Palynological indicators of mangrove habitat in the Kolleru Lake region during the Early to Middle Holocene

A. Bhattacharyya[1,*], K. Nageswara Rao[2], S. Misra[1], K. Ch. V. Nagakumar[2], G. Demudu[2] and B. Hema Malini[3]

[1]Birbal Sahni Institute of Palaeobotany, Lucknow 226 007, India
[2]Department of Geo-Engineering, and
[3]Department of Geography, Andhra University, Visakhapatnam 530 003, India

Auger drilling up to about 10–12 m depth at four locations in the periphery of the Kolleru Lake revealed three sediment units – upper coastal alluvium (Unit 3), middle black sticky clay with decomposed plant material (Unit 2) and lower yellow amorphous clay with concretions and dark brown hard clay with gypsum crystals (Unit 1). Palynological analysis and ^{14}C dating of sediments revealed prevalence of mangrove pollen in Unit 2 during 10,842–6,068 cal yrs BP. Subsequently, absence of mangrove pollen and presence of charcoal pieces in Unit 3 indicate terrigenous inputs into the area thereafter. The study reports on the possible occurrence of mangrove habitat in the Kolleru Lake region during the Early to Mid-Holocene.

Keywords: Mangrove, palynology, palaeoclimate, sediment units.

KOLLERU is the largest freshwater lake situated between the two major river deltas of the Godavari and Krishna in the tropical environment along the east coast of India (Figure 1). The lake is a shallow wetland with its depth ranging between 0.5 and 2.0 m in summer, covering an area of about 245 sq. km. Kolleru was designated as a wetland of international significance under the Ramsar Convention[1], serving as a flood-balancing reservoir and a haven for many species of resident and migratory birds[2,3] over an area of about 910 sq. km. Although the origin of the Kolleru Lake is not clearly known, earlier studies based on the identification of relict sandy beach ridges and dating of fossil shells in the area suggested that the shoreline of Mid-Holocene age was right up to the lake, thereby indicating that the Lake was perhaps formed as a coastal lagoon[3–6]. The present palynological study of the shallow subsurface sediments in the Kolleru Lake region is aimed at finding pollen/spore content of halophytic vegetation, which might serve as a proxy evidence for understanding possible occurrence of a brackish water body in the past.

Shallow subsurface sediments are recovered through boreholes drilled at four sites, viz. Prattipadu (PP), Mahileswaramu (MW), Pedda Nindrakolanu (PN) and Ramayagudem (RG) located outside the present water-spread area of the Kolleru Lake (Figure 1). The geographic coordinates (latitudes and longitudes) and approximate elevations of the drill sites were estimated using a hand-held GPS instrument and topographic maps (Table 1). Borehole drilling up to a depth of 9.5 m at PP, 12.5 m at MW, 11.0 m at PN and 12.0 m at RG was carried out using an auger that was manually rotated with simultaneous pushing. The auger was pulled out at 0.5 m depth intervals and bulk samples were collected from the bottom of the spiral head of the auger. Based on the nature of the sediment thus recovered, three broad sediment units are noted at all the four sites (Figure 2). The upper light-coloured sandy silty clay (Unit 3) appears to be a part of the fluvial plain seen to the immediate northern, eastern and western sides of the area (fine sandy beach ridge plain fringes the southern, i.e. seaward margin of the Lake). The thickness of Unit 3 is variable between 1.1 and 2.5 m at the four locations (Figure 2). Unit 2 forming the middle part of the borehole sections comprises black sticky clay with abundant decomposed plant material and shell fragments. The sediment of this unit is akin to that of the present lake bed. The thickness of this unit is about 6.0 m at PP, 4.5 m at MW, 4.0 m at PN and 7.5 m at RG (Figure 2). The lower Unit 1, characterized by yellow amorphous clay with concretions and light to dark brown hard clay with gypsum crystals, appears to have been subjected to surficial weathering under dry conditions prior to the deposition of the overlying sediment Units 2 and 3.

Eleven samples from Unit 2 (two from PP, three from MW, two from PN and four from RG site) were dated by ^{14}C method at Birbal Sahni Institute of Paleobotany (BSIP), Lucknow. All the eleven radiocarbon dates were calibrated according to CALIB v.6.0. The ages referred to in this study are average values of the calibrated time intervals at 2σ range. These dated subsurface sediments from Unit 2 and the sediments that have been picked up from the surface (Unit 3) of the four borehole locations have been processed for pollen analysis following the standard procedure for separation of spore/pollen from the sediment[7,8], i.e. by treating the material with mild alkali (10% potassium hydroxide), 40% hydrofluoric acid, followed by acetolysis (9 : 1 acetic anhydride and sulphuric acid) to eliminate humic and silici-clastic components and for clarity of spore/pollen structure respectively.

The recovered pollen from both the upper and the middle units of the sediment (Figure 3) was identified by comparing them with the pollen slides of the common coastal plants available at the BSIP herbarium and also by comparing with published photographs of pollen of many mangrove taxa[9]. Ecology of diversified mangrove taxa is noted from the literature[10,11]. Palynomorphs identified were counted and quantitatively analysed using TILIA software. To avoid over representation of spore/pollen of

*For correspondence. (e-mail: amalava@yahoo.com)

Table 1. Location details of boreholes from the Kolleru Lake periphery

Borehole location	Latitude (N)	Longitude (E)	Approximate elevation (m)	Drilling depth (m)	Drilling period
Prattipadu	16°32′44.77″	81°10′12.03″	+4.4	9.5	April 2010
Mahileswaramu	16°37′23.96″	81°08′27.18″	+3.1	12.5	April 2010
Pedda Nindrakolanu	16°43′40.58″	81°23′00.97″	+3.0	11.0	April 2010
Ramayagudem	16°38′48.26″	81°22′08.05″	+2.6	12.0	April 2010

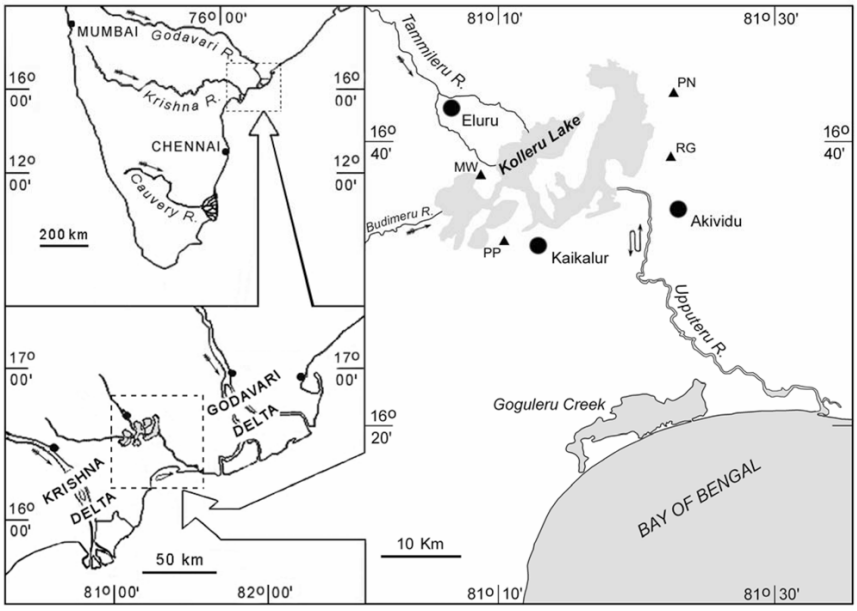

Figure 1. Location of the Kolleru Lake between the Krishna and Godavari deltas. The four black triangles indicate the location of the shallow borehole sites around the lake. PN, Pedda Nindrakolanu; RG, Ramayagudem; PP, Prattipadu; MW, Mahileswaramu.

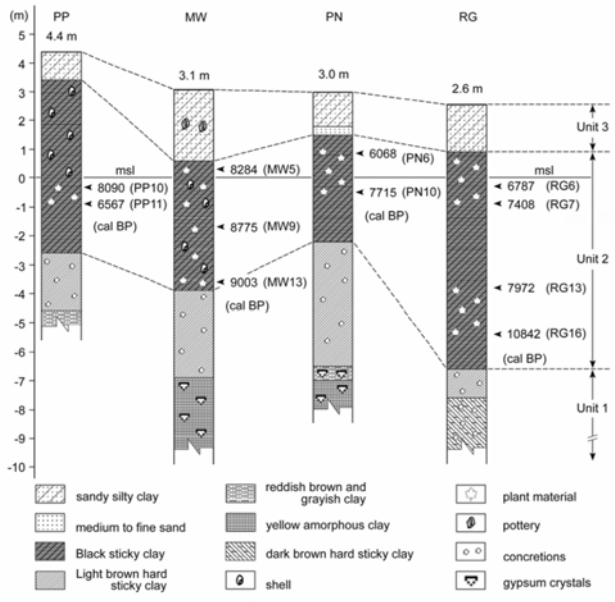

Figure 2. Borehole log sections showing the relative positions of the dated samples which have also been analysed for pollen content.

aquatics, ferns and algal elements which may mask the presence of other types in the pollen diagram, were excluded from the total pollen/spore count while estimating the sum of the pollen. Percentages of pollen from the mangrove and other plants are calculated from this total, whereas aquatic taxa, ferns and algal spores are calculated in relation to total pollen count. Pollen spectra for the sediments of Units 2 and 3 are shown in the pollen diagram, i.e. Figure 4. Samples without any spore/pollen are categorized as 'barren' in the diagram.

Two of the four surface samples (Unit 3), MW1 and PN1, are devoid of pollen grains but revealed only charcoal pieces, whereas the other two surface samples, PP1 and RG1, have yielded spore/pollen of Poaceae, Arecaceae, monolete and trilete fern along with fungal remains of *Alternaria*. In addition, some Theca amoebians and Pseudoschizaea (smooth-walled) cysts were also observed from these samples.

However, the subsurface sediments from the middle units (Unit 2) of all the four sites revealed abundant mangrove pollen. Around 10,842 cal yrs BP (RG16), high percentage representation of core mangrove, viz. species of *Rhizophora*, *Ceriops*, *Bruguiera* along with *Heritiera* sp. indicated that much of the area in the vicinity of RG site was perhaps covered by mangroves around that time. This phase may correspond to the extensive distribution of mangroves associated with the intensification of southwest monsoon[12,13], rapid melting of Himalayan glaciers and sea-level rise[14] in early Holocene. Subsequently, the period between 9003 and 8775 cal yrs BP seems to be

Figure 3. Pollen of core and peripheral mangroves along with algal and fungal remains recovered from the sediments around the Kolleru Lake. A, B, *Avicennia marina*; C, *Kandelia candel*; D, E, Cheno/Ams; F, Poaceae; H, I, *Acanthus*; J, Q, *Kandelia candel*; K, *Avicennia bicolor*; L, *Rhizophora mucronata*; G, M, N, *R. apiculata*; O, *Bruguiera cylindrica*; P, *Ceriops decandra*; R, *Rhizophora lamackii*; S, Dillenia; T, U, Fern spore; V, *Cosmarium*; W1, *Pseudoschizaea* (corrugated form); W2, *Pseudoschizaea* (smooth form); X, Foraminiferal lining; A1–A25, Fungal remains.

unfavourable for the mangroves in the area, especially on the landward side of the lake as represented by MW site. Similar situation has also been recorded from Sundarban Biosphere in the Ganga–Brahmaputra Delta[15]. Mangroves at MW5 (8284 cal yrs BP) were represented by *Avicennia marina* (4.17%), *Avicennia alba* (1.67%), *Kandelia candel* (2.50%), whereas non-mangrove taxa were represented by Cheno/Ams (9.17%), Poaceae < 40 μm (11.67–13.33%) and > 40 μm (7.50%) and *Cosmarium* (59.17%). Around 8090 cal yrs BP several mangroves flourished, viz. species of *Rhizophora* along with *Bruguiera gymnorhiza*, *Ceriops decandra* and *Kandelia candel*, besides other plants belonging to Cheno/Ams and Poaceae. The period during 7972–7715 cal yrs BP was also favourable for the growth of *Rhizophora*, *Avicennia* spp., *Ceriops decandra* and *Bruguiera cylindrica*. Subsequently though, the *Rhizophora* spp. had declined around 7408 cal yrs BP the other taxa, viz. *C. decandra* and *Avicennia* spp. increased at RG7. Later sediments are found devoid of mangrove pollen in some locations represented by the sample RG6 (6787 cal yrs BP), which showed only charcoal pieces as in modern sediments. On the other hand, PP11 (6567 cal yrs BP) and PN6 (6068 cal yrs BP) yielded pollen grains of diversified mangrove taxa. Spatial variation in the spread of mangrove in the area is also notable as the MW site showed presence of very few of its pollen,

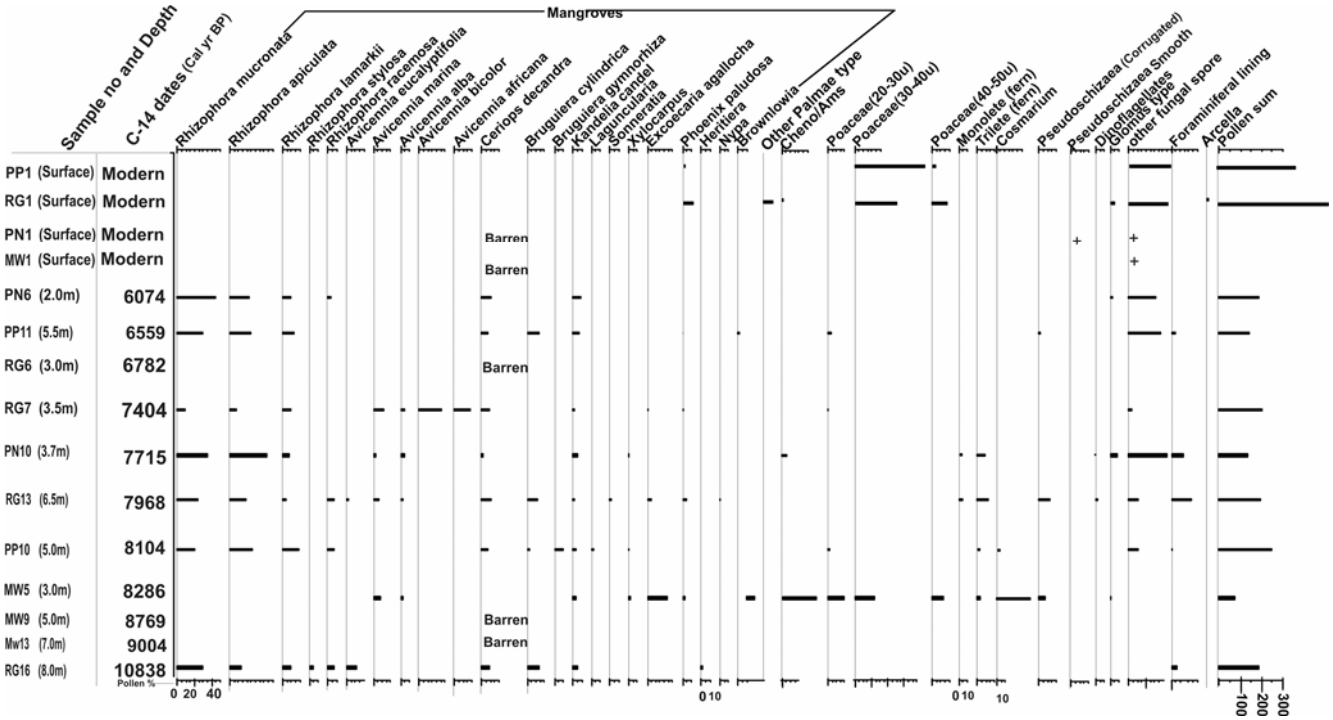

Figure 4. Pollen diagram comprising pollen spectra of both surface (modern) and ^{14}C-dated subsurface sediments collected from the four boreholes outside the present water-spread area of the Kolleru Lake.

that too only in MW5 sample (8284 cal yrs BP), unlike at the other three sites which are closer to the seaward margin of the lake.

Further, in the sediments of the upper unit in the area, Pseudoschizaea cysts are found with smooth walls, whereas in the middle unit these cysts which are dated 8090–6567 cal. yrs BP have corrugated walls. Generally, the species with corrugated walls indicate brackish water environment, whereas those with smooth walls suggest freshwater environment[16–18]. This also supports the inference that brackish conditions favourable for the growth of mangroves prevailed in the Kolleru Lake area during the Early to Mid-Holocene.

A number of studies revealed the occurrence of mangroves from different parts of the Indian coast. An analysis of mangrove history of the Pulicat Lake (a coastal lagoon on the east coast of India at the southern end of Andhra Pradesh state) indicated that mangroves flourished at about 6650 yrs BP, whereas the periods around 3100–2799 and 2599–2250 yrs BP were found unfavourable for mangroves[19]. Further north of the Pulicat Lake, in the 2000–1500 yrs BP (ref. 20) shallow subsurface sediments of Iskapalli lagoon that fringes the coast in the Penner delta, presence of mangrove pollen has been recognized. From Bengal Basin, reports indicated occurrence of a good mangrove cover around 6500 yrs BP (ref. 21). Studies from the western part of the Sundarban Biosphere in the Ganga–Brahmaputra Delta revealed that the mangroves flourished during the early Holocene (9980 cal yrs BP). They disappeared ca. 9240 cal yrs BP, but reappeared by 7560 cal yrs BP. Around 4800 cal yrs BP the intertidal habitat was largely favourable for mangroves in the Sundarbans[22]. In and around the Chilika Lake, Odisha, the favourable period of luxuriant mangroves was found to be during 9500–7500 yrs BP, whereas decline of mangroves was recorded around 2000 yrs BP (ref. 23). From the west coast of India, the history of mangroves goes back to the late Pleistocene, where mangroves flourished around 40,000–28,000 yrs BP, decreased during 22,000–18,000 yrs BP, attained their optimal growth during 11,000 yrs BP and became scarce during 5000–4000 yrs BP (ref. 24). An earlier study on the marine sediments of southwest coast revealed that during the time-span of 20,000 yrs BP, the mangroves proliferation was maximum around 11,000 yrs BP when the SW monsoon was vigorous[25].

In the light of the widespread occurrence of mangrove pollen from different coastal sediments around the Indian coastal region, the presence of abundant mangrove pollen in the subsurface sediments of Kolleru Lake region may be considered to indicate prevalence of mangrove habitat in the region during the Early to Mid-Holocene. Occurrence of mangrove pollen in the sediment approximately 7.0 m below the present sea level (e.g. at RG 16) indicates a possible intertidal environment at that level. However, the available data are not sufficient to ascertain whether the sea level was lower than present during the Early to Mid-Holocene, or there was post-depositional subsidence that led to vertical stacking of sediment in the area.

The presence of abundant mangrove pollen and Pseudoschizaea cysts with corrugated walls in the peripheral

parts of the Kolleru Lake suggests the probable existence of a larger brackish water body in the region during the Early to Mid Holocene. Obviously, with the diminishing marine influence due to the seaward shift of the shoreline and continued inflows through Tammileru and Budimeru rivers, the Kolleru Lake region has become a freshwater zone.

The present study reports on the existence of mangrove vegetation in the Kolleru Lake region, strengthening the earlier inferences on the existence of a back-barrier coastal lagoon when the shoreline was right up to the southern (seaward) margin of the lake. However, the present study is insufficient to understand the origin of the Kolleru Lake. Further systematic studies based on analysis of continuous undisturbed core sediments from the region are necessary to unravel the palaeoclimatic and palaeoenvironmental history of the Kolleru Lake vis-à-vis Holocene sea-level changes and tectonic subsidence, if any, in the region.

1. Anon., International Conference on the Conservation of Wetlands and Waterfowl, Ramsar, Iran, 30 January–3 February 1971.
2. Pattanaik, C., Prasad, S. N., Nagabhatla, N. and Finlayson, C. M., Kolleru regains its grandeur. *Curr. Sci*., 2008, **94**, 9–10.
3. Nageswara Rao, K., Krishna, G. M. and Hema Malini, B., Kolleru lake is vanishing – a revelation through digital processing of IRS-ID LISS-III sensor data. *Curr. Sci*., 2004, **86**, 1312–1316.
4. Nageswara Rao, K., Evolution of landforms in the area between the Krishna and Godavari deltas. *Indian Geogr. J*., 1985, **60**, 30–36.
5. Sadakata, N. and Nageswara Rao, K., Radiocarbon ages of the subsurface sediments in the Krishna delta and their geomorphological implications. *Q. J. Geogr.*, 1997, **49**, 163–170.
6. Nageswara Rao, K., Nagakumar, K. Ch. V., Subraelu, P., Demudu, G., Reddy, B. V. and Hema Malini, B., Kolleru Lake revisited: the post 'Operation Kolleru' scenario. *Curr. Sci*., 2010, **98**, 1289–1291.
7. Fageri, K. and Iversen, J., *Text Book of Pollen Analysis*, Munksgaard, Copenhagen, Denmark, 1975.
8. Moore, P. D., Webb, J. A. and Collinson, M. E., *Pollen Analysis*, Oxford Blackwell Scientific Publications, 1991.
9. Thanikaimoni, G., *Mangrove Palynology*, Travaux de la section Scientifique et Technique, French Institute of Pondicherry, Puducherry, 1987.
10. Kumudranjan, N. and Mandal, R., *Ecology and Biodiversity of Indian Mangroves, Part I & Part II, Global Status*, Daya Publishing House, Delhi, 1999.
11. Mandal, R. N. and Naskar, K. R., Diversity and classification of Indian mangroves: a review. *Trop. Ecol*., 2008, **49**, 113–146.
12. Prell, W. L., Marvil, R. E. and Luther, M. E., Variability in upwelling fields in the northwestern Indian Ocean: data-model comparison at 9000 year BP. *Palaeoceanography*, 1990, **5**, 447–457.
13. Naidu, P. D. and Malmgren, B. A., A high-resolution record of Late Quaternary upwelling along the Oman Margin, Arabian Sea based on planktonic foraminifera. *Palaeoceanography*, 1996, **11**, 129–140.
14. Fairbanks, R. G., A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature*, 1989, **342**, 637–642.
15. Sen, N. and Kumudranjan, N., *Algal Flora of Sundarban Mangals*, Daya Publishing House, Delhi, 2003, pp. 134–135.
16. Carrión, J. S. and Navarro, C., Cryptogam spores and other non-pollen microfossils as sources of palaeoecological information: case-studies from Spain. *Ann. Bot. Fenn.*, 2002, **39**, 1–14.
17. Davis, O. K., Rapid climatic change in coastal southern California inferred from pollen analysis of San Joaquin marsh. *Quaternary Res*., 1992, **37**, 89–100.
18. Sen, P. K. and Banerjee, M., Palyno-plankton stratigraphy and environmental changes during the Holocene in the Bengal Basin, India. *Rev. Palaeobot. Palynol.*, 1990, **65**, 25–35.
19. Farooqui, A. and Vaiz, G. G., Holocene sea level and climatic fluctuations: Pulicat lagoon – a case study. *Curr. Sci*., 2000, **79**, 1484–1488.
20. Seetharamaiah, J., Farooqui, A., Suryabhagavan, K. V. and Nageswara Rao, K., Evolution of Iskapalli lagoon in Penner delta region, east coast of India – a sedimentological and palynological approach. *Indian J. Mar. Sci.*, 2005, **34**, 267–273.
21. Barui, N. C., Floral diversity of mangrove plants with reference to palaeoenvironment during Holocene in Bengal Basin, India. *Quat. Int*., 2011, **229**, 89–93.
22. Halit, A. K. and Behling, H., Holocene mangrove and coastal environment changes in the western Ganga–Brahmaputra Delta, India. *Veg. Hist. Archaeobot.*, 2008, **18**, 159–169.
23. Khandelwal, A., Mohanti, M., Rodriguez, F. G. and Scharf, B. W., Vegetation history and sea level variation during the last 13,500 years inferred from a pollen at Chilka Lake, Orissa, India. *Veg. Hist. Archaeobot.*, 2006, **17**, 335–344.
24. Kumaran, K. P. N., Nair, K. M., Shindikar, M., Limaye, R. B. and Padmalal, D., Stratigraphical and palynological appraisal of the Late Quaternary mangrove deposits of the west coast of India. *Quaternary Res.*, 2006, **64**, 418–431.
25. Van Campo, E., Monsoon fluctuation in two 20,000-yr BP oxygen-isotope/pollen records off Southwest India. *Quaternary Res*., 1986, **26**, 376–388.

ACKNOWLEDGEMENTS. We thank the Department of Science and Technology, New Delhi for financial support through a multi-disciplinary and multi-institutional research project (NRDMS/11/1174/06), of which the work embodied in this paper pertains to the sub-project #2. We also thank Dr N. C. Mehrotra, Director, BSIP, Lucknow for providing the necessary facilities and Prof. P. Rajendraprasad, Andhra University, Visakhapatnam for support and encouragement. A.B. and S.M. thank ISRO–IGB for financial support.

Received 4 November 2011; revised accepted 20 November 2012