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Stable isotopic variations in foraminiferal test from Arabian Sea and its relation to the annual south-west monsoonal rainfall over the Indian subcontinent

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Examination of $\delta^{18}O$ estimations from the planktonic foraminifera, *Globigerinoides ruber* (white variety), collected at fortnightly intervals using deep sea sediment traps moored at depths of 1000 and 2787 m in the eastern Arabian Sea (15° 28′ N and 68° 45′ E) shows very little variation during May to October 1987 — the period of intense southwest monsoon activity over the north Indian Ocean and the adjoining land mass. This implies that the sea surface temperature in this part of the Arabian Sea did not change significantly during the study period. As the monsoonal rainfall of 1987 over the subcontinent was anomalously weak in nature, the above observational finding of low swing in $\delta^{18}O$ values underlines the use of seasonal variability in the planktonic foraminifera as a proxy for the monsoon performance.

THE western Indian Ocean and the marginal sea — Arabian Sea — experience premonsoonal warming and monsoon-induced cooling each year accompanied by a drop in temperature of 3–4°C. This is more so in the equatorial region beginning from the coast of Somalia. Interestingly, events leading to irregularities in this process contribute to drought over the Indian subcontinent. Coastal upwelling, offshore advection, advection of relatively cold waters from the southern hemisphere, strong southwest monsoon winds, etc. are the most important contributors to the overall cooling of waters of the Arabian Sea[1–4].

Due to summer monsoon winds, large scale upwelling and intense vertical mixing take place in the Arabian Sea over different time and spatial scales[5]. During the years of normal monsoonal regime, the cycles of warming and cooling episodes occur in a near periodic way. Departures from this contribute to prevalence of unusual conditions of monsoons over the subcontinent. For example, during the last decade, the years 1980, 1983, 1987 and 1988 (considered as drought years) showed anomalous behaviour in the sea surface temperature (SST) resulting in continuance of the warmer conditions[4].

In the past there have been several attempts to derive statistical correlations between the summer monsoon rains over the Indian subcontinent and SST[6,7]. If any naturally available sensor that either records or carries the signatures of variations in SST exists, one then can make use of it to establish the empirical correlations. The oxygen isotopic ratio $^{18}O/^{16}O$ (expressed as $\delta^{18}O$ in per mil) in the planktonic foraminifera is one such indicator, that reflects the ambient temperature of water in which the foram thrives[8–10]. $\delta^{18}O$ of calcite shows an increase by about 0.25 per mil when the temperature decreases by 1° C (ref. 11). It is, therefore, possible to use the $\delta^{18}O$ content of the surface dwelling foraminifera to make inferences about the sea surface conditions that prevailed during their growth.

Foraminiferal $\delta^{18}O$ studies from the Arabian Sea sediment core samples indicated a reduction in the summer monsoon intensity during the last glacial maximum[12–14]. Prediction of changes over shorter time-scales of one decade or so may not pose any difficulty when changes over thousands of years could be resolved. For example, Chakraborty and Ramesh[15] have examined the possibility of the use of $\delta^{18}O$ and $\delta^{13}C$ contents in the corals from Lakshadweep to detect or to isolate years with climatologically significant events like droughts. They documented low amplitudes of $\delta^{18}O$ during 1987 — a year of drought. Apart from this, one also commonly notices year-to-year changes and their prediction using $\delta^{18}O$ on yearly basis may well be more meaningful. At this stage, the author attempts to address the possibility to document the signature of events of this nature. Here the occurrence of drought in the year 1987, as reflected in the temperature pattern of SST derived from $\delta^{18}O$ in the living foraminifera from the Arabian Sea, has been demonstrated.

The planktonic forams were collected using PARAFLUX Mark VI sediment traps from the eastern Arabian Sea (15° 28′ N, 68° 45′ E). The traps were first deployed in May 1986, and recovered and redeployed

Table 1. Isotopic data for the Eastern Arabian Sea (EAST-03) sediment trap

Start (y/m/d)	End (y/m/d)	$\delta^{18}O$ shallow (1987)	$\delta^{18}O$ deep (1987)	$\delta^{18}O$* deep (1986)
87/05/12	87/05/24	−2.32	−2.17	
87/05/24	87/06/06	−2.41	−2.20	
87/06/06	87/06/18	−2.09	−2.22	
87/06/18	87/07/01	−2.34	−2.31	
87/07/01	87/07/13	−2.14	−2.20	
87/07/13	87/07/26	−2.41	−1.68	
87/07/26	87/08/07	−2.13	−2.27	
87/08/07	87/08/20	−2.37	−2.41	
87/08/20	87/01/01	−2.56	−2.54	
87/09/01	87/09/14	−2.46	−2.48	
87/09/14	87/10/21	NM		
86/07/01	86/07/14			−3.01
86/07/14	86/07/27			−2.14
86/07/27	86/08/09			−2.71
86/08/22	86/09/04			−2.54
86/09/04	86/09/17			−2.91
86/09/17	86/10/13	NM		
86/10/13	86/10/26			−3.12

*Curry *et al.*[17].

twice in November 1986 and May 1987 (ref. 16).

The sediment trap fraction sample (> 63 μm) was dried and *G. ruber* were hand-picked from the 250–500 μm size fraction for isotopic analysis. Then the isotopic analysis was carried out using standard procedures[17,18] in a Finnigan MAT-251 mass spectrometer with an overall precision of ±0.09 per mil[18]. $\delta^{18}O$ values were reported relative to V-PDB standard.

$\delta^{18}O$ values of *G. ruber* in the samples are given in Table 1. The $\delta^{18}O$ shows minor changes (from −2.09 to −2.56) centred around −2.32±0.16 per mil for shallower depth and (−1.68 to −2.54) with an average of (−2.25±0.24) per mil for deeper location. Information on salinity and its variation at these levels, however, has been limited to that available in the archives. A higher degree guesstimate for the upper limit of the variation in salinity during May to August could be at about ~ 1 ppt. This can change the $\delta^{18}O$ values at best by 0.3 per mil[8,19]. Following the thermodynamics of sea water and the fact that the temporal variations in the salinity away from the coastal boundary are marginal, variability in the $\delta^{18}O$ could only arise due to variations in the temperature. So much so, changes in the $\delta^{18}O$ could be interpreted in terms of SST fluctuations.

The $\delta^{18}O$ values from May to September show very little variations indicating that there is no cooling due to summer monsoon in 1987. Meteorologically, as the year 1987 has been labelled as one of drought[20], it is likely that the summer monsoon cooling was not significant. The studies of Chakraborty and Ramesh[15] who noticed a weaker signal of $\delta^{18}O$ (−5.4 to −5.1 with a range of 0.3 ‰) during 1987 in a coral compared to the $\delta^{18}O$ signal in the range of 0.9 ‰ in the previous years of good monsoon lend further support to this observation. In 1986, the samples from the deeper location presented variations in $\delta^{18}O$ (−2.14 to −3.12) of about 1 per mil (Table 1). This indicates the impact of cooling by monsoonal upwelling and vertical mixing. This drastic change in the intra-annual variability in $\delta^{18}O$ for 1986 and 1987 could then be due to the drought condition of 1987. A comparison of the total settling fluxes in the western Arabian Sea trap (16° 15′, 60° 28′) during corresponding months of 1986 and 1987 shows that the total flux is lower in 1987 by a factor of 2. This indicates weak upwelling during 1987.

In conclusion, *G. ruber* responds isotopically to the changes in the surface water conditions fairly quickly. It has shown the signature of the drought during 1987 and assisted to establish that $\delta^{18}O$ of *G. ruber* could be a reliable proxy indicator of monsoon performance. Stable isotope analysis of *G. ruber* for a few more monsoon and drought years probably confirm this.

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A new occurrence of alkaline lamprophyre near Kellampalle, Prakasam District, Andhra Pradesh, India

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A plug of alkaline lamprophyre (sannaite), covering an area of about five square metres, occurs within the tholeiitic gabbros of Kellampalle complex (Prakasam District), Andhra Pradesh. The lamprophyre is characterized by ocellar structure, and porphyritic and panidiomorphic textures. Euhedral to subhedral phenocrystic amphibole (ferrohastingsite) and biotite are set in a groundmass composed of amphibole, biotite, orthoclase perthite and traces of titanaugite, apatite and calcite. The ocelli are composed of orthoclase perthite and traces of apatite. The mineral assemblage of the lamprophyre represents a frozen sample of a uniquely complete magma system that was composed of a melt (groundmass) + suspended crystals (phenocrysts) + volatile phase (H_2O/CO_2-rich minerals). The association of alkaline lamprophyre and tholeiitic gabbro near Kellampalle possibly represents either heterogeneity, or varying depth levels of melting, within the mantle—the lamprophyric magma having a relatively deeper source.

In the Prakasam alkaline province of Andhra Pradesh[1], typical lamprophyres occur in the Elchuru[2,3], Settupalle[4] and Purimetla[5] complexes and, an olivine basalt dyke of lamprophyre affinity occurs in the Uppalapadu complex[6]. In all these complexes, the lamprophyres (representing the latest magmatic event in the province) cut across the nepheline syenites, quartz syenites, malignites and shonkinites. The present report deals with a new occurrence of an alkaline lamprophyre within tholeiitic gabbros, a hitherto unreported association in the province, at a place 5.5 km NE of Kellampalle (15 34′ N:79 47′ E) in the Prakasam District of Andhra Pradesh.

The Kellampalle lamprophyre occurs as a plug covering an area of about five square metres, and makes sharp contacts with the gabbros; it has no chilled margins, thus reflecting relatively long-lived melt flow in the channelway[7]. The body is presumed to be emplaced during a local extensional regime[8].

The lamprophyre contains uniformly distributed, subspherical and irregular masses of leucocratic minerals called 'ocelli' that are distinct within a dark-coloured, aphanitic matrix (Figure 1). The boundary between the ocelli and matrix is sharp, and the size of the spherical bodies varies from 3 mm to 8 mm. The lamprophyre exhibits pitted weathered surface due to removal of ocelli in solution.

Megascopically, the Kellampalle lamprophyre is melanocratic to mesocratic (colour index about 60), compact, heavy and fine-grained. Under the microscope, it exhibits the porphyritic and panidiomorphic textures typical of, but not exclusive to, lamprophyres (Figure 2). Euhedral to subhedral phenocrysts of dark-green to yellowish green amphibole (ferrohastingsite) and castellated biotite are set in a fine-grained

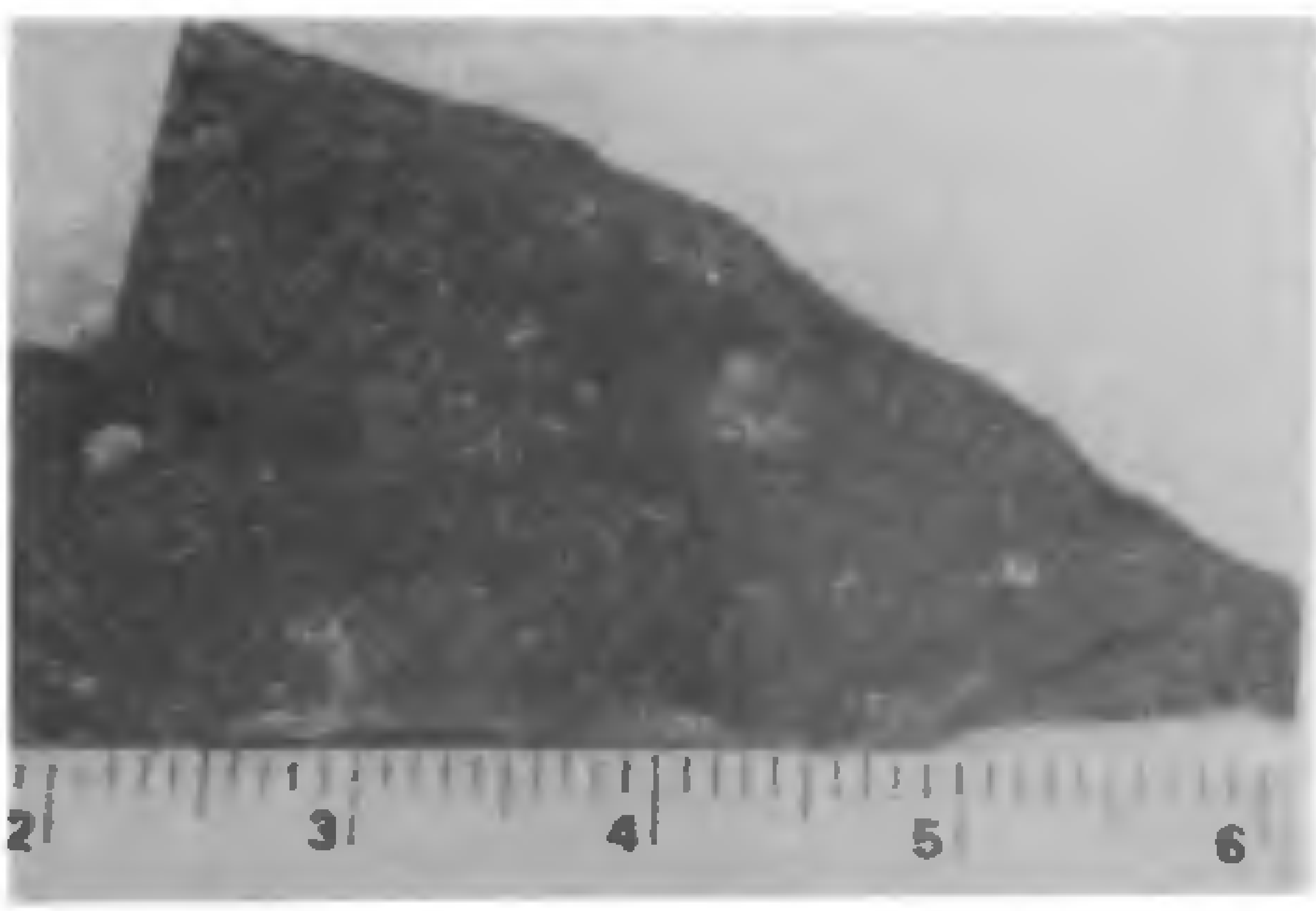

Figure 1. Lamprophyre showing leucocratic ocelli within a dark-coloured, aphanitic groundmass. The scale is in inches.