Hashimi (1980) have drawn Holocene climatic inferences from the sediments of the western Indian continental shelf. The inferences were based on data of the distribution and abundance of the two most prominent sedimentary facies: the relict carbonate sediments and rocks, and the modern terrigenous clastics present on the western Indian shelf (Nair et al., 1978, Hashimi et al., 1978). It was concluded that the presence of extensive carbonate sediments, carbonate cemented rocks, dead algal and coral reefs on the outer continental shelf points to circumstances in which warmer climates and low terrestrial run-off were dominant. Furthermore, the quartz grains of the outer shelf are an order of magnitude larger in size (0.8 mm) than those on the inner shelf (0.01 mm) implying intensified fluvial processes at the time of deposition of the relict sands. Assuming no tectonic change, intensification of fluvial processes can result from short lived bursts of heavy rainfall quite unlike the pattern of rainfall prevailing over India today. These converging lines of evidence, therefore, indicate an arid climate during the late Pleistocene and the contrast between the carbonate and clastics on the shelf suggests rapid change from arid to humid climate.

Similar conclusions were drawn by Singh et al. (1972) and Street and Grove (1976) after the studies of the lake levels in India and Africa. Singh et al. (1972) concluded that the pre-Holocene arid phase came to a sudden end around 10,000 yrs B.P. resulting in the infilling of the lake basins (Sambhar, Didwana and Lunkarasar of Rajasthan, northwestern India) with

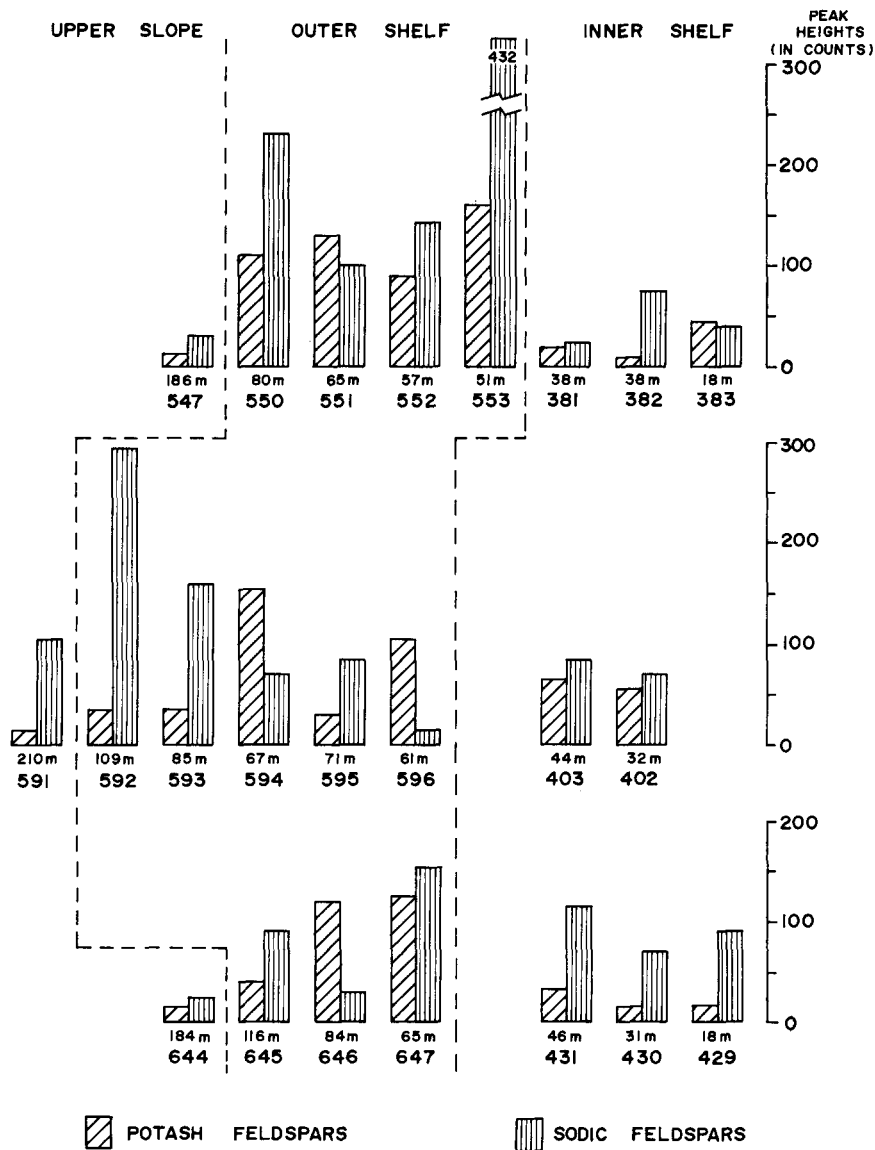


Fig.3. Bar diagram of peak heights of sodic and potassic feldspars along three transects (locations in Fig.1). Note the relatively greater abundance of feldspars in the outer shelf and dominance of sodic over potassic feldspars.

fresh water. Street and Grove (1976) concluded on the basis of their studies of a large number of African lakes that the period 12,500–10,000 yrs B.P. is the African counterpart of the late glacial. It is evident from their studies that the arid conditions lasted until about 10,500 yrs B.P. when there was a brief drop in the lake level in some tropical basins. Watson et al. (1984),

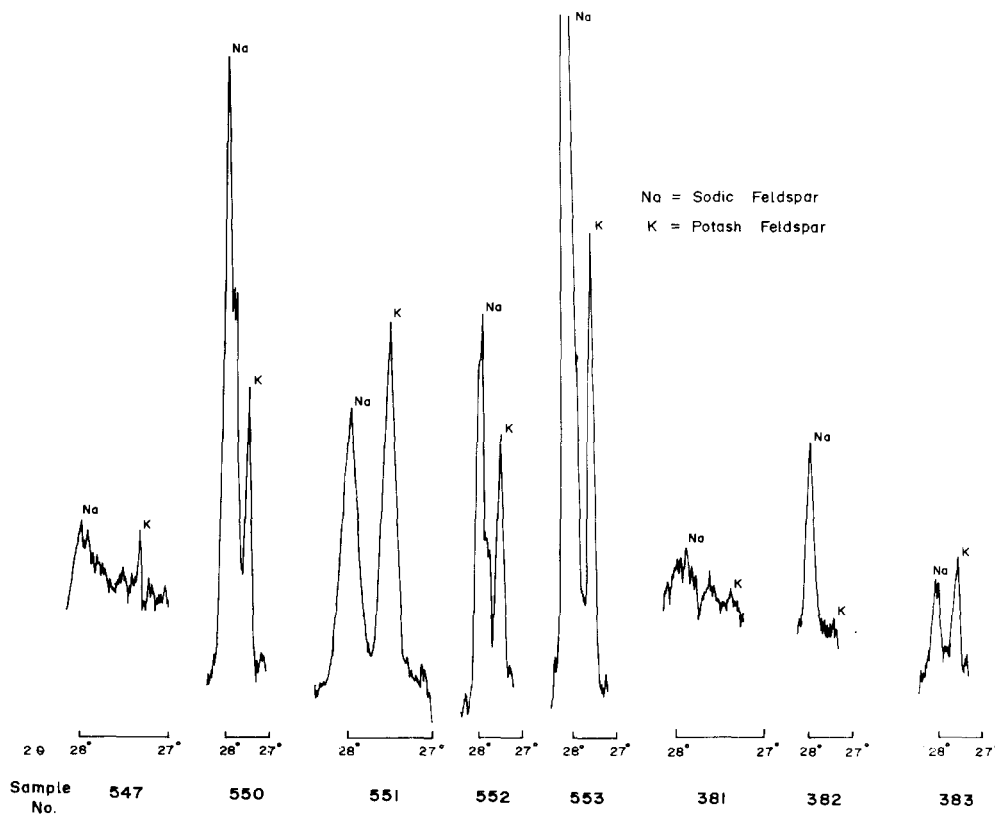


Fig.4. X-ray diffractograms of a representative sample transect (location in Fig.1).

based on the study of colluvial sediments and paleosol in South Africa, arrived at semi-arid climatic inferences.

The distribution of feldspar shows low values on the inner shelf and slope and high on the outer shelf. The high values of the outer shelf may be attributed to the arid conditions on land which tend to preserve the feldspar from weathering. An additional fact suggesting aridity is that within the feldspar group the sodic feldspars are more abundant than potash feldspars. It is only under tropical weathering conditions that relative to sodic, potash feldspars are more stable (Glennie, 1970). Under desert conditions on the other hand both tend to be preserved (Glennie, 1970) and the relative variation in abundance in the shelf sediments would be determined by their relative abundance in the host rocks, which in the present instance are Archaean granites and gneisses. From Fig.3 it is evident that in all three profiles, in 75% of the samples, sodic feldspar exceeds potash feldspar whereas in the inner shelf samples out of a total of nine, six samples show sodic feldspar well in excess of potash feldspar. The outer shelf is a region of non-deposition at present and its sediments and rocks have a ^{14}C age of 9000–12,000 yrs. Therefore, the feldspars present in these sediments

represent conditions prevailing at 11,000 yrs B.P. On the other hand the inner shelf feldspar, a product of the present-day humid climate, shows low values.

These results concur with Damuth and Fairbridge (1970) and Fairbridge (1976) who found that off Brazil the offshore samples in the tropical Atlantic show a domination of feldspars but the present day deposits are rotted to kaolinite which they attribute to humid tropical conditions wherein chemical weathering is deep and pervading. Our findings, though from a restricted geographic location and necessarily tentative in nature, also appears to lend support to the conclusion of Williams (1975 and references therein) that the late Pleistocene tropical aridity was a global feature.

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