Age and mineralogy of the miliolites of Saurashtra and Kachchh, Gujarat

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The miliolites of Saurashtra and Kachchh are impure carbonates of marine origin that range in age from ~30 to ~235 kyr and have implications to neotectonism and sea level changes. The clay mineralogy of their detrital fractions has bearing on the weathering intensity of the region and source of the clays during the late Quaternary.

Introduction

ONE of the very abundant, and important Quaternary deposits of Gujarat are the impure carbonate rocks known as miliolites[1–3]. In Saurashtra[4–6], they occupy an area of about 5300 km^2 whereas in Kachchh they occur in patches[5,7]. These deposits attracted the attention of many an earth scientist as they hold clues to sea level changes, neotectonism and the existence of prehistoric man in western India[5,8,9]. Studies using U, C and O isotopes indicate that the miliolite carbonate is formed under marine conditions, only its occurrences have been attributed to marine and/or aeolian processes[10].

Age

Initial attempts using radiocarbon yielded ages from 11 to 35 kyr[11,12]. It soon became clear that in view of the recrystallization effects involving modern waters which contain substantial amounts of ^{14}C and the realization that nuclear weapons have significantly contaminated marine environment as well as the surficial waters on land, the ^{14}C ages would have no bearing on the antiquity of the carbonate rocks[10,13,14]. The most commonly employed dating method for the late Quaternary carbonate deposits including the miliolites is $^{230}Th/^{234}U$ (refs. 13, 15, 16). A suitable leaching technique was developed for impure carbonates and this technique has been extensively used to date several miliolites from Saurashtra[15–20]. All dates obtained using the $^{230}Th/^{234}U$ method are plotted in Figure 1. These range from 30 kyr to 235 kyr for both Saurashtra and Kachchh miliolites. In general, many of the miliolites are in the range of 30–120 kyr; only at a couple of locations in Kuchchh and in a small patch in the southern Saurashtra coastal belt, older miliolites of ages 139 kyr to 235 kyr are found (Figure 1). These ages have been corroborated by the studies carried out by Bruckner *et al.*[21]. The fact that old (beyond the dating range of ^{14}C viz. ~40 kyr) miliolites yield young ^{14}C ages (<40 kyr) and that all miliolites are not datable using $^{230}Th/^{234}U$ indicates that recrystallization/diagenesis has set in. However, in a large number of cases, the secondary effects are at small/negligible levels so as to yield meaningful ages.

Composition

Chemical-mineralogical composition

Compositionally, the miliolites are carbonate rocks, the $CaCO_3$ content averaging 90% in the Saurashtra miliolites[22] and ranging from 40 to 90% in the Kachchh miliolites. The carbonate part contains principally calcite with aragonite as a minor component. The aragonite contents in the Saurashtra miliolites range from nil to 36.1% (mean = 7.6%). Neither $CaCO_3$

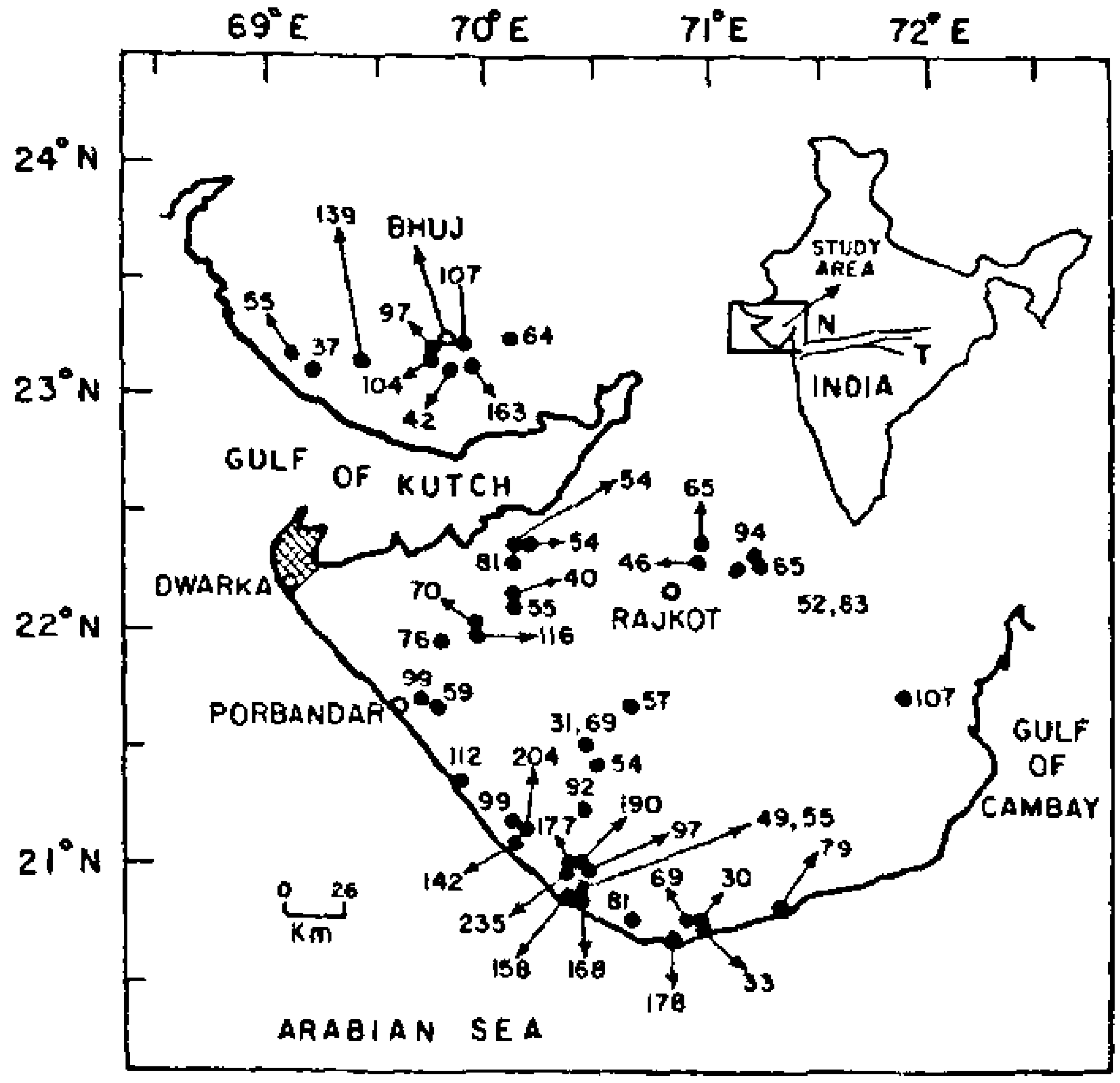

Figure 1. Kachchh and Saurashtra regions of Gujarat, where the miliolite deposits are located. Numbers shown are the Th-U ages in kilo years (kyr). Hatched area north of Dwaraka is the region of coral occurrences. N and T in the inset figure indicate rivers, Narmada and Tapi respectively. Details on ages can be found in references[13,18–20].

nor the aragonite contents of the miliolites show any pattern of variation from coast to inland, there is only a scatter[22]. The non-carbonate material, which is referred to as 'detrital' was seperated into clays and silt + sand fractions. The silt + sand fraction was further separated into magnetic and non-magnetic fractions. Magnetite and maghaemite are the principal magnetic minerals. Feldspars, olivines, pyroxenes, horn-blend, quartz and opaques are present in the non-magnetic fraction. The quartz contents of the Saurashtra miliolites range from nil to 12.6% averaging 2.7%. Here again, there is no systematic variation from coast to inland regions.

Clay mineralogy

A detailed study of the mineralogy of the clays, separated from dated miliolites of Saurashtra and Kachchh[23] indicated that smectite, illite are by far the more abundant clay minerals with kaolinite and chlorite ratio, making only about 10% each. The kaolinite/chlorite ratio remained close to unity during the entire time period viz. 30–235 kyr represented by the miliolites (Fig. 2). In general, one expects smectite to be the most dominant clay mineral as it is formed by the weathering of basalts. The Deccan Trap basalts are the main rocks of both Saurashtra and Kachchh. Indeed it is the case with illite/smectite ratio averaging 1.22 during the past about 120 kyr (Table 1). In the older miliolites (age > 140 kyr), illite is greater than smectite, the illite/smectite ratio is 0.79 showing the dominance of illite which is principally derived from the weathering of granites. The detrital characteristics of the miliolites of both these groups from Saurashtra are given in Table 1. It should be noted that the detrital contents of the Saurashtra miliolites in general range from 0.9 to 47.6%, averaging 12.8%, whereas the Kachchh miliolites analysed for clays have close to ~40% detritus. To further understand the detrital contribution to clay mineralogy, in the case of the Saurashtra miliolites, the detrital contents for miliolites with smectite > 60% and those with illite > 60% were determined. It is seen that the smectite-enriched-miliolites have on an average 28.7% detritus compared to 7.8% present in illite dominated ones. It is envisaged that whenever there was more intense weathering, smectite enriched local sources dominated over the illite contributing ones (e.g. the Indus River transported weathered products of Himalayan granites). It is possible that weathering was relatively more intense in the Saurashtra region during the period 50–120 kyr compared to the earlier period viz. 140–235 kyr.

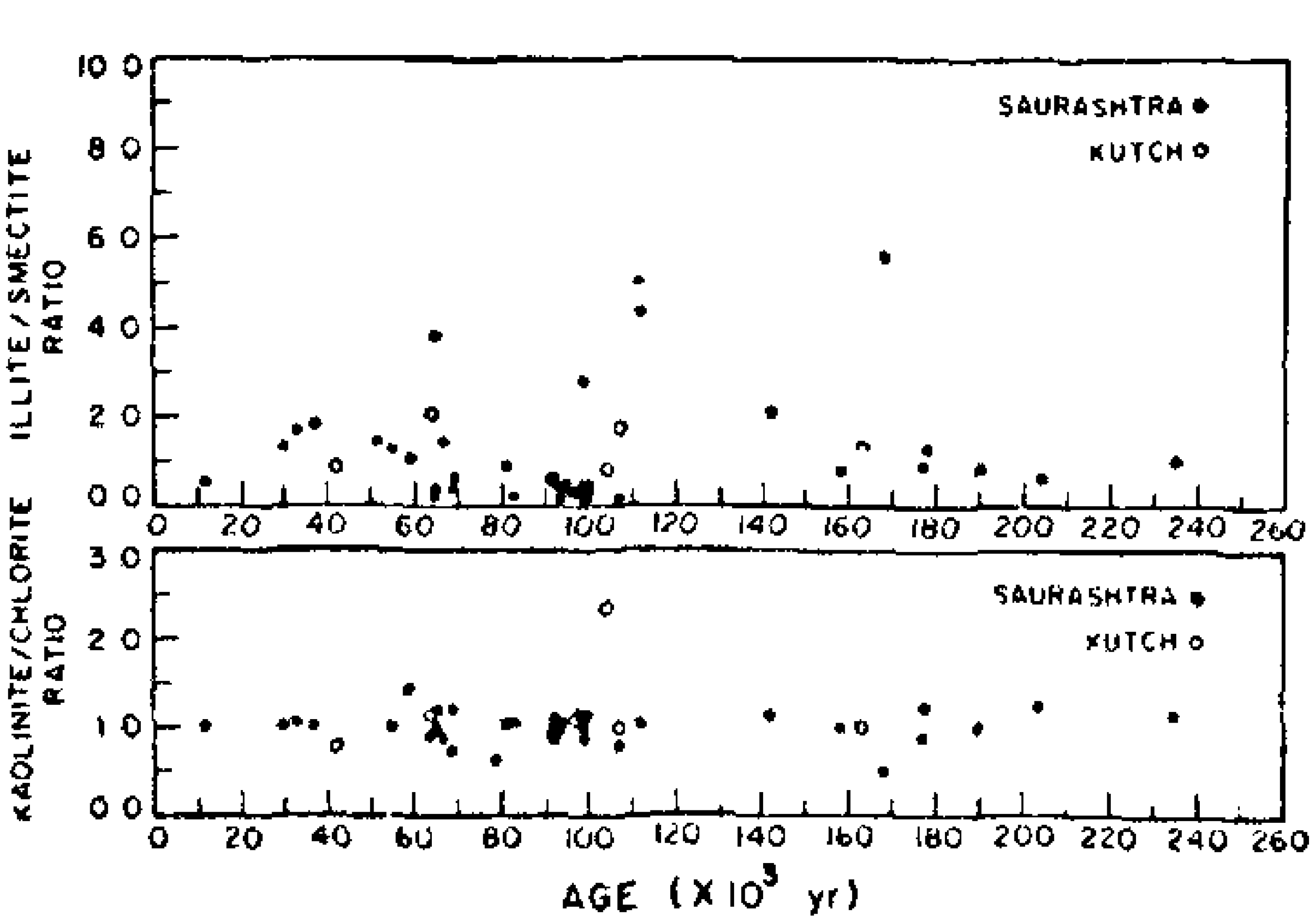

Figure 2. Illite/smectite and kaolinite/chlorite ratios as function of age for miliolites of Saurashtra and Kachchh[23].

Table 1. Detrital characteristics* of dated miliolites from Saurashtra

	Age	
Characteristic	(30–110) kyr	> 140 kyr
Detrital content (%)	14.2	9.2
Smectite (%)	46.7	32.8
Illite (%)	36.7	40.1
Kaolinite (%)	9.4	13.5
Chlorite (%)	9.8	13.6
Illite/Smectite	0.79	1.22
Kaolinite/Chlorite	0.96	0.99

*Based on averages of 43 samples (ref. 23).

The geochronological studies so far carried out have helped in assigning a lower age limit to the emergence of Paleolithic man in Saurashtra[24] and in providing a time frame for processes like neotectonics leading to coastal instability, eustatism and aeolian activity in Western India[10,25,26].

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Sediment load of Indian rivers

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The annual sediment load of Indian rivers is a little more than 1.2 billion tonnes which is roughly 10% of the global sediment flux to the world oceans. Indian rivers show pronounced seasonal and spatial variability in their sediment discharge. Further, lithological contributions and anthropogenic impacts are pronounced on the sediment load of several Indian rivers.

Introduction

THE greatest sediment yields are generally associated with rivers draining areas of intensive tectonic activity. The loess areas of China have likewise a very high sediment yield[1]. The Himalayan rivers draining the tectonically active belts, show a very high yield. The present estimates of sediment yield of the Ganga and Brahmaputra together is about a billion tonnes/yr[2] compared to the global annual sediment flux of about 15 billion tonnes/yr[3]. Table 1 summarizes the sediment erosion values for the rivers draining the Indian Subcontinent.

Spatial variability

Spatial variability of sediment load is evident in large river basins, primarily in response to lithological and geomorphological variations. This is illustrated in Figures 1*a* and *b* for the Godavari and the Mahanadi rivers, respectively. Obviously, the sedimentary rocks and easily weatherable igneous rocks (such as the Deccan Trap) contribute the bulk of the sediments to the river systems though they may not occupy vast areas of the drainage basins. The time-lag between erosion and sediment transported by large rivers today may represent episodes of erosion back in time, often a few decades, centuries or even millinia ago. Further, not all sediments eroded reach the oceans: This is very well illustrated for the Krishna River–the Krishna has a sediment load of $67,000 \times 10^3$ t/yr at Morvakonda but damming of the river and other human activities have reduced the load to $4,100 \times 10^3$ t/yr at its mouth at Vijayawada just a hundred km downstream[4].

All rivers show pronounced spatial variations primarily in response to the river-bed slope and also the gradual build-up of the urban areas. For example, the sediment load of the Ganga at Haridwar is 16 million tonnes/yr, whereas 1500 km downstream at Farakka, it is 800 million tonnes/yr[5]. Of course within such a large stretch of a river, sediment contributions from individual tributaries vary from a low 7 million tonnes/yr for the Gomti River at Lucknow to a high of 140 million tonnes/yr for the Yamuna River at Allahabad. Similarly for the Krishna River, a small upstream

Table 1. Sediment yield of rivers in the Indian sub-continent.

River	Basin area (km^2)	Run-off (10^6 m^3/yr)	Sediment load (10^6 t/yr)
Ganga[2]	7,50,000	4,93,000	329
Brahmaputra[2]	5,80,000	5,10,000	597
Indus[3]	9,70,000	2,38,000	100
Irrawady[3]	4,30,000	4,22,000	265
Narmada[8]	87,900	46,700	70
Tapi[8]	49,000	18,000	25
Godavari[9]	3,13,000	92,200	170
Krishna[4]	2,51,400	32,400	4
Mahanadi[7]	41,000	54,500	15.7
Mahi[6]	25,500	11,000	9.7
Brahmani[6]	28,200	16,300	20.4
Kaveri[6]	66,300	21,500	1.5