

shear and acceleration present. Thus it may perhaps be the necessary condition but not sufficient. This added with the regularity of Weyl and Ricci curvatures, and energy conditions may lead to sufficiency. We have also verified that the metric (5) is geodesically complete¹³ for $\alpha \geq 0$, $\alpha + \beta \geq 0$, $\alpha \geq \beta$, $a \geq 0$, $a \geq b$, $a + b \geq 0$, and $b \leq 0$.

The metric (5) with (6) can as well be cast in the form

$$ds^2 = (1 + k^2 t^2)^{\alpha-1} (1 + m^2 r^2)^a dt^2 - (1 + k^2 t^2)^\alpha (1 + m^2 r^2)^{a-1} dr^2 - (1 + k^2 t^2)^\beta (1 + m^2 r^2)^b dz^2 - r^2 (1 + k^2 t^2)^\alpha (1 + m^2 r^2)^c d\phi^2 \quad (7)$$

which reduces to the FRW from (2) for $\alpha = \beta = 1$, $a = c = 0$ and $b = 1$, where $T(t) = (1 + k^2 t^2)$. It is interesting that if one just uses hyperbolic or $(1 + k^2 t^2)$ functions, which are clearly the obvious choice for singularity-free spacetime, one ends up with the family of singularity-free models. However the cylindrical symmetry seems to play an important role. The above prescription does not obviously work in spherical symmetry. A tentative prescription for a singularity-free spacetime may be as follows: Use non-singular elementary functions having no zeros as metric potentials, and ensure regularity of Weyl and Ricci curvatures with non-zero shear and acceleration. This is just the broad setting, the fluid consistency conditions and energy conditions are then to be satisfied. This prescription does yield acceptable fluid models for cylindrical symmetry.

One may ask the question, how robust is the singularity-free framework in relation to accommodating other force fields? It turns out that viscosity cannot be included without sacrificing positivity of viscosity coefficients for all time¹⁴ while the radial heat flow can easily be included¹⁵. Both the cases above can be generalized to have radial heat flow. Note that for $\rho = \mu p$, μ can have the only two discrete values ($\mu = 1, 3$). If we introduce massless scalar field along with perfect fluid in the case (i), the resulting fluid can have an equation of state, $4 > \mu > 3$, opening out a narrow window for μ .

Finally, the most pertinent question for the singularity-free models is: how to evolve them into the (present day) FRW models? The question is inherently very difficult because the former are cylindrically symmetric wherein a direction is singled out while the latter are spherical having no identifiable direction. It may be noted that the ratio of shear to expansion, that measures the anisotropy, is a constant for these models. We have here established a linkage between the two, which may help in reconciling them together. The affirmative answer to this question will have very important bearing on our overall cosmological perception of the Universe and, in particular, for the early Universe cosmology. The other question is, do there exist general solutions without any symmetry or is

cylindrical symmetry singled out for singularity-free solutions? Details will be given in the forthcoming paper¹⁶.

1. Senovilla, J. M. M., *Phys. Rev. Lett.*, 1990, 64, 2219.
2. Ruiz, E. and Senovilla, J. M., *Phys. Rev.*, 1992, D45, 1995.
3. Wainwright, J. and Goode, S. W., *Phys. Rev.*, 1980, D22, 1906.
4. Feinstein, A. and Senovilla, J. M. M., *Class Quantum Grav.*, 1989, 6, 189.
5. Davidson, W., *J. Math. Phys.*, 1990, 32, 1560.
6. Patel, L. K. and Dadhich, N., *Astrophys. J.*, 1992, 401, 433.
7. Patel, L. K. and Dadhich, N., *J. Math. Phys.*, 1993, 34, 1927.
8. Hawking, S. W. and Ellis, G. F. R., *The Large Scale Structure of the Universe*, Cambridge University Press, 1973.
9. Murphy, J. M., *Phys. Rev.*, 1973, D8, 4231.
10. Berkenstein, D. and Meisels, A., *Astrophys. J.*, 1980, 237, 342.
11. Chinea, F. J., Fernandez-Jombrna, L. and Senovilla, J. M. M., *Phys. Rev.*, 1992, D45, 481.
12. Patel, L. K. and Dadhich, N., Preprint: IUCAA-1/93.
13. Dadhich, N. and Patel, L. K., Preprint: IUCAA 20/93.
14. Patel, L. K., and Dadhich, N., Preprint IUCAA-21/92.
15. Patel, L. K. and Dadhich, N., Preprint: IUCAA-2/93, to appear in *Class. Quantum Grav.*,
16. Dadhich, N., Patel, L. K. and Tikekar, R., Preprint. IUCAA 19/93.

ACKNOWLEDGEMENTS. L.K.P. and R.T. thank IUCAA for hospitality.

Received 14 July 1993; accepted 26 October 1993

Note added in the proof. Since the submission of the paper we have proved the general result establishing the uniqueness of the metric (5) with (6) for singularity-free fluid models when space-time metric is separable in space and time coordinates.

Use of organic geochemical markers in elucidating the origin of salinity in coastal groundwaters

V. N. Varma and B. S. Sukhija

National Geophysical Research Institute, Hyderabad 500 007, India

The present paper demonstrates the possible application of organic geochemical markers in elucidating the origin of salinity in coastal groundwaters. The study carried out in the ground waters, estuarine sediments and aquifer material in the coastal Karaikal region of Cauvery delta has shown that the estuaries/modern marine bodies and their intrusions in groundwaters can be evidenced by the presence of hopanoic and vaccenic acids whereas the palaeomarine intrusions in groundwater have the signatures of biomarkers like those of palmitoleic and oleic acids. This finding is supported by iodide/chloride ratio and radiocarbon dating of groundwaters.

THE study of salinity in groundwaters has gained importance as being one of the environmental problems. Moreover, the salinity of groundwater has direct bearing on agriculture. The salinity in the groundwater could be due to a number of natural

phenomena like (i) ancient marine transgression, (ii) present-day estuary and seawater intrusions, (iii) solutions and minerals and concentration of constituents by filtration by clays, (iv) aerosols precipitation, etc. The preventive measures to be taken for curbing salinization of groundwaters would be very different in the case of present day seawater compared to those in the case of palaeomarine intrusion. Thus, it is imperative to know the origin of salinity in groundwater if steps are required to be taken to improve the quality of such groundwaters.

Of late, isotope approach has gained a lot of importance in elucidating the origin of salinity¹. Recently, certain organic geochemical markers²⁻⁷ generated due to bioactivity have been identified which are associated with marine, carbonaceous and petroleum sediments. The organic compounds identified in aquifers of different stratigraphic formations are mostly lipids derived from plant and animal tissues. The important types of tissue lipids include⁸ steranes, triterpanes, monounsaturated fatty acids, etc., which are characteristic biomarkers of the marine sediments. Further in the estuaries, hopanes and their derivatives synthesized from blue-green algae and by particular land plants are found to be present in them, thus serving as biomarkers for estuary-affected groundwaters. Further in the geological time scale, these compounds are bacteriologically converted into other compounds with different molecular structures (due to molecular rearrangement and other biochemical factors) when locked up in the sediments under anoxic conditions. For example, Hostettler *et al.*³ have shown the presence of the mature sterane and hopane biomarkers for the bay and a suite of polycyclic aromatic hydrocarbons (PAH) dominated by pyrene, fluoranthene and phenanthrene, which are typical of estuarine markers worldwide; Blumer and Cooper⁴ had indicated the isoprenoid acids like trimethylpentadecanoic acids (TMPD), tetramethylheptadecanoic acids (TMHD) to be present in ancient marine sediments as mainly post-depositional products.

With the objective of exploring the possibility of using certain organic markers present in the groundwater and in marine sediments in elucidating the origin of salinity, the present research work was carried out in the coastal aquifers and in the present-day marine bodies of coastal Karaikal region, 320 km south of Madras (Figure 1). Our findings indicate the absence of lipids of hopane and hopanoic acids and vaccenic acid in certain groundwaters, but their presence in modern marine bodies like estuary/bay and groundwaters ingressed by such water bodies due to overexploitation. Thus, this study demonstrates the application of organic geochemical markers' approach for this purpose. The results are supported by iodide/chloride ratio and radiocarbon dating of groundwater samples.

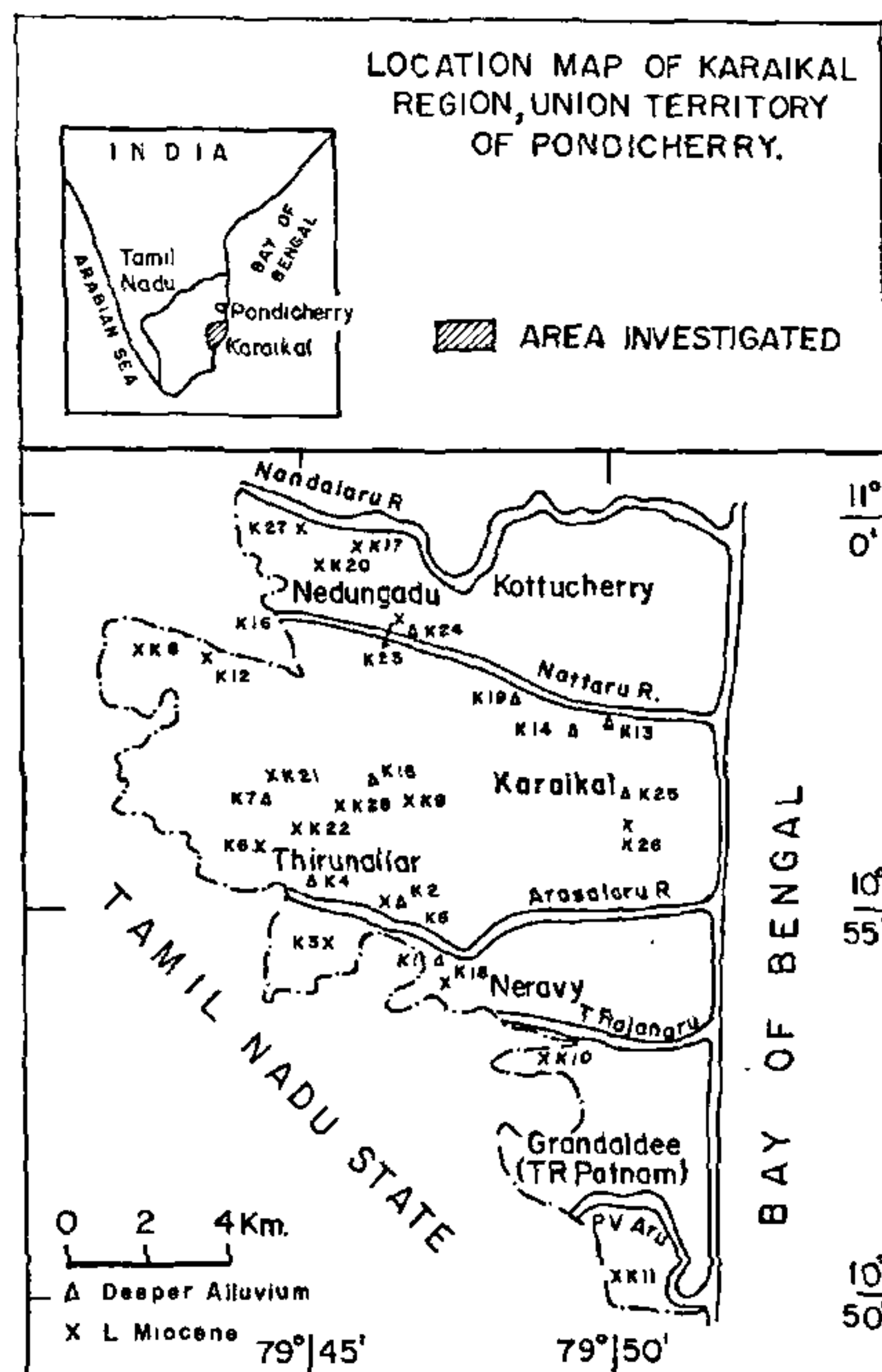


Figure 1. Well location map of Karaikal region

Hydrogeologically⁹ the Karaikal region possesses the following groundwater structures.

Formation	Aquifer type	Average depth	TDS (mg/l)	EC ($\mu\text{S/cm}$)
Quaternary				
Recent	Phreatic	up to 30 m	< 500	< 750
Pleistocene	Confined	40-60 m	1500-2500	2200-3700
Tertiary				
Pliocene	Confined	60-120 m	10000	15000
Lower Miocene	Confined	200-450 m	< 1000	< 1500

The salinity is moderately high in deeper alluvial, slightly high in lower Miocene and extremely high in the Pliocene aquifers. Therefore, the Pliocene groundwater is absolutely unfit for irrigation and domestic purposes. However, the alluvial and lower Miocene groundwaters are being utilized in conjunction with surface waters.

In the Karaikal region, there are about 28 wells in the lower Miocene and seven wells in the deeper alluvial formation. We obtained water samples from different formations (lower Miocene and deeper alluvium) at

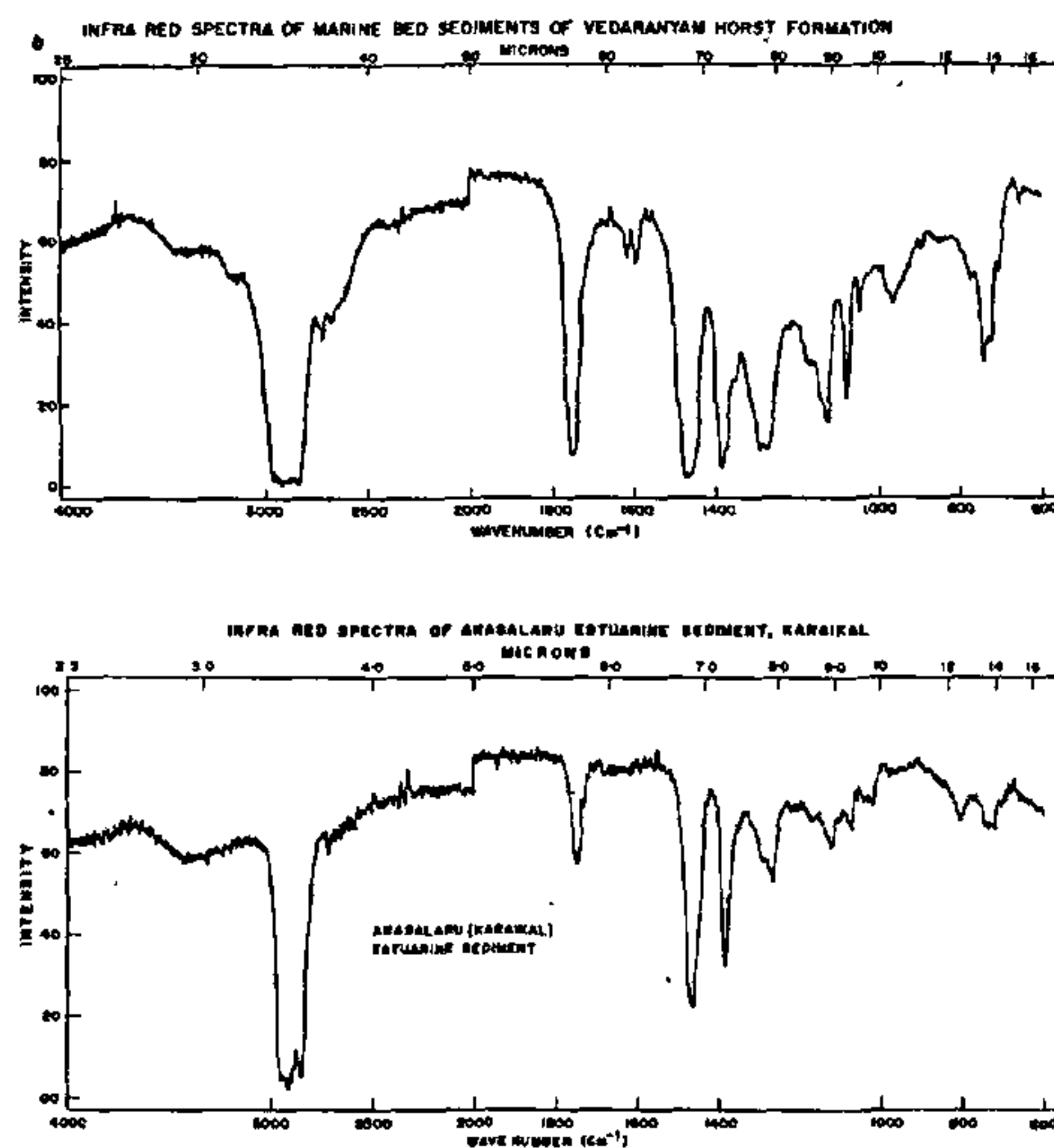
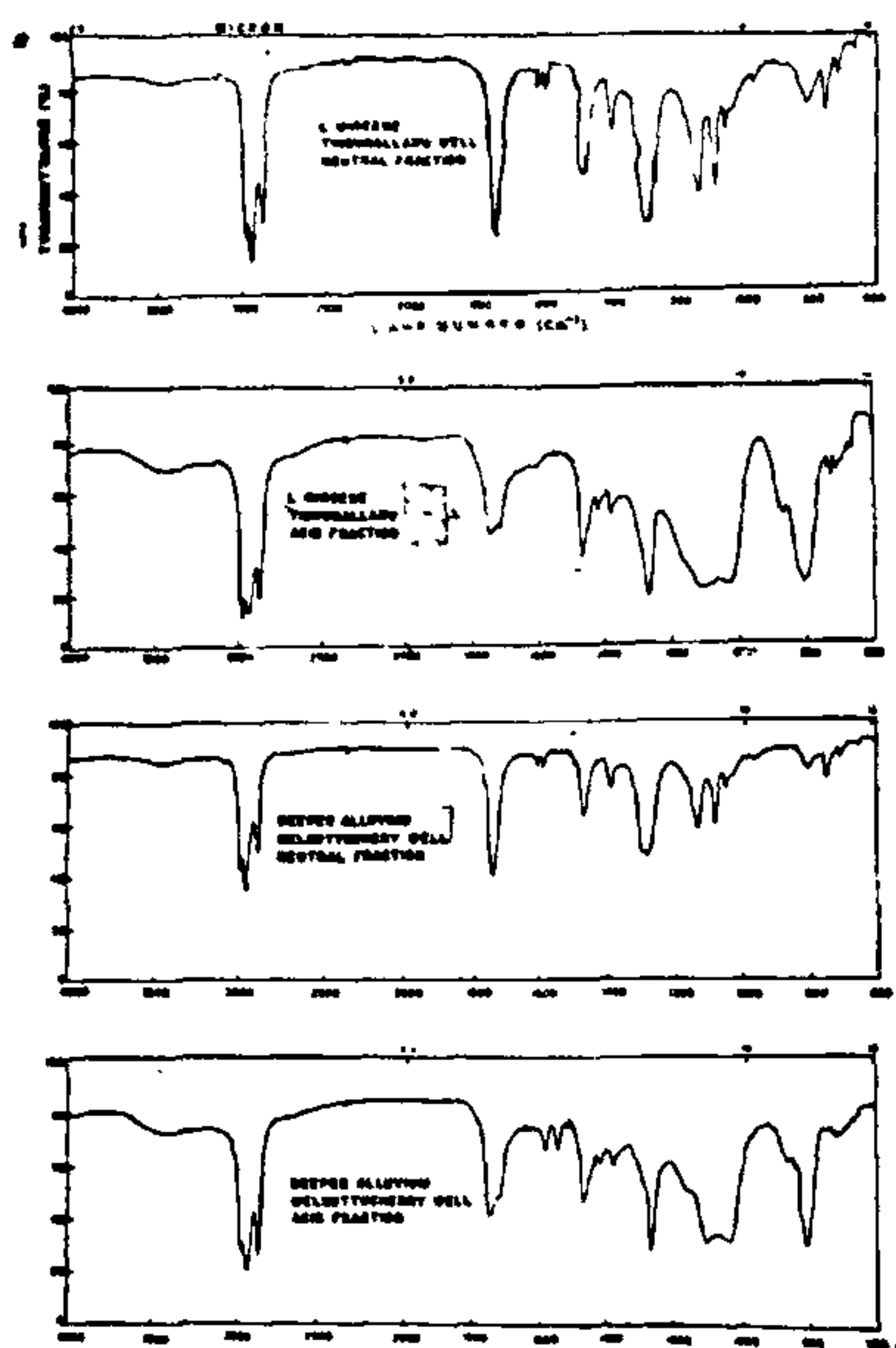


Figure 2. IR spectra of *a*, Karaikal region groundwaters, *b*, marine sediment bed and Arasalaru estuarine sediment.

various locations in the Karaikal region. The samples collected (Figure 1) were utilized for chemical (chloride and iodide measurements) and isotopic measurements (^{14}C and ^3H). Organic geochemical spectral and chromatographic analyses were done to detect specific organic compounds in some selected samples representing different formations. At the time of collection, some of the deeper sampled wells were in flowing condition and the others were pumped out. Marine sediments at 100 and 200 m depths were collected from the Vedaranyam borehole while being drilled and sediments from Arasalaru estuary and the Bay of Bengal off Karaikal coast (Figure 1) were also collected.

Organic geochemical analyses were conducted on two groundwater samples from the lower Miocene formation, viz. Thirunalluru (K-9) and Madur (K-6) and on three groundwater samples from deeper alluvial formations, viz. Melkottucherry (K-13), Agalancan (K-4) and Sorakudy (K-15). For processing of each sample, 100 l of water samples from each well head was collected and treated with chloroform-methanol mixtures (2:1) for extracting organic compounds – comprising mainly fats and lipids – from the water samples following the method of Folich¹⁰. After the treatment, the organic residue (around 750 mg in each case) was fractionated into acid and neutral parts using

aqueous saturated sodium bicarbonate method. These organic fractions were subjected to infrared (Perkin-Elmer meter) and mass spectroscopies (F-Mat) and, finally, organic compounds were ascertained with chromatographic isolations and identifications.

The IR spectra of organic extracts of groundwater samples (Figure 2*a*) and marine pliocene sediment samples (Figure 2*b*) show characteristic absorbances around 1600 cm^{-1} and 1700 cm^{-1} as wave numbers and also at 960 cm^{-1} , which supports the idea of probable occurrence of olefins and unsaturated fatty acids in groundwaters and in pliocene marine bed aquifer material; however, these are found to be absent in the estuarine sediment sample (Figure 2*b*). Further, for the organic extracts of groundwater and marine sediments, the mass spectral ion peaks (Figures 3*a, b*) at $m/z = 254, 282, 296$ signify the occurrences of palmitoleic and oleic acids and methyl oleate, respectively, and/or their trans-isomers. The presence of IR peak at 960 cm^{-1} in the organic extracts of groundwaters and marine sediments supports the acid conversion from cis to trans forms in isomeric configuration due to clay catalytic conversion at deeper depths⁵. Thin-layer chromatographic (TLC) (Figure 4*a*) separations (silica gel E Merck impregnated with silicon oil; acetic acid-water-ethyl-acetate solvent system; iodine vapour spotting for unsaturation; copper

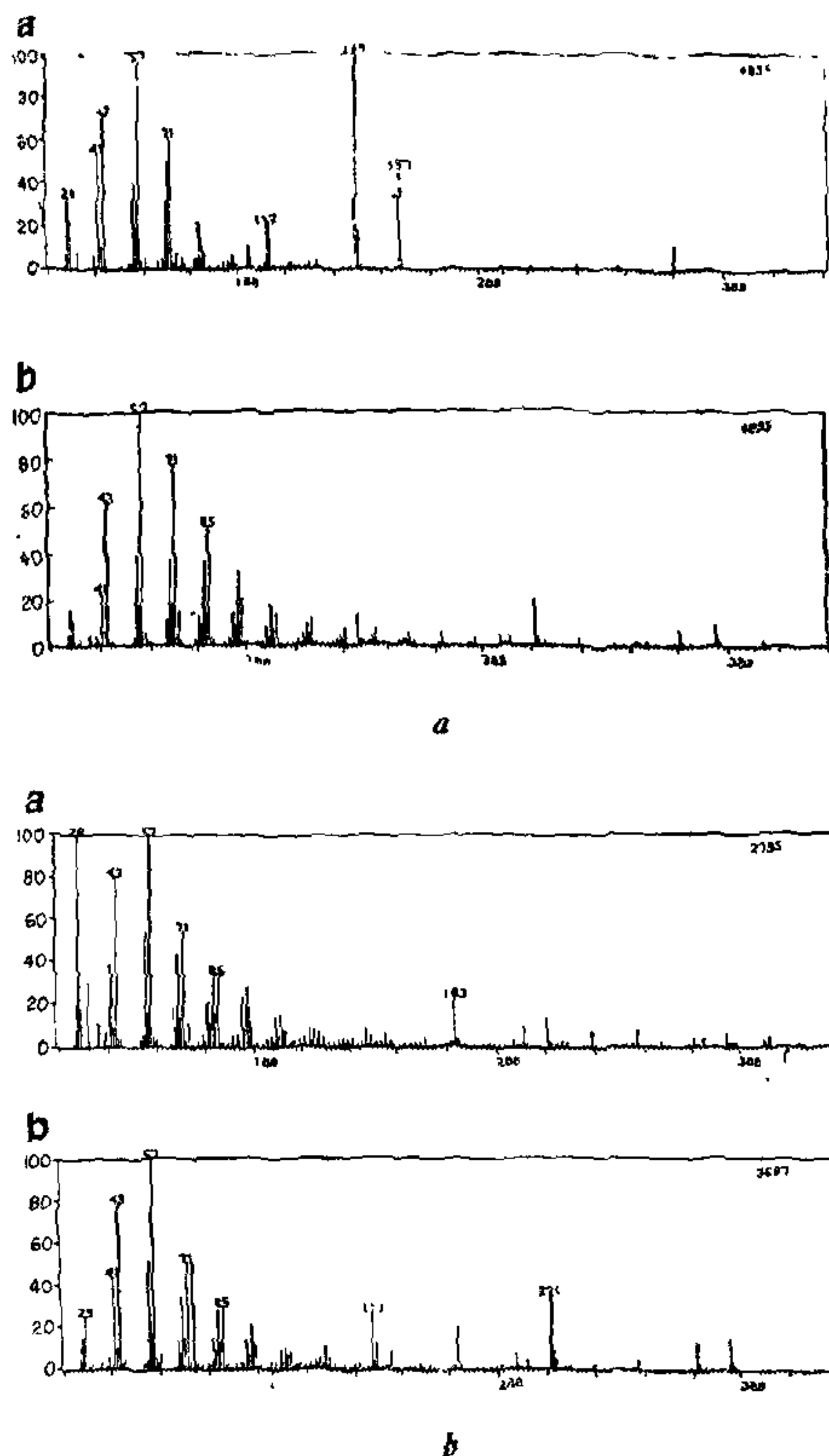


Figure 3. Mass spectra of *a*, neutral fractions, *b*, acid fractions. *a*, *b*, top: L. Miocene-Thirunallaru well, *a*, *b* bottom. Deeper Alluvium-Melkottuchery well.

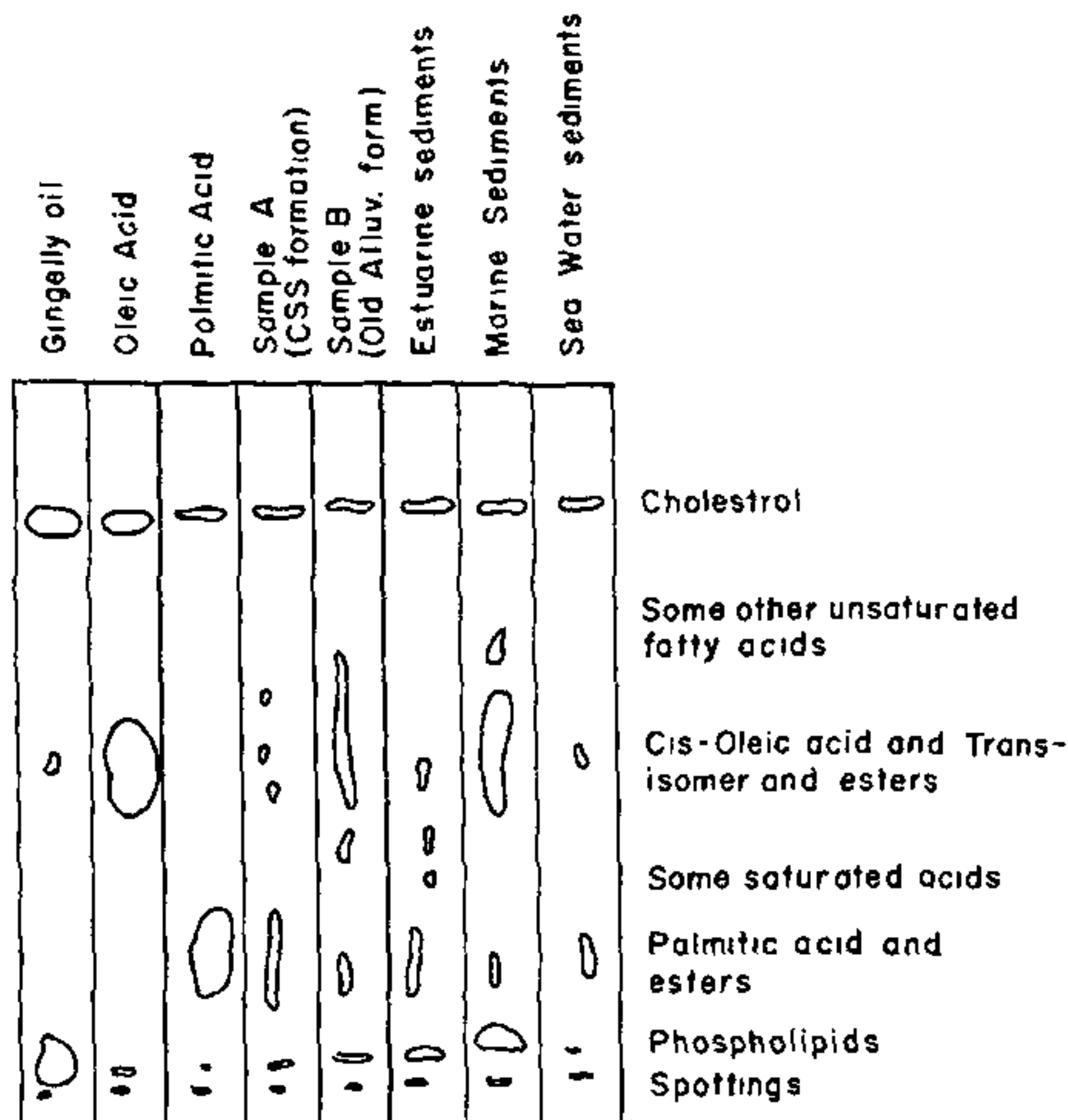
acetate spray spotting for saturated fatty acids) carried out under reverse-phase condition confirmed the presence of C-16 and C-18 monounsaturated fatty acids in higher concentrations in groundwaters sampled from Melkottucherry and Thirunallaru wells and in marine bed sediments compared to those in the estuary and bay sediments. These, on the other hand, reveal higher concentrations of vaccenic acid and lower concentration of monoenoic acids⁶. The gas-chromatographic (Figure 4 *b*) experiment (Silar column; column temp. 200–250°C at 10°C/min; FID detector) on the Sorakudy (deeper alluvium) well water sample which was saponified and methylated had elucidated the presence of palmitoleic, oleic and linoleic fatty acids, having retention times at 5.77, 7.48 and 8.68 min, respectively

(with linseed ester as the standard sample) (see Figures 5 *a*, *b*). The other most pronounced mass ion peaks in the mass spectra are at $m/z = 191, 231, 368$. These indicate the presence of lipid class of 17 α (H)-, 21 β (H)-hopane and hopanoic acids with C-29 and C-30 carbon numbers (triterpanoic acids) in estuarine sediments (organic fractions) (Figure 5 *a*, *b*)^{11, 12}. Such signatures were not traced out in the spectra of marine bed and in the selected groundwater samples except those of Madur and Agalancan groundwater samples (K-6 and K-4), wherein the estuarine component could be identified by the presence of hopanoic and vaccenic acids (Figure 6 *a*, *b*). In contrast to this, Figure 7 shows the absence of hopanoic and vaccenic acids in the case of pliocene sediments. The estuarine influence in groundwaters is confirmed by the relative younger radiocarbon ages (for sample K-4, see Table 1). The presence of vaccenic acid in Madur groundwater sample (K-6) was established by the mass fragmentary ion features at $m/z = 129, 228$ (pretreating with bromine and methanol additives and later purified by TLC) (Figure 6 *c*)^{6, 13}.

Sr^{2+} and I^- are some of the minor ions generally employed to study the palaeosalinity in groundwaters^{14, 15}. Corals and phaeophyceae marine organisms concentrate iodine and bromine in sediments. Iodine exists mainly as iodide and iodate forms in groundwaters, depending upon pH-Eh variations. For our study, total iodine in water samples was estimated following the method of Sandell and Kelthoff¹⁶, using kinetic spectrophotometer (sensitivity up to ng/l). Table 2 shows the I^- and Cl^- concentrations of some of the water samples from different geological formations as well as those from the Arasalaru estuarine and bay water samples. I vs I/Cl plot can be used to discriminate the old and modern saline waters as shown in Figure 8 (refs. 16, 17). In this figure, most of the selected groundwater samples cluster between 10^{-4} and 10^{-3} , showing them to be old saline waters compared to the modern estuarine and seawaters. High iodide values are attributed to long residence time of groundwaters.

To further confirm our results, the natural isotopic measurements using short-lived tritium 3H isotope (half-life 12.43 yr) and long-lived radiocarbon ^{14}C (half-life 5730 yr) were conducted to find out the apparent ages of groundwater samples collected in the study area. Low-level 3H and ^{14}C measurements were carried out using gas proportional counters¹⁸. The results are presented in Table 1 and the uncorrected ages are estimated based on 100 pmc (per cent modern carbon) initial activity. Deep groundwaters in Lower Miocene, however, have radiocarbon contents below 7 pmc and are devoid of tritium, corresponding to uncorrected ages of about > 20000 yr. As discussed earlier, barring one sample, viz. Agalancan (K-4) -

a



b

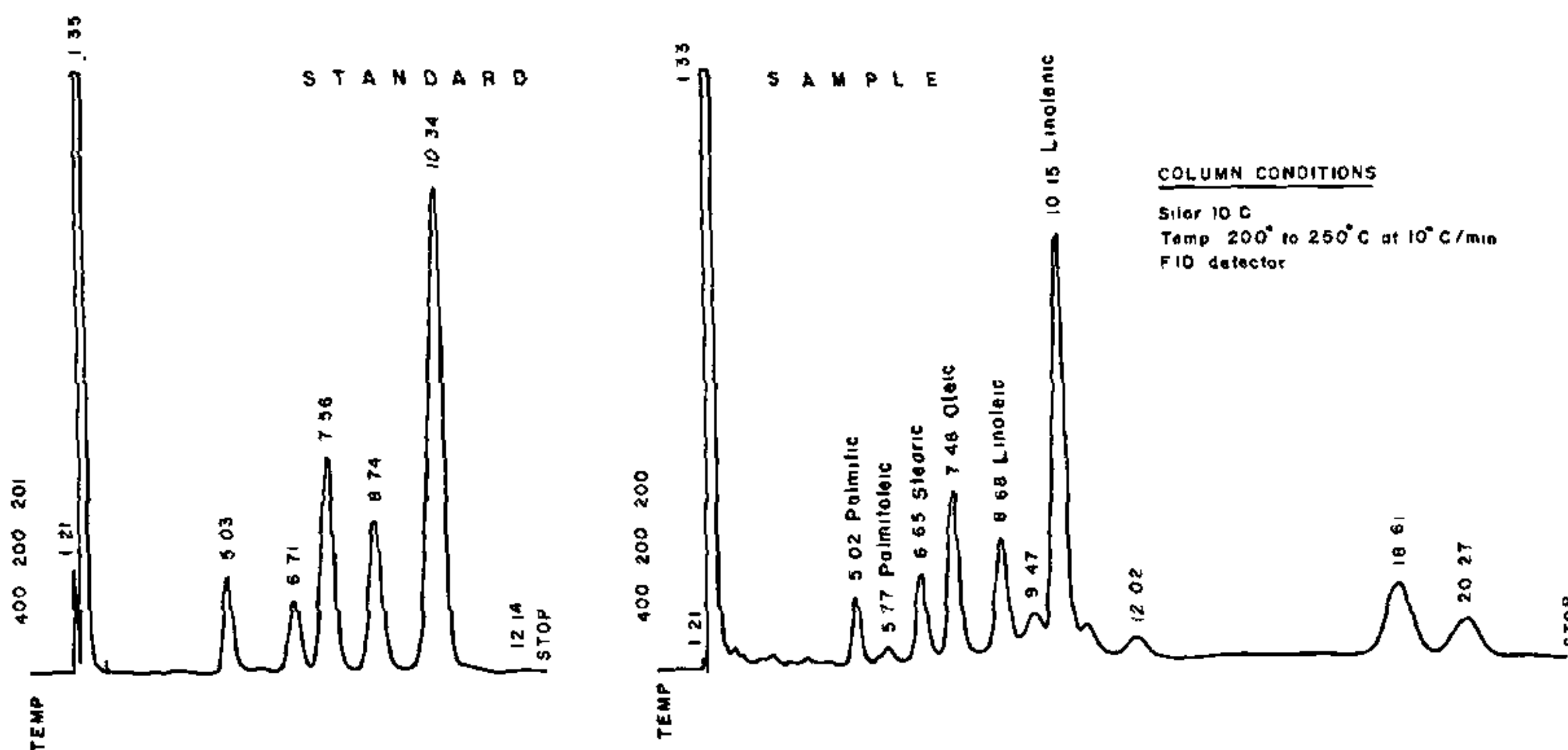
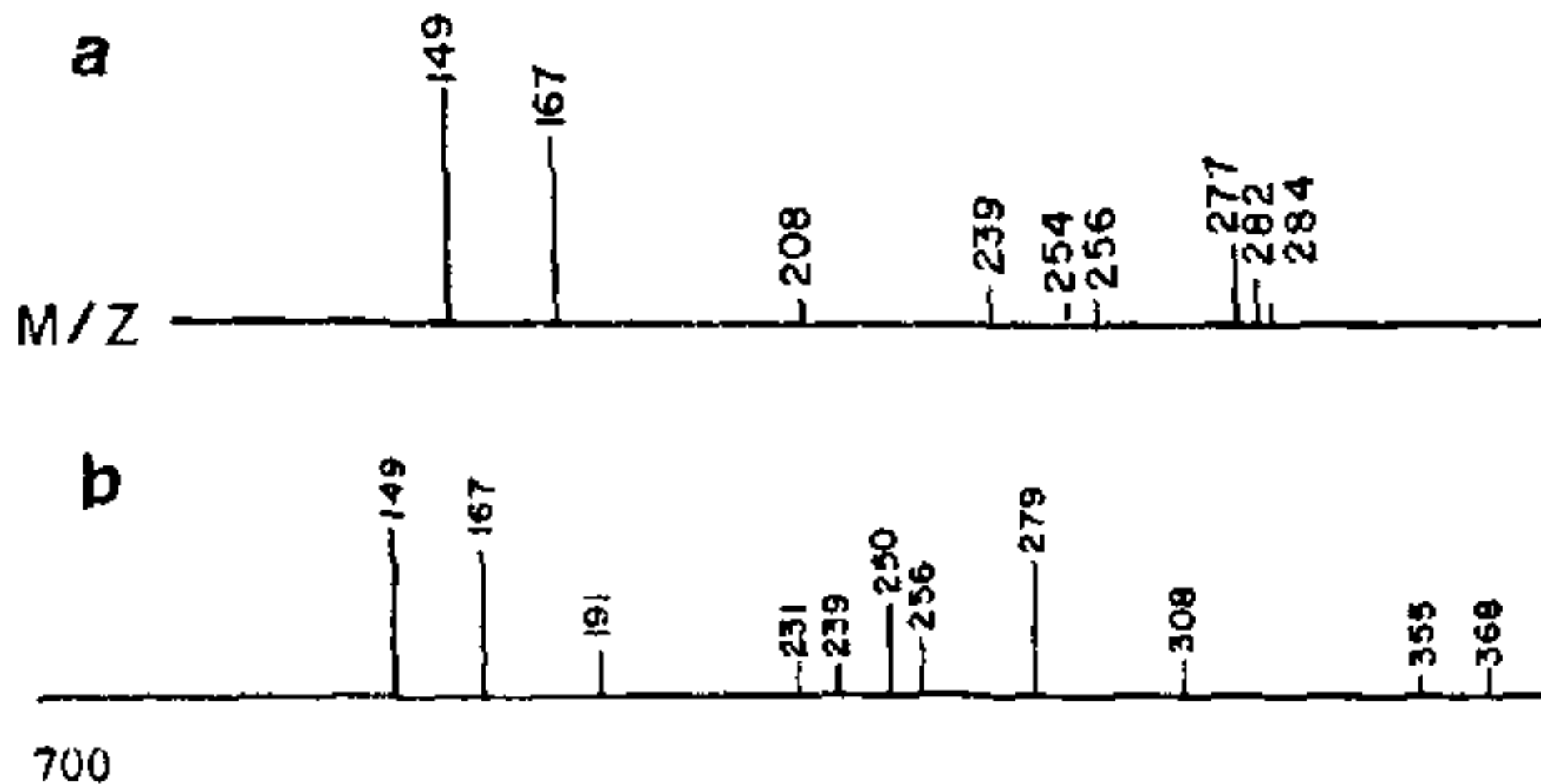


Figure 4. a, TLC response on oleic and palmitic acids and their esters in groundwater samples of Karaikal region with marine bed sediment (Vedaranyam), estuarine sediment (Karaikal) and sea sediment (Karaikal); b, Gas-chromatographic separation of fatty acids in deeper alluvial groundwater (Site Sorakudy).



which showed the presence of hopanoic acid and ingress from the tributaries/estuaries and has a much lower age – all the selected alluvial groundwaters show apparent groundwater ages of the order of 7000–10000 yr, and are characterized by the absence of hopanoic and vaccenic acids and the presence of palmitoleic and oleic acids.

Figure 5. Mass spectra of a, marine bed sediment sample; b, Arasalaru estuarine sediment sample. (M/Z of 254 and 282 represent palmitoleic and oleic acid, respectively, and 191, 231 and 368 represent hopanoic acid)

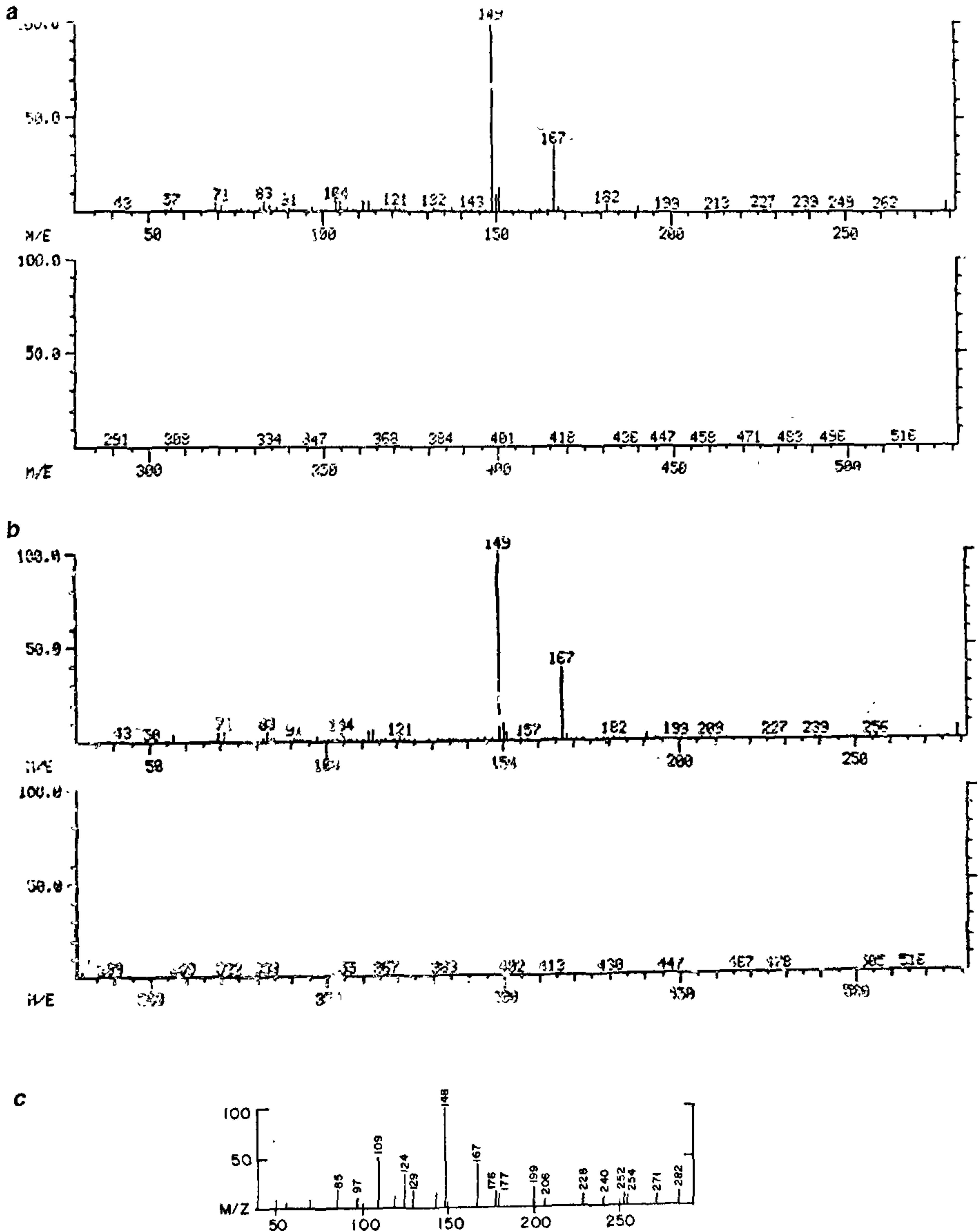


Figure 6. Mass spectra of *a*, Agalancan; *b*, Madur samples; *c*, groundwater sample (Madur; L. Miocene) to investigate the presence of vaccenic acid (pre-treated with methanol/bromine).

Table 1. Tritium and radiocarbon data of sampled wells of Karaikal region

Sample code	Location	Per cent modern carbon	Uncorrected ¹⁴ C ages	Tritium units
Lower Miocene				
K-8	Ambagarthur	2.19 ± 1.41	31,604 ± 6355 yr	≤ 5
K-9	Thirunallaru	0.66 ± 1.38	≥ 32000 yr	≤ 5
K-10	Polagam	0.600 ± 1.38	≥ 32000 yr	≤ 5
K-11	Vanjore	4.41 ± 1.43	25813 ± 2775 yr	≤ 5
K-12	Kannapur	2.58 ± 1.42	30252 ± 5016 yr	≤ 5
K-17	Agaram Kurumbagarm	3.09 ± 1.32	28748 ± 3788 yr	≤ 5
K-18	Kakamozhi	1.60 ± 1.16	≥ 32000 yr	≤ 5
K-21	Sethur	3.43 ± 1.37	27887 ± 3486 yr	≤ 5
K-20	Thennangudy	2.28 ± 1.41	31245 ± 5979 yr	≤ 5
K-23	Mathalangudy	7.03 ± 1.38	21948 ± 1648 yr	≤ 5
Deeper alluvium				
K-4	Agalancan	62.64 ± 1.73	3867 ± 228 yr	--
K-15	Sorakudy	29.35 ± 1.33	10134 ± 1375 yr	--
K-16	Annavasal	42.92 ± 1.63	6993 ± 314 yr	--
K-19	Vadamattam	41.22 ± 1.62	7328 ± 325 yr	--

Table 2. Iodide and chloride values of Karaikal groundwaters

Well no. and site	I (µg/l)	Cl (mg/l)	I/Cl
Seawater	50	18000	2.8 × 10 ⁻⁶
Arasalaru estuary	240	19100	1.3 × 10 ⁻⁶
K-18; Kakamozhi (LM)	106	372	2.85 × 10 ⁻⁴
K-14; Vadamattam (LM)	120	481	2.49 × 10 ⁻⁴
K-2; Pettai (DA)	130	2470	5.26 × 10 ⁻⁴
K-7; Madur (DA)	120	208	4.28 × 10 ⁻⁴
K-15; Sorakudy (DA)	112	540	2.07 × 10 ⁻⁴
K-8; Ambagarthur (LA)	115	257	4.36 × 10 ⁻⁴
K-17; Agaram Kurmbaram (LM)	90	163	5.53 × 10 ⁻⁴
K-11; Vanjore (LM)	109	418	2.63 × 10 ⁻⁴
K-13; Melkottucherry (DA)	122	770	1.58 × 10 ⁻⁴
K-4; Agalancan (DA)	96	315	3.00 × 10 ⁻⁴

LM, Lower Miocene; DA, Deeper alluvium.

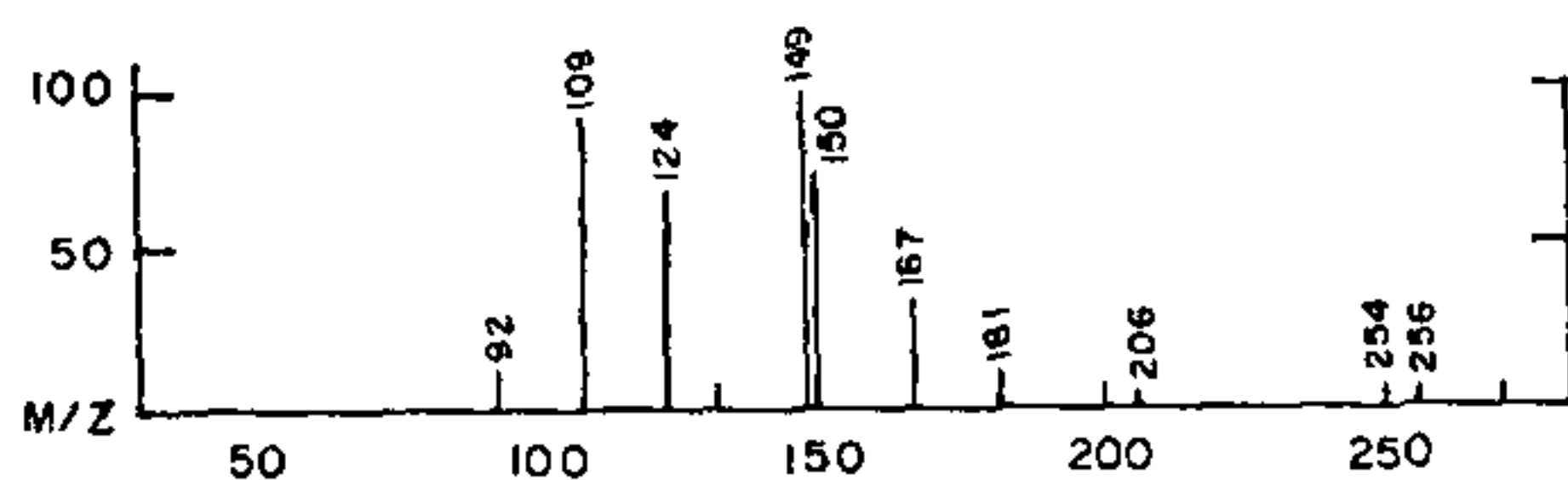


Figure 7. Mass spectra of marine bed sediment pre-treated with methanol bromine shows the absence of vaccenic acid.

It is concluded that certain organic geochemical biomarkers such as triterpanoic and monoenoic acids, viz. hopanoic and vaccenic acids, which are present in the modern estuarine and surface marine sediment material

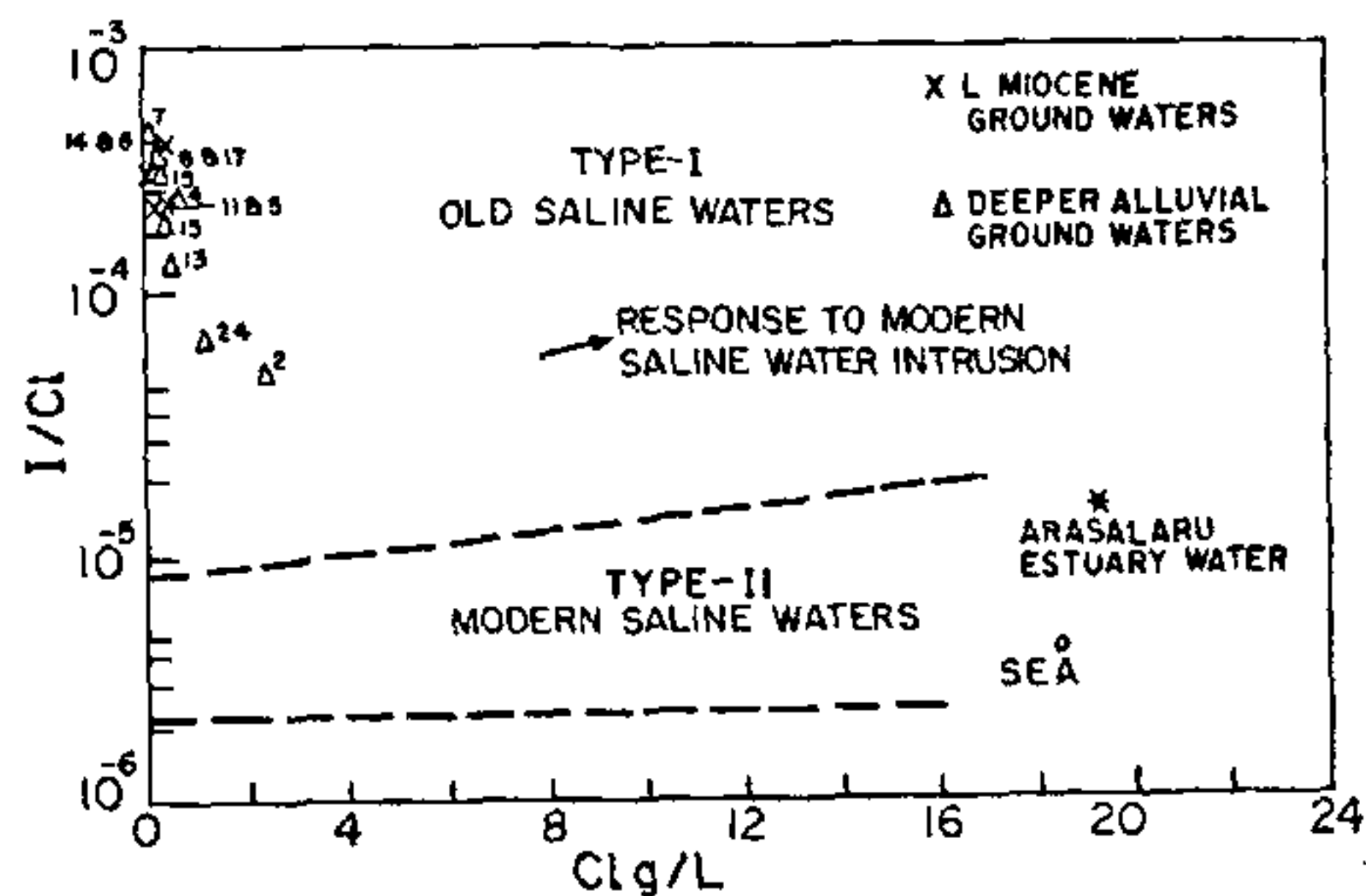


Figure 8. Characterization of groundwater salinities of Karaikal region aquifers using iodide-chloride chemistry.

can be employed in identifying the origin of modern marine salinity intrusion in groundwaters. Further, their absence accompanied by the presence of palmitoleic and oleic acids can be exploited to identify the palaeomarine intrusions. These findings are supported by *I/Cl* ratio as well as by radiocarbon ages.

1. Gat, J. and Gonfiantini, R., IAEA Tech. Report Series, Vienna, 1981, vol. 210, pp. 24-334.
2. Brassel, S. C. and Eglinton, G., *Org. Mar. Geochem.*, 1986, 2, 24.
3. Hostettler, F. D., Rapp, J. B., Kven, K. A. and Luoma, S. N., *Geochim. Coschim. Acta*, 1989, 53, 1563-1576.
4. Blumer, M. and Cooper, W. J., *Science*, 1967, 158, 1463-1464.
5. Van Vleet, E. S. and Quinn, J. G., *Nature*, 1976, 262, 126-128.
6. Gillian, F. T., Johns, R. B., Verheyen, T. V. and Nichols, P. D., *Adv. Org. Geochem.*, 1983, pp. 198-206.
7. Reed, E. W., *Geochim. Coschim. Acta*, 1977, 41, 241-247.
8. Douglas Waples, *Organic Geochemistry for Exploration Geologists*, Human Resources Dev. Corp'n, Boston, 1982, pp. 7-10 & 87.
9. Natarajan, P. and Sankaran, M., Central Groundwater Board Tech. Report, 1980, 6, 10-14.
10. Folich, V., *Gen. Biol. Chem.*, 1957, 226, 497.
11. Jeffrey, L. M., Pasby, B. F., Stevenson, B. and Hood, D. W., *Adv. Org. Geochem.*, Pergamon Press, Oxford, 1964, 15, 189.
12. Brassel, S. C., Gowar, A. P. and Eglinton, G., *Adv. Org. Geochem.*, Douglas, Pergamon Press, Oxford, 1979, 12, 422.
13. Shantha, N. C. and Kaimal, T. N. B., *Lipids*, 1984, 19, 971-974.
14. Chave, K. E., *Geochemistry of Water*, Halsted Press, USA, 1978, pp. 297-310.
15. Rao, S. M., Jain, S. K., Navada, S. V., Nair, A. R. and Shivanna, K., *Isotope Techniques in Water Resources Development*, IAEA, Vienna, 1987, SM-299/76, pp. 403-425.
16. Lloyd, J. W., Howard, K. W. F., Pacey, N. R. and Fellam, J. H., *J. Hydrol.*, 1982, 57, 247-265.
17. Evans, D., Lloyd, J. W. and Howard, K. W. F., *Hydrogeology of Salt Water Intrusion*, IAH-SWIM papers, GambH & Co, Hannover, 1991, vol. 11, pp. 79-94.
18. Sukhija, B. S., *Geophys. Res. Bull. (India)*, spl. vol., 1982, 20, 225-242.

ACKNOWLEDGEMENTS. We thank Dr Harsh K. Gupta, Director, NGRI, for his interest; the Director of Agriculture, Pondicherry, for permitting V. N. V. for pursuing studies at NGRI; Dr Kaimal, IICT, for chromatographic measurements; Dr Sivakumar and Mrs. Kamala, National Institute of Nutrition, for iodide analyses; Mr P. Natarajan for providing information on hydrogeology; Dr D. V. Reddy and Sri P. Nagabhushanam, NGRI, in preparation of the paper.

Received 15 September 1992; revised accepted 15 May 1993

Availability of photosynthetically active radiation in Antarctica

A. B. Dhaulakhandi, R. P. Joshi and M. C. Joshi

Defence Agricultural Research Laboratory, Post Box 40,
Haldwani 263 139, India

We report here the photosynthetically active radiation (PAR) variations at Antarctica (latitude 70°S)

for the year 1991. The variations in PAR are intense in Antarctica, because of its unique polar position and weather conditions. We present here the data on clear day PAR variations at Maitri station and inside the greenhouse at Maitri station, collected during the 10th Indian Scientific Expedition to Antarctica (1990-92) for one full year. The peak levels occurred at the local noon at 11 h (GMT). The peak level at Maitri station was 89.28 klux in December, followed by 86.17 klux in January. The PAR was zero in June and July. The peak level inside the greenhouse was 50 klux in December. The PAR levels were almost symmetric with respect to the mid-point of the year. The PAR decreases from January to June and then increases from August to December.

ANTARCTICA is an isolated glacial continent having an area of 14 million km². Only 2% of this area is free from ice. The region experiences the most adverse environmental conditions, the average temperature ranging from 0.4°C in summer to -40°C in winter. The Antarctic climate is characterized by strong blizzards, high albedo and six-month-long night and day with increased UV radiation. Antarctica receives lesser amounts of solar radiation because of its polar position; however, the daily total radiative energy received during summer at the south pole is about the same as that received in equatorial regions¹.

Increased scientific activity in the continent and the prolonged stay of scientists initiated experiments on growing plants for fresh food²⁻⁵. The studies on Antarctic flora and Polar Horticulture stimulated the collection of data on photosynthetically active radiation (PAR)⁶. The information presented here includes the clear-day averaged data collected during the 10th Indian Scientific Expedition to Antarctica.

The study was conducted at Maitri station (latitude 70°45'39.4", longitude 11°44'48.6"). Luxmeters and a

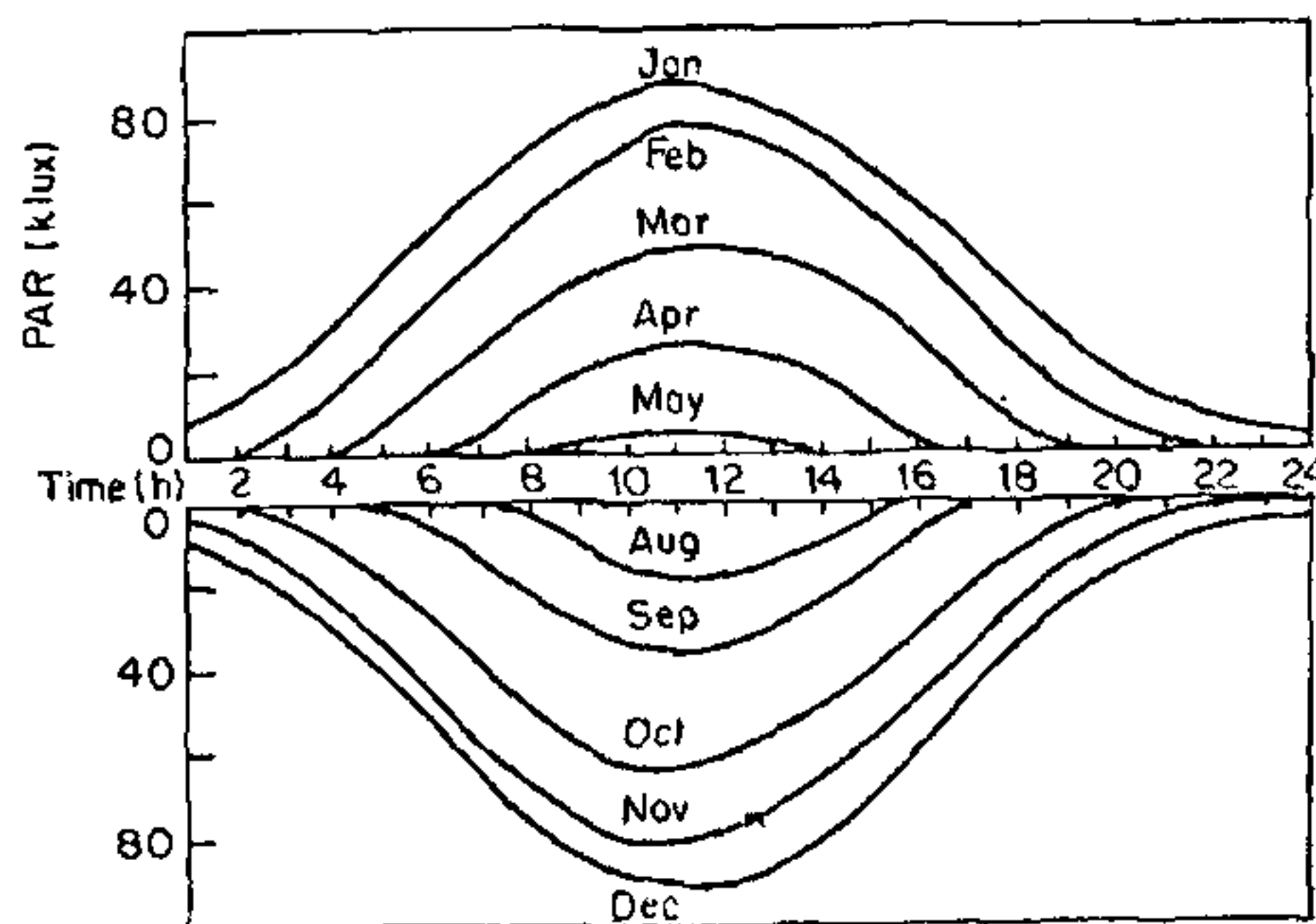


Figure 1. PAR in Antarctica (at Maitri station).