

Figure 2. Absorption spectrum of *a*, pyrrole monomer; *b*, polypyrrole; *c*, iodine-doped polypyrrole.

value of the band gap determined from the spectrum did not show appreciable variation with ageing. With increase in dopant concentration, the band gap of the samples decreased. Preliminary studies on the conductivity of the doped sample support the conclusions of spectral studies. It was observed that the resistance of the sample decreased with increase in temperature, yielding a negative temperature coefficient of resistance.

1. Bakshi, A. K., *Sci. Rep.*, March 1989, p. 141.
2. Morita, S., Sawa, G., Mizutani, T. and Ieda, M., *J IEEE (Jpn)*, 1972, 92, 65.
3. Hong, K. and Rubner, M. F., *Thin Solid Films*, 1989, 179, 215.

ACKNOWLEDGEMENTS. We thank Dr V. P. N. Nampoori and Dr C. P. G. Vallabhan for suggestions. We also thank CSIR and DST, New Delhi for financial assistance.

12 October 1990; revised accepted 31 October 1991

Petrography and geochemistry of the Miocene Limestone of Saurashtra, Gujarat, West India

Arun Kumar, Pratul K. Saraswati and S. V. Navada*

Department of Earth Sciences, Indian Institute of Technology, Bombay 400 076, India

*Isotope Division, Bhabha Atomic Research Centre, Bombay 400 085, India

Petrographically, the carbonate rocks of Saurashtra are of four major types, viz. foraminiferal wackestone, molluscan wackestone, foraminiferal packstone and algal foraminiferal packstone. Geochemical and stable-isotope analysis of these rocks indicates low strontium, high manganese and depletion in $\delta^{18}\text{O}$. We suggest that these are the effect of diagenetic alteration.

THE coastal regions of Saurashtra, fringed by the Deccan Trap and the Miliolite Limestone, has isolated

patches of a richly fossiliferous limestone. Fedden¹ gave a detailed geological account of the area and referred these limestones to be of Miocene age. Later, Mohan and Chatterji² recognized three beds which are distinct faunistically. They are:

'Orbiculina' Limestone—Marly limestone containing *Austrotrillina howchini*, *Taberina malabarica*, *Lepidocyclina(N) borneensis* and *Lepidocyclina(N) morgani*.

Visawara Limestone—Yellow to dark yellow, compact limestone, faunal assemblage same as in 'Orbiculina' Limestone except the absence of *Taberina malabarica*.

Bhatia Limestone—Dark yellow to brown, hard compact lateritic limestone containing *Miogyopsina irregularis*.

The Bhatia Limestone overlies the trap-derived laterite. The contact between the two, however, is not clear in any of the sections. The Bhatia limestone also contains grey calcareous clay, in its basal part, which has been observed only in a well section at Nandana. This grey calcareous clay yielded a rich assemblage of benthic foraminifera. The samples for the present study were collected from Bhatia, Bhogat, Nandana, Visawara and Khorasa (Figure 1).

A petrographic study of these limestones shows that they fall into packstone and wackestone types. The dominant bioclasts are molluscs, foraminifera, ostracoda, bryozoa, echinoids and algae. The petrographic types are:

Foraminiferal wackestone. Foraminiferal wackestone consists of benthic foraminiferal framework, along with a few molluscan bioclasts in a micritic matrix. The skeletal fragments constitute about 30%. The foraminifera are mainly represented by operculinids, textularids and a few miliolids. The larger foraminifera are rare in Khorasa section but abundant in Visawara. The cement

is a brownish-coloured, cloudy micrite, which is neomorphosed at places to sparry calcite. Patchy occurrence of sparry calcite in an otherwise micritic matrix, and rarity of enfacial junctions suggest neomorphism. Foraminiferal chambers are filled with micrite cement and ferruginous material. Vuggy porosity and intergranular porosity are also observed. This type is represented in Visawara and Khorasa sections.

Molluscan wackestone. These wackestones are characterized by the presence of molluscan shell fragments. Other main skeletal particles are larger foraminifera and algae. It differs from the foraminiferal wackestone by common occurrence of molluscan shell and near absence of miliolids, textularids and operculinids. Ferruginous coating over bioclast grains is frequently seen. Matrix is mainly micritic, which is partially sparitized at places. The isopacheous fibrous cement occurs as a coating over the shell fragments and is followed by equant cement. Shelter porosity is partially filled by sparry calcite. This rock type occurs in Nandana section.

Foraminiferal packstone. The organic framework of foraminifera in these packstones is cemented by a cloudy microcrystalline calcite. The clear, transparent, sparry calcite is of neomorphic origin which occurs either in the foraminiferal chambers or sometimes as allochemical grains. The allochemical grains constitute up to 40 to 50% and are in grain-to-grain contact. It consists dominantly of larger foraminifera, including *Lepidocyclina* and *Miogyopsina*. Algal grains and some other bioclasts are generally fractured and broken, probably because of early compaction. Acicular cement is quite common over the fragments. Leaching effect is also observed and the main porosity types are intraparticle and vuggy.

Algal foraminiferal packstone. Algae, foraminifera, bryozoa and echinoid fragments are the main allochemical constituents of the algal foraminiferal packstone. The total bioclasts are more than 50%. The foraminifera includes *Miogyopsina*, *Lepidocyclina*, *Austrotrillina*, *Operculina*, small rotalines and some miliolids. The algae are mainly represented by *Lithophyllum*, whose cellular structure, branching form and good preservation distinguish these coralline algae from others. The allochemical constituents are in grain-to-grain contact in a micritic matrix. The micritic envelopes are developed around some of the bioclasts. At places these micritic envelopes are fractured and broken. This rock type is better represented at Bhatia-Bhogat and Khorasa area.

Chemical analysis of some selected limestone samples was carried out to determine the average content of major and trace elements. The samples were mainly analysed for Ca, Mg, Si, Ba, Sr and Mn. Calcium and magnesium were determined by conventional EDTA

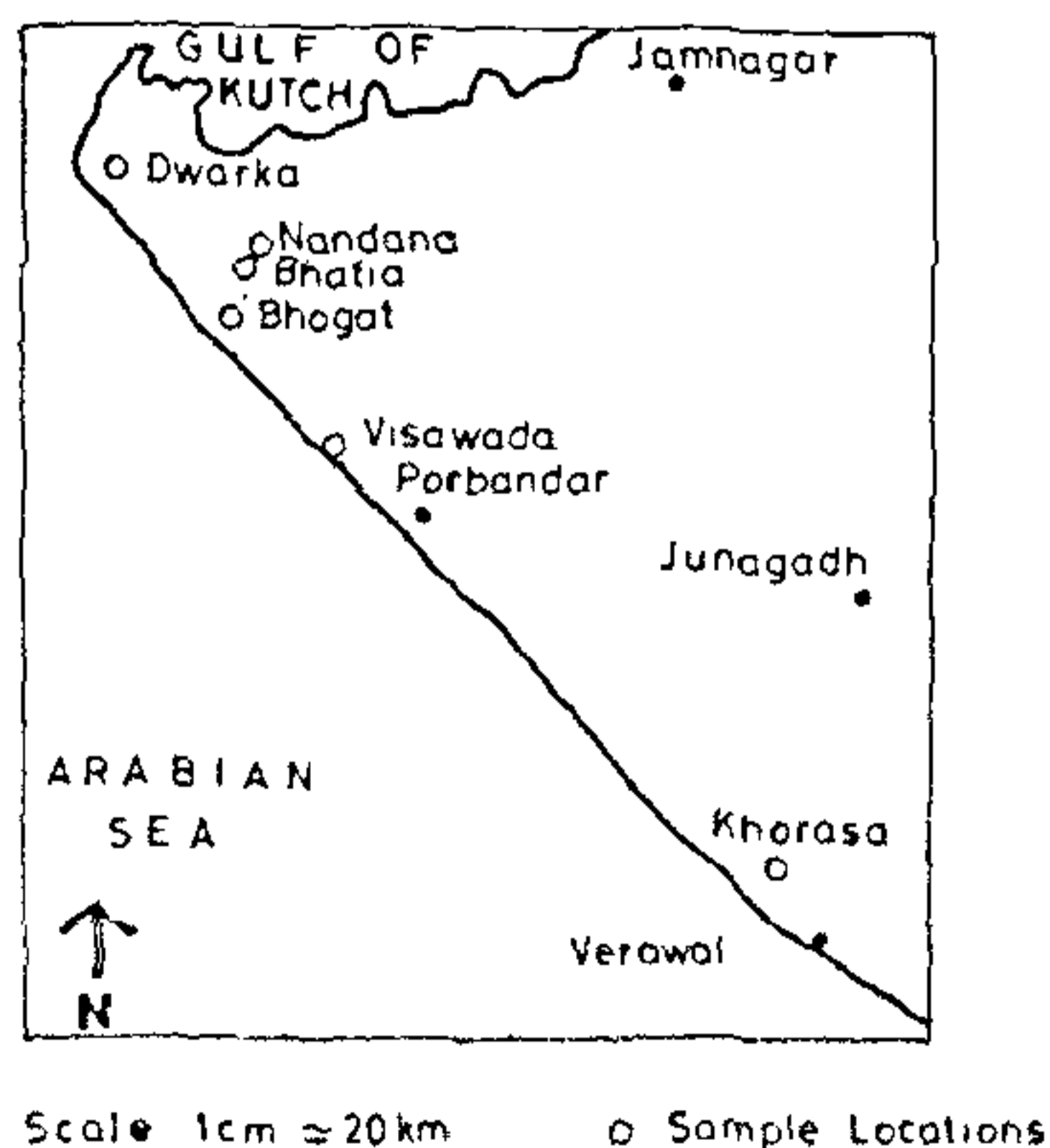


Figure 1. Location map of the Miocene limestone.

Table 1. Geochemical and stable isotope analysis of limestone samples

Sample no	Ca (%)	Mg (%)	Si (%)	Fe (%)	Sr (ppm)	Ba (ppm)	Mn (%)	wrtPDB	wrtPDB
PD 89-1	46.26	3.01	1.18	2.74	70.3	296.0	0.10	-	-
PD 89-4	50.70	6.40	1.22	2.97	63.8	247.4	0.22	-4.4	-3.7
PD 89-10	52.20	10.66	1.02	2.71	94.6	241.8	0.15	-	-
PD 89-11	46.26	2.00	1.80	1.17	114.3	238.1	0.09	-	-
PD 89-13	43.46	4.01	3.24	2.31	43.7	70.4	0.25	-2.5	-5.3
PD 89-14	49.77	1.92	11.48	2.25	99.5	424.8	0.03	-	-
PD 89-15	-	-	-	-	-	-	-	-2.9	-4.5
PD 89-18	36.45	2.00	3.34	10.85	79.7	471.1	0.23	-	-
PD 89-20	-	-	-	-	-	-	-	-2.6	-5.0
PD 89-23	54.68	4.01	5.31	2.97	81.6	119.5	0.21	-2.8	-5.5
PD 89-25	43.46	3.00	0.96	4.59	163.3	310.8	0.40	-2.5	-3.1
PD 89-26	47.66	4.00	3.36	6.51	162.2	221.4	0.24	-	-

titration method, whereas Si content was taken as the evaporation loss after the samples were treated with HF. The other elements, viz. barium, iron, manganese and strontium were analysed on ICP.

Calcium content in Saurashtra limestones ranges from 37% to 55%. It is highest in Visawara limestone and relatively low in Bhatia limestone and 'Orbiculina' limestone. Similar trend is observed in silica content. Majority of the samples are almost pure carbonates. The Mg content is as low as 1.9% and goes up to 10.6%. Manganese in these limestones ranges from 0.10% to 0.40%, whereas iron ranges between 1.2% and 10.8%. The concentration of Sr varies from 44 ppm to 163 ppm only, which is low compared to its normal value in carbonates. A decreasing trend in strontium values has been worked out from younger to older beds. The low amount of strontium can be attributed to diagenesis. Barium content is low in Visawara limestone as compared with the overlying and underlying beds.

Both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ (Table 1) are depleted compared to the values for the Early Miocene times in the Indian Ocean region³. If this is assumed to be the original value of the sea-water, and that the carbonate was precipitated in equilibrium, the temperature obtained would be anomalously high for this period. Thus, the depletion in isotopic composition is due to reequilibration with isotopically lighter pore waters. The recrystallization of the original carbonate mud to neomorphic spar and the presence of more than one generation of cement are indicative of diagenetic effect. The $\delta^{18}\text{O}$ versus $\delta^{13}\text{C}$ plot (Figure 2) of these limestones on the diagram by Keith and Weber⁴, places them mostly in freshwater carbonates. The enclosing fauna are typically marine ruling out the possibility of a freshwater origin. However, reequilibration of the original isotopic values with meteoric water can result in depleted values of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ as obtained for the carbonates of this region. As stated above, the textural data and the chemical data (like low Sr and high Mn content) are indicative of the diagenetic alteration of the original carbonates. The proximity of many of the points to the

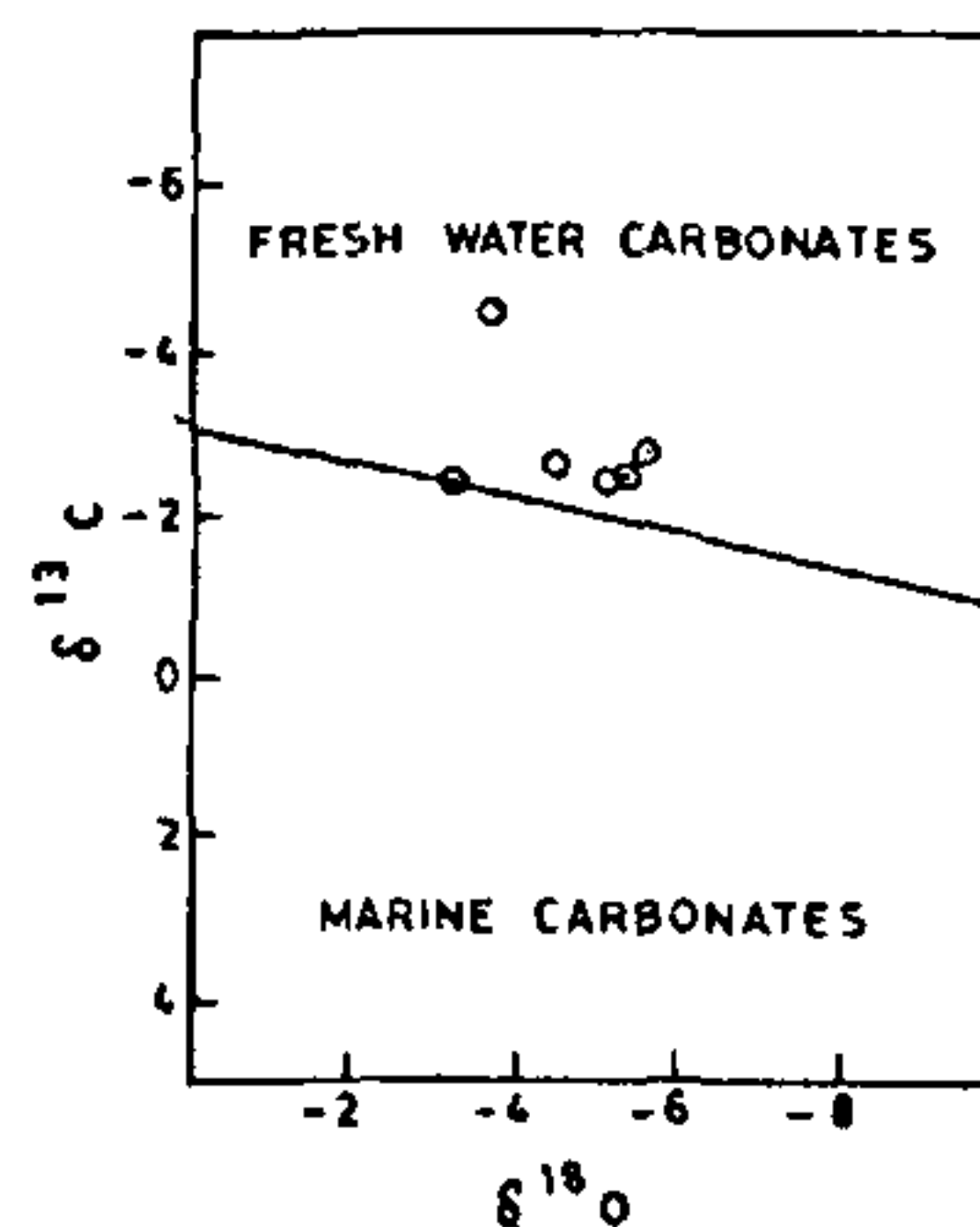


Figure 2. Scatter diagram of $\delta^{18}\text{O}$ vs $\delta^{13}\text{C}$ of the Saurashtra limestone. (The discriminant line is after Keith and Weber⁴.)

discriminant line suggests that diagenesis might have occurred in a transitional environment.

It is concluded that the Miocene limestones of Saurashtra are of wackestone and packstone types. The Ca and Si contents are relatively higher in Visawara limestone and low in Bhatia limestone and 'Orbiculina' limestone. Strontium shows decreasing trend from younger to older beds. No such systematic variation is observed in stable isotope values. The depletion in the stable isotope ratios, low strontium and high manganese content is attributed to diagenesis.

1. Fedden, F., *Geol. Sur. Mem.*, 1884, 21, 1.
2. Mohan, K. and Chatterji, A. K., *Micropaleontology*, 1956, 2, 349.
3. Oberhansli, H., *Marine Micropaleontol.*, 1986, 10, 91.
4. Keith, M. L. and Weber, J. N., *Geochim. Cosmochim. Acta*, 1964, 28, 1787.

ACKNOWLEDGEMENT. We thank Mr I. S. Iyer, ONGC, Bombay, for suggestions.

13 June 1991; revised accepted 12 November 1991