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Pre-Deccan Campanian acidic volcanism on Laccadive ridge: Implications on the nature of its underlying crust

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Abstract

The Laccadive-Chagos Ridge (LCR) is a prominent aseismic ridge in the Indian Ocean. The origin and nature of the crust beneath the LCR have been debated. Based on Ar-Ar geochronology of the volcanic basement rocks from ODP wells 713 and 715 from Chagos and Maldives ridges, a hotspot trail model was proposed for the genesis of the LCR. On the other hand, based on geophysical studies, the LCR has been inferred as a continental sliver/hyperextended continental crust which has undergone heavy underplating and Reunion hotspot volcanism. Even though these two different hypotheses differ on the genesis and nature of the LCR, both agree that the ridge experienced extensive Reunion hotspot trail volcanism, making the crust's nature challenging to decipher. We report Ar-Ar ages of two rhyolite rock samples from a well drilled on the Padua bank located on the northern extent of the Laccadive ridge. These acidic rocks are at a depth of ~1700m and ~2300m and underlie the Tertiary sediments forming the basement in this well. The previously determined K-Ar geochronology ages are 60.2 Ma and 102 Ma. The precise Ar-Ar dates of these rocks determined in the present study are 76.2 ± 0.4 Ma and 77.5 ± 0.5 Ma (2σ) respectively. These acidic rocks (78-76 Ma) coupled with onshore acidic rocks of the St-Mary's island (87-84 Ma) and Ezhimala (95-93 Ma) suggest continuous extension between the India and Laccadive ridge after the Indo-Madagascar continental breakup (88 Ma). Contrary to the earlier hypothesis, the acidic rocks of Laccadive Ridge are older than the Reunion Plume trail volcanism (62-60 Ma). The geophysical and geochronological evidence suggests that the Laccadive ridge is continental in nature, and the volcanism predates the Reunion plume volcanism. These evidences suggest that the Laccadive Ridge is a continental thinned crust that has undergone rift-related volcanism rather than a hotspot trail.

Abstract figure:

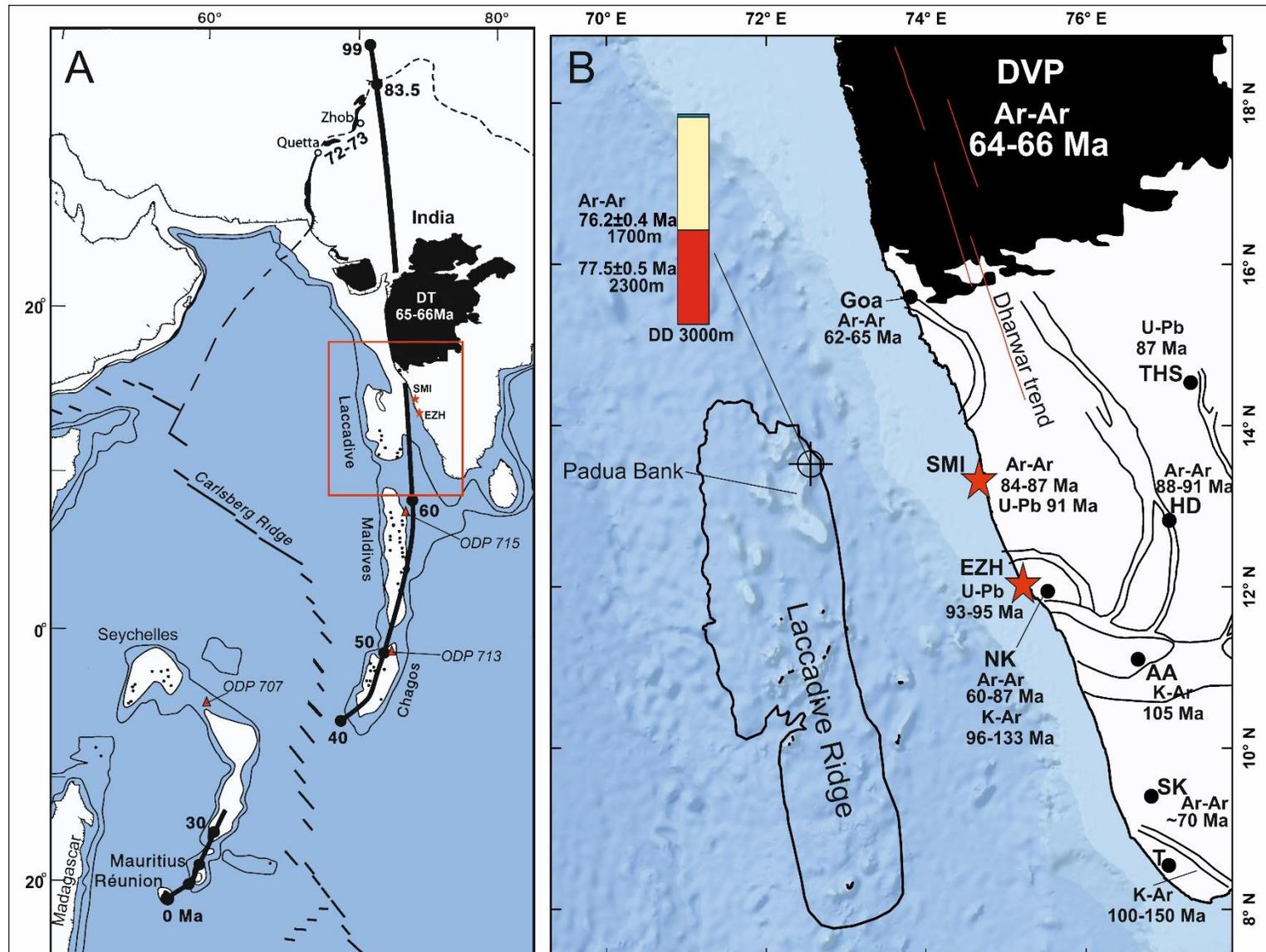


Figure (A): Map showing Laccadive-Chagos Ridge, ODP wells (707, 713, 715) and some important features of the Indian Ocean. The study area is marked by red rectangular outline. Re-union Hotspot track (Modified after Mahoney et. al, 2002) is given in black solid line from 0-99 Ma . Figure (B): Map showing the ages of previously studied magmatic rocks onshore and the ages of offshore rocks from this study. The location and generalized litho-column of the well is also given (blue: sea column; yellow: sediments; red: acidic rocks). The Laccadive Ridge is marked by bold black line. Black lines onshore represents Precambrian shear zones. Red lines: trend of Precambrian rift zones in Dharwar craton (Bhattacharya and yateesh 2015) DVP: Deccan Volcanic Province; THS: Thimmasamudram dykes; SMI: St. Mary's Islands Volcanics; HD: Huliurdurga dykes; NK:North Kerala dykes; AA: Agali-Anaikatti dykes; EZH: Ezhimala Igneous Province; SK: South Kerala dykes, T: Trivandram dykes. Red stars are acidic outcrops.

Introduction

The Laccadive-Chagos Ridge (LCR) is a prominent aseismic ridge in the Indian Ocean. The origin and nature of the crust beneath the LCR have been debated. Based on Ar-Ar geochronology of the volcanic basement rocks from ODP wells 713 and 715 from Chagos and Maldives ridges, a hotspot trail model was proposed for the genesis of the LCR (Duncan and Hargraves 1990, Mahoney et al. 2002). On the other hand, based on geophysical studies, the LCR has been inferred as a continental sliver/hyperextended continental crust which has undergone heavy underplating and Reunion hotspot volcanism (Bhattacharya and Yateesh 2015 and references therein). Even though these two different hypotheses differ on the genesis and nature of the LCR, both agree that the ridge experienced extensive Reunion hotspot trail volcanism, thereby making the crust's nature challenging to decipher.

The present study focuses on the northern part of LCR, the Laccadive Ridge/Plateau. The objectives of the present study are to understand its temporal evolution and the nature of the crust beneath it. We used Ar-Ar geochronology to date two rhyolite rock samples from the well drilled on the Padua bank located on the Laccadive ridge. So far, this is the only well drilled on the Laccadive Ridge that encountered igneous rocks. These acidic rocks are at a depth of ~1700m and ~2300m and underlie the Tertiary sediments forming the basement in this well.

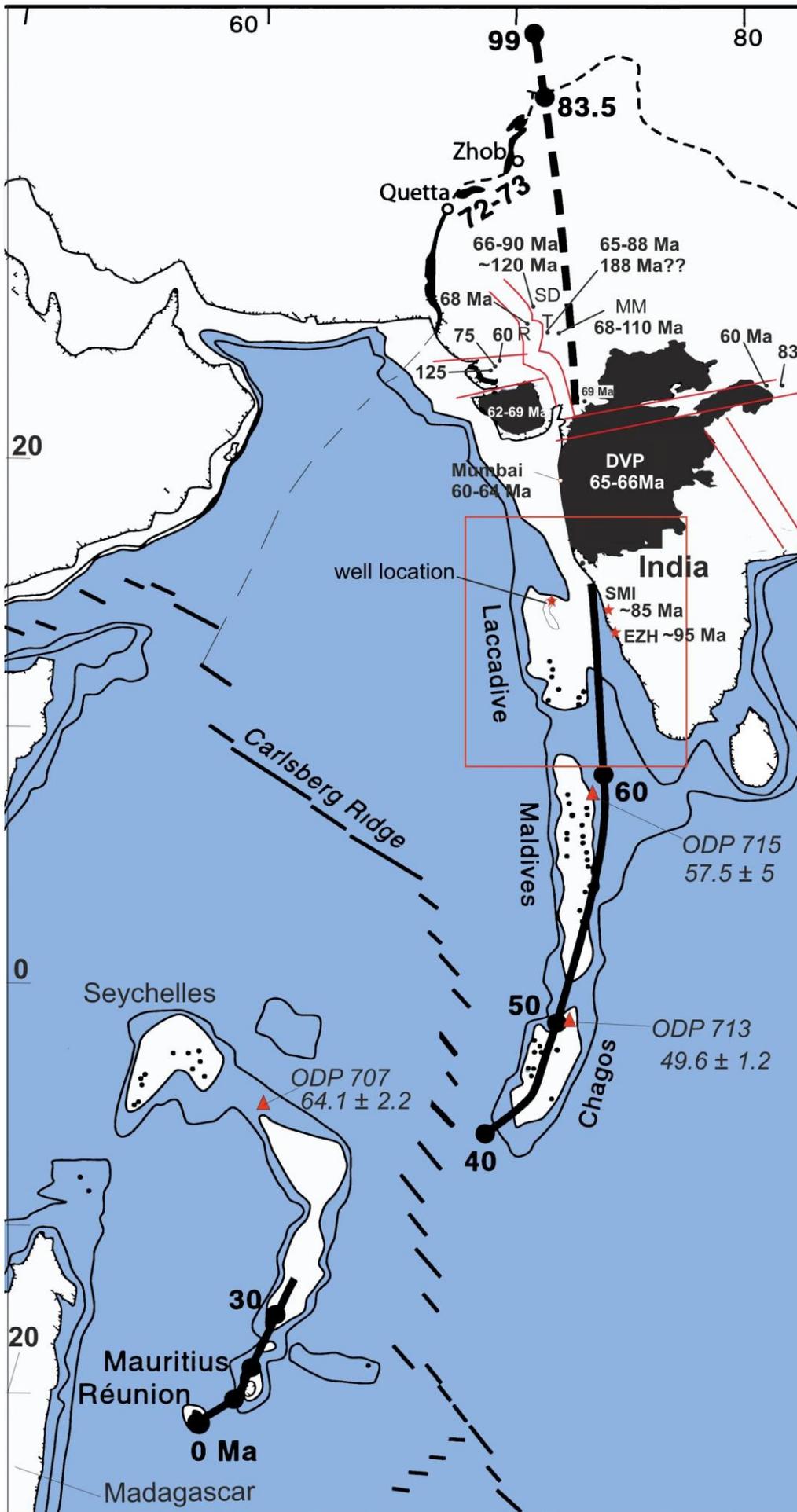


Figure1:

Map showing Laccadive-Maldives-Chagos Ridge, ODP wells (707, 713, 715) and some important features of the Indian Ocean. The study area is marked by red rectangular outline. Re-union Hotspot track is given in black solid line from 99 Ma to

present. The range of published ages for the Cretaceous-Palaeocene magmatic rocks are given. (Modified after Mahoney et. al, 2002). SD: Sarnu-Dandali; M: Mundwara; T: Taveedar; R: Raageswari; SMI: St. Mary's Island; EZH: Ezhimala Igneous Complex.

Methodology:

Fresh rock chips (~10 g), devoid of secondary minerals were crushed, cleaned in deionized water in an ultrasonic bath, and sieved. About 0.02 g of 220-180 microns' fraction was packed in the aluminium capsule. The Minnesota hornblende reference material (MMhb-1) of age 523.1 ± 2.6 Ma (Renne et al. 1998) and high-purity CaF_2 and KSO_4 salts were used as monitor samples. High-purity nickel wires were placed in both sample and monitor capsules to monitor the neutron fluence variation, which was typically ~5 per cent. The aluminium capsules were kept in a 0.5 mm thick cadmium cylinder and irradiated in the heavy water- moderated DHRUVA reactor at the Bhabha Atomic Research Centre (BARC), Mumbai, for ~100-160 hr. The irradiated samples were repacked in aluminium foil and loaded on the extraction unit of a Thermo-Fisher Scientific noble gas preparation system. Argon was extracted in a series of steps up to 1350°C in an electrically heated ultrahigh vacuum furnace. After purification using Ti-Zr getters, the argon released in each step was measured with a Thermo-Fisher ARGUS VI mass spectrometer (equipped with five Faraday cups fitted with 10 resistors) located at the National Facility for Ar/Ar Geo-thermochronology in the Department of Earth Sciences, IIT Bombay, India.

Interference correction factors for Ca and K-produced Ar isotopes based on analysis of CaF_2 and K_2SO_4 salts were $(^{36}\text{Ar}/^{37}\text{Ar})$ Ca, $(^{39}\text{Ar}/^{37}\text{Ar})$ Ca and $(^{40}\text{Ar}/^{39}\text{Ar})$ K for each irradiation are given in results section. Ar blank contributions were 1–2 per cent or less for all temperature steps. Following the procedure described in Dalrymple et al. (1981), Venkatesan et al. (1993) and McDougall & Harrison (1999), the neutron fluence variation during the irradiation was determined using Co γ -activity of the irradiated nickel wires kept with the monitor as well as the individual samples. Values of the irradiation parameter J for the sample was determined by normalizing the variations in the Co γ -activity in the nickel wires kept with the sample to the activity associated with the nickel wire kept with the monitor. Fluence-corrected value of J for

each sample is given in the supplementary file. The plateau age reported comprise a minimum of 45 per cent of the total Ar released and four or more successive degassing steps whose mean ages overlap at the 2σ level excluding the error contribution (0.5 per cent) from the J value. The data were plotted using the program Isoplot/Ex v. 3.75 (Ludwig 2012). The plateau age, isochron age, inverse isochron age and trapped argon compositional ratio are given in the results section. All the errors are calculated for 2σ .

Ar- Ar geochronology results:

The data obtained from Ar-Ar geochronology analysis is presented in age spectrum, isochron and inverse isochron plots. The two samples have atmospheric value for the trapped argon composition within uncertainty limits. The mutually indistinguishable plateau, isochron and inverse isochron ages implying the ages are true crystallisation ages. The results are summarized below.

Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology results of the samples from Laccadive ridge

Sample	Steps	^{39}Ar %	Plateau			Isochron				Inverse isochron			
			Age (Ma)	MSWD	p	Age (Ma)	Trap	MSWD	p	Age (Ma)	Trap	MSWD	p
1733m#54	8	86.2	76.2 ± 0.4	0.36	0.92	76.3 ± 0.7	294.7 ± 4.8	0.22	0.97	76.4 ± 0.6	294.5 ± 3.2	0.41	0.87
2300m#48	9	65.8	77.5 ± 0.5	0.58	0.80	77.4 ± 1.7	295 ± 14	0.06	1.00	77.5 ± 1.4	295 ± 10	0.12	1.00

Reactor parameters for interference corrections.

Irradiation no.	CaF_2		K_2SO_4
	$^{36}\text{Ar}/^{37}\text{Ar}$	$^{39}\text{Ar}/^{37}\text{Ar}$	$^{40}\text{Ar}/^{39}\text{Ar}$
IRRN #48	0.005703	0.001085	0.138147
IRRN #54	0.002105	0.001166	0.042708

International standards used for validation of the results

AGE (Ma)		
Standard #IRRN	Present work	Recommended
FCs (Sanidine) #48	28.3 ± 0.2	28.02 ± 0.3
GA1550 (Biotite) #54	98.7 ± 1.5	98.8 ± 1.0

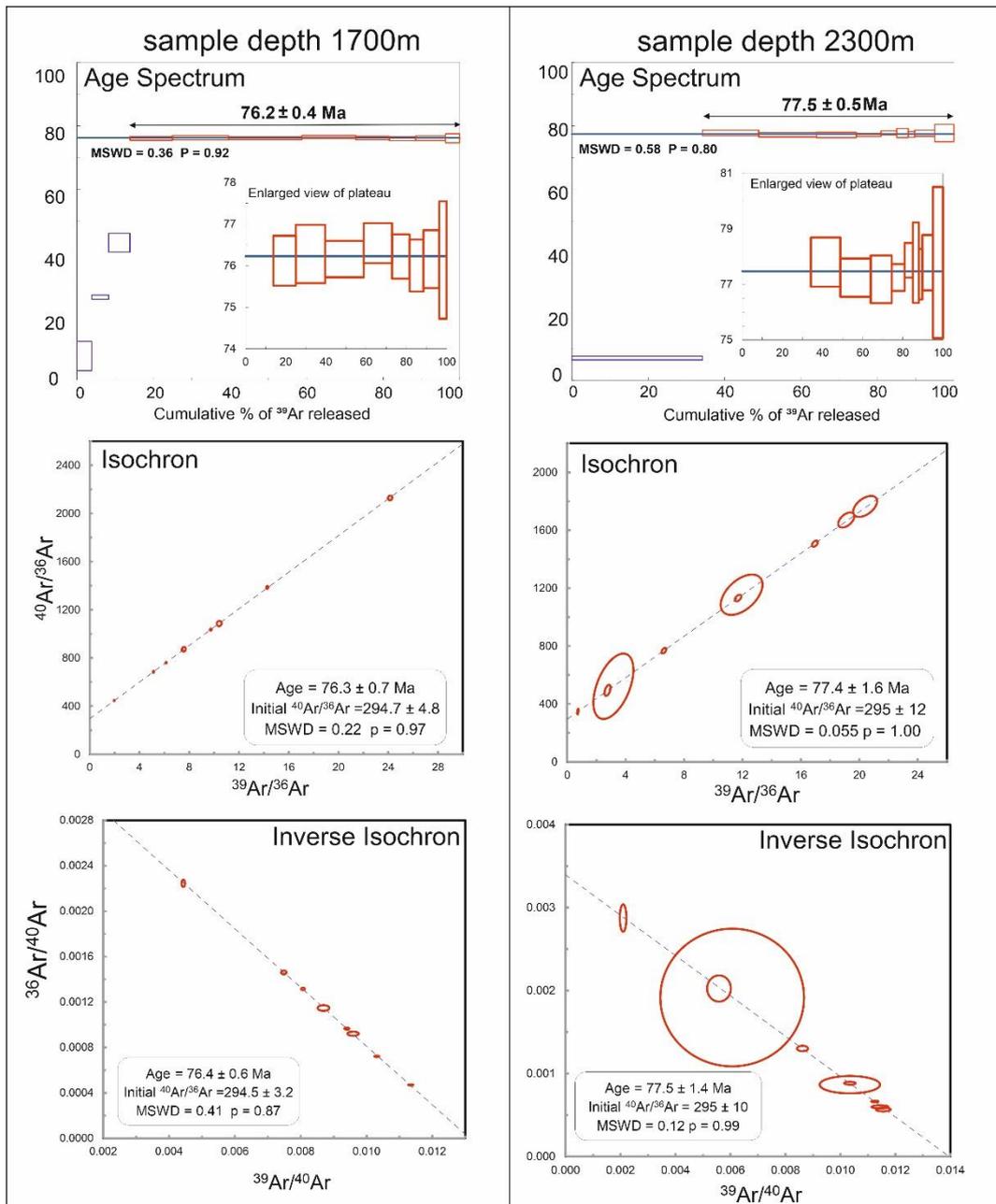


Figure: Isotope correlation diagrams: Age spectrum, isochron and inverse isochron.

Discussion:

Contrary to the earlier hypothesis, the volcanic rocks sampled from Laccadive Ridge are older than the Reunion Plume trail volcanism (62-60 Ma). The geophysical and geochronological evidence suggests that the Laccadive ridge is continental in nature, and the volcanism predates the Reunion plume volcanism. These evidences indicate that the Laccadive Ridge is a thinned continental crust that has undergone rift-related volcanism rather than a hotspot trail.

Highlights:

The 76-78 Ma acidic volcanism on the Laccadive Ridge is older than the Réunion Hotspot track volcanism (~62 Ma).

The geophysical evidence, coupled with the new Ar-Ar geochronology ages, support the continental nature of Laccadive Ridge.

Post-Indo-Madagascar breakup at 88 Ma, rifting might have continued between Laccadive Ridge and India, giving rise to the acidic volcanism at 76-78 Ma.

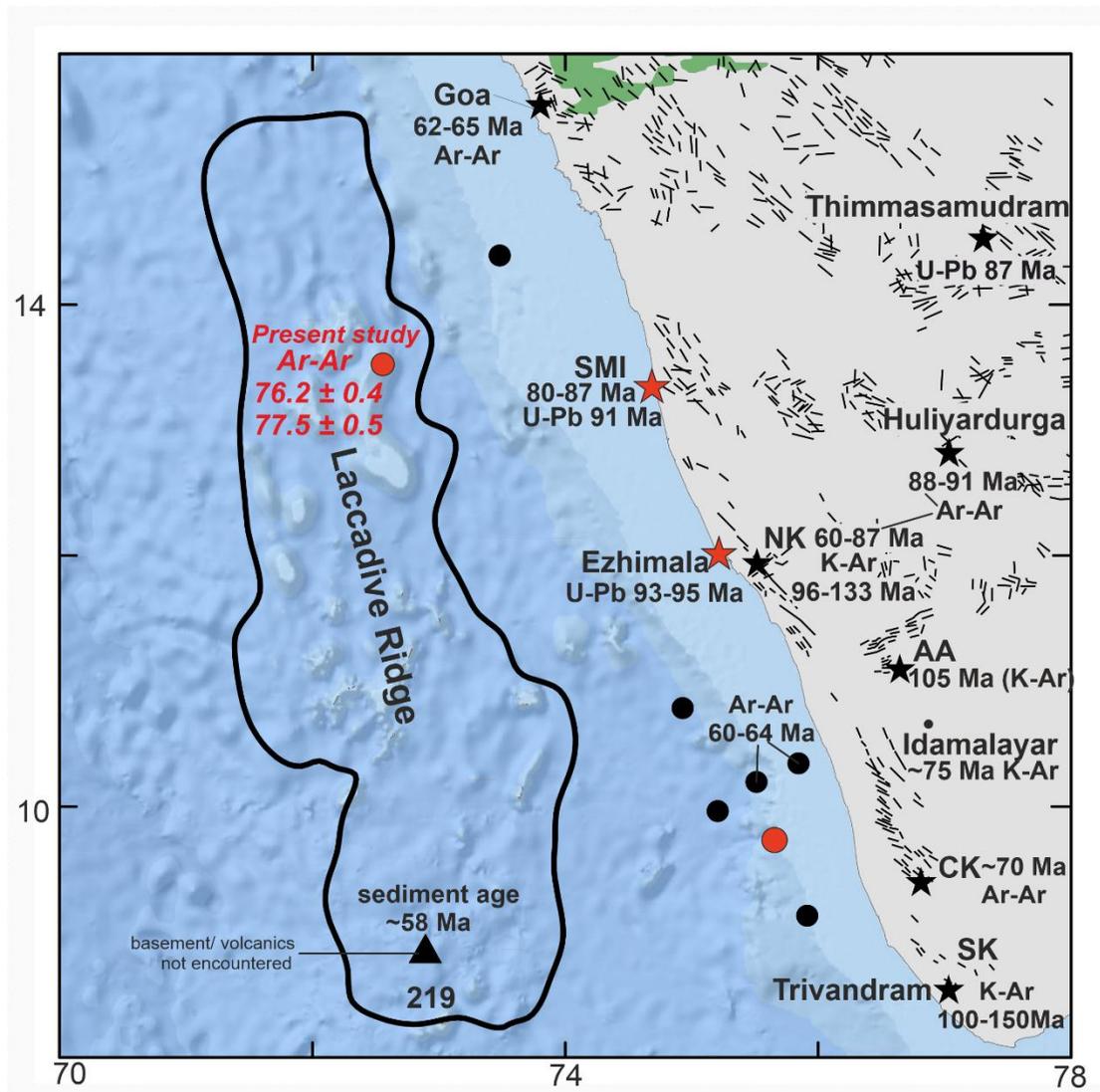


Figure (B): Map showing the ages of previously studied magmatic rocks onshore and the ages of offshore acidic rocks from this study. The Laccadive Ridge is marked by bold black line. SMI: St. Mary's Islands Volcanics; NK: North Kerala dykes; AA: Agali-Anaikatti dykes, SK: South Kerala dykes. Red colour filled stars and circles represent acidic rocks. U-Pb, Ar-Ar and K-Ar ages of the cretaceous magmatic rocks are given.

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