ACKNOWLEDGEMENTS. We thank Drs V. Balaram and P. K. Govil for their help during chemical analysis at the National Geophysical Research Institute, Hyderabad. We also thank Drs S. M. Naqvi, S. H. Jafri, R. Srinivasan and V. Divakara Rao for fruitful discussions and suggestions. This work was supported by a fellowship grant from CSIR, New Delhi.

Received 2 December 1991; accepted 18 December 1992

Sulphur enrichment in a sediment core from the central western continental margin of India

P. S. Rao and Ch. M. Rao

National Institute of Oceanography, Dona Paula, Goa 403 004, India

Anomalous sulphur values in relation to organic carbon have been found in the sediments of a core collected from the central western continental margin of India. The relationship between organic carbon and sulphur is similar to that of the sediments deposited in anoxic environment. Our study indicate that the excess sulphur is mainly due to the addition of sulphides from the shallow regions by mass sedimentation processes rather than water column sulphide formation as observed in anoxic environment.

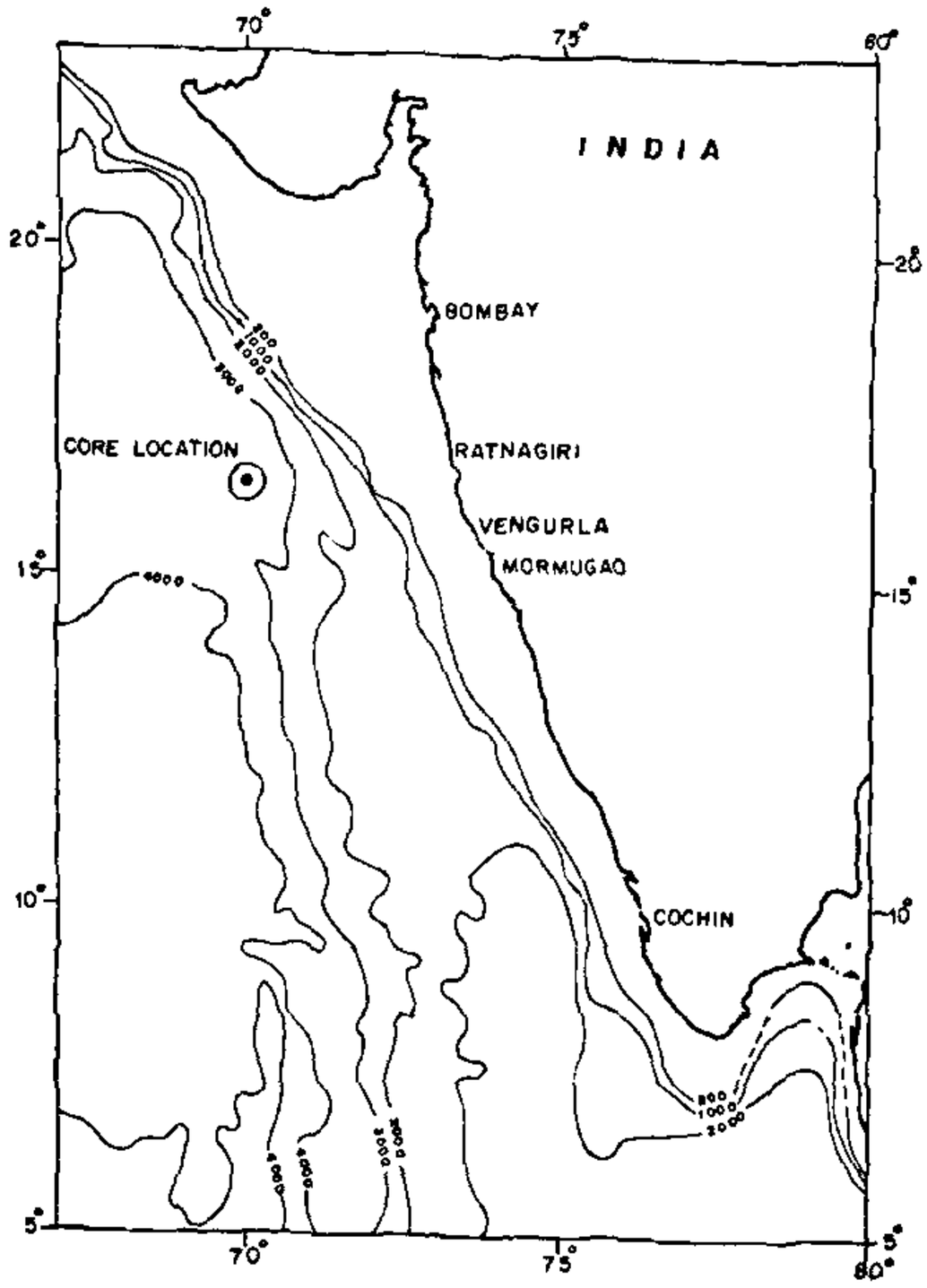

Figure 1. Location of the core. Simplified bathymetry of the western continental margin of India. Depth contours in meters.

MARINE sediments rich in organic carbon are also usually rich in sulphur content and much of the sulphur is in the form of pyrite[1]. Pyrite is formed owing to interaction of reactive iron with H_2S, which is produced by the reduction of interstitial dissolved sulphate by bacteria using sedimentary organic matter as energy source and reducing agent[2]. In normal marine sediments (sediments overlain by oxygenated bottom water), a linear relationship is expected between organic carbon and sulphide sulphur, as 1 g carbon is oxidized for each 4/3 g H_2S sulphur produced[3]. If a constant proportion of total deposited organic matter is reduced to form pyrite, the remaining organic matter should correlate positively with pyrite sulphur, and the regression line pass through the origin and the average S/C ratio is 0.36 (refs. 2,3).

The occurrence of pyrite has been reported from the Arabian Sea sediments[4]. We discuss here the relationship between organic carbon and sulphur in a 12-m-long sediment core collected from the central western continental margin of India (latitude 16°26′N, longitude 69°57′E, water depth 3627 m, Figure 1). Subsamples collected at 5-cm and occassionally at 10-cm interval were washed with distilled water and rendered salt- and pore-water free. Organic carbon content was determined with CHN analyser (Perkin-Elmer model 200B). Reduced sulphur content was determined gravimetrically according to the method of Vogel[5]. To avoid dilution effects of carbonate, the sulphur values were recalculated on a carbonate-free basis. Organic carbon varied from 0.5 to 5.9 wt% and sulphur from 0.28 to 3.65 wt%. The S/C ratios changed from 0.263 to 2.764. Figure 2 is a plot between organic carbon and sulphur. The regression line (line 1) intersects S-axis positively at 0.908 with a slope of 0.291. The correlation between organic carbon and sulphur is 0.416. Also shown in Figure 2 are the regression lines for normal marine sediments[3] (dashed line) and surficial sediments of the Black Sea[6] (line 2). The similarity between line (1) and line (2) and the distribution of points in the C–S plot indicate that the sediments are enriched in sulphur compared to normal marine sediments, as most of the points fall above the dashed line. The Black Sea is a different oceanograaphic environment from other seas, as it has a layer of H_2S laden water in its water column[7]. The positive S-axis intercept in the C–S plot of the Black Sea sediments (line 2) results from the addition of sulphides at the sediment water interface, that formed due to reaction of water column produced H_2S with iron[8].

The Arabian Sea experiences a well-developed

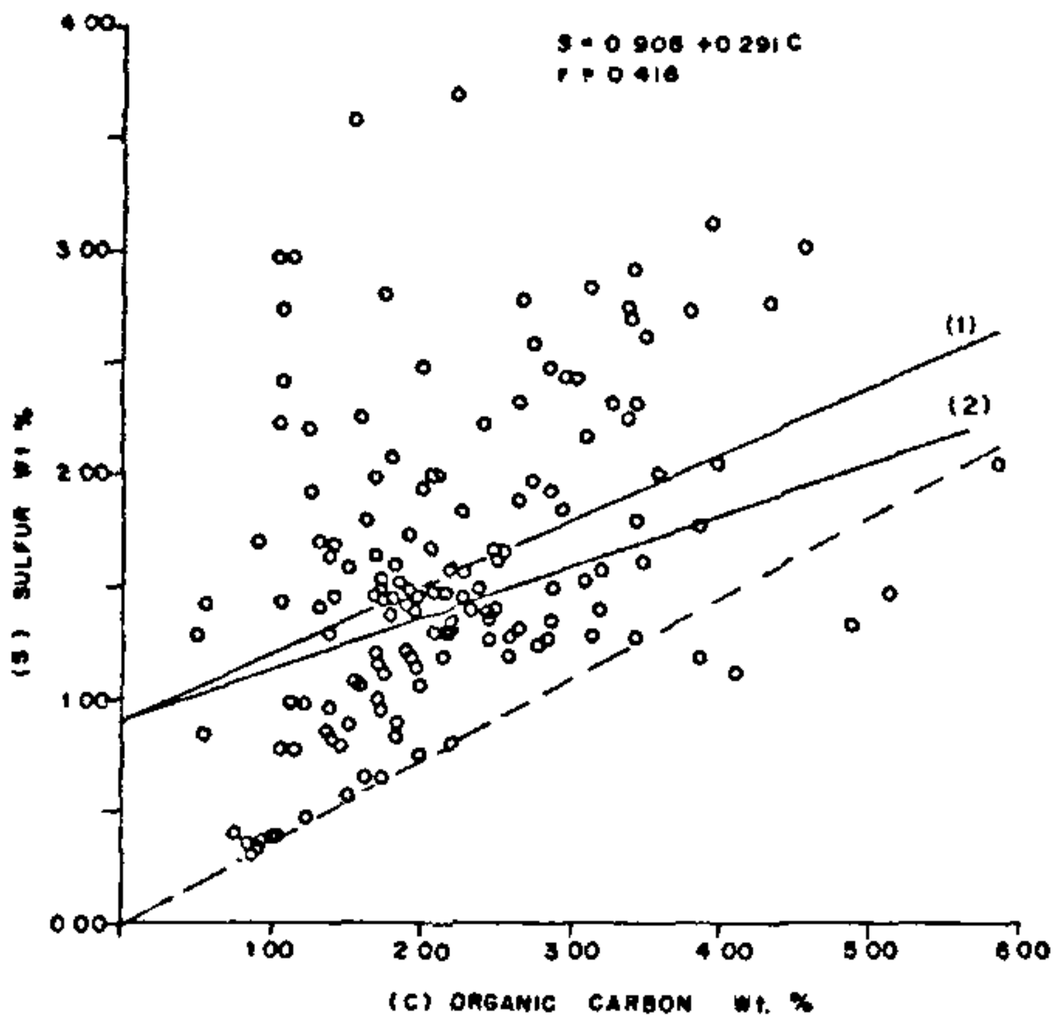

Figure 2. Plot of organic carbon versus sulphur. Dashed line represents the regression line for normal marine sediments[3]. Line (1) for the present core. Line (2) for surficial sediments of the Black Sea[6]. Both the lines intersect S-axis positively, indicating an additional source of sulphur.

oxygen minimum zone between water depths 150 and 1500 m. The dissolved oxygen content is often less than 3 μmoll^{-1} in the depth range of 200 to 1000 m and renders the environment reducing and biochemical reduction of nitrate[9]. However, the occurrence of the subantarctic mode water within the oxygen-poor waters prevents the Arabian Sea from turning completely anoxic at mid-depth[9]. Moreover, the dissolved oxygen content in the deep waters is as high as 3.0 ml l^{-1} (ref. 10). Therefore, excess sulphur in the sediments could not be attributed to water column production of H_2S.

The sedimentological investigation suggests that the core consists of interbedded foraminiferal ooze and turbidites. Turbidites comprise of ooids, shallow water benthic foraminifera and shell fragments. Microscopic observations of coarse fraction reveal the dominance of ooids at six intervals (235–245, 365–375, 535–560, 665–675, 735–740 and 990–1000 cm from core top), which are associated with the turbidite layers[4]. The lithological and sedimentological characteristics indicate that the core can be divided into four units that have been deposited by normal and mass sedimentation processes[11]. Unit one is from the surface to 50 cm, unit two between 50 and 750 cm, unit three from 750 to 990 cm and unit four from 990 cm to the bottom of the core. Organic carbon and sulphur contents in unit one are comparatively low and range from 0.76 to 1.23 wt% and 0.28 to 0.43 wt% respectively. Large variations in organic carbon (0.5–5.9 wt%) and sulphur contents (0.53–3.56 wt%) are noticed in unit two sediments. In unit three sediments, though the organic carbon fluctuated between 1.33 and 5.16 wt%, sulphur does not vary significantly (low 1.09%, high 1.97%). Organic carbon content in unit four varied from 1.06 to 2.68 wt% and sulphur from 0.61 to 2.04 wt%. Among these units, unit one closely follows the regression line of the normal marine sediments, whereas the highest values for sulphur and organic carbon are found in unit two (Figure 3).

The sediments of unit one are moderate yellowish brown in colour and comprises of hemipelagic globigerina ooze that have been deposited by normal settling through water column. Unit two sediments consists of foraminiferal ooze and calcareous marl which are disrupted by the presence of turbidites. The dominance of benthic foraminifera, shells of shallow origin and ooids indicates that the sediments of unit two have been transported from the outer-shelf and upper-slope regions through mass sedimentation processes such as slumping and debris flows[12]. The slope sediments comprise of both biogenic and terrigeneous matter with high organic carbon content. If the organic

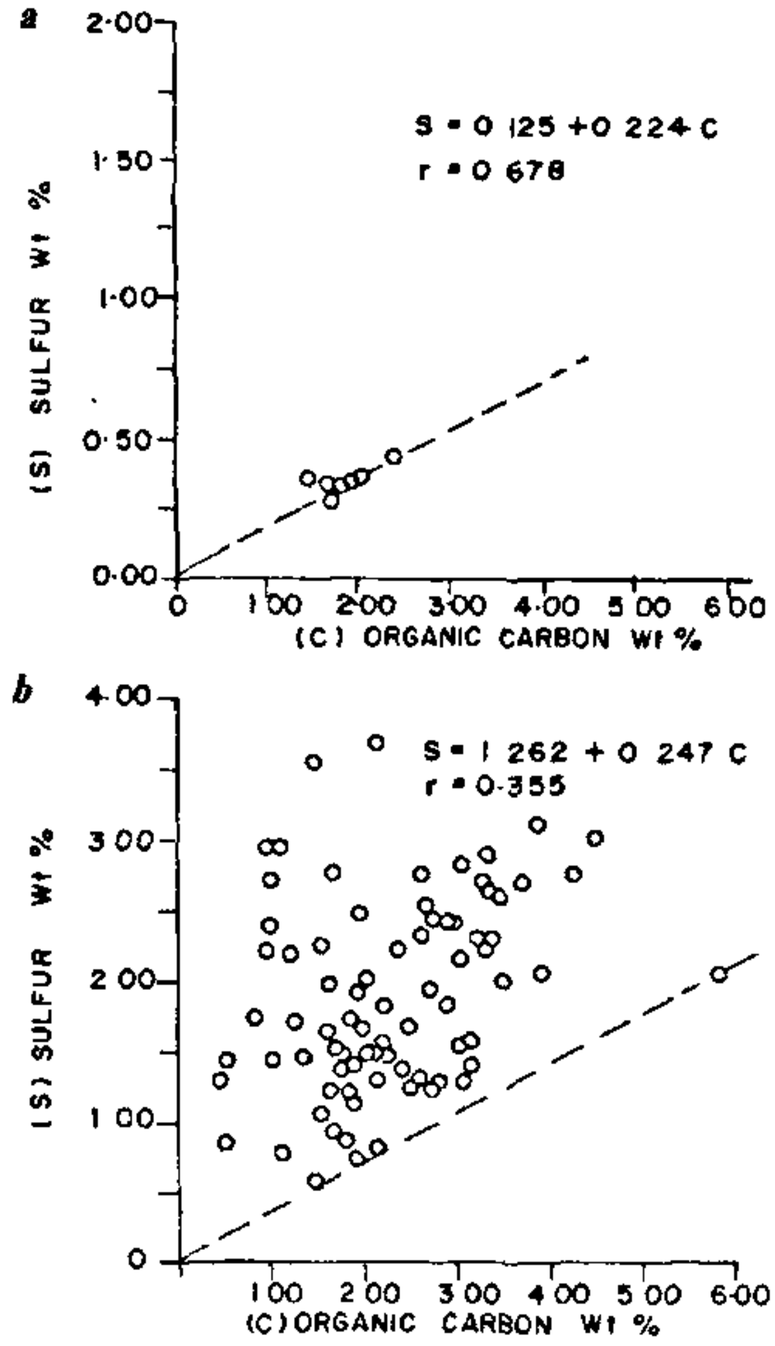

Figure 3. *a*, Organic carbon versus sulphur in unit one (0–50 cm) sediments. The regression line and data points closely follow the best fit line for normal marine sediments. *b*, Organic carbon versus sulphur in unit two (50–750 cm) sediments. The regression line intersects the S-axis positively, suggesting the enrichment of sulphur Also, note that the points fall above the normal regression line.

matter supply is sufficient to consume oxygen within pore waters, sulphate reduction occurs and results in metal sulphide precipitation[2]. Dispersed grains of pyrite were found in the slope sediments off Ratnagiri and Vengurla, between water depths 200 and 400 m. Therefore it is suggested that the sulphides and organic matter from the slope region have been transported to the present site along with the sediments by slumping and debris flows. Considerable amounts of organic matter might have been destroyed while passing through oxygenated bottom waters, whereas sulphides in the form of pyrite might have been deposited unaltered, affecting the organic carbon–sulphur relationship. Due to rapid sedimentation, however, some organic matter would also be deposited which is responsible for diagenetic pyrite formation and further sulphide accumulation.

1. Goldhaber, M. B. and Kaplan, I. R., *Mar. Chem.*, 1980, **9**, 95.
2. Berner, R. A., *Geochim. Cosmochim. Acta*, 1984, **48**, 605.
3. Goldhaber, M. B. and Kaplan, I. R., in *The Sea* (ed. E. D. Goldberg), John Wiley & Sons, New York, 1974, pp. 605.
4. Rao, P. S., Rao, Ch. M. and Reddy, N. P. C., *Deep-Sea Res.*, 1988, **35**, 1215.
5. Vogel, A. I., *Quantitative Inorganic Analysis*, Wiley, New York, 1961, pp. 1216.
6. Raiswell, R. and Berner, R. A., *Am. J. Sci.*, 1985, **285**, 710.
7. Ross, D. A. and Degens, E. T., *The Black Sea*, AAPG Mem., Tulsa, 1974, 20, pp. 593.
8. Leventhal, J. S., *Geochim. Cosmochim. Acta*, 1983, **47**, 133.
9. Naqvi, S. W. A., *J. Mar. Res.*, 1987, **45**, 1049.
10. Wyrtki, K., *Oceanographic Atlas of the International Indian Ocean Expedition*, National Science Foundation, Washington DC, 1971, pp. 531.
11. Rao, P. S. and Rao, Ch. M., Proceedings of the International Symposium on the Oceanography of the Indian Ocean, National Institute of Oceanography, Goa, 1992, (in press).
12. Rao, P. S., *Geo-Mar. Lett.*, 1989, **9**, 85.

Received 15 July 1991; revised accepted 5 February 1992

Subrecent remains of great one-horned rhinoceros from southern West Bengal, *India*

M. Ghosh, U. Saha, S. Roy and B. Talukder
Zoological Survey of India, New Alipur, Calcutta 700 053, India

We report here subfossil remains of the great one-horned rhinoceros for the first time from southern West Bengal. The finding testifies that, like the recently extinct lesser one-horned rhinoceros (*Rhinoceros sondaicus*), a clan of the greater one-horned rhinoceros also thrived in the riverine grass-jungles close to the Sunderban mangrove swamps about 3000 years ago.

DURING May 1990, some skeletal remains of one ponderous animal were unearthed by a fisherman while venturing to deepen a puddle in Ramchandrapur village (*c.* 22° 25′ 50″ N, 88° 24′ 42″ E) under Bon-Hugli Panchayat, P. S. Sonarpur in south 24-Parganas, West Bengal (Figure 1). We examined the silty pit four metre below the surface from where the bones were recovered and collected the material. On closer examination and comparison, the remains appeared to belong to some massive subadult rhino, akin to the great one-horned rhinoceros.

The description and measurements of the specimens are given below. Class, Mammalia; Order, Perissodactyla; *Family, Rhinocerotidae.*

Rhinoceros unicornis Linnaeus: The great one-horned rhinoceros.

Broken mandible with body, having eruptive secondary I_2 on each side, P_4, M_1, M_2 and embedded M_3 on the right ramus; sternal bone, three fragmentary ribs; 7th thoracic vertebra; distal end of right radius; cuneiform of right manus; right astragalus.

The specimens (Figure 2) are not fossilized and the porosities in the spongy bone are visible. Of course, these have become slightly heavier and little carbonized. The pit underlies a four-m thick stratum of sandy clay (Figure 3) and just above a layer of peaty clay. About 50 cm below the peat, a soft, little sticky and dark clay bed was encountered. A sample akin to this soft clay from 550 cm below at Bagerhat (22° 24′ N, 88° 25′ E), a closely situated site under the same geographical unit,

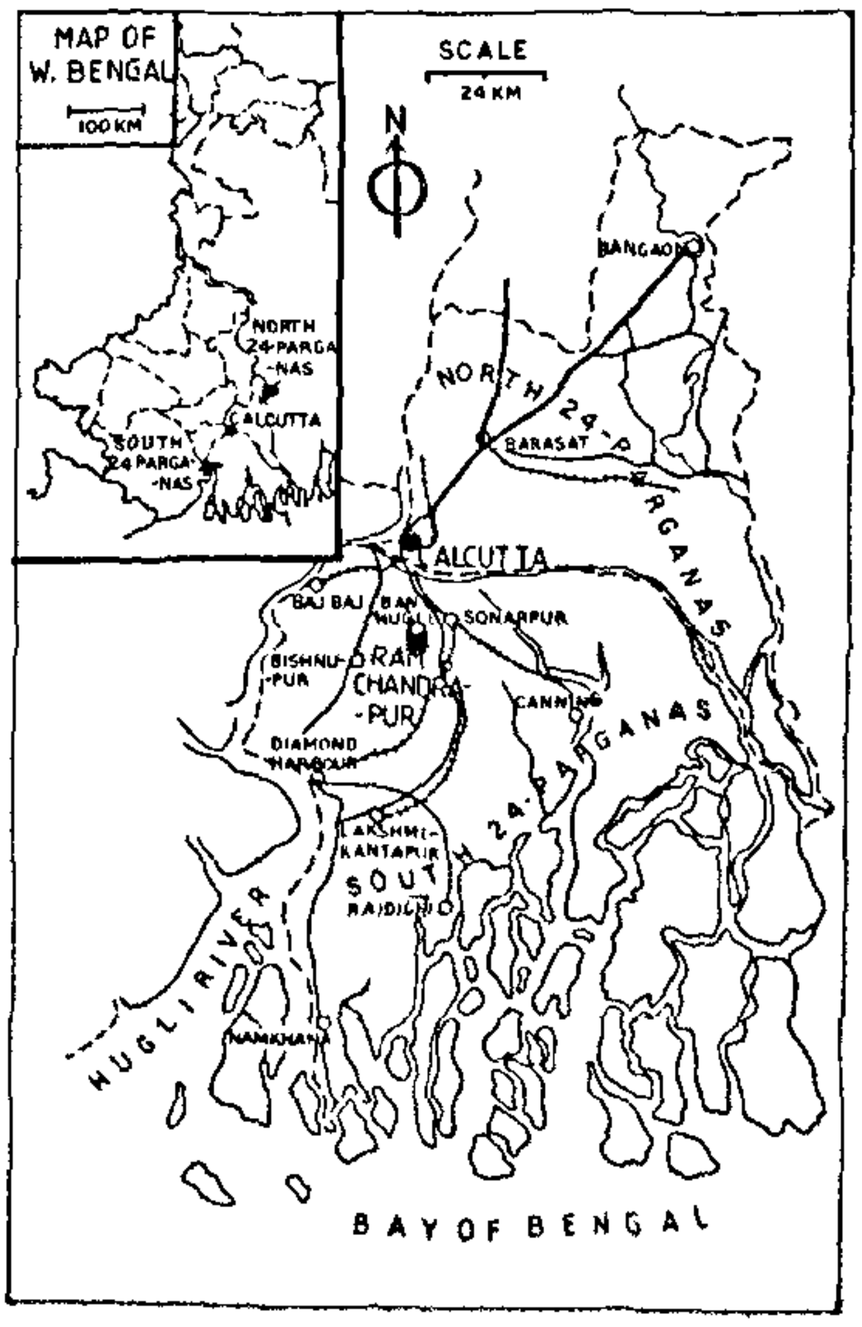

Figure 1. Location of Ramachandrapur village.