

***Gallitellia* – a proxy for palaeo-monsoonal upwelling on the western coast of India?**

Anupam Ghosh^{1,*}, Sourav Saha²,
Pratul Kumar Saraswati¹, Santanu Banerjee¹,
Stuart Burley³ and T. K. Gundu Rao⁴

¹Department of Earth Sciences, and

⁴Sophisticated Analytical Instrument Facility,

Indian Institute of Technology Bombay, Mumbai 400 076, India

²BG India, BG House, Hiranandani Gardens, Mumbai 400 076, India

³Cairn Energy (India), 4th Floor, Vipul Plaza, Sun City,
Gurgaon 112 002, India

A planktonic foraminifer, *Gallitellia vivans*, has been recorded in the Quaternary sediments exposed in the Gulf of Cambay. Its occurrence in the sediments dated ~50 ka and ~125 ka respectively, is identical to peak occurrence of monsoon upwelling indicator, *Globigerina bulloides* in the Arabian Sea and the continental record of monsoon enhancement in Mahi and Narmada estuaries. The species is known as a tracer of high run-off, environmentally unstable and upwelling conditions. The study suggests the possibility of using *G. vivans* as monsoon tracer, similar to the well-established biological proxy *G. bulloides*.

Keywords: *Gallitellia vivans*, *Globigerina bulloides*, monsoon tracer, palaeoenvironment, upwelling.

COASTAL upwelling is a dynamic process involving the interaction of atmospheric circulation with the ocean surface and continental boundaries. It is most common during the monsoons that are strongest over the western part of Indian Ocean and the Arabian Sea. Reports of greater abundance of planktonic foraminifer *Globigerina bulloides* coincide with the spatial variation of upwelling along the western continental margin of India^{1,2}. The species is therefore a standard proxy of monsoonal upwelling in the geologic past. The present-day estuarine sediments of the Gulf of Cambay, lying in the active monsoonal zone, contain tide-drifted planktonic foraminifer, *Gallitellia vivans*. The species is a surface-dweller and known to occur characteristically in unstable environments, partially enclosed basins with high run-off and upwelling currents³. Its occurrence in the modern sediments of the Gulf led to the present work to investigate its presence in the Quaternary sediments exposed along the coast, for a possible biological proxy of monsoon and related upwelling.

The Gulf of Cambay is a large macrotidal, estuarine embayment extending northwards inland into southern and western Gujarat, on the west coast of India, for some 350 km (Figure 1). Several major rivers, including the

Sabarmati, Mahi, Narmada and Tapi, meander across the Gujarat plains and bring sediment derived from the Deccan and Aravalli sources to this macrotidal zone. Tides in the gulf are semi-diurnal with a spring tide range of up to 11 m and are the highest in the waters surrounding India⁴. Except during monsoons, large waves are not observed on the sea surface in this region. The study area thus represents a macro-tidal estuary in a high monsoon rainfall and has a high sediment discharge. The coast and deeply incised cliffs along the banks of rivers flanking the estuarine embayment expose Late Pleistocene and Holocene age sediments.

The present study investigates a Quaternary marine sequence exposed at Ambheta (21°40'49"N; 72°35'42"E) in the Narmada estuary. A detailed sampling of the section was done to carry out micropalaeontologic analysis. Particular emphasis was placed on examining the finest fraction (# 63 µm mesh) that usually contains triserial planktonic foraminifer, *Gallitellia*, if present^{5,6}. The ~2.2 m thick section exposed at Ambheta (Figure 2) was divided into four facies association based on lithology, texture, sedimentary structure, geometry and foraminiferal assemblage. At the base a 30 cm thick, planar, laminated, heterolith facies are characterized by millimetre-scale intercalations of organic clay and white-to-grey siltstone. Parallel lamination was the most characteristic sedimentary structure within the facies; unidirectional ripple laminae were found occasionally. Well-preserved species of benthic foraminifera *Ammonia*, *Florilus*, *Quinqueloculina*, *Bolivina*, *Brizalina*, *Cibicides*, *Uvigerina* and *Spiroloculina* were abundant. Associated planktonic foraminifera included *Gallitellia*, *Globigerina* and *Globigerinoides*. Contact with the overlying facies was sharp. The assemblage suggests inner-shelf to mid-shelf deposition. Intensely bioturbated alternation of clay and silt characterized the inclined silt-shale alternation facies overlying the basal unit. The diversity and abundance of foraminifera decreased and planktonic foraminifera become rare towards the upper part of this facies. Bioturbation destroyed the original structures present in the beds, rendering massive appearance to the bed. Vertical burrows which branch out at the bottom were also present. The foraminiferal assemblage of this section suggests shallowing to a marginal marine environment. This was overlain gradationally by shelly siltstone-mudstone facies that comprises of silt/clay alternations at the bottom, which became more clayey towards the top. Shell fragments were evenly distributed within the facies and characterized by the presence of bivalves in their life-mode position. Crude cross-bedding defined by shell fragments was observed in this facies. The lower part of this facies was characterized by *Ammonia*, *Elphidium*, *Quinqueloculina*, *Cibicides* and reworked foraminiferids, indicating shallow inner shelf environment of deposition. Its upper part exhibited higher diversity and abundance of foraminiferal assemblage similar to facies of basal unit, indicat-

*For correspondence. (e-mail: geoanupam@iitb.ac.in)

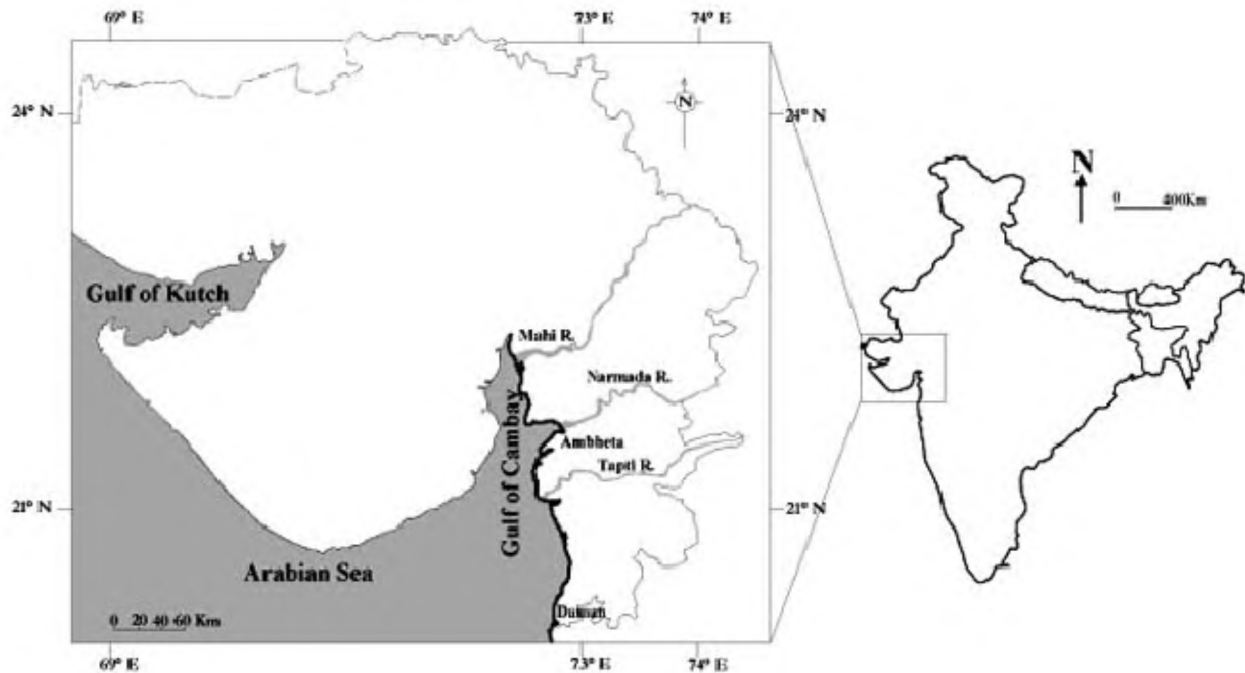


Figure 1. Location map of the study area along the Gulf of Cambay.

ing a deeper inner-shelf to mid-shelf condition of deposition. The top-most part of the section was characterized by silty sand facies. It shows crudely cross-stratification, defined by the shell fragments. The facies was characterized by dominance of silty sands (up to 80%). Low foraminiferal abundance, comprising *Ammonia*, *Elphidium* and *Quinqueloculina* and reworked foraminifera and fragments of molluscs and decapods characterized this facies. Fragments of molluscs and decapods were common to abundant in this unit, representing a marginal marine environment. The molluscan shells of the silty sand facies and shelly siltstone–mudstone facies were dated using the ESR method, which indicated an age of $\sim 30 \pm 10$ and $\sim 90 \pm 10$ ka respectively. Extrapolating these dates, the planar, laminated, heterolith facies thus likely represents the deposit of Last Interglacial sea-level highstand (~ 125 ka).

The Narmada marine clay–silt sequence was interpreted to represent two cycles of relative sea-level rise with palaeo-bathymetry reaching 30–40 m. Peak abundance of *Gallitellia* (Figure 2) was observed at the upper part of the shelly siltstone–mudstone facies (~ 50 ka) and in planar, laminated, heterolith facies (~ 125 ka). *G. vivans* constituted up to 20% of the total foraminifera (TFN) in the planar, laminated, heterolith facies. *G. bulloides* also occurred in this interval, constituting up to 8% of the TFN and $\sim 25\%$ of the total planktonic foraminifera. The next higher abundance of *G. vivans* was in the top part of the shelly siltstone–mudstone facies, where it constituted 5% of the TFN. Similar peak abundances of *G. bulloides*

(an established indicator of monsoonal upwelling) have been recorded at identical age intervals ~ 50 and ~ 125 ka in deep-sea sediment cores from the Arabian Sea⁷. The continental record of the monsoonal activity in the Mahi River⁸, north of the Narmada estuary, also suggests the development of an enhanced monsoon during 30–50 ka, 70–100 ka and 125 ka, consistent with the presence of *Gallitellia* in the Ambheta section as well as chemical proxy Ba/Al palaeoproductivity tracer⁹. A good abundance of *G. vivans* was also recorded⁸ in the Holocene palaeo-mudflats exposed along the Narmada and Mahi rivers, dated as 6 ka. Incidentally, the SW monsoon intensification was at its peak between 10 and 5 ka¹⁰. Although a more detailed geochronology is required to be worked out, the present records of *Gallitellia* broadly correspond to three interglacials, MIS 1, 3 and 5.

Gallitellia, a recent guembelitrinid, was first reported from the surface sediments off Little Ki Island, New Guinea¹¹. Similar reports of *Gallitellia* were documented from the Persian Gulf¹², the Gulf of Mexico, North and South Pacific Ocean and the Indian Ocean¹³. The genus is characterized by minute, thin-walled calcareous test, triserial in nature, distinct chambers, sub-globular, fine perforations and aperture having a small semicircular opening. It dominates the fauna in small-sized fractions of surface sediments of this area. To date published literature on monsoonal upwelling on the western continental margin of India has not reported the presence of this triserial planktonic foraminifer, although it has been earlier recorded from the Indian Ocean in the southern part

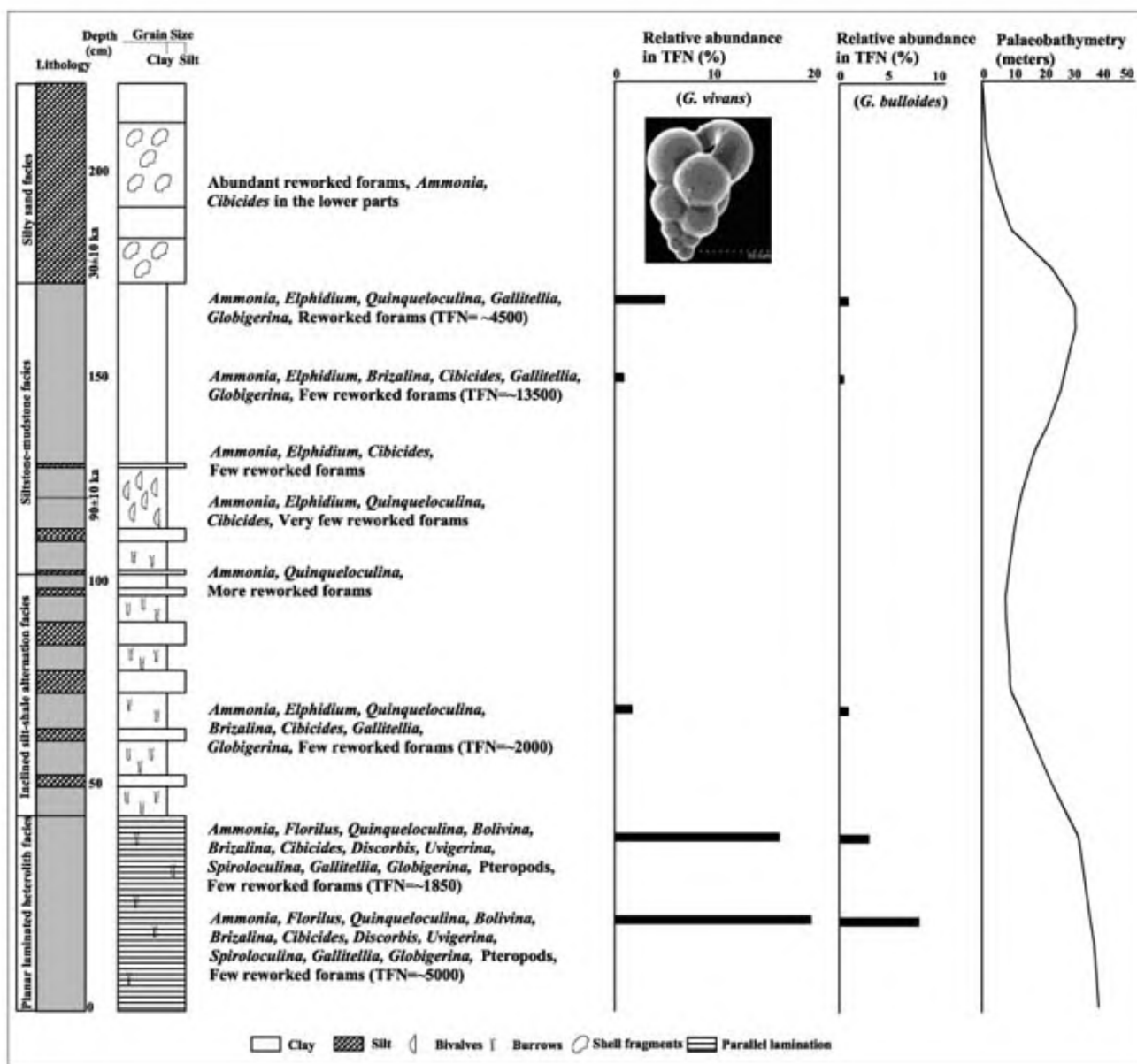


Figure 2. Graphic log of the Ambheta section, Narmada estuary, showing foraminiferal assemblage, the relative abundance of *Gallitellia vivans* and *Globigerina bulloides* in total foraminifera per gram of sediments (TFN) and palaeobathymetry curve. (Inset) SEM image of *G. vivans*.

of India³. This may be due to either the extremely small size (<63 µm) of the genus or its restricted geographic preferences to estuarine embayments.

The living and fossil tri-serial planktonic foraminifera are excellent tracers of environmentally unstable conditions such as shelf and marginal seas with high run-off and upwelling conditions^{3,13}. The occurrence of *G. vivans* in certain Pleistocene intervals of the Gulf of Cambay corroborates the continental records of monsoon in western India, and biological and geochemical proxies of monsoon intensification in the equivalent marine sediments of the Arabian Sea. Thus, *G. vivans*, with its preferred habitat of both high run-off and upwelling conditions, can also

be used as a monsoon tracer, similar to the well-established biological proxy *G. bulloides*.

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First observations of free oscillations of the earth from Indian superconducting gravimeter in Himalaya

B. R. Arora^{1,*}, Kamal², Amit Kumar², Gautam Rawat¹, Naresh Kumar¹ and V. M. Choubey¹

¹Wadia Institute of Himalayan Geology, Dehradun 248 001, India

²Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee 247 667, India

The first Indian superconducting gravimeter (SG) was installed in March 2007 at the Multi-Parametric Geophysical Observatory of the Wadia Institute of Himalayan Geology, in the Himalaya near the Main Central Thrust at Ghuttu, Uttarakhand, India. Almost immediately after installation, the free oscillations excited after the Solomon Islands earthquake ($M = 8.1$) were

well recorded on the SG. The frequency and amplitude of several of these oscillations have been estimated in the present study and compared with the earlier global observations. The results are in tandem with similar studies carried out using a global dataset from the seismometers and SG. The present study validates the quality of the recorded data to search minute (submicrogal) coseismic/precursory gravity signals to large earthquakes and sets the background for future low-frequency seismological research in the country. Some new applications of SG data are also discussed.

Keywords: First observations, free oscillations, Indian superconducting gravimeter.

THE first Indian superconducting gravimeter (SG) was installed at the Multi-Parametric Geophysical Observatory (MPGO) established recently by the Wadia Institute of Himalayan Geology (WIHG), at Ghuttu (30.53°N, 78.74°E), Garhwal Himalayas, Uttarakhand. Set up as a part of the Mission mode project on seismology, the MPGO is designed to study the earthquake precursors in an integrated manner¹. The MPGO is equipped with Overhauser magnetometer, tri-axial fluxgate magnetometer, magnetotelluric, SG, ULF-band induction coil magnetometer, radon data-logger, water-level recorders and is backed by the dense network of broad-band seismometers (BBS) and Global Positioning System (GPS). High-precision equipment have the requisite sensitivities to record characteristic stress-induced perturbations² in magnetization, resistivity and density in the focal zone of the impending earthquake, whereas opening of minor cracks, influx of fluids and material strengthening during the earthquake preparatory cycle can be searched through the distinct space-time patterns in micro-seismicity, seismic wave-velocity alterations, crustal deformation, anomalous electromagnetic and inert gas emission as well as by rapid changes in hydro-dynamical parameters. The first installation of the SG at Ghuttu has been carried out with the ultimate objective of monitoring minute (submicrogal-level) variations in the gravity field of the earth due to small tectonic deformations and/or mass redistribution arising due to strain accumulation in association with the on-going collision between India and Asia, and to study co-seismic/precursory gravity signals, if any, to a large earthquake³.

In principle, the design of the SG-sensing element is similar to an inverted spring-mass system. A small, superconducting spherical mass levitates on the magnetic field of a loop current in a superconducting coil. Any change in gravity, however small, causes a vertical shift in the position of the sphere that can be recorded. The detailed working procedure of the SG can be found in Goodkind⁴. Figure 1 shows the internal structure of the gravity-sensing unit (inset) as well as various components of the SG supplied by M/s GWR, USA. The complete gravity-sensing unit (GSU) that includes superconducting magnets, a niobium sphere, temperature-control circuitry and

*For correspondence. (e-mail: arorabr@wihg.res.in)