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Stalagmite $\delta^{18}O$ variations in southern India reveal divergent trends of Indian Summer Monsoon and East Asian Summer Monsoon during the last interglacial

Narayana C. Allu [a], Manish Tiwari [b], Madhusudan G. Yadava [c], Nguyen Chi Dung [d], Chuan-Chou Shen [d], Sarang P. Belgaonkar [a], Rengaswamy Ramesh [c, *], Amzad H. Laskar [c]

[a] Centre for Earth and Space Sciences, University of Hyderabad, Gachibowli, Hyderabad, 500 046, India
[b] National Centre for Antarctic and Ocean Research (NCAOR), Vasco da Gama, Goa, 403 804, India
[c] Geoscience Division, Physical Research Laboratory, Navrangpura, Ahmedabad, 380 009, India
[d] High-Precision Mass Spectrometry and Environmental Change Laboratory (HISPEC), Department of Geosciences, National Taiwan University, Taipei, 10617, Taiwan, ROC

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A B S T R A C T

Indian monsoon variations for the period around ~100 ka have not been documented from terrestrial archives, while limited data do exist from the Indian Ocean. Some paleoceanographic studies have reported abrupt and stepwise changes in the monsoon intensity during the last deglaciation, but similar observations have not been possible for earlier periods such as the interglacial to glacial transition, mainly because of the coarse resolution (~500 to 1000 years) provided by marine archives of that age. Here, we report a new $\delta^{18}O$ data set from a stalagmite (3-ACN) that grew in the Belum caves, Andhra Pradesh, a semi-arid region in southern India, with a resolution of ~85 years. Age assignment to different growth layers consistent with associated analytical errors indicates that the record could span ~9 ky during part of Marine Isotope Stage (MIS) 5d-c, from ~108 to ~99 ka. $\delta^{18}O$ variations in this stalagmite, if interpreted using the 'amount effect', i.e., ^{18}O depletion of ~1.5‰ per 100 mm increase in monsoon rainfall, indicate a step-like increase during the transition from the cooler stadial MIS 5d to warmer interstadial MIS 5c, signifying an abrupt reduction in monsoon rain. The new data presented highlight divergent trends between the Indian and the East Asian Summer Monsoons for a time period for which not many high-resolution comparisons are available.

1. Introduction

Speleothems, cave deposits that form in karst topography (Ford and Williams, 2007; Narayana et al., 2014), consisting of stalactites, stalagmites and flowstones, have been shown to be excellent archives of past monsoon fluctuations with high resolution (Lauritzen and Lundberg, 1999; Wang et al., 2001, 2008; Fleitmann et al., 2003; Yadava and Ramesh, 2005a, 2005b, 2006, 2007; Cobb et al., 2007; Wang and Chen, 2012; Moseley et al., 2014). This is because they faithfully record the oxygen isotopic composition of local precipitation, which might depend either on local temperature or the amount of precipitation, or both (Dansgaard, 1964). Karst formations exist in Peninsular India, which receives maximum rainfall during the southwest monsoon (June to September), accounting for 70–90% of the annual rainfall (IMD, 1999; Yadava et al., 2004, 2007). The northeast monsoon (winter monsoon, during October to December) that accounts for the remainder is active mainly over southern parts of the Peninsula. In tropical India, the major growth of speleothem occurs during the wet season. A few speleothem data sets that have been reported from India have provided reconstruction of the past monsoon rain mainly during the Holocene (*e.g.*, Sinha et al., 2007). Some cave locations are still being explored (*e.g.*, Sanwal, et al., 2013; Lone et al., 2014). As long term temperature variations in the tropics are usually quite small (< a few °C), the $\delta^{18}O$ of speleothem calcite is usually interpreted based on the 'amount effect', whereby the $\delta^{18}O$ of tropical precipitation decreases by ~1.5‰ for every 100 mm increase in the monthly rainfall (Dansgaard, 1964; Yurtsever and Gat, 1981). We present $\delta^{18}O$ data from a 54 cm long fossil stalagmite dated by U–Th mass spectrometry. This stalagmite grew in the Belum cave (15°6′N; 78°6′E;

* Corresponding author.
E-mail address: rramesh@prl.res.in (R. Ramesh).

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367 m above m.s.l.) in the Cuddapah Basin, Andhra Pradesh, India (Fig. 1). It spanned a part of Marine Isotope Stage 5 (MIS 5d to c), from ~99 to ~108 ka. Indian monsoon activity during this stage is not known from terrestrial archives, but only known with some coarse resolution from a few marine records in the Indian Ocean (Anderson and Prell, 1993; Emeis et al., 1995; Clemens and Prell, 1996, 2003, 2007; Reichart et al., 1997, 1998; Schulz et al., 1998).

2. Geology of the study area

The study area, a part of Cuddapah sedimentary basin (Fig. 1) of Proterozoic age (GSI, 1997; Narayana et al., 2014), is populated by limestone caves decorated with a number of stalagmites, stalactites and flowstones. The Belum caves are situated in the Precambrian Narji limestone terrain, which belongs to the Jammalamadugu Group of the Kurnool Supergroup. These are overlying the Cuddapah Supergroup. The limestones are bluish gray, fine-grained, and well-bedded. These limestone beds are overlain by sandstones, quartzite, and conglomerates of the Banganapalli Group, which in turn is overlain by the Narji Limestone. The Auk Shale overlies the Narji Limestone (Table 1). The caves are 15 m above a 35 m escarpment, and this rules out permanent ground water contribution to speleothem formation in this cave. The stalagmite strewn floors have a variety of limestone slabs and boulders as well as weathered shale. The caves are small and narrow, typically 0.5 m to 1.5 m wide. However, the passage is on the average ~9 m high, on two sides, and has galleries 15 m long, which narrow down to corridors less than 1.5 m wide (Narayana et al. 2014).

Table 1
General geological and stratigraphic succession of the Belum cave area, Kurnool District, Andhra Pradesh, India.

Group	Formation	Lithology
Kurnool	Panyam	Quartzite
	Awk	Shale (variegated)
	Narji	Limestone
	Banaganapalli	Quartzite, sandstone, grit & minor conglomerate (diamondiferous)
Unconformity		
Lower Cuddapah Supergroup	Cumbhum	Shales/slate
	Tadipatri	Dolomite/limestone/shale
	Vempalle	Dolomites, shale
Eparchaean unconformity (nonconformity)		
Archaean gneisses/greenstones/mafic – ultramafic dykes		

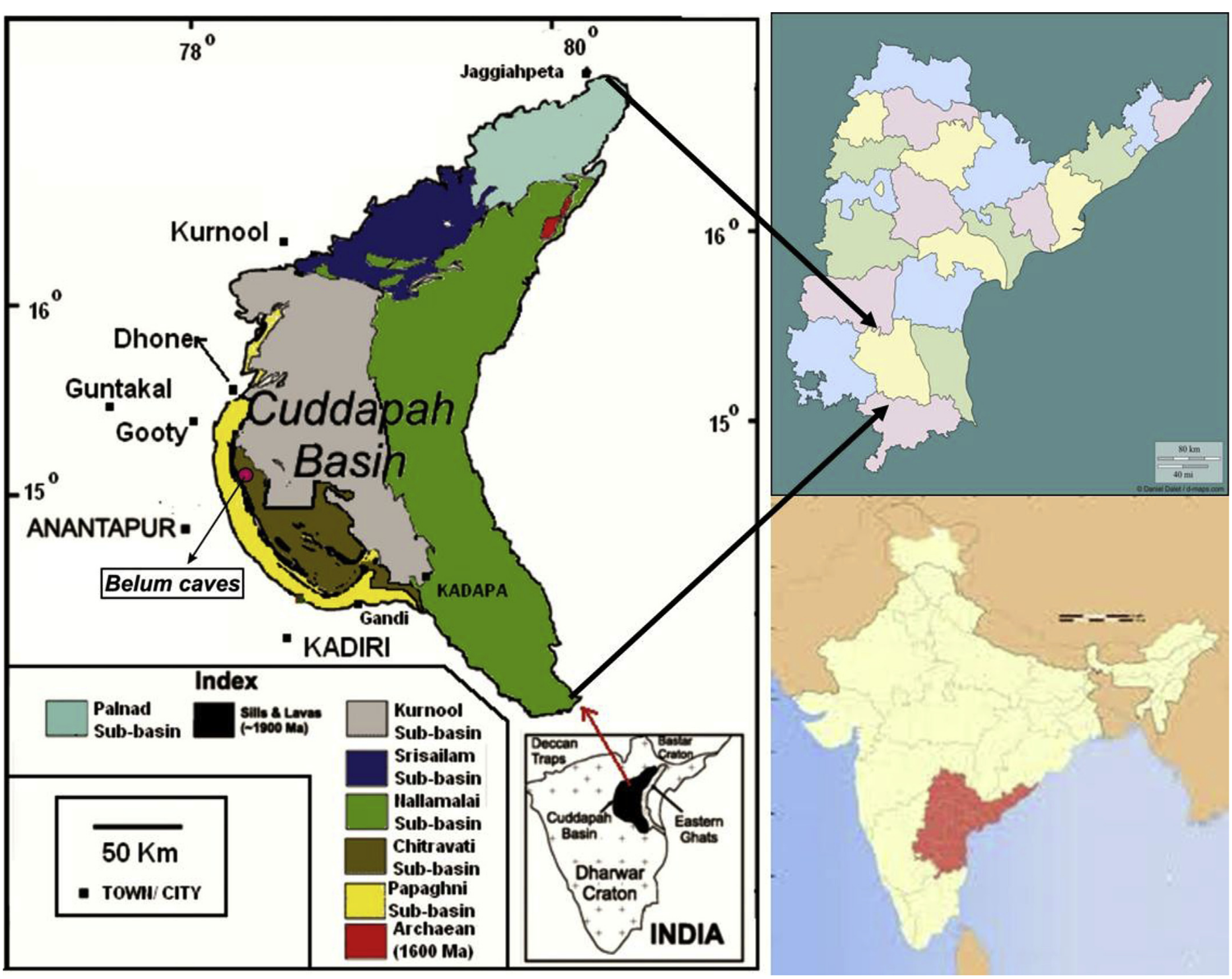

Fig. 1. Map showing the Cuddapah basin and location of Belum caves, southern India.