
संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती
मराठी विभाग
आणि
अखिल भारतीय मराठी साहित्य महामंडळ
संयुक्तपणे आयोजित
चर्चासत्र
मराठी : अभिजात, बोली आणि उपयोजित
दि. २४ सप्टेंबर २०१६
उद्घाटन समारंभ
गाडगे बाबा अमरावती विद्यापीठ


संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती
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अखिल भारतीय मराठी साहित्य महामंडळ
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मराठी : अ


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मराठी विभाग
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Government of India
Department of Atomic Energy (DAE)
Board of Research in Nuclear Sciences (BRNS)

Dr. S.Dutta
Programme Officer (RTAC)

BRNS Secretariat, 1st Floor, CC,
BARC, Trombay, Mumbai-400085.
Phone: +91-2225595331
Email: dsubrata@barc.gov.in

No: 35/14/30/2016-BRNS/35259 Date: 07/11/2017

OFFICE MEMORANDUM

Sub: **Renewal-cum-additional** R/P entitled "Gamma irradiated enhancement of Artemisinin production from A. annua L. and process optimization" under Dr. Anita Surendra Patil, Professor, Department of Biotechnology, Sant Gadge BabaAmravati University, Amravati-444 602, MS bearing sanction 35/14/30/2016-BRNS with RTAC, BRNS.

In continuation of this Department's OM of even number dated 09/08/2016 on the recommendations of the Board of Research in Nuclear Sciences (BRNS), I am pleased to convey the administrative approval of the President of India for the continuance of captioned project during **2017-2018** and sanction to incur an expenditure of **Rs. 5,59,875/- (Rupees five lakh fifty nine thousand eight hundred seventy five only)** as detailed below:

Item of expenditure	**Year 2 (2017-2018)**
Staff Salary - JRF (1)	300000
Consumables	150000
Travel - PI	15000
Contingencies *	* 60000
Overheads	34875
Total(INR)	**559875**

* **This includes additional grant of ₹.30,000/-.**

2. The grant remaining unspent under the Heads "Equipments","Consumables" and "Overheads" for the year 2016-2017 are only allowed to be carried forward to the current financial year 2017-2018. Unspent balance under other heads will be adjusted while releasing the subsequent grant.
3. The expenditure involved is debitable to the following Head of Account: **3401 00 004 27 02 31**
4. This issues with the concurrence of Scientific Secretary, BRNS and IFA.

Subrata Dutta

Dr. S.Dutta

Pay & Accounts Officer, DAE, Mumbai-400 001

Copy forwarded to:

1. Director of Audit, Scientific Department, AEAP,OYC,CSM Marg, Mumbai-400 001.
2. Joint Secretary (R&D), DAE, Anushakti Bhavan, CSM Marg, Mumbai-400 001.
3. Registrar, Sant Gadge Baba Amravati University, Amravati-444 602, MS.

4. Principal Investigator(PI): Dr. Anita Surendra Patil, Professor, Department of Biotechnology, Sant Gadge Baba Amravati University, Amravati-444 602, MS.

A. The actual amount of grant-in-aid that would be released will be limited to the actual expenditure up to 31st March 2017 subject to the maximum recommended by the Board.

B. In accordance with Rule 30 of the General Financial Rules 2005, this sanction will lapse if no payment in whole or part is made during a period of twelve months from the date of issue of this sanction letter.

C. The PI is authorized to incur the expenditures towards the general administrative requirements of the project and towards fees payable to Auditor/Chartered Accountant for audit of accounts of the project, from the funds sanctioned under "overhead" for the project.

D. The other Terms and Conditions governing the payment of the grant-in-aid have already been sent to you while sanctioning the grant for the first year of the project.

E. Grant for the second year will be released in FULL (unspent balance of previous year and Interest earned will be adjusted) on receipt of the bill IN DUPLICATE in prescribed FORM-II along with the following documents.The data for these documents are required to be filled online and a printout of the same should be forwarded to the undersigned after obtaining original signatures of the concerned officials.

(a) Utilization Certificate (FORM-III) for the preceding year.

(b) Statement of Accounts signed by Internal Auditor/ Accountant of the Institution/ University (FORM-IV) for the preceding year. Interest earned in previous year should be reflected in the Statement of Accounts.

(c) Copy of appointment order and joining report of the staff appointed for the project along with Minutes of the Selection Committee.

(d) An Inventory of euipment (FORM-V).

F. PLEASE NOTE THAT CLAIM(S) SHALL BE SUBMITTED TO THIS DEPARTMENT WELL IN ADVANCE BEFORE THE END OF THE FINANCIAL YEAR IN WHICH THE CLAIM IS DUE. OTHERWISE, THE SANCTIONED GRANT WILL BE LAPSE.

G. Renewal/ Extension Application: Principal Investigator (PI) is required to upload by January 15 a pdf copy of duly signed renewal/ extension application in the prescribed Form-PRA after logging into his/her account at www.daebrns.gov.in . Template for Form-PRAcan be downloaded from website www.daebrns.gov.in . All applications received shall be examined by experts from the field and PIs may be invited to a Technical Programme Discussion Meeting (TPDM). Renewal of the project will be based on the recommendations of the TPDM, Advisory Committee and the Board.

5. AAO (Cheque), DAE, Anushakti Bhavan, CSM Marg, Mumbai-400 001.
6. Co-Investigator (CI): Dr Ramesh Satdive, Nuclear Agriculture and Biotechnology, Bhabha Atomic Research Centre, Trombay, Mumbai- 400085, Email : rameshsatdive@gmail.com, Mobile :9769735571 .
7. Member Secretary (RTAC) : Dr Ashutosh Dash, adash@barc.gov.in; Ph:+91-2225595372 .
8. Principal Collaborator(PC): Dr. D. P. Fulzele, Nuclear Agriculture and Biotechnology, Bhabha Atomic Research Centre, Trombay, Mumbai- 400085, Email : dfulzele@hotmail.com, Mobile :9869327940 .

Subrata Dutta

Dr. S.Dutta

Note:

1. Please quote the Sanction Number 35/14/30/2016-BRNS in all your correspondence with BRNS.
2. Kindly upload renewal/extension forms and update the Statement of Accounts, details of Bank Account, Equipment and staff appointed, after clicking view application the menu available on the top left corner needs to be populated by the PI. Henceforth the office memorandum (OM) or all other letters would be downloadable from PI's account. Hard copies would no more be posted. All the forms mentioned in the sanction letter and the terms and conditions are also available on the website. In case of any difficulty, please call up the undersigned.
3. Please note that as per the goverment orders under **Direct Benefit Transfer (DBT)scheme, the staff salary has to be transferred to his/her bank account.** Accordingly, Aadhar Number(UID) of the appointed staff, Bank Account details and the Mobile number linked to the bank account should be obtained and it should be intimated to this office.

Final Report and Grant Utilization Certificate of MRP

In Vitro Production And Process Optimization Of Camptothecin (An Anticancer Drug) From *Nothapodytes nimmoniana* Graham: A Rare Endangered Medicinal Plant From Western Ghats Of Maharashtra (F.No.42-212/2013 (SR)

SUBMITTED TO

UNIVERSITY GRANTS COMMISSION, BAHADUR SHAH ZAFER MARG

NEW DELHI - 110 002

SUBMITTED BY

DR. ANITA PATIL(PI)
Professor
Department of Biotechnology
SGB Amravati University,
Amravati (M.S)

DR. SURENDRA PATIL (Co- PI)
Professor
College Of Horticulture
Dr. P. D. K.V
Krishi Nagar, Akola (M.S)

UNIVERSITY GRANTS COMMISSION
BAHADURSHAH ZAFAR MARG
NEW DELHI-110002

STATEMENT OF EXPENDITURE IN RESPECT TO MAJOR RESEARCH PROJECT

1 Name of Principal Investigator : Dr. Anita Surendra Patil

2 Department of Principal Investigator University/College : Department Of Biotechnology
Sant Gadge Baba Amravati University,
Amravati (M.S) 444 602

3 UGC Approval Letter No. & Date : F. No.42-212/2013 (SR) dated 22 March, 2013

4 **Title of Research Project :** *In Vitro* Production And Process Optimization Of Camptothecin (An Anticancer Drug) From *Nothapodytes Nimmoniana* Graham: A Rare And Endangered Medicinal Plant From Western Ghats Of Maharashtra.

5 Effective Date of Starting Project : 26-04-2013

6. a Period of Expenditure : 01/04/16 to 31/03/17

b Details of Expenditure

S. No	Item	Total Amount Approved	Amount Approved (Rs)		Total Grant Received	Expenditure Incurred (Rs)
			Ist Grant	2nd Grant		
1	Books and Journals	-	Nil	-	-	-
2	Equipment (Interest 49,700)*	3,50,000=0	3,50,000=0	-	3,50,000=0	3,99,700=0
3	Contingency	30,000=0	15,000=0	12,000=0	27,000=0	27,000=0
4	Field Work/Travel	30,000=0	15,000=0	12,000=0	27,000=0	27,000=0
5	Hiring Services	30,000=0	15,000=0	12,000=0	27,000=0	27,000=0
6	Chemicals and Glassware	1,75,000=0	87,500=0	70,000=0	1,57,500=0	1,53,957=0
7	Overhead	76,300=0	76,300=0	-	76,300=0	76,300=0
8	Any other items (Please specify) Interest*	56,440=0	56,440=0	-	56,440=0	56,440=0
9	Project Fellow Salary	5,28,000=0	2,64,000=0	1,89,600=0	4,53,600=0	4,57,143=0
	Total (Rs)	**12,19,300=00**	**8,79,240=00**	**2,95,600=0**	**11,74,840=0**	**11,68,100=0**

*** Amount of interest Rs 49,700/- is incurred on Equipment grant**

c. Staff : Project Fellow

Date of Appointment: 26/6/13

S.no	Expenditure Incurred	From to	Amount Approved (Rs)	Expenditure Incurred (Rs)
1	Project Fellow (1st and 2nd 14000/- p.m. & 3rd year 16,000/-)	26/6/13 to 13/03/16	4,53,600=00	4,57,143=0

1. It is certified that the appointment(s) have been made in accordance with the terms and conditions laid down by the Commission.

2. It as a result of checks or audit objective, some irregularly is noticed, laterdate, action will be taken to refund, adjust or regularize the objected amounts.
3. Payment @ revised rates shall be made with arrears on the availability of additional funds.
4. It is certified that the expenditure of **Rs. 11,68,100/-** (Rupee Eleven Lakh, Sixty Eight Thousand and one hundred only) out of the grant received **Rs. 11,18,400/-** (Rupee Eleven Lakh, eighteen thousand and four hundred only) and interest **Rs. 56,440/-** (Fifty Six Thousand four hundred fourty only)received from the University Grants Commission under the scheme of support for Major Research Project entitled **"*In Vitro* Production and Process Optimization of Camptothecin (An Anticancer Drug) from *Nothapodytes nimmoniana* Graham: A Rare and Endangered Medicinal Plant from Western Ghats of Maharashtra"**vide UGC letter No. F.No.42-212/2013 (SR) dated 22 March, 2013has been utilized for the purpose for which it was sanctioned in accordance with the terms and conditions laid down and that the balance of **Rs6740=0** remaining grant unutilized will be refund back to the University Grants Commission.

SIGNATURE OF PRINCIPAL

Dr. Anita S. Patil
Professor
Department of Biotechnology
Sant Gadge Baba Amravati University
Amravati (M.S.)

INVESTIGATOR

SIGNATURE OF THE CO-INVESTIGATOR

(Dr. Surendra R. Patil)
Professor (Horticulture)
Department of Fruit Science
College of Horticulture
Dr. P D. K. V., Akola (M.S.)

REGISTRAR/PRINCIPAL

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

Final Report of the work done on the Major Research Project

1. Project report No. : **Final Report**

2. UGC Reference No. : **F. No.42-212/2013 (SR)**

3. Period of report from : 3 Years from 1.04.2013 to extension to 31.03.2017

4. Title of research project : ***In Vitro* Production and Process Optimization of Camptothecin (An Anticancer Drug) from *Nothapodytes nimmoniana* Graham: A Rare and Endangered Medicinal Plant from Western Ghats of Maharashtra**

5. (a) Name of the Principal Investigator : Dr. Anita Surendra Patil,
Professor
Department of Biotechnology
Sant Gadge Baba Amravati University,
Amravati (M.S) 444 602

(b) Department and University/College where work has progressed:

Department of Biotechnology,
Sant Gadge Baba Amravati University,
Amravati (M.S) 444 602

6. Effective date of starting of project: 26-04 -2013

7. Grant approved and expenditure incurred during the period of the report:

a. Total amount approved : **Rs. 12,19,300/-**

b. Total expenditure Rs. : **Rs. 11,68,100/-**

c. Report of the work done: (Please attach a separate sheet): Attached Appendix-I

Annexure - IV

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG, NEW DELHI – 110 002

STATEMENT OF EXPENDITURE INCURRED ON FIELD WORK

GRANT RECEIVED: Rs. 27,000=00

Name of the Principal Investigator: Dr. Anita Surendra Patil

Name of the Place visited	**Duration of the Visit**		**Mode of Journey**	**Expenditure Incurred (Rs)**
	From	To		
Melghat Forest Region	28-7-14	30-7-14	Taxi	4,885=0
UGC New Delhi	28-2-14	30-2-14	Train	5,570=0
UGC New Delhi	5-1-16	12-1-16	Train	2,125=0
Mumbai, Alibag, Western Ghats	8-12-16	12-12-16	Train/Taxi	14,420=0
Total				**27,000=0**

Certified that the above expenditure is in accordance with the UGC norms for Major Research Projects.

SIGNATURE OF PRINCIPAL INVESTIGATOR

Dr. Anita S. Patil
Professor
Department of Biotechnology
Sant Gadge Baba Amravati University
Amravati (M.S.)

SIGNATURE OF THE CO-INVESTIGATOR

(Dr. Surendra R. Patil)
Professor (Horticulture)
Department of Fruit Science
College of Horticulture
Dr. P D. K. V., Akola (M.S.)

REGISTRAR/PRINCIPAL
(Seal)

REGISTRAR
Sant Gadge Baba
Amravati University,
Amravati.

Annexure - V

UNIVERSITY GRANTS COMMISSION

BAHADUR SHAH ZAFAR MARG

NEW DELHI - 110 OO2

UTILIZATION CERTIFICATE

It is certified that the expenditure of Rs. 11,68,100=0 (Rupees Eleven lakh sixty eight thousand one hundredonly) out of the grant received Rs. 11,18,400=0 (Rupees Eleven lakh eighteen thousand four hundred only) and interest Rs. 56,440/- (fifty six thousand four hundred fourty only) received from the University Grant Commission under the scheme of support for Major Research Project entitled "***In Vitro* Production and Process Optimization of Camptothecin (An Anticancer Drug) from *Nothapodytes nimmoniana* Graham: A Rare and Endangered Medicinal Plant from Western Ghats of Maharashtra** " vide UGC letter **F. No.42-212/2013 (SR)** dated **22 March, 2013** has been fully utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down and that the balance of **Rs 6740=0** remaining grant unutilized will be refunded back to the University Grants Commission.

SIGNATURE OF THE
RINCIPAL INVESTIGATOR
(Seal)

Dr. Anita S. Patil
Professor
Department of Biotechnology
Sant Gadge Baba Amravati University
Amravati (M.S.)

REGISTRAR
(Seal)

REGISTRAR
Sant Gadge Baba
Amravati University,
Amravati.

STATUTORY AUDITOR

SIGN OF CO-INVESTIGATOR

(Dr. Surendra R. Patil)
Professor (Horticulture)
Department of Fruit Science
College of Horticulture
Dr. P D. K. V., Akola (M.S.)

3. Anita Surendra Patil, Ankit Subhash Kale, Surendra Rajaram Patil, Hariprasad Madhukarrao Paikrao (2016). Validation of accumulation of camptothecin content, an anti-cancer alkaloid in *Nathopodytes nimmoniana* graham. In phenotypic variants: method for identifying high-yielding sources of alkaloid. International Journals of Pharmacy and Pharmaceutical Sciences. Vol 8,Issue 9, pp 19-23.

Paper presented in conferences/symposia: 04

1. Mahure, S. M, Patil A.S. and Patil SR. Extraction and HPLC purification of anticancer drug camptothecin from Nathopodytes nimmoniana.101 Indian Science Congress,2-7 Feb, 2014. Abs no 176, section XIV-plant Science, University of Jammu.
2. Anita Patil, Surendra Patil, Ankit Kale. Process optimization for *In Vitro* Production and Confermation of Camptothecin –an anticancer frug from Nathopodytes nimmoniana.4th *Bhartiya Vigyan Sammelan & Expo* 2015. 6th -8th February 2015,Goa Organized by Vigyan Bharti Government of goa; Goa University. National
3. Anita Patil –"Validation of Accumulation of Camptothecin Content, An Anticancer Alkaloid In Nathopodytes nimmoniana Graham. In Phenotypic Variants: Method for Identifying High-Yielding Sources of Alkaloids" OP 45 National Conference of " Plant Diversity: Past and Present(Pdpp-2016)", held during 30th-31st December,2016 Dept of Botany,SGBAU.
4. Anita Patil and Ankit Kale –Validation of Antiurolithiatic Potential of Abutilon Indicum(L.) and Passiflora Incarnata. OP51.". National Conference On plant Diversity Past and Present(Pdpp-2016)", held during 30th-31st December,2016 Dept of Botany,SGBAU.

(d) Other impact, if any : Nil

SIGNATURE OF PRINCIPAL INVESTIGATOR
Dr. Anita S. Patil
Professor
Department of Biotechnology
Sant Gadge Baba Amravati University
Amravati (M.S.)

SIGNATURE OF CO-INVESTIGATOR
(Dr. Surendra R. Patil)
Professor (Horticulture)
Department of Fruit Science
College of Horticulture
Dr. P. D. K. V., Akola (M.S.)

REGISTRAR/PRINCIPAL
REGISTRAR
Sant Gadge Baba
Amravati University,
Amravati.
(Seal)

An inexpensive Method for the determination of oxalate in rine and assessment of hyperoxaluria by nano-based paper strip technique (RGSTC/File-2011/DPP-166/CR-42 dated 27/2/2017)

UTILIZATION UPTO 31/8/2019

SUMMITTED TO

Rajiv Gandhi Science and Technology Commission (RGSTC)
Government of Maharashtra, Mumbai-400032

SUMMITTED BY

Dr. Anita Surendra Patil
Professor & Principal Investigator
Department of Biotechnology

Dr. Gajanan G. Muley
Assistant Professor and Co-Investigator
Department of Physics

Sant Gadge Baba Amravati University,
Amravati 444602(M.S)

Dr.Hariprasad M. Paikrao
Assistant Professor and Co-Investigator
Government Institute of Forensic Science, Aurangabad

RAJIV GANDHI SCIENCE & TECHNOLOGY COMMISSION
GOVERNMENT OF MAHARASHTRA, MUMBAI
UTILIZATION CERTIFICATE
FOR THE FINANCIAL YEAR 2018-2019

1. Title of Project: **An inexpensive Method for the determination of oxalate in urine and assessment of hyperoxaluria by nano-based paper strip technique'**

2. Name of the Institution : Department of Biotechnology, Sant Gadge Baba Amravati University, Amravati, Maharashtra (India)

3. Principal Investigator : Dr. Anita Surendra Patil, Professor, Dept. of Biotechnology,SGB Amravati University, Amravati,444602
Co-Investigator : Dr. Gajanan G. Muley, Assistant Professor, Dept. of Physics, SGB Amravati University, Amravati 444602
Co-Investigator : Dr. Hariprasad Madhukarrao Paikrao, Assistant Professor, Government Institute of Forensic Science, Aurangabad (M.S)

4. RGSTC Sanction latter No & Date Sanctioning the Project : No: RGSTC/File-2011/DPP-166/CR-42 dated 27th March 2017

5. Amount brought forward from the previous financial year quoting RGSTC letter no. and date in which the authority to carry forward the said amount was given :
i) Amount : **Rs. 1,72561=00**
ii) Letter No : RGSTC/File-2011/DPP-166/CR-42
iii) Date : 8/1/2019

6. Amount Received during the financial year 2018-2019:
i) Amount : Rs.**6,60000**=00
ii) Letter No : RGSTC/File-2011/DPP-166/CR-42
iii) Date : 8/1/2019

7. Total amount that was available for the expenditure : **Rs. 8,32561=00**

8. Actual Expenditure (excluding commitments) Incurred during the financial Year 2018-2019. : **Rs. 7,70639=00**

9. Balance amount available at the end of the financial year : **Rs.** 61,922=00

10. Unspent balance refunded, if any (details of cheque no.etc): Nil

11. Amount to be carried forward to the next financial year **Rs.** 61,922=00

UTILIZATION CERTIFIACTE

Certified that out of Rs. **660000=00** (Six lakh and sixty thousand only) of grants-in-aid sanctioned during the year 2018-2019 in favor of **PI-Dr. Anita Surendra Patil** under this commission/Department letter/order No: RGSTC/File-2011/DPP-166/CR-42 dated 27/3/2017, and unspent balance of the previous year **Rs. 1,72561=00 (One lakh seventy two thousand five hundred and sixty one only)** and **interest (Nil)**, a sum of **Rs. 7,70639=00 (Seven lakh seventy thousand six hundred and thirty nine only)** has been utilized for the purpose for which it was sanctioned and that the balance **Rs. 61,922=00 (Sixty one thousand nine hundred and twenty two only)** of remaining unutilized at the end of the year will be adjusted towards the grants-in-aid payable during the next year i.e. 2019-2020.

Sign of PI
Date:

Dr. Anita S. Patil
Professor & Prin. Investigator
MRP-RGSTC (Mumbai)
Department of Biotechnology
Sant Gadge Baba Amravati University
Amravati (M.S.)

Sign of Head Account officer of University
Date:

FINANCE & ACCOUNTS OFFICER
SANT GADGE BABA AMRAVATI UNIVERSITY,
AMRAVATI.

Registrar
Date:

Registrar
Sant Gadge Baba
Amravati University

Detail Statement of Expenditure
For Financial Year (1/4/2018 to 31/8/2019)

Sr. No (I)	Sanctioned Heads (II)	Carry forward Amount for II[nd] year	Funds allocated (Indicate Sanctioned or revised in Rs.**6,60,000=00** (Total project fund) (III)	Expenditure Incurred in 2018-19	Balance as on 31/8/2019	Remark if any
1	Salaries/Wages		Amount Received 2[nd] Year	2[nd] Year		Rs. 61,922=0 forwarded for 2019-2020
2	Equipment	Nil	Nil	Nil	Nil	
3	Staff Salary	77468=0	3,36000 =00	3,99468=00	14,000=00	
4	Consumables	4742=00	2,00,000=00	1,65854=00	38,888=00	
5	Travels-PI	1070=00	20,000=00	12,036=00	9,034=00	
6	Analytical Charges	Nil	24,000=00	24,000=00	Nil	
7	Contingencies	Nil	30,000=00	30,000=00	Nil	
8	Overheads	89,281=00	50,000=00	1,39,281=00	Nil	
	Total	**Rs. 1,72561=00**	**Rs. 6,60000=00**	**Rs. 7,70639=00**	**Rs.61,922 =00**	

Sign of PI
Date:
Dr. Anita S. Patil
Professor & Prin. Investigator
MRP-RGSTC (Mumbai)
Department of Biotechnology
Sant Gadge Baba Amravati University
Amravati (M.S.)

Sign of Head Account officer of University
Date:
FINANCE & ACCOUNTS OFFICER
SANT GADGE BABA AMRAVATI UNIVERSITY,
AMRAVATI.

Registrar
Date.
Registrar
Sant Gadge Baba
Amravati University

No.DST/INT/AGR/P-03/2015
Government of India
Ministry of Science & Technology
Department of Science & Technology
(International Division)

Dated 19.06.2015

ORDER

Sanction of the President is hereby accorded for incurring an expenditure not exceeding **Rs. 11,94,000/- (Rupees eleven lakh ninety four thousand only)** in connection with the implementation of Indo-Argentina Joint research project entitled **"Biosynthesis of silver nanoparticles, the nanofunctionalization by essential oils and evaluation of . . . . . leading to formulation of antimicobials",** under the Indo-Argentina programme of Cooperation to be implemented by Indian P.I. Dr. Mahendra Rai, Department of Biotechnology, SGB Amravati University, Amravati, Maharashtra-444602. in collaboration with Argentinean counterpart Dr. Susana Zachino, Pharmacognosy Are, Faculty of Biochemical and Pharmaceutical Sciences, Suipacha, National University of Rosario, Rosario, Argentina, for a total duration of three years from the date of receipt of initial grant .

The composition of the team is as under:-

	Indian Side Co-PI		Argentinean Side Co-PI
Co-PI-I	Dr. A.K. Gade, Asstt. Prof. Amravati University, Amravati, Maharashtra	Co-PI-I	Dr. Marcos DeritaNational University of Rosario, Argentina

The break-up of approved expenditure is as indicated below and no reappropriation (from one budget head to the other) shall be allowed under this project

Sl. No.	Budget Head	1st yr	2nd yr	3rd Year	total
1.	Number of visits (1 every year in each direction)	1 visit	1 visit	1 visit	3 visits
2.	Air Far Int'l' air travel (shortest route) by lowest Economy class (to & fro) for visit of Indian participants to Argentina including Domestic travel in India, Silver class medical insurance and visa fee @ Rs. 2,00,000/- per visit. (1st & 3rd visit of 21days each & 2nd visit of 90 days by Indian PI/Student/Young researcher)	2,00,000	2,00,000	2,00,000	6,00,000
3.	Lodging & boarding for Argentina Scientist in India Accommodation charges @ Rs. 2000/- per day	42,000	1,80,000	42,000	2,64,000
4.	Living allowance (per diem) @ Rs. 2500 per day for short term visit and Rs. 60,000 per month for long term visits incldg. expenses towards local travel, airport transfer etc. (1st & 3rd visit of 21days each & 2nd visit of 90 days by Argentina /Student/ researcher)	52,500	1,80,000	52,500	2,85,000
5.	Consumables and Contingencies	15,000	15,000	15,000	45,000
6	Total :- (2+3+4+5+)	3,09,500	5,75,000	3,09,500	11,94,000

2. Sanction of the President is also accorded for release of initial grant of Rs. **3,09,500/- (Rupees three lakh nine thousand five hundred only)** and the payment of this amount may be made to DDO, DST by means of electronic transfer(E-transfer) for the account of **Registrar, SGB Amravati university, Amravati. Maharashtra**.

Contd. . . P/2

-Name/Designation of account holder : **Registrar, SGB Amravati university, Amravati.**
-Bank Account No. : **20115413704 (S/B)**
- Name of Bank & Address : **Bank of Maharashtra, SGB University Branch,Tapovan Road Amravati**
- IFSC Code : **MAHB0001331**
-MICR Code : **444014001**

(This sanction order being 1st installment for implementation of this project, no UC/ SE is due from the grantee institute against this project at this stage).

3. **Under the existing terms and conditions, sending side will bear the international air travel (air tickets and host side will bear the cost of lodging and boarding including perdiem of the scientist visiting under the project.**

4. All project related Visits to be undertaken by the scientists from either side in connection with the implementation of the project shall require prior approval from this Department separately on a case to case basis before any expenditure is incurred in this regard.

5. As per MOF instructions dated 13.07.2009 all cases of air travel both domestic and international, the officials may travel only by Air India. For travel to stations not connected by Air India the officials may travel by Air India to the Hub/Point closest to their eventual destination, beyond which they may utilize the services of another airline which should also preferably be an alliance partner of Air India.

6. The institute will maintain separate audited accounts for the project and the amount of grant will be kept in a bank account earning interest. The interest earned should be reported to DST while submitting the Statement of Expenditure/Utilization Certificate. The interest thus earned will be treated as a credit to the institute to be adjusted towards further installment of the grant.

7. This sanction is subject to submission of Utilization Certificate (UC) and audited statement of the expenditure(SE) along with up to date progress report at the end of each financial year for the grants already received under the project and seeking specific approval of this Department for carry forward of unspent funds to the next financial year for utilization of project and list of exchange visits of scientists under the project.

8. **As per latest instructions of Ministry of Finance (Department of Expenditure), Agencies will have to enter & upload the Utilization Certificate in PFMS portal besides sending it in physical form to this Division. The next installment will be released only after confirmation of the entry of Utilization Certificate in the PFMS**

9. As per rule 211 (i) of GFR, the accounts of the project shall be open to inspection by sanctioning authority/audit whenever the institute is called upon to do so.

10. The expenditure involved shall be met out of the budget head under Demand No.86-Department of Science and Technology -3425-Other Scientific Research (Major Head) 60.798 International Cooperation (Minor Head) -12-S&T Cooperation with Other Countries-12.00.31-Grants-in-aid (Plan) during the year 2015-2016.

11. This issues under the delegated powers to the Ministries/Departments and with the concurrence of IFD vide Dy. No. C/1235 /IFD//2015-2016, dated 11.06.2015.

12. This Sanction Order has been entered in Grant in aid Register (2015-16) at Sl. No. 207

(Dr. Jagdish Chander)
Scientist'G'

Contd. . . P/3

To

The Pay & Accounts Officer,
Dept. of Science and Technology, New Delhi

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4. Registrar, SGB Amravati university,Tapovan Road, Amravati-444602, Maharashtra.
5. Dr. Mahendra Rai, Department of Biotechnology, SGB Amravati University, Tapovan Road, Amravati-444602, Maharashtra.
6. Sanction folder.

(Dr. Jagdish Chander)
Scientist'G'

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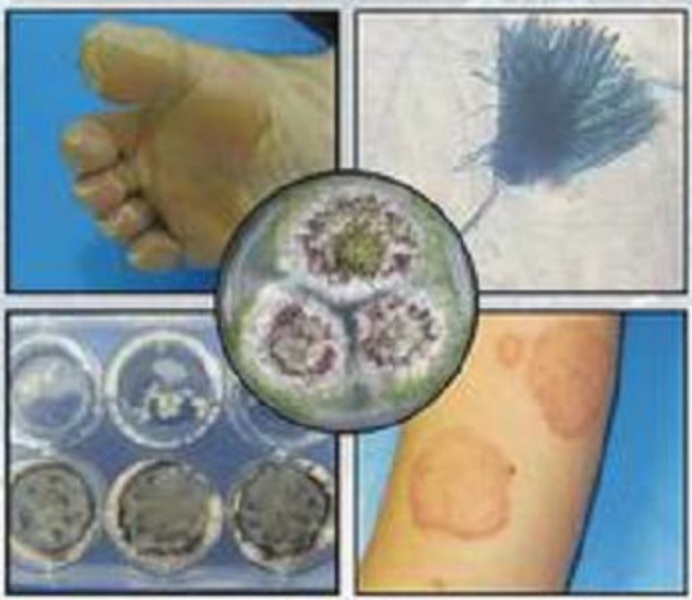

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Mechanisms and New Antimicrobial Approaches

By Kateryna Kon, Mahendra Rai · 2016

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ISBN:	9780128036686, 0128036680	Page count:	436
Published:	14 June 2016	Format:	E-book
Publisher:	Elsevier Science	Language:	English
Author:	Kateryna Kon, Mahendra Rai	Editors:	Kateryna Kon, Mahendra Rai

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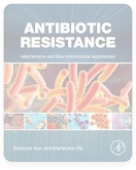

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Originally published: 14 June 2016

Editors: Kateryna Kon, Mahendra Rai

Subject: Medical / Pharmacology, Medical / Microbiology, more

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Search Kateryna Kon

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Dr Mahendra Rai is Professor and Head of the Department of Biotechnology at Amravati University in Maharashtra, India. He has approximately three decades of teaching and research experience. The main focus of his research is plant and nano-based bioactives against human pathogenic microbes.

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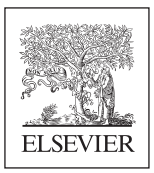

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Nanotechnology for Bioenergy and Biofuel Production

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ISSN 2196-6982 ISSN 2196-6990 (electronic)
Green Chemistry and Sustainable Technology
ISBN 978-3-319-45458-0 ISBN 978-3-319-45459-7 (eBook)
DOI 10.1007/978-3-319-45459-7

Library of Congress Control Number: 2016959554

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

There is a greater need to search for alternative sources of energy due to the limited availability of fossil fuels. The use of biofuels is the common alternative in front of the whole world, and its use is significantly increased in many countries. Generally, biodiesel is used as a fuel for diesel engines due to its technical, environmental, and strategic advantages. Apart from these, biodiesel is technically competitive with conventional, petroleum-derived diesel fuel and requires virtually no changes in the fuel distribution infrastructure. Other advantages of biodiesel as compared to petrodiesel include reduction of most exhaust emissions, biodegradability, higher flash point, inherence, and the fact that it is of domestic origin. However, ethanol is mostly used for Otto cycle engines as an alternative to gasoline.

Nanotechnology is one of the most important research areas in the twenty-first century. The potential applications of nanobiotechnology in the production of sustainable bioenergy and biosensors have encouraged researchers in recent years to investigate new novel nanoscaffolds to build robust nanobiocatalytic systems. Different kinds of nanomaterials have been developed as per the need for application purpose.

Various metal nanomaterials are found to have direct or indirect application in the production of biofuels. Among these, nanoparticle-mediated enzyme hydrolysis of lignocellulosic residues for the production of ethanol is in practice. Magnetic and metal oxide nanoparticles such as TiO_2, ZnO, SnO_2, etc. are commonly used matrices for enzyme immobilization. Magnetic nanoparticles are found to have potential uses in the field of biofuel and bioenergy, i.e., in the production of bioethanol from lignocellulosic materials by immobilization of enzymes like cellulases and hemicellulases by physical adsorption, covalent binding, cross-linking, or specific ligand spacers. Such nanomaterials are generally called as nanocatalysts, which are fabricated by immobilizing enzymes with functional nanomaterials as enzyme carriers.

The book would be immensely useful for a diverse group of readers including physicists, chemists, microbiologists, biotechnologists, food technologists, agriculture engineers, nanotechnologists, and those who are interested in clean technologies. The students should find this book useful.

Amravati, Maharashtra, India — Mahendra Rai
Lorena, SP, Brazil — Silvio Silvério da Silva

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Nanotechnology Applied To Pharmaceutical Technology

Mahendra Rai · Carolina Alves dos Santos
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Nanotechnology Applied To Pharmaceutical Technology

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ISBN 978-3-319-70298-8 ISBN 978-3-319-70299-5 (eBook)
https://doi.org/10.1007/978-3-319-70299-5

Library of Congress Control Number: 2017957191

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
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Preface

Pharmaceutical technology is based on the use of different technologies for the preparation and development of pharmaceutical products. It is a branch of the pharmaceutical sciences constantly linked to the development and use of innovative technologies for the production and development of products with maximum effectiveness, adequate dosage, and stable formulations, aiming at different applications in living beings.

Nanotechnology is a recent, highly interdisciplinary and versatile branch of science that allows to develop products with interesting and novel structural characteristics totally different from those obtained by the compounds in their conventional form, a fact that attributes differentiated properties and specific interaction mechanisms, which adds technological value to the newly developed products. Thus, the use of nanotechnology in the pharmaceutical science promotes the design and development of products known as nanopharmaceuticals, which are composed of nanoscale properties with slow drug release systems, as stabilizers of formulations, pharmaceutical activities, or systems for detection and evaluation. The possibility of obtaining different mechanisms of response provided by the nanotechnologically developed products allows varied combinations enriching the range of products to be developed from this technology.

In this context, the book seeks to integrate the pharmaceutical sciences with nanotechnology as a way to obtain innovative products and solutions applied to the pharmacy. It provides the reader with a broad vision where nanotechnology is employed with different perspectives and applications. This approach focuses on the application of nanotechnology in pharmaceutical technology and also represents an interdisciplinary nature that can be used by people interested in expanding their knowledge in applied nanotechnology.

The present book is highly interdisciplinary and would be very useful for a diverse group of readers including pharmacologists, nanotechnologists, microbiologists, biotechnologists, clinicians, and those, who are interested in development of nanoproducts. The students should find this book useful and reader-friendly.

Amravati, India — Mahendra Rai
Sorocaba, Brazil — Carolina Alves dos Santos

The original version of the book was revised.
The incorrect country name in preface "Sorocaba, India"
has been corrected as "Sorocaba, Brazil".

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Biomedical Applications of Metals

Springer

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ISBN 978-3-319-74813-9 ISBN 978-3-319-74814-6 (eBook)
https://doi.org/10.1007/978-3-319-74814-6

Library of Congress Control Number: 2017964444

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature
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Mahendra Rai · Jayanta Kumar Biswas
Editors

Nanomaterials: Ecotoxicity, Safety, and Public Perception

Springer

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ISBN 978-3-030-05143-3 ISBN 978-3-030-05144-0 (eBook)
https://doi.org/10.1007/978-3-030-05144-0

Library of Congress Control Number: 2018962789

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Foreword

Nanotechnology is an important and enabling technology today. With the confluence of ideas from diverse disciplines, it is anticipated to positively affect various facets of our lives. Nanomaterials derive their strength by harnessing the property, which with decrease in particle size surface area of materials increases, and some novel properties emerge. This fundamental premise paves way to many possibilities as envisioned by Richard Feynman, "There is Plenty of Room at the Bottom" for "manipulating and controlling things on a small scale". Nanomaterials are expected to enable many innovations in the form of diverse devices, processes and products in the domains of medicine, energy, environment, and others.

The last two decades or so have witnessed a burst of interest and activity in synthesis, characterization, and application of nanomaterials. There is much scope for developing ecotoxicological information. The nanomaterials could interact with different biotic and abiotic factors in the environment and cause adverse biological and ecological effects at different levels. To assess environmental risks, scientific data and knowledge on transport of nanomaterials in the environment and their effects on health are to be properly examined.

Future development of nanotechnology should be accompanied with research on (eco)toxicity associated with possible risks by analyzing behavior and fate of nanomaterials in the ecosystem inclusive of its biotic organisms and human health. There must be a reasonable concern about plausible and potential hazards, based on scientific investigation.

Given the vibrancy of nanoscience and technology, the edited book entitled *Nanomaterials: Ecotoxicity, Safety, and Public Perception* is a topical and useful book providing the state of knowledge on ecotoxicity of nanomaterials and safety issues. The book consists of 17 chapters arranged in three sections dealing with ecotoxicity, risk, and safety issues, regulations and public perceptions. All the chapters have been written by experts from different countries, who have offered authoritative treatments of nanoecotoxicological aspects. It has dealt with nanomaterials in food, soil, medicine, and unintentionally produced nanomaterials, and addresses key issues of ecotoxic effects of nanomaterials on life and environment

including humans. It has iterated the need for an increased level of understanding of risks and vulnerabilities that are likely to influence public, regulatory, and non-governmental activities. The book has been designed with adequate coverage for a multisectorial audience of academics, researchers, students, professionals, and policy-makers. I congratulate the editors for their endeavor in producing this useful book.

Bangalore, India

C. N. R. Rao
Linus Pauling Research Professor

Preface

Nanoscience and nanotechnology refer to the control and manipulation of matter at nanometer dimensions for tailoring and hybridizing the physical, biological, and engineering properties of matter. It is a burgeoning, vibrant, and promising field which has offered the possibilities and stunning new achievements as envisioned by Richard Feynman (1959): "There is plenty of room at the bottom". Nanotechnology is not only an emerging field of study, it has become an industry with transforming effects. The use of nanomaterials is expected to offer great promise for diverse devices, procedures, and products in the domains of consumer goods, medicines, energy, environment, and many others. But there is the other side of the coin; the environment is prone to suffer from nanopollution and toxic insult due to release and build up of nanocontaminants during different phases of lifecycle of nanomaterials, viz., production, transportation, disposal, entry into ecosystems, accumulation, bioconcentration, transfer across trophic boundaries, etc. The NMs raise the possibility that they could interact with and cause adverse biological effects at cellular, subcellular, and molecular levels. Assessing potential environmental/ ecological risks requires quality information on transport and fate of nanoparticles in the environment, exposures, and vulnerabilities of organisms to the nanomaterials and standard methods for assessing toxicity for aquatic or terrestrial organisms and human health. Nanomaterial toxicity is extremely complex, and our understanding about ecotoxicity is very fussy and incomplete. The systematic risk characterization and evaluation of the safety of nanomaterials require a multidisciplinary approach and convergence of knowledge and efforts from researchers and experts from toxicology, biotechnology, materials science, chemistry, physics, engineering, and other branches of life sciences. Although studies are beginning to appear in the literature addressing the toxicity of various nanomaterials and their potential for exposure, at this stage definitive statements regarding the impacts of nanomaterials on human health and the environment remain sketchy and scanty. Because of our limited understanding of the environmental implications of nanomaterials, there remains a gulf between their promises and pitfalls although the flourishing development of new nanomaterials as well as emerging new applications. No doubt present time demands a clarion call for an increased level of

precautions with regard to nanomaterials, as has happened with other emerging contaminants and technologies (e.g., biotechnology). The perceptions of risks and of benefits will vary and are likely to influence public, regulatory, and non-governmental activities regarding risk and benefit evaluations. The Triple Helix, i.e., academia, government, and industry, needs to be extended to a fourth dimension, the civil society, because of the latter's role and relevance in today's world. Since people are receptive to fictional representations as they shape their imaginaries, the "nanomania" has rather alienated the entertainment and leisure industry, and given rise to misconceptions, misunderstandings, and distorted views regarding this particular technology rather than contributed to a rational and genuine discussion. *Quo vadis*? Where will we go? Systematic identification and assessment of the risks posed by any new technology are essential. Systematic research into the flip side of this new technology, especially the risks that it entails, is essential. A prudent, integrated, and holistic approach is required to develop best practices based on the scientific understanding about what we know and what we don't know but need to know so that the engines of creation would not become the engines of destruction.

With suitable breadth of coverage, this edited book has been *designed, written, and organized* for the broad-spectrum multisectorial audience of researchers, students, professionals, and policy-makers. It is expected to be a pointer and reference resource and will cater to the needs of the researchers, professionals as well as the graduate and postgraduate students of nearly every discipline of science and engineering—toxicology, biotechnology, chemistry, physics, biology, medical science, material science & engineering, environmental science, and environmental engineering, who are interested to know the ecotoxicological aspects of the nanomaterial and the potential hazards and risks involved therein. This book would be an inspirational comprehensive resource for researchers, environmental professionals and practitioners as well as industrial portfolio holders, who are interested to earn a working knowledge of this fascinating field of Nanotechnology and Nanotoxicology.

This book includes important chapters written by specialists and experts in the concerned topic, and hopefully it will win wide acceptance among the undergraduate and graduate students of chemistry, biochemistry, pharmacology, microbiology, biotechnology, and allied subjects. It will be very useful for researchers working in nanotechnology, nanobiotechnology, toxicology, microbiology, ecology, and other related fields.

Last but not the least, we hope, this edited book surely will evoke some surprise and shock, hope and despair, and stimulate resolution and action through concerted and collaborative efforts of appropriate bodies to shape the nanoworld and save Mother Nature.

Amravati, India — Mahendra Rai
Kalyani, Nadia, India — Jayanta Kumar Biswas

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Mahendra Rai is a Senior Professor and Basic Science Research Faculty Fellow (UGC) at the Department of Biotechnology, Sant Gadge Baba Amravati University at Amravati, Maharashtra, India. He was a Visiting Scientist at the Department of Bioenergetics, University of Geneva, Switzerland and at the Department of Plant Protection of Debrecen University, Debrecen, Hungary. He visited the Department of Chemical Biology, University of Campinas, Brazil under Indo-Brazil Research Programme (DST-CNPq collaboration). He was Visiting Professor in Nicolaus Copernicus University, Torun, Poland and was invited by State University of Campinas, Brazil. He was also Visiting Professor in Ostrava, Czech Republic, and Department of Pharmacognosy, University of Rosario, Argentina.

His area of expertise includes microbial biotechnology and nanobiotechnology. His present research interests are nanobiotechnology in medicine and agriculture. He has published more than 380 research papers in national and international journals. In addition, he has edited/authored more than 47 books and 6 patents.

Jayanta Kumar Biswas is an Associate Professor at Department of Ecological Studies and International Centre for Ecological Engineering, University of Kalyani. He obtained M.Sc. in Zoology, M.Phil. in Ecology, and Ph.D. on ecotechnological management of aquatic systems. His interest and expertise span the following focal areas: ecotoxicology and bioremediation of toxic metal(loid)s; ecological engineering and ecotechnological remediation of water and soil contaminants; environmental microbiology; nanobiotechnology. He received many awards and fellowships including Fellow, National Environmentalists Association, Zoological Society of India, Zoological Society, Kolkata, Senior Scientist Award & Gold Medal (ZSI), Best Research Paper Award (AESA), Outstanding Reviewer Award (Chemosphere (Elsevier) & Environmental Geochemistry and Health (Springer); National Merit Scholarship (MHRD, GoI), etc. He is credited with publishing 125 research papers in reputed journals. He is serving as editorial board member of several international journals of repute, namely Science of the Total Environment (Elsevier); Environmental Geochemistry and Health (Springer); Current Pollution Reports (Springer); Energy & Environment (SAGE).

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Part I
Ecotoxicity

Chapter 1
Nanomaterials: What Are They, Why They Cause Ecotoxicity, and How This Can Be Dealt With?

Mahendra Rai, Indarchand Gupta, Avinash P. Ingle, Jayanta Kumar Biswas and Olga V. Sinitsyna

Abstract Nanomaterials have been benefiting human by their wide applications in different fields. Till date, many types of natural and engineered nanomaterials have been reported. Each of them has specific characteristics, which are helpful in deciding their use for particular application. Although they are beneficial to the human beings, there is probability of their harmful effects on the ecosystem. After the desired use of the nanomaterials, they are routinely disposed of into the environment either intentionally or unintentionally. This scenario can create the harmful environment for the whole ecosystem. The ecotoxicity of nanomaterials is an imperative point to be considered for the safety of flora and fauna. Hence, with argument on their characteristics and applications, their safety for human and environment should also be considered. Therefore, the present chapter introduces the nanomaterials, encompasses the discussion on major types of nanomaterials, which are being available naturally and others that are synthesized artificially. The parameters which make

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M. Rai and J. K. Biswas (eds.), *Nanomaterials: Ecotoxicity, Safety, and Public Perception*, https://doi.org/10.1007/978-3-030-05144-0_1

nanoparticles harmful to ecosystem have also been discussed. Moreover, the special emphasis is given on how the scientific community can deal the situation to avoid the harmful effects of nanoparticles so that it can be beneficial to mankind without causing any damage to ecosystem.

Keywords Nanoparticles · Engineered nanomaterials · Toxic effects · Ecotoxicity

1.1 Introduction

Materials, which consist of particles with at least one dimension smaller than 100 nm, are called nanomaterials. The era of the increasing popularity of the nanomaterials began with the discovery of fullerenes in 1985 by Harold Kroto, James Heath, Sean O'Brien, Robert Curl, and Richard Smalley (Kroto et al. 1985). According to The Nanodatabase (2018), commercial products containing fullerenes are already on the market. These are rackets for tennis and badminton, and skin care products. Another database, The Nanotechnology Consumer Product Inventory, was created in 2005 to document the emergence of nanotechnology products in the consumer market (Vance et al. 2015). The number of products in the Inventory is constantly growing. The most advanced category for the introduction of nanomaterials is the Health and Fitness. Oxides of titanium, silicon and zinc are the most produced nanomaterials worldwide, and silver nanoparticles (AgNPs) are the most popular additive in products (Vance et al. 2015). The nanoparticles act as antimicrobial agents, pigments, UV filters, protective coatings, reinforcing additives, etc. The global market of the nanomaterials is growing rapidly. According to a pessimistic forecast, its value will reach $11.3 billion in 2020, and an optimistic forecast predicts the market value of $55.0 billion in 2022 (Inshakova and Inshakov 2017).

The active use of the nanomaterials raises the question of their safety for the environment. The first publication considering the potential ecological impacts of the engineered nanomaterials appeared after more than 15 years of the widespread development of nanotechnology (Colvin 2003; Skjolding et al. 2016). A new discipline, nanoecotoxicology, began to study the environmental effects of nanoscale materials. The evaluation of the behavior and fate of the nanomaterials in complex environmental matrices is an extremely challenging problem (Boyes et al. 2017). The possible release of the nanoparticles into the environment should be considered across the entire life-cycle of a product, including manufacture, use, and disposal. The nanoparticles can possess not only advantageous but also unique toxic properties different from the bulk materials. Potential adverse effects should be taken into account from the cellular level to the whole ecosystem. The environmental hazard evaluation, based on dose-by-mass, may not be valid for the nanomaterials, and the question on the relevant dose-metrics in nanoecotoxicology is still open.

How to use the gifts of nanotechnology and protect the environment from the possible harmful effects is one of the most pressing issues of today. In the present chapter, we try to answer these major questions.

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Editors

José L. Martinez

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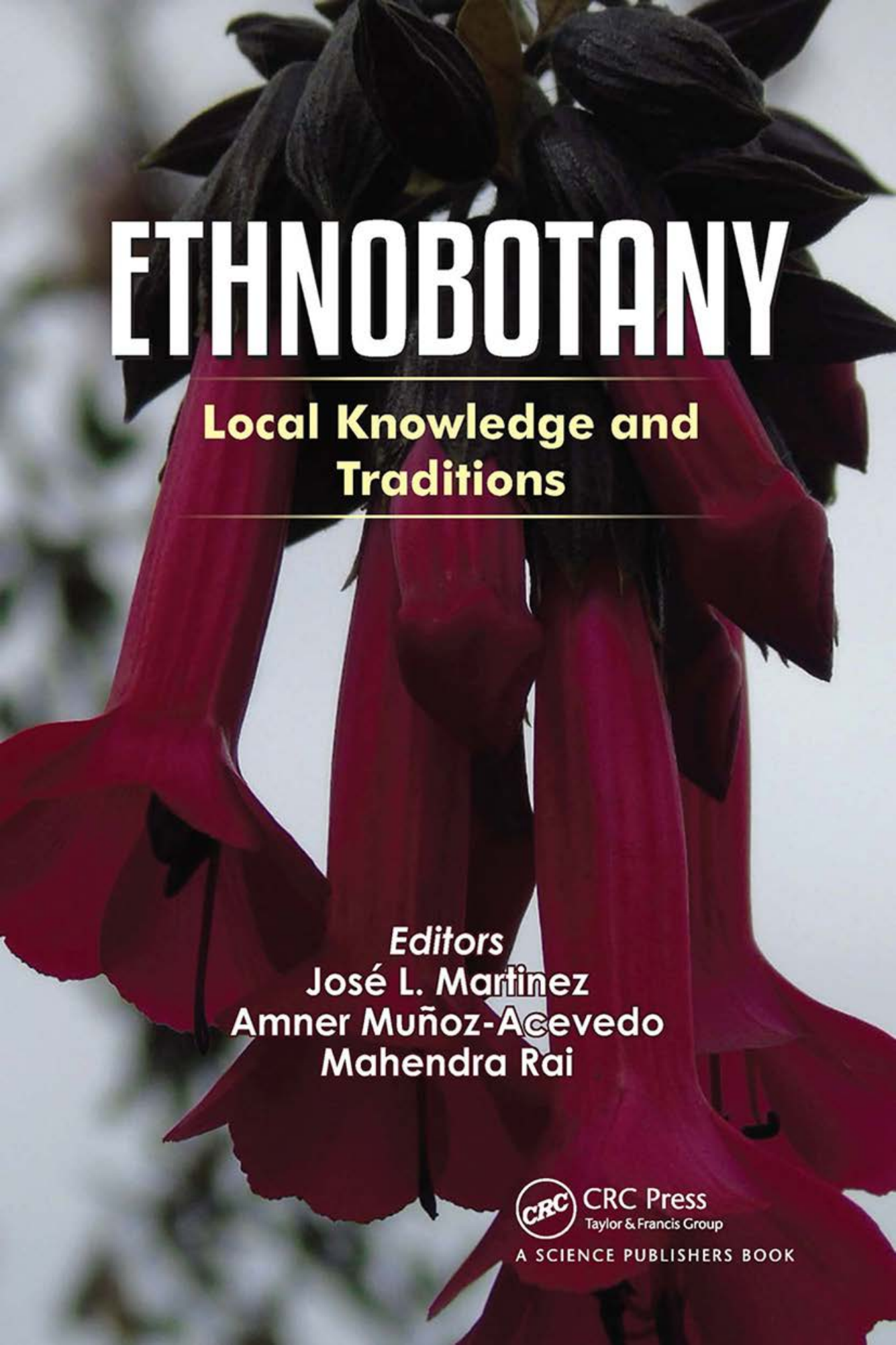
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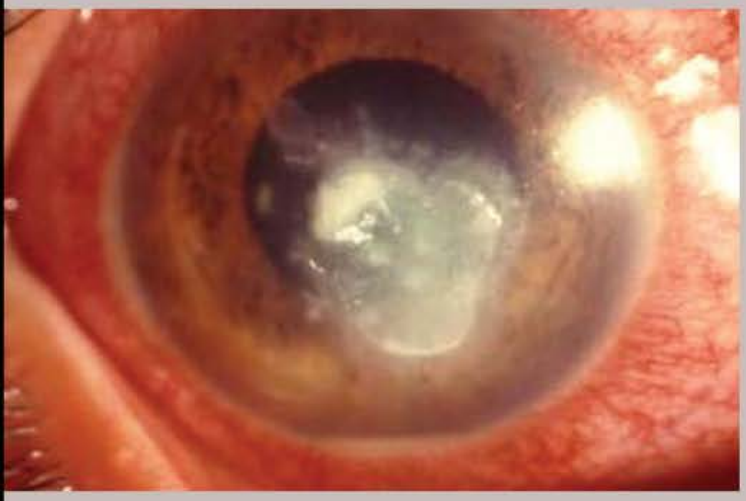

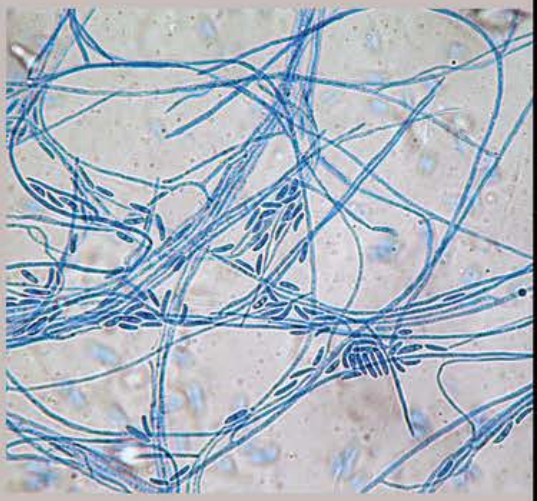

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ISBN 978-3-030-41857-1 ISBN 978-3-030-41858-8 (eBook)
https://doi.org/10.1007/978-3-030-41858-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

In the era of the Fourth Industrial Revolution, several technologies are poised to bring swift changes in the approach and the living style of mankind. Nanotechnology is one of such fields that has multifaceted applications in healthcare ranging from medicines, surgical materials to devices and even means to prevent diseases. Initially, nanotechnology was looked upon for novel and targeted drug delivery systems, but now it is used for precision medicine for prevention of disease through appropriate medical gazette.

The book entitled *Nanoformulations in Human Health: Challenges and Approaches* edited by Dr. Sushama Talegaonkar and Dr. Mahendra Rai focusses on the application of nanoformulations in human healthcare. The authors have dedicated years in the field of nanomedicine and have carried out original research work achieving numerous milestones in their professional journey. They have helped many students and scholars in this field. This book reflects dedication, hard work, and collaborative efforts of the authors. I congratulate the authors and contributors for ensemble of in-depth information in simple language. I am sure that the book will prove to be useful to healthcare specialists including researchers, scholars, and academicians.

This book provides comprehensive information of nanomedicine with special emphasis on drug targeting, theranostics, chronic disorders, and topical afflictions. There is a specific emphasis on preformulation of active pharmaceutical ingredients, advantages of nanoformulations over conventional therapy, and formulation, characterization, and application of various nanocarriers. Parts have been dedicated entirely on various routes of drug delivery like ocular, topical, and nose-to-brain targeting along with elaborate chapters covering diseases like glaucoma, epilepsy, colonic ailments, candidiasis, neuropathic pain, respiratory disorders, tuberculosis, and cancer.

R. K. Goyal
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Preface

Nanotechnology, i.e., the science of nanosized agents, is one of the fastest-growing fields which is on its way of giving breakthroughs to the healthcare industry. Nano-agents usually are in the size range of 1–100 nm. Owing to their extremely small size and majorly large surface area, they possess distinct special characteristics which enable them to do wonders in biomedical applications. Characteristics like ability to cross the cell membrane and increased reactivity make them more useful than conventional therapy. Particularly in biomedical sciences, nanotechnology can be used for therapy and diagnostics. In addition to their therapeutic properties, they are more commonly used to carry the therapeutic agents to the diseased site in the body, thus achieving targeted therapy. Delivery of drugs through a nano-agent directly to the target site also results in a decrease of the required dose of the active agent. More recently, the application of nanotechnology has been explored for monitoring the progress and success of therapy inside the body. Many countries are now investing in developing nanotechnology for healthcare applications. For instance, the first generation of cancer drugs delivered via nanoparticles has already been approved by the US Food and Drug Administration (FDA).

However, nanoformulation for healthcare is also a topic of hot debate as this minute size also brings the concern of toxicity. Though regardless of the varying opinions, the research and development have actively been going on to take nanotechnology to the commercial level to be used for the benefits of the health of humans.

The main goal of the book titled *Nanoformulations in Human Health: Challenges and Approaches* is to serve as a complete reference guide to understand the role of nanotechnology in the healthcare system and as a ready reference for all aspects related to the theme. The book is intended to provide a multidisciplinary approach signifying the role of nanosizing in the treatment of various challenging diseases. It is planned to highlight the pathophysiology of disease with special emphasis on various targets, receptors, biomarkers, and transporters associated with the disease. Young researchers/scientists who plan to initiate research in this important field would find this book extremely relevant and handy. Each chapter of this book will be immensely useful to identify the new targets for drug delivery systems and drug discovery. This book is a true amalgamation of the experience and

expertise of all the contributors in the field of nanotechnology especially in designing novel nanoformulations in the treatment of various challenging diseases. It is an exhaustive compilation of the multifaceted arena of nanoformulations in the healthcare system.

This book includes six parts concerning nanoformulations: Part I includes emerging trends and challenges in the area; Part II describes their role in drug targeting; Part III incorporates applications in ocular diseases; Part IV deliberates role in topical diseases; Part V discusses their role in natural therapeutics delivery; and finally, Part VI focuses on other applications such as in respiratory diseases, tuberculosis, and cancer.

The book would cater to the needs of postgraduate students of pharmacy, nanotechnology, and biotechnology, medical students, and researchers. In addition, the book will also be very useful for the pharmaceutical industries, regulatory bodies, pharmacy, medical institutes, etc. involved in research and development activities related to drug discovery, newer treatment modalities, and technology.

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Priority Research Centre for Healthy Lungs, Hunter Medical Research Institute (HMRI) & School of Biomedical Sciences and Pharmacy, University of Newcastle, Callaghan, NSW, Australia

Discipline of Pharmacy, Graduate School of Health, University of Technology Sydney, Ultimo, NSW, Australia

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Iman Ehsan Department of Pharmaceutical Technology, Jadavpur University, Kolkata, India

Reema Gabrani Department of Biotechnology, Jaypee Institute of Information Technology, Noida, UP, India

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Ridhima Wadhwa Faculty of Life Sciences and Biotechnology, South Asian University, New Delhi, India

Part I

Emerging Trends and Challenges in Nanoformulations

Princeton University **Department of Geosciences**
Guyot Hall, Princeton, New Jersey 08544-1003
Telephone: 609-258-4100
Fax: 609-258-1274
December 13, 2017

Prof. Dr. Murlidhar Chandekar
Vice-Chancellor
Sant Gadge Baba Amravati University
Amravati -444602 (MS) India
Email: murlidhar.chandekar@gmail.com

Re: Permission for Prof. Dr. S. Khadri to join our fieldwork Feb. 1-Feb. 15, 2018.

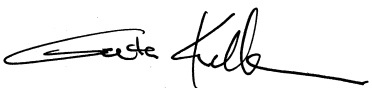
Respected Dr. Murlidhar Chandekar

For the past five years Dr. Syed Khadri, Head of Geology at Amravati University, has collaborated with our team of geologists from Princeton University (USA) and the University of Lausanne (Switzerland) on Deccan Trap studies, including high-resolution U-Pb zircon dating of Deccan volcanic eruptions. Our team has been very successful in obtaining the first U-Pb ages of Deccan basalt flows (Schoene et al., 2014, 2015, Science). In subsequent fieldwork we collected many more red boles for dating and this work has also been very successful in adding many new high-precision U-Pb age dates for the Deccan Traps. This work is now being written up for submission to a high-profile journal. This high precision Deccan geochronology will have far-reaching implications for understanding the nature and tempo of eruptions, gas emissions and their devastating effects globally leading to the mass extinction at 66 Ma.

Despite the considerable success so far we have not quite hit the jackpot – which is dating the killer lava flows that caused the mass extinction. But we are very close. In fact, we have dated lava flows that are just 60,000 years below the mass extinction. This is why we need to renew our fieldwork with an intensive search for the killer lava flows precisely at the mass extinction horizon now U-Pb dated elsewhere at 66.021±0.024 Ma.

For this reason we are planning our next phase of fieldwork for February 1-15, 2018. Dr. Syed Khadri is a critical and necessary member of our international team as he has much experience in Deccan Trap studies and leads our team in fieldwork. I am contacting you in the hope that you will grant Dr. Khadri permission to join us in fieldwork and continue this critically important research project. Thank you for your consideration of this request.

Sincerely,



Prof. Gerta Keller
Department of Geosciences
Princeton University
Princeton NJ 08544, USA
email: gkeller@princeton.edu

Princeton University **Department of Geosciences**
Guyot Hall, Princeton, New Jersey 08544-1003
Telephone: 609-258-4100

February 13, 2020

Dr. Prof. Syed Khadri
Professor and Head, Department of Geology
SGB Amravati University, Amravati-444602 (MS) India

Dear Syed

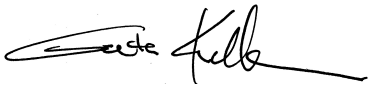
It is a pleasure to write a letter of intent to collaborate with you and Dr. Jahnavi Punekar (IITB) on your endeavor to establish the Lonar Science Centre at Amravati with a Field Station and Planetarium at the Lonar Crater in India's Deccan Volcanic Province. I congratulate you both for taking the initiative for this important project, which will be a great asset to India's for student education, science and research, furthering the integration of multidisciplinary projects in India, as well as attracting collaboration with foreign scientists.

Thank you for inviting me to participate in this project. I will be most happy to contribute to this project with my experience working in India over more than a dozen years specializing in Deccan volcanism and associated environmental and climate changes and the likely cause of the end-Cretaceous mass extinction.

My team closely collaborated with you over the past 10 years especially on Deccan volcanism with much success. I introduced Princeton's geochronologists to date Deccan eruptions, a project that has been highly successful and you have been a most important integral part of this effort. The Western Ghats eruptions and Malwa Plateau have now been dated based on high-resolution U-Pb zircon dating that resulted in influential *Science* publications (Schoene et al., 2015, 2019; Eddy et al., in press). This effort has already brought many foreign teams to India to investigate the age, nature and environmental effects of Deccan volcanism. In addition, it has re-invigorated India's scientists working on Deccan Traps and brought them important international attention and collaboration with foreign teams.

I believe the panned Field Station and Planetarium at Amravati with the Field Station and Planetarium at the Lonar Crater in India's Deccan Traps will further invigorate the both India's science education and foreign collaboration. I wish you success in this endeavor and look forward to participate.

Sincerely,



Prof. Gerta Keller
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UNIL | Université de Lausanne
Institut des sciences de la Terre
bâtiment Géopolis bureau 3879
CH-1015 Lausanne

Prof. Dr. Thierry Adatte
Tel. 0041 21 692 3526

Prof. Dr. Murlidhar Chandekar
Vice-Chancellor
Sant Gadge Baba Amravati University
Amravati -444602 (MS) India
Email: murlidhar.chandekar@gmail.com

Lausanne, 12.12. 2018

Concerns: Permission for Prof. Dr. S. Khadri to join our fieldwork Feb. 1-Feb. 12, 2019

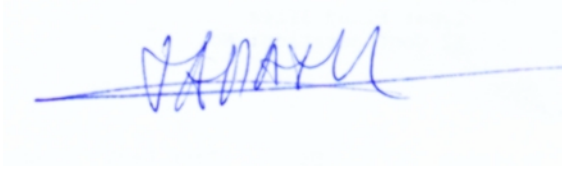
Respected Dr. Murlidhar Chandekar

For the past five years Dr. Syed Khadri, Head of Geology at Amravati University, has collaborated with our team of geologists from the University of Lausanne (Switzerland) and Princeton University (USA) on Deccan Trap studies, including high-resolution U-Pb zircon dating of Deccan volcanic eruptions. Our team has been very successful in obtaining the first U-Pb ages of Deccan basalt flows (Schoene et al., Science 2015). In subsequent fieldwork we collected many more red boles for dating and this work has also been very successful in adding many new high-precision U-Pb age dates for the Deccan Traps. This work has been now accepted in the prestigious journal Science. This high precision Deccan geochronology will have far reaching implications for understanding the nature and tempo of eruptions, gas emissions and their devastating effects globally leading to the mass extinction at 66 Ma. In 2018, we have have extended our dataset to the eastern part of Deccan Trap, around Hyderabad, but we still need to complete our dataset in western India (Gujarat). For this reason, we are planning our next phase of fieldwork for February 1-12, 2019. Dr. Syed Khadri is a critical and necessary member of our international team since he has much experience in Deccan Trap studies and leads our team in fieldwork. I am contacting you in the hope that you will grant Dr. Khadri permission to join us in fieldwork and continue this critically important research project.

Thank you for your consideration of this request.

Sincerely,

Prof. Dr. T. Adatte



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Prof. Dr. Thierry Adatte
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Prof. Dr. Murlidhar Chandekar
Vice-Chancellor
Sant Gadge Baba Amravati University
Amravati -444602 (MS) India
Email: murlidhar.chandekar@gmail.com

Re: Permission for Prof. Dr. S. Khadri to join our fieldwork January 5 - 22, 2020

Respected Dr. Murlidhar Chandekar

For the past five years Dr. Syed Khadri, Head of Geology at Amravati University, has collaborated with our team of geologists from the University of Lausanne and Princeton University (USA) on Deccan Trap studies, including high-resolution U-Pb zircon dating of Deccan volcanic eruptions. Our team has been very successful in obtaining the first U-Pb ages of Deccan basalt flows (Schoene et al., Science 2015, 2019). This high precision Deccan geochronology will have far reaching implications for understanding the nature and tempo of eruptions, gas emissions and their devastating effects globally leading to the mass extinction at 66 Ma.

We recently got some news data from the Malwa area (Narmada River). these data demonstrate that the lower Malwa Plateau basalts are temporally correlative with the first pulse of Deccan volcanism and provide new constraints on its initiation and duration. The first eruptive pulse is coeval with a ~200 kyr period of global warming, and we suggest that eruption through the sedimentary rocks of the Narmada-Tapti rift basin provided the necessary CO_2 to drive this warming through contact metamorphism of some Permian coal levels. We need to sample these coal levels (Indore-Jabalpur-Nagpur) in order to evaluate the Mercury, Sulfur and carbon contents. Another part of the fieldtrip will be will be focused on additional sampling of the Western Ghats basalt flows to refine our age model.

For this reason, we are planning our next phase of fieldwork for January 5-22 2020. Dr. Syed Khadri is a critical and necessary member of our international team since he has much experience in Deccan Trap studies and leads our team in fieldwork. I am contacting you in the hope that you will grant Dr. Khadri permission to join us in fieldwork and continue this critically important research project. Thank you for your consideration of this request.

Sincerely,

Prof. Dr. T. Adatte

PURDUE UNIVERSITY | Earth, Atmospheric, and Planetary Sciences
COLLEGE OF SCIENCE

Michael P. Eddy

Assistant Professor | mpeddy@purdue.edu | (336) 302-4411 | michaelpeddy.com
EAPS Department | 550 Stadium Mall Dr. | Purdue University | West Lafayette, IN 47907

January 10, 2020

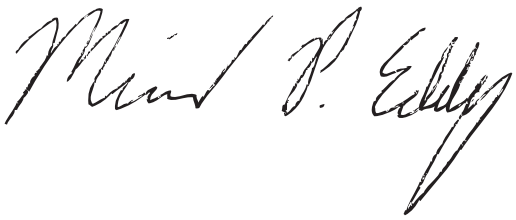
Dr. Syed F.R. Khadri
Sant Gadge baba Amravati University
Amravati, India

Dear Professor Khadri,

This letter expresses my enthusiastic interest to collaborate with you in joint scientific projects involving the geological evolution of India. In particular, I am interested in continuing our collaboration on the geochronology of the Deccan Traps, as well as your new effort to study the Lonar Crater. I believe that this partnership will benefit both of our universities through continued interaction between Indian and US students and faculty, production of high quality analytical and field data, and publication and dissemination of our research in renowned academic journals. I believe that this partnership will continue to strengthen ties between the Indian and US scientific communities, and I look forward to our continued collaboration.

Please let me know if there is any additional information I can provide.

With best regards,



Dr. Michael P. Eddy

Princeton University **Department of Geosciences**
Guyot Hall, Princeton, New Jersey 08544-1003
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November 23, 2015

Dr. Mohan Khedkar
Vice-Chancellor
Sant Gadge Baba Amravati University
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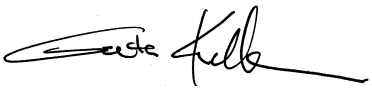
Email: vc@sgbau.ac.in
Fax: 0091-721-2662135/266949

Respected Dr. Mohan Khedkar

For the past two years Dr. Syed Khadri, Head of Geology at Amravati University, collaborated with our team of geologists and geochronologists from Princeton University (USA) and the University of Lausanne, Switzerland, on Deccan Trap studies and in particular to conduct high-resolution U-Pb zircon dating of Deccan volcanic eruptions. Our team has been extremely successful to date in obtaining the first U-Pb ages of Deccan basalt flows and the first results have been published in Science (Dec. 2014 and Jan. 2015). This was the first step in what are revolutionary results for high precision Deccan geochronology with far-reaching implications for understanding the nature and tempo of eruptions and gas emissions and their devastating effects globally leading to the mass extinction 65 m.y. ago. In our January 2015 fieldwork we collected a series of samples that have also yielded promising results and also revealed where additional fieldwork is necessary for the next step in this geochronology study, which will result in excellent publications in high-visibility international journals.

For this reason we are planning our next phase of fieldwork for January 15-31, 2016. Dr. Syed Khadri is a critical and necessary member of our international team as he has much experience in Deccan Trap studies and leads our team in fieldwork. I am contacting you once again in the hope that you will grant Dr. Khadri on duty permission to join us in fieldwork as a part of our International Research Collaboration and continue this critically important research project. Thank you for your consideration of this request.

Sincerely,



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October 26, 2016

Dr. Muralidhar Chandekar
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muralidhar.chandekar@gmail.com/vc@sgbau.ac.in

RE: This letter requests permission for Prof. Syed Khadri to lead fieldwork in the Deccan Traps for an international team of scientists during Jan. 15-31, 2017.

Respected Dr. Muralidhar Chandekar:

I'm Professor Keller at Princeton University contacting you in regards to permission for Professor Syed Khadri, Head of Geology at Amravati University, to participate and lead our ongoing international research collaboration with fieldwork scheduled between Jan. 15-31, 2017. This international research collaboration is between Princeton University and Sant Gadge Baba University and includes: Prof. Syed Khadri, Profs. Gerta Keller and Blair Schone from Princeton University, Dr. Thierry Adatte from the University of Lausanne, Switzerland, Prof. Jahnavi Punekar, Indian Institute of Science Education and Research Pune, Dr. Eric Font, University of Lisbon, Portugal, Dr. Michael Eddy, MIT, Boston, and several graduate students. Professor Syed Khadri is an integral part of our team as well as our team leader in conducting fieldwork because of his extensive expertise in Deccan volcanism.

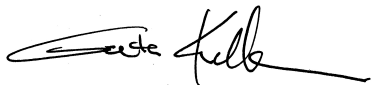
Background: Our research project is on the *Chronology of Deccan Volcanism* and concentrates on the most important outstanding problem in Deccan research, namely determining the absolute age, the rate and tempo of basalt eruptions and their cause-and-effect relationship to the mass extinction at the end of the Cretaceous 66 million years ago. We began this project in 2013 and have been fantastically successful in age dating even individual lave eruptions revealing that over 3200 m of lava erupted in about 750,000 years with about 2000 m over just 250,000 years leading up to the mass extinction. This was the first step with revolutionary results for high precision Deccan geochronology with far-reaching implications for understanding the nature and tempo of eruptions and gas emissions and their devastating effects globally. This paper was published in Science January 2015 (Schoene et al) and accompanied by much international publicity. Since then our research has spawned numerous other teams working on Deccan volcanism as well as all other mass extinctions associated with volcanism.

Our research is continuing with even greater success thanks to yearly fieldwork lead by Dr. Syed Khadri. We have now succeeded in even higher resolution U-Pb age dating of Deccan lava flows, which narrows the voluminous lava flows down to the time of eruption that directly ended with the mass extinction (a paper is being prepared for publication in Science or Nature).

But our research is far from over, besides our work in the Western Ghats, we must now concentrate outside this area to evaluate the geographic distribution of lava flows, which is necessary to obtain estimates of the volume and rate of lava eruptions and gas emissions that are critical for modeling the climatic and environmental effects that appear to have caused the mass extinction. Also time is of essence because so many other teams have now embarked on Deccan studies. For these reasons we plan to conduct fieldwork during January 15-31, 2017.

Prof. Syed Khadri is an important member of our scientific team and his participation and extensive knowledge of the Deccan Traps are critical for the success of this project. For these reasons we kindly ask that you may grant permission to Dr. Syed Khadri to participate and lead our fieldwork. Our past successes virtually assure even greater success based on the upcoming fieldwork. It also assures a high visibility role for all participating institutions in this project.

Thank you for your consideration of this request.
Sincerely,



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September 28, 2018

Prof. Dr. Murlidhar Chandekar
Vice-Chancellor
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Amravati -444602 (MS) India
Email: murlidhar.chandekar@gmail.com

Re: Permission for Prof. Dr. S. Khadri to participate in documentary film on Deccan volcanism.

Respected Dr. Murlidhar Chandekar

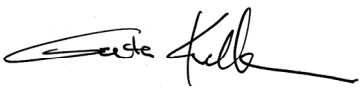
I write to you to ask your permission for Dr. S. Khadri to participate in a documentary film on Deccan volcanism from October 27 through October 31, 2018.

For the past five years Dr. Syed Khadri, Head of Geology at Amravati University, has been a very important collaborator in my team of geologists from Princeton University (USA) studying the Deccan Traps. These studies have been highly successful and have received major media attention. Thanks to our research, Deccan volcanism as a driver of the dinosaur mass extinction is now of intense interest by several documentary filmmakers in the USA. I have chosen one highly regarded team of NYC filmmakers to create a documentary film on Deccan volcanism highlighting our research advances. This team will accompany my fieldtrip to the Deccan Traps at the end of October 2018.

Participation of Dr. Syed Khadri in this documentary is important because of his critical contributions to the successful research. His participation is also very beneficial for Amravati University as it highlights the important science contributions of one of your faculty members in what is expected to become an outstanding and internationally distributed science documentary on the Deccan Traps and the mass extinction.

Thank you for considering this request.

Sincerely,



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Earth and Planetary Science Letters 540 (2020) 116249

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

U-Pb zircon age constraints on the earliest eruptions of the Deccan Large Igneous Province, Malwa Plateau, India

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ARTICLE INFO

Article history:
Received 8 November 2019
Received in revised form 5 March 2020
Accepted 31 March 2020
Available online xxxx
Editor: H. Handley

Keywords:
Deccan
K-Pg
Late Maastrichtian warming event
U-Pb zircon geochronology

ABSTRACT

Climate instability driven by emission of volatiles during emplacement of large igneous provinces (LIPs) is frequently invoked as a potential cause of mass extinctions. However, documenting this process in the geologic record requires a holistic understanding of eruption rates, the location of eruptive centers, and potential sources of climate-changing volatiles. We present new chemical abrasion–isotope dilution–thermal ionization mass spectrometry (CA-ID-TIMS) U-Pb zircon geochronology from Malwa Plateau basalts on the northern margin of the Deccan LIP, India. These basalts have been previously interpreted as either an extension of the province's main volcanic stratigraphy or as an independent eruptive center active up to millions of years prior to the main eruptive phase. Our data instead demonstrate that the lower Malwa Plateau basalts are temporally correlative with the first pulse of Deccan volcanism and provide new constraints on its initiation and duration. Paleomagnetic data further indicate that upper Malwa Plateau basalts may be age-equivalent to the second, third, and fourth pulses of Deccan volcanism. The relative thicknesses of age-equivalent packages of basalt are consistent with eruption of the Deccan LIP from a southward-migrating eruptive center. The first eruptive pulse is coeval with a ~200 kyr Late Maastrichtian warming event preserved globally in contemporaneous stratigraphic sections. We propose that the first pulse of Deccan magmatism was more voluminous in the north, where it erupted through organic-rich sedimentary rocks of the Narmada-Tapti rift basin. Thermal metamorphism of these sediments could have been a source of sufficient CO_2 to drive the Late Maastrichtian warming event, which if true would reconcile the apparent dampened warming signals associated with later Deccan eruptive pulses.

1. Introduction

The temporal relationship between emplacement of large igneous provinces (LIPs) and mass extinctions is well known (e.g., Courtillot and Renne, 2003). However, the potential causal relationship between volcanic eruptions and paleo-environmental change remains uncertain. The most commonly proposed driver of paleo-environmental degradation is the syn-eruptive release of volatiles such as CO_2, CH_4, and SO_2 (e.g., Self et al., 2006). The ocean-atmosphere residence times of these gases differ dramatically, 10^3–10^5 yr (CO_2) and 10^0–10^1 yr (CH_4, SO_2), and climate change driven by release of these volatiles acts on similar timescales (e.g., Self et al., 2006). Potential sources of these volatiles during LIP eruption are basaltic magmas and their differentiation products or crustal rocks that are metamorphosed during magma transport, emplacement, and eruption (Svensen et al., 2004; Self et al., 2006). Thus, precise chronologies of LIP eruption, robust estimates for eruptive tempo, and knowledge of the underlying crustal composition are all prerequisites to assessing the efficacy of LIP emplacement in driving climate change and environmental catastrophe.

Eruptions of the Deccan LIP in India (Fig. 1A) span the latest Cretaceous through the earliest Paleogene and has, along with the Chicxulub bolide impact (e.g., Alvarez et al., 1980), been implicated in driving the end-Cretaceous mass extinction and late Cretaceous environmental instability (Courtillot et al., 1988). Recent geochronologic results from the Western Ghats region of

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https://doi.org/10.1016/j.epsl.2020.116249
0012-821X/

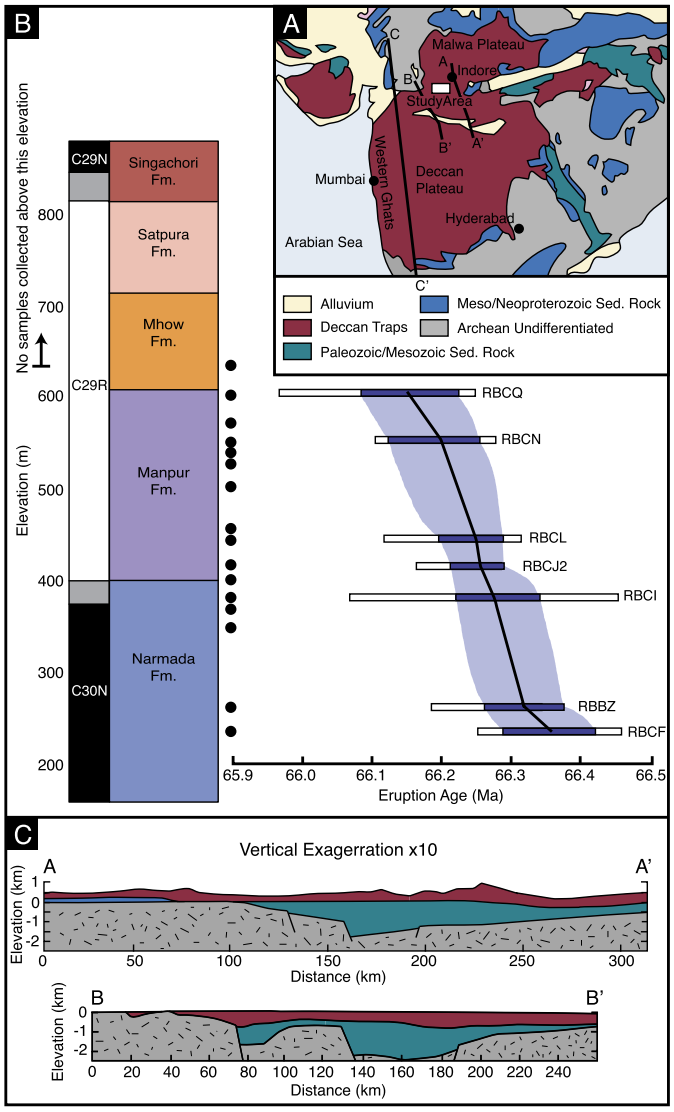

Fig. 1. A) Simplified geologic map of Deccan large igneous province showing the study location on the southern margin of the Malwa Plateau relative to the Western Ghats and the location of the Paleozoic-Mesozoic 'Gondwana' sedimentary sequences (modified from Lehman et al., 2010). B) Generalized stratigraphic column for the southern Malwa Plateau basalts in the vicinity of Mandu-Mhow-Singachori (Khadri, 2003), showing the elevation of formation boundaries and magnetic polarity chrons, including flows with transitional polarity in gray. The locations of sampled 'red boles' are denoted as black circles and the U-Pb eruption ages for the seven 'red boles' that are interpreted to contain volcanic ash are shown. Each eruption age is shown as a white rectangle (i.e., eruption age interpreted from each sample's selected zircon) and a blue rectangle. The latter interpretation refines eruption ages by using the law of superposition and a Bayesian Markov Chain Monte Carlo technique (e.g., Schoene et al., 2019). C) Interpreted upper crustal seismic cross sections across the northern Deccan LIP showing the buried Narmada-Tapti rift (Kaila, 1988; Verma and Banerjee, 1992). (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

India have refined the eruptive chronology of the Deccan LIP (Schoene et al., 2019; Sprain et al., 2019), but these datasets disagree on their preferred models of either pulsed (Schoene et al., 2019) or near-constant (Sprain et al., 2019) eruption rates. Furthermore, the general applicability of either of these eruptive models to the entire province remains tenuous due to uncertainties in the correlation between the volcanic stratigraphy of the Western Ghats (Cox and Hawkesworth, 1985; Beane et al., 1986) and outlying areas. These correlations were previously established using geochemical and morphological similarities between packages of basalt (e.g., Lightfoot et al., 1990; Mitchell and Widdowson, 1991; Khadri et al., 1999; Jay and Widdowson, 2008) and largely ignore the possibility of lateral changes in basalt flow morphology; broad geochemical similarities between different basalt formations; and the potential for magnetostratigraphy in different areas to record different magnetic reversals (e.g., Kale et al., 2019). Based on regional geologic mapping by the Geological Survey of India, Kale et al. (2019) proposed that the Deccan LIP represents a composite volcanic pile composed of several major eruptive centers that were active over several Myr. Such an interpretation challenges the regional significance of any eruptive model inferred solely from geochronologic data within the Western Ghats (Schoene et al., 2019; Sprain et al., 2019), as province-scale models of basalt volume are dependent on long-distance correlation of geochemically-defined basalt formations.

The most robust way to temporally correlate basalt packages within a LIP is by using independent geochronologic constraints from many different areas to develop a high-resolution age model. To this end, we present new U-Pb zircon geochronology from the Malwa Plateau on the northern margin of the Deccan LIP (Fig. 1A). The Malwa Plateau includes ~21,000 km^3 of basalt and has been interpreted to represent a spatially distinct flow field based on flow morphology (Kale et al., 2019). Our new U-Pb dates provide a new age model for the area and an independent means of correlating eruption of Malwa Plateau basalts with both eruption of Western Ghats basalts and global paleoenvironmental records.

2. Malwa Plateau basalts

The Malwa Plateau comprises an area of ~80,000 km^2 along the northernmost margin of the Deccan volcanic province (Fig. 1A). The stratigraphic thickness of basalts within the plateau ranges from >500 m in the south to ~200 m in the northwest and Schöbel et al. (2014) used these constraints to estimate that ~21,000 km^3 of basalt is currently preserved. However, prior to erosion the Plateau's volume was likely much greater. The basalts in this region have been classified into five geochemically defined formations and are named from stratigraphically lowest to highest: the Narmada Fm., Manpur Fm., Mhow Fm., Satpura Fm., and Singachori Fm. (Fig. 1B: Rao et al., 1985; Khadri, 2003). The Geological Survey of India has proposed an alternative stratigraphic nomenclature that divides the basalts of the Malwa Plateau into eight formations on the basis of flow morphology (summarized in Kale et al., 2019). However, in this study we utilize the geochemically-defined stratigraphy, because flow morphology can change laterally in time-equivalent basalt flows, and the geochemically-defined stratigraphy of the Western Ghats (Cox and Hawkesworth, 1985; Beane et al., 1986) has been successful in identifying temporally distinct eruptive packages (e.g., Schoene et al., 2019).

The stratigraphy of the Malwa Plateau spans two magnetic reversals, from normal-to-reverse polarity and reverse-to-normal polarity (Fig. 1B: Pal and Bhimasankaram, 1976; Rao et al., 1985; Khadri and Nagar, 1994; Khadri et al., 1999; Khadri, 2003; Schöbel et al., 2014). While this sequence of reversals has been linked to the C30n-C29r-C29n sequence preserved in the basaltic stratigraphy of the Western Ghats region (Rao et al., 1985; Khadri et al., 1999; Khadri, 2003; Schöbel et al., 2014), this correlation has been largely untested with geochronologic data. A single ^{40}Ar/^{39}Ar analysis of a plagioclase separate obtained at the base of the stratigraphy along the Plateau's western margin produced a date of 67.12 ± 0.44 Ma (2σ), suggesting that the oldest basalts in this area are from C30n (Schöbel et al., 2014). However, the general applicability of this result remains uncertain. The upper reversal, from reverse-to-normal polarity, is only preserved at the highest elevations on the southern Malwa Plateau, suggesting that most of the flows recording this transition have been eroded away (Khadri, 2003).

Table 1
U-Pb eruption/deposition ages.

Sample	Latitude (°N)	Longitude (°E)	Elevation (m)	Age (Ma)	− (Ma, 2.5% C.I.)	+ (Ma, 97.5% C.I.)
RBCQ	22.36098	75.72529	606	66.150	0.067	0.065
RBCN	22.41410	75.58862	554	66.199	0.074	0.055
RBCL	22.38527	75.53110	447	66.250	0.052	0.039
RBCJ2	22.37889	75.53228	417	66.256	0.042	0.034
RBCI	22.37673	75.53067	383	66.275	0.053	0.066
RBBZ	22.29716	75.37197	263	66.320	0.057	0.057
RBCF	22.30058	75.50123	237	66.358	0.070	0.065

3. U-Pb zircon geochronology methods and results

To better constrain the age of the Malwa Plateau basalts, we collected interflow paleosols, locally called 'red boles', for U-Pb zircon geochronology. Some red boles contain volcanic ash (e.g., Widdowson et al., 1997) and have been successfully sampled for U-Pb zircon geochronology in the Western Ghats (Schoene et al., 2019). While, the source of silicic volcanic ash remains uncertain, descriptions of poorly dated, but broadly coeval, rhyolitic complexes in the north of the Deccan Province suggest that small volume rhyolitic volcanism was ongoing during LIP emplacement (e.g., Rao, 1971).

Samples for U-Pb zircon geochronology were obtained from three transects over an area of ∼400 km^2 along the southern margin of the Malwa Plateau (Fig. 1A). They were dated using a modified version of chemical abrasion–isotope dilution–thermal ionization mass spectrometry (CA-ID-TIMS) following the methods presented in Schoene et al. (2019), and were projected onto a regional stratigraphic column (Fig. 1B) following Khadri (2003). The trace element composition of each zircon was measured using the methods presented in Schoene et al. (2010) and a quadrupole–inductively coupled plasma–mass spectrometer (Q-ICP-MS) at Princeton University. Zircon photographs, U-Pb isotopic and compositional data, and more detailed methods are presented in the supplementary material.

Of eleven red bole samples that yielded zircon, four contained limited zircon; clearly detrital, rounded, Precambrian grains; or Cretaceous zircon with no clear geochemical relationship. Samples with a significant detrital component are not unexpected in this area, as the presence of inter-trappean sedimentary beds within the Malwa Plateau basalts suggests that the region was at low elevation during basalt eruptions (e.g., Tandon et al., 1995). Seven samples contained coherent age populations of euhedral zircon that we interpret to come from silicic volcanic ash. These populations preserve geochemical trends consistent with pre-eruptive, closed-system magmatic differentiation (Fig. S2) and were used to estimate eruption dates using a Bayesian Markov Chain Monte Carlo (MCMC) technique that assumes a pre-eruptive zircon age distribution bootstrapped from the selected zircons (Table S2: Keller et al., 2018). These eruption ages are further refined utilizing the law of superposition and a second Bayesian MCMC model to generate an age model for the dated stratigraphy (Table S3: e.g., Schoene et al., 2019). The resulting eruption age estimates are presented in Table 1. Alternative estimates based on different priors and more conventional data interpretation techniques are presented in Table S2. All uncertainties are analytical only and are reported at the 95% credible interval-level. The inclusion of systematic uncertainties, such as those associated with the calibration of the EARTHTIME ^{202}Pb-^{205}Pb-^{233}U-^{235}U isotope dilution tracer and the U decay constants, is necessary for comparison with other geochronologic methods, and these uncertainties are reported in Table S3.

4. Discussion

4.1. Age of the C29n/C29r magnetic reversal

The magnetic polarity reversal sequence preserved within the southern Malwa Plateau basalts was previously assumed to be correlative to the C30n-C29r-C29n magnetic polarity chrons (Khadri et al., 1999; Khadri, 2003; Schöbel et al., 2014). Our dates bracket the lower reversal to between 66.275 +0.066/−0.053 Ma and 66.256 +0.034/−0.042 Ma (Fig. 1B), confirming that it is C30n/C29r. reversal Using our stratigraphic age model and an elevation of 400 m, we can further refine the date of this reversal 66.266 +0.060/−0.049 Ma. This date is consistent with several previous estimates for this reversal, including a U-Pb zircon date from a transitional polarity basalt flow in the Western Ghats (Schoene et al., 2019); sanidine ^{40}Ar/^{39}Ar dates from interbedded tuffs in the terrestrial Hell Creek Fm. in Montana (Sprain et al., 2015); and astrochronologic estimates from the late Cretaceous/early Paleogene marine sedimentary sections in northern Spain (Batenburg et al., 2012), ODP Hole 762C (Thibault et al., 2012), ODP Holes 1267B, 762C, and DSDP 525A (Husson et al., 2011), and ODP Hole 1262 (Barnet et al., 2019). Notably, however, our date is 170 kyr younger than a recent estimate for the C30n/C29r reversal based on U-Pb zircon dates of ash beds within the Denver Basin, Colorado (Clyde et al., 2016). This discrepancy may be the result of variations in sediment accumulation rates within the terrestrial Denver Basin, because the Clyde et al. (2016) study did not bracket the C30n/C29r reversal, but rather projected their stratigraphic age model down-section over ∼30 m. Regardless, the convergence of datasets pointing to a date of 66.266 +0.060/−0.049 Ma provides another important tie point with which to compare the eruptive history of the Deccan LIP to global paleoenvironmental records.

4.2. Correlation to the Western Ghats

Most studies of the Deccan LIP have attempted to correlate volcanic sections over broad areas of the province using basalt geochemistry (e.g., Lightfoot et al., 1990; Mitchell and Widdowson, 1991; Khadri et al., 1999; Jay and Widdowson, 2008). However, there are limits to this approach (e.g., Kale et al., 2019). For example, there is the possibility that the province is composed of multiple eruptive centers that each records a distinct geochemical evolution through time (e.g., Kale et al., 2019). Correlation based on time provides a more robust means to reconstruct eruptive histories, obviating the need for assumptions regarding geochemical homogeneity of coeval lavas across the province.

Fig. 2 shows a correlation scheme for the Malwa Plateau and Western Ghats using U-Pb zircon dates from this study and from Schoene et al. (2019). Importantly, our dates demonstrate that emplacement of the Narmada Fm. is temporally correlative with emplacement of the Jawhar Fm. (Fig. 2). However, the oldest date for the Narmada Fm. is ∼60 kyr older than the oldest date in the Jawhar Fm., extending initiation of the first eruptive pulse within the Deccan LIP to at least 66.358 +0.065/−0.070 Ma. The overlying Manpur Fm. is temporally correlative with the remainder of

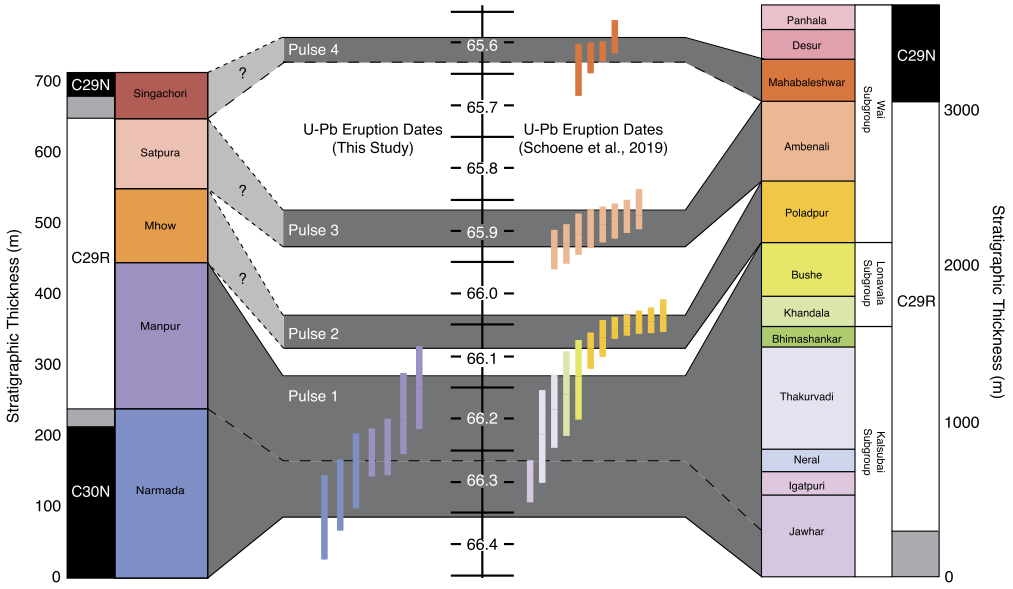

Fig. 2. Stratigraphic correlation diagram of the southern Malwa Plateau basalts and the basaltic stratigraphy of the Western Ghats. U-Pb zircon age constraints are shown as bars color-coded to correspond to their respective formations and are derived from Bayesian Markov Chain Monte Carlo eruption (e.g., Keller et al., 2018) and stratigraphic (e.g., Schoene et al., 2019) age models derived from the distribution of zircon ages in each sample and their relative stratigraphic positions. All of the dates are from either Schoene et al. (2019) or this study. A combination of paleomagnetic and U-Pb zircon geochronologic constraints suggest that the stratigraphy of the southern Malwa Plateau basalts record the same four eruptive pulses as outlined in Schoene et al. (2019).

the Kalsubai and Lonavala subgroups (Fig. 2). We currently have no direct age constraints for the Mhow, Satpura, or Singachori Fms. However, if the upper magnetic reversal in the Malwa Plateau represents the C29r/C29n reversal, then the Mhow and Satpura Fms. are constrained to be younger than 66.137 $+0.112/-0.170$ Ma and older than the U-Pb date for the C29r/C30n reversal of 65.631 $+0.053/-0.030$ Ma (Figs. 1 and 2; Schoene et al., 2019). The Singachori Fm. is exposed as only erosional remnant at high elevations on the southern margin of the Malwa plateau, but must be temporally correlative to the Mahabaleshwar Fm. in the Western Ghats since both formations record the C29r/C30n magnetic reversal (Fig. 2: Khadri, 2003). Given these constraints, we suggest that the most parsimonious correlation is that the Mhow, Satpura, and Singachori Fms. record the second, third, and fourth eruptive pulses of Schoene et al. (2019) and are temporally correlative to the Poladpur, Ambenali, and Mahabaleshwar Fms., respectively. However, these temporal correlations should remain speculative until they are directly tested with additional geochronologic data. Regardless, the Malwa Plateau basalts must contain one or more hiatuses in eruption, or at least extreme changes in eruption rate, as a constant rate would predict a much thicker section of basalt between the Manpur Fm. and the C29r/C30n magnetic reversal. The alignment of U-Pb zircon eruption dates between the Narmada and Manpur Fms. with the first pulse of magmatism in Schoene et al. (2019); the requirement for hiatuses or extreme changes in eruption rate within the section; and the preliminary temporal correlations with the rest of the Western Ghats stratigraphy, all suggest that the same pulses identified in Schoene et al. (2019) are likely present in the Malwa plateau but with different relative thicknesses. Moreover, these observations are not compatible with an interpretation of near-constant Deccan eruptions (Sprain et al., 2019).

A single $^{40}Ar/^{39}Ar$ date of a plagioclase separate from the Malwa plateau has been used to suggest that eruptions in this area started by 67.12 ± 0.44 Ma (2σ: Schöbel et al., 2014). This sample was collected from a different part of the plateau than our study area, and is thus difficult to directly compare with our results. The contact between basalt and basement is not exposed in our study area along the Narmada River, and >100 m section of basalt is present beneath our stratigraphically lowest sample. Thus, an older history of eruptions is possible. However, we suggest that any earlier eruptions within the Deccan LIP were volumetrically minor, because our age constraints for the onset of the first pulse of magmatism align with the initial downturn of $^{187}Os/^{188}Os$ in ocean sediments globally (Fig. 3A).

4.3. Implications for the architecture of the Deccan eruptive edifice

An understanding of the extent of Deccan eruptions through time is necessary to confidently constrain eruption volumes and tempos. Existing models have focused on either a single source (Model A in Mitchell and Widdowson, 1991; Jay and Widdowson, 2008); a southward-migrating central eruptive center, consistent with the passage of India over the Reunion hotspot (Devey and Lightfoot, 1986; Model B in Mitchell and Widdowson, 1991); or multiple eruptive centers that are distinct in time and space throughout the province (e.g., Kale et al., 2019). Our new data from the Malwa Plateau provide an important test for each of these models.

The temporal correlation between the Malwa Plateau basalts and the stratigraphy of the Western Ghats suggests that they record the same or a similar history of pulsed eruptions (Fig. 2). The continuity of these pulses over large regions is consistent with, but does not require, sustained volcanic activity from a central eruptive center, rather than several centers that were widely dispersed and behaving independently (e.g., Kale et al., 2019). Future studies of basalt geochemistry, morphology, and flow direction placed within a robust temporal framework will be able to assess whether coeval magmas across the province share the same petrogenetic and eruptive history or reflect coincidental eruptions from multiple distinct centers.

Assuming that the shared history between the Malwa Plateau and Western Ghats reflects the behavior of a central eruptive center, we can assess whether the basalts on the northern margin of the province are consistent with a center that remained stationary or migrated to the south through time. Existing maps from the southern Deccan LIP show southward attenuation of the formations of the Western Ghats and a consistent onlapping of flow

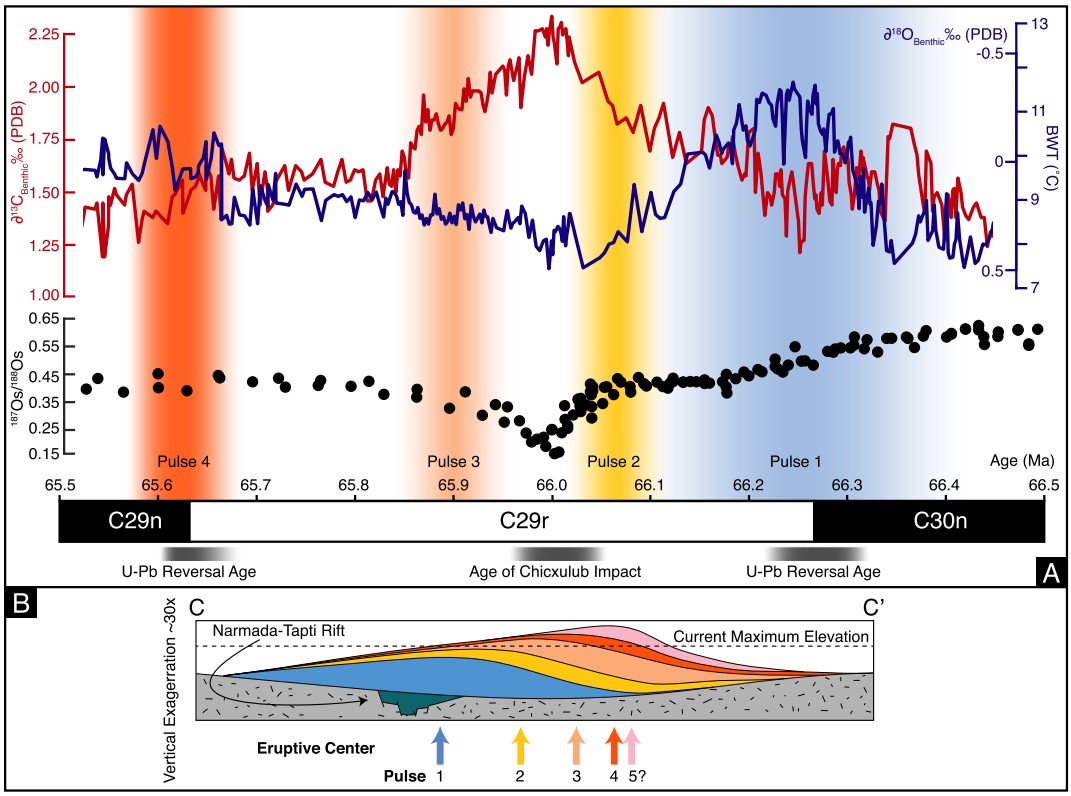

Fig. 3. A) Variation in benthic foraminifera $\delta^{18}O$ and $\delta^{13}C$ from ODP site 1262 (Barnet et al., 2019) compared to changes in $^{187}Os/^{188}Os$ in ocean sediments from both outcrop and ODP core (Robinson et al., 2009; Ravizza and VonderHaar, 2012) and the timing and duration of the four eruptive pulses identified for the Deccan LIP by Schoene et al. (2019) and this study defined by the 95% credible intervals of the youngest and oldest U-Pb zircon eruption age in each pulse. The uncertainty of the U-Pb zircon dates for the C29r/C29n reversal (Schoene et al., 2019), Chicxulub impact (Clyde et al., 2016; Schoene et al., 2019), and C30n/C29r reversal (*this study*) are also shown. B) Schematic cartoon showing the proposed development of the Deccan LIP as a series of shield volcanoes with eruptive centers progressively migrating to the south through time (Devey and Lightfoot, 1986; Model B in Mitchell and Widdowson, 1991) and corresponding to the four (or five) eruptive pulses identified within the province. We speculate that the first Deccan eruptive pulse erupted through volatile-rich Narmada-Tapti rift basin sedimentary rocks, while subsequent pulses erupted through only granitic and gneissic basement.

fields to the south (Devey and Lightfoot, 1986; Model B in Mitchell and Widdowson, 1991). These observations are consistent with either of the proposed eruptive histories. However, both possibilities make specific predictions about the geometry of coeval flows along the north of the province. A central eruptive center should show symmetry with the map patterns in the south, with onlapping formations through time northward, while a migrating eruptive center should show progressive offlapping of formations as it moved southward.

The recognition that the ~460 m thick Narmada and Manpur Fms. are temporally correlative to the Lonavala and Kalsubai subgroups of the Western Ghats provides a test of coeval magma thickness in both the northern and southern parts of the province. Using the exposure limit of these two subgroups in the southern Western Ghats and assuming a stationary eruptive center near Nashik (e.g., Model A in Mitchell and Widdowson, 1991), coeval flows are predicted to be thin to nonexistent in the Malwa Plateau. The presence of thick, temporally correlative flows to these subgroups is, instead, consistent with a southward-migrating eruptive center (e.g., Devey and Lightfoot, 1986; Model B in Mitchell and Widdowson, 1991).

Fig. 3B shows a cartoon of how we envision the geometry of the province, with each eruptive pulse identified in Schoene et al. (2019) forming a shield volcano as the eruptive center migrated progressively to the south. It remains unclear if the undated Panhala and Desur Fms. (Fig. 2) represent a fifth eruptive pulse or are part of the eruptive pulse that includes the Mahabaleshwar Fm. Regardless, this architecture needs to be considered in future Deccan volume estimates. A first order consequence of this geometry is that the relative volume of the first pulse of magmatism is significantly increased over the estimates presented in Richards et al. (2015).

Richards et al. (2015) calculated the total volume of the province by approximating each formation as a cone with a height equal to the maximum exposed thickness and diameters of 250 km for the Kalsubai and Lonavala subgroups and the Panhala and Desur Fms. and 600 km for the Poladpur, Ambenali, and Mahabaleshwar Fms. This approach results in a total volume of 602,700 km^3, of which 23% belongs to the formations that compose the first eruptive pulse of Schoene et al. (2019). Recalculating the LIP volume using the same method but treating each pulse (including a hypothetical fifth pulse consisting of the Panhala and Desur Fms.) as a cone with a radius of ca. 440 km, similar to Model B in Mitchell and Widdowson (1991), gives a total volume of 737,900 km^3, with 59% erupted during the first pulse. These revised volumes suggest that both Sprain et al. (2019) and Schoene et al. (2019) underestimated the eruption rates associated with the Kalsubai and Lonavala subgroups by using the Richards et al. (2015) model and highlight the importance of stratigraphic and geochronologic controls in constraining the eruptive volume of LIPs. The discrepancy also suggests that any conclusions drawn from modeling the climate response to the emplacement of the Deccan LIP (e.g., Hull et al., 2020) should be tempered by the uncertainties associated with each volume model, including variations in the volume of offshore basalt, in the volume of basalt that was eroded following eruption, and in the stratigraphic architecture that arises from multiple and/or migrating eruptive centers.

4.4. Relationship to Late Maastrichtian climate instability

A 200 kyr period of ~2.5–8 °C warming and subsequent cooling before the end Cretaceous extinction, named the Late Maastrichtian warming event, has been inferred on the basis of $\delta^{18}O$ in benthic foraminifera (Fig. 3A: e.g., Li and Keller, 1998; Barnet et al., 2018), pedogenic carbonate (Nordt et al., 2002), and bivalve shells (Petersen et al., 2016), as well as changes in leaf morphology (Wilf et al., 2003). The onset of this excursion is temporally correlative with the first pulse of Deccan volcanism identified by Schoene et al. (2019) and the initial downturn in oceanic $^{187}Os/^{188}Os$ toward more radiogenic values (Fig. 3A: Robinson et al., 2009; Ravizza and VonderHaar, 2012), suggesting a potential causal relationship between the two events. Direct CO_2 emissions from basalt are unlikely to cause this magnitude of warming, except at extreme eruption rates (e.g., Self et al., 2006), which is difficult to reconcile with the likely longer duration and lower eruption rates inferred from this first eruptive pulse (Schoene et al., 2019). More puzzling is the observation that the other, shorter, and possibly more intense pulses of Deccan volcanism did not lead to records of warming on timescales >100 kyr (Fig. 3A). One possibility is that the second eruptive pulse was associated with shorter-term warming preserved in only a few locations due to widespread hiatuses in sedimentation (e.g., Punekar et al., 2014). Moreover, there is the possibility that shorter-term (≤100-kyr) warming events occurred throughout the earliest Paleogene (e.g., Coccioni et al., 2010; Lyson et al., 2019). Nevertheless the temporal correlation of these proposed warming events with eruption of the Deccan LIP is not fully constrained and their global significance remains debated due to the absence of correlative $\delta^{18}O$ excursions in benthic foraminifera (see discussion of DAN-C2 event in Barnet et al., 2019).

Our observation that the dominant volume of erupted material in the northern part of the Deccan LIP is temporally correlative with the first pulse of volcanism may provide a means to explain the Late Maastrichtian warming event. First, the increased areal extent of the basalts that compose the first eruptive pulse suggests a much larger eruptive volume than the estimates used in Schoene et al. (2019). Second, an inferred northern eruptive center for the first magmatic pulse would place it within the Narmada-Tapti Rift (Fig. 3B), where dike swarms have been previously documented (e.g., Vanderkluysen et al., 2011) and a gravity anomaly suggests large volumes of mafic rock in the middle to lower crust (Verma and Banerjee, 1992). This rift is well characterized in seismic lines through the northern part of the province and consists of 1.5-2 km of sedimentary rock (Fig. 1C: Kaila, 1988; Verma and Banerjee, 1992). These rocks can be traced laterally into sedimentary sequences on the margin of the Deccan LIP that record terrestrial Carboniferous to Cretaceous shallow marine sedimentation, including abundant Carboniferous and Permian coal (Veveers and Tewari, 1995). We suggest that initial eruption of Deccan basalts through the Narmada-Tapti Rift may have provided a critical source of greenhouse gases via metamorphism of organic rich sedimentary rock. This mechanism is widely invoked to have driven catastrophic CO_2 and CH_4 emissions during in late Permian during emplacement of the Siberian Traps (e.g., Svensen et al., 2009); in the early Jurassic during emplacement of the Karoo-Ferrar basalts (e.g., Svensen et al., 2007); and at the Paleocene-Eocene Thermal Maximum (PETM) during emplacement of the North Atlantic Igneous Province (e.g., Svensen et al., 2004). A relatively small −0.6‰ $\delta^{13}C$ excursion in benthic foraminifera during the late Maastrichtian warming event (Fig. 3A) has been used to argue against volumetrically significant addition of isotopically light organic ($\delta^{13}C = -25‰$) carbon (Barnet et al., 2018). However, quantifying the expected change in global $\delta^{13}C$ due to emission of these gases over the 200 kyr event duration depends on several unconstrained factors including the rate of organic matter burial in carbon sinks, the ratio of organically-derived greenhouse gases relative to volcanic CO_2 ($\delta^{13}C = -6‰$), and the rate of greenhouse gas emission. Thus, the relatively small $\delta^{13}C$ excursion observed during the Late Maastrichtian warming event (Fig. 3A) may not be sufficient to preclude protracted addition of isotopically light carbon during this time.

If our hypothesis is correct, southward movement of the Deccan eruptive center off of the Narmada-Tapti rift and onto bedrock entirely composed of Precambrian granite and gneiss minimized this extra source of greenhouse gas and may explain the more subdued climate proxy record associated with later pulses of Deccan volcanism. In this case, if the second pulse of the Deccan LIP played an important role in climate instability immediately predating the Chicxulub impact and mass extinction, either a) evidence for shorter-term (≤100 kyr) global greenhouse conditions is not preserved in most studied stratigraphic sections due to sedimentary erosion and/or hiatuses, b) an efficient silicate weathering feedback buffered atmospheric greenhouse conditions, and/or c) the effect of short-term global cooling from sulfur aerosols may have been an important contributor to environmental decline and accelerated extinction rates.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The Princeton University Department of Geosciences Scott Fund and NSF grant EAR-1454430 (B.S. and G.K.) supported field and lab work. Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security LLC for the U.S. Department of Energy, National Nuclear Security Administration under contract DE-AC52-07NA27344. This work is LLNL contribution LLNL-JRNL-793751. This manuscript benefited from the thoughtful comments of two anonymous reviewers.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.epsl.2020.116249.

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MASS EXTINCTION

U-Pb constraints on pulsed eruption of the Deccan Traps across the end-Cretaceous mass extinction

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Temporal correlation between some continental flood basalt eruptions and mass extinctions has been proposed to indicate causality, with eruptive volatile release driving environmental degradation and extinction. We tested this model for the Deccan Traps flood basalt province, which, along with the Chicxulub bolide impact, is implicated in the Cretaceous-Paleogene (K-Pg) extinction approximately 66 million years ago. We estimated Deccan eruption rates with uranium-lead (U-Pb) zircon geochronology and resolved four high-volume eruptive periods. According to this model, maximum eruption rates occurred before and after the K-Pg extinction, with one such pulse initiating tens of thousands of years prior to both the bolide impact and extinction. These findings support extinction models that incorporate both catastrophic events as drivers of environmental deterioration associated with the K-Pg extinction and its aftermath.

Continental flood basalt provinces are characterized by eruption of >1 million km^3 of basalt over a period of <1 million years (*1*, *2*), representing the largest volcanic events on Earth. Four of the five most severe Phanerozoic mass extinctions [~541 million years (Ma) ago to the present] coincided with emplacement of one of these provinces (*3*). Although the temporal link between flood basalts and extinctions is well established, the mechanisms by which eruptions drive extinction are poorly understood (*4*). Two models of environmental change from volcanic activity relate to eruptive volatile emissions (*1*, *4*). The first is volcanogenic CO_2 release, with associated global warming, ocean acidification, and carbon cycle disruption. The second is SO_2 injection into the stratosphere and its conversion to sulfate aerosols, causing global cooling, acid rain, and ecosystem poisoning (*5*). The predicted time scales of these perturbations contrast sharply. The emission of SO_2 from a single eruption would produce years of cooling, whereas accumulated greenhouse warming from CO_2 can be sustained for many thousands to tens of thousands of years. Testing the effects of this interplay on ecosystems thus requires precisely calibrated volcanic eruption rates that can be correlated to high-resolution climate proxy and biostratigraphic data.

We applied U-Pb zircon geochronology to construct a precise temporal record of eruption within the Deccan Traps volcanic province, India (Fig. 1). The province is temporally correlated to the K-Pg mass extinction, in which roughly three-fourths of life on Earth was eradicated, including non-avian dinosaurs (*6*). Previous attempts to constrain eruption rates were limited by poor stratigraphic coverage and/or high analytical uncertainties (*7*–*12*). We used U-Pb geochronology by isotope dilution–thermal ionization mass spectrometry (ID-TIMS) (*13*), which provides analytical uncertainties (±2σ) as low as 40,000 years (40 ka) for individual dated zircons. Our sampling covers the nine major Deccan formations in the Western Ghats, where the most voluminous (>90% total volume) and complete Deccan exposures are preserved (*14*–*17*) (Fig. 1). We sampled both coarse-grained basalts and sedimentary beds between basalt flows that infrequently contain zircon-bearing volcanic ash (*11*) (fig. S1). These beds, locally termed "redboles," range from oxidized volcaniclastic material with visible lithic fragments and phenocrysts to paleosol-type horizons produced by in situ weathering of flow tops (*18*, *19*). Of 141 sampled redboles and coarse-grained basalts (Fig. 1 and figs. S1 and S2), 23 redboles and one basalt sample yielded sufficient zircon (≥5 crystals) to estimate an eruption age, including four distinct bole horizons and one basalt previously presented by Schoene *et al.* (*11*). Pristine volcanic crystal morphology indicates minimal transportation or reworking of zircon in a sedimentary environment. Consequently, we inferred that this volcaniclastic, zircon-bearing material was incorporated into redboles as air fall tuff, consistent with some redboles containing a high-SiO_2 (nonbasaltic) component (*19*), and that these zircons provide a robust means for dating Deccan eruptive stratigraphy.

To estimate the eruption date and associated uncertainty for each sample, we developed an approach using Bayesian statistics to account for the probability distribution of zircon dates and their analytical uncertainties (*20*) (fig. S6). Although we considered alternative data interpretations (*13*), they do not affect the conclusions of this study. Twenty-one of 24 dated horizons are from five stratigraphic sections along prominent roads in the Western Ghats, providing complete coverage of the upper four Deccan formations (Fig. 1 and figs. S1 and S2). The remaining three samples span the lower five Deccan formations, where redboles are rare and less likely to contain zircon.

When compiled into a composite stratigraphic section (Fig. 1), almost all samples follow anticipated "younging-up" temporal order based on the independently defined regional stratigraphy (*14*–*17*) (figs. S2 and S7). The exception is the Katraj Ghat south of Pune city, where two samples from what was mapped as upper Poladpur Formation are ~100 ka younger than samples near the Poladpur-Ambenali contact in other sections. To resolve this discrepancy, we placed the Poladpur-Ambenali contact in the Katraj Ghat section as ~100 m lower than previously mapped. This simple adjustment does not violate geochemical or geological observations in the stratigraphy, as the Poladpur-Ambenali contact is geochemically transitional in published datasets (*14*). Furthermore, our placement of the contact is consistent with geochemical studies of the nearby Sinhagad Fort section suggesting that the Poladpur Formation is relatively thin just south of Pune (*14*).

To further refine the composite stratigraphic age model, we used a Bayesian Markov chain Monte Carlo (MCMC) model in which stratigraphic superposition is imposed on U-Pb zircon dates (*13*, *21*) (Fig. 1). The result is a deposition age estimate for each dated horizon, incorporating dates from all beds above and below each sample to produce an internally consistent age model (Fig. 1). The accuracy of refined age estimates depends solely on sample placement in proper stratigraphic order and is independent of samples' exact stratigraphic heights.

To calculate volumetric eruption rates through the Deccan Traps, we adopted the volume model of Richards *et al.* (*22*), in which units of the Wai subgroup (i.e., the Poladpur, Ambenali, and Mahabaleshwar Formations) were interpreted as more voluminous than is apparent from their proportionate thickness in the Western Ghats. This assertion carries nontrivial uncertainties, but we believe it is justified given the correlation of these formations to basalt flows on the province's periphery, including massive flows that traveled ~1000 km to India's eastern shore (*23*, *24*). Although different volume models produce changes in the magnitude of calculated eruption rates, the timing of peak eruption rates is unaffected by either the volume model or the interpretation approach of the zircon data (*13*) (figs. S8 and S9). Additional uncertainty relates to the unconstrained mass and

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age of Deccan basalt that is currently submerged and inaccessible off India's western shore. We consider this uncertainty to be intractable because current volume models cannot account for this mass component of the province. Consequently, all eruption rates are likely minimum estimates, although we also cannot assess whether the offshore component erupted during the same time intervals as that of the Western Ghats.

We converted our age model into a probabilistic estimate of volumetric flux of basaltic lava using outputs from the MCMC algorithm (Fig. 2). Our results showed that the Deccan Traps erupted in four high-volume events, each lasting ≤100 ka, separated by periods of relative volcanic quiescence. The first event corresponded to the eruption of the lowermost seven formations from ~66.3 to 66.15 Ma ago; the second to the Poladpur Formation from ~66.1 to 66.0 Ma ago; the third to the Ambenali Formation from ~65.9 to 65.8 Ma ago; and the fourth and final to the uppermost Mahabaleshwar Formation, from ~65.6 to 65.5 Ma ago.

Our Deccan eruption model (Fig. 2) constrains the volcanic tempo with high resolution, providing a means to correlate eruption records with biostratigraphic and climate proxy data across the K-Pg extinction. Our model places the second pulse of Deccan volcanism (Poladpur Formation, 66.1 to 66.0 Ma) as slightly predating a published U-Pb zircon date for the K-Pg boundary (KPB), defined as the Ir anomaly and associated fallout from the Chicxulub impact, within the Denver Basin, Colorado (*25*). For consistency, we applied the Bayesian approach to that dataset (*25*) to estimate a date of 66.016 ± 0.050 Ma ago for the KPB [95% credible interval, internal uncertainties only (*13*)]. Comparison of our data with recently published $^{40}Ar/^{39}Ar$ geochronology from the Deccan Traps and the Chicxulub impact (*12*, *26*) is currently not possible at the necessary level of precision given systematic bias between the two dating methods, primarily related to uncertainty in ages of $^{40}Ar/^{39}Ar$ fluence monitors and the values of the ^{40}K decay constant and physical constants (*13*). Assuming that the Chicxulub impact coincides exactly with the main phase of extinction, the MCMC model outputs from our Deccan data demonstrate a ~90% probability that the Poladpur Formation eruption pulse began tens of thousands of years before the K-Pg mass extinction event.

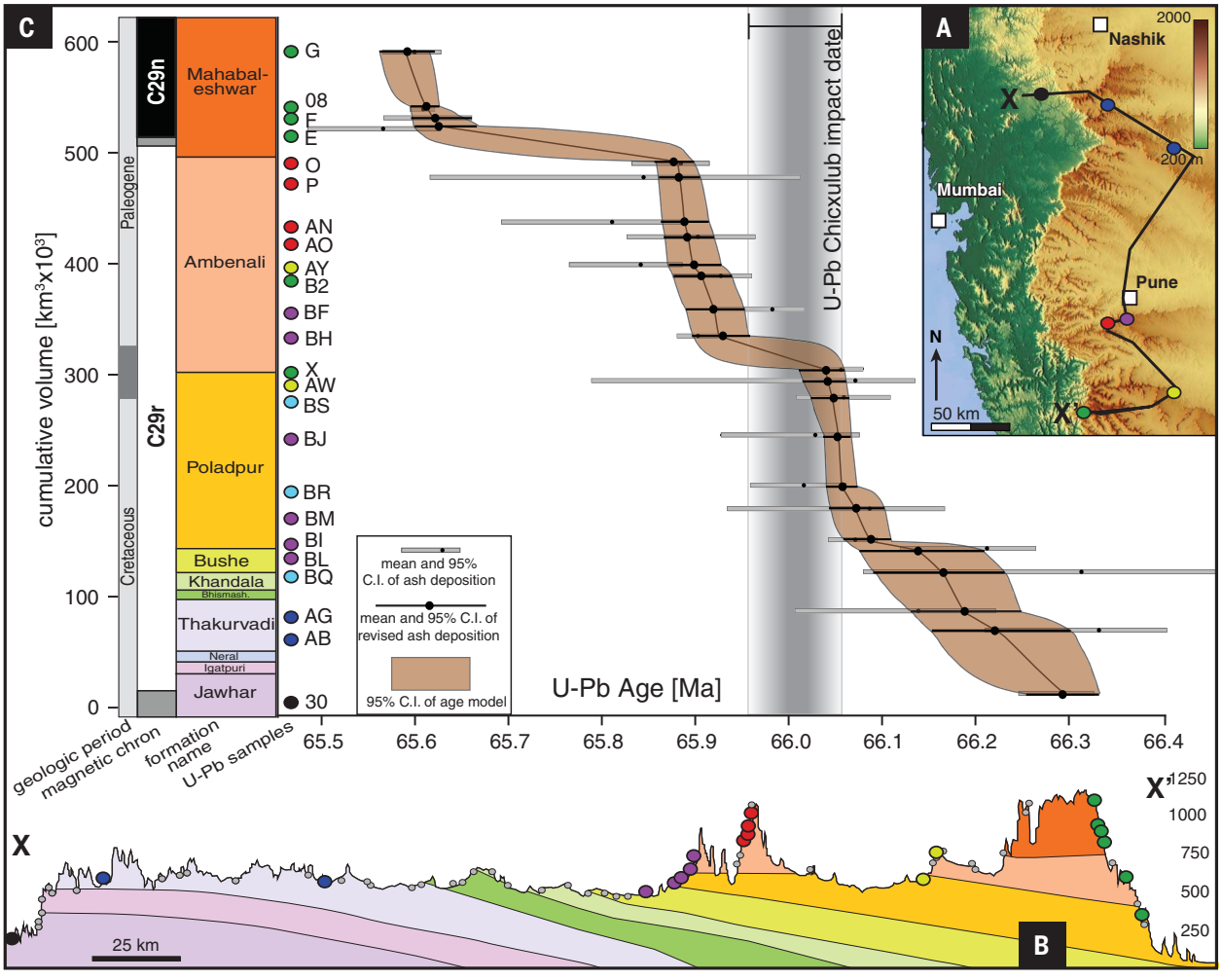

Fig. 1. Stratigraphy, sampling transects, and U-Pb age model for the Deccan Traps. (**A**) Elevation map of study location in the Western Ghats, India. A black segmented line denotes cross section X-X′ as shown in (B). Sampling transects are located by colored dots. (**B**) Geologic cross section through the field area, with sample locations indicated. Different basalt formations in the Deccan Traps are color-coded to the stratigraphic column in (C). Cross section is based on previous work (*14*–*17*), modified according to our geochronology. (**C**) Volumetric stratigraphic column and magnetic chrons of the major formations of the Deccan Traps (*22*, *45*). The plotted sample heights ("RB" sample prefix omitted) are based on the composite stratigraphic section compiled in fig. S2. The age model for the Deccan Traps, based on our U-Pb geochronology, is shown with 95% credible intervals. Horizontal gray bars indicate eruption ages derived from populations of zircon dates from each horizon; black horizontal bars show dates refined from the stratigraphic Bayesian model. The vertical gray-shaded bar shows an age for the Chicxulub impact (*25*).

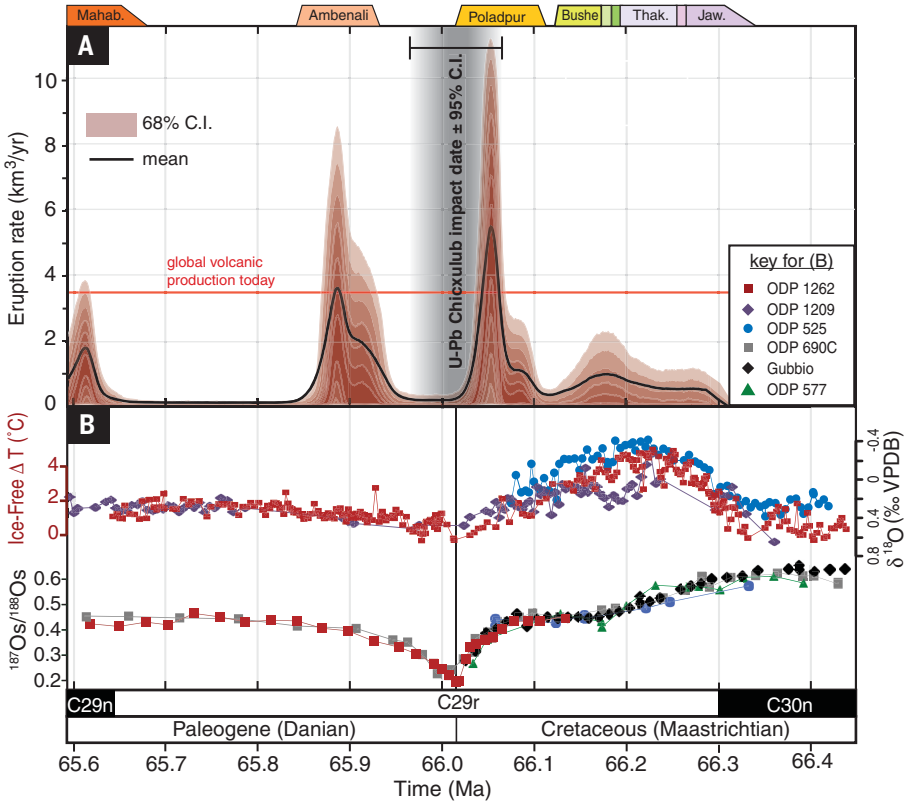

Fig. 2. Eruption rate model for the Deccan Traps, based on U-Pb geochronology. (**A**) Results from the MCMC algorithm used to generate the age model in Fig. 1, converted to a probabilistic volumetric eruption rate for the Deccan Traps shown with contours up to 68% credible intervals. The U-Pb date for the Chicxulub impact is the same as in Fig. 1. Total global volcanic productivity (~3 to 4 km^3/year) includes mid-ocean ridges and volcanic arcs (*28*). (**B**) Compilation of proxy records from ODP cores and outcrops. Upper data points are $\delta^{18}O$ of species-specific benthic foraminifera from ODP 525 (*46*), ODP 1262 (*36*), and ODP 1209 (*37*); VPDB, Vienna PeeDee Belemnite standard. Temperature is calculated for benthic foraminifera *Nuttallides truempyi* in ODP 1262 (*36*). Osmium isotopic records come from bulk carbonate from both ODP cores and outcrop (*40*, *41*). Age models are described in (*13*).

The K-Pg extinction preserves the only known mass extinction that coincides with both a large igneous province and a bolide impact. As such, several hypotheses have been forwarded in which the impact triggered or modulated volcanic eruptions. Although the most recent iteration of this hypothesis concedes initiation of Deccan eruptions several hundred thousand years before the impact, it proposes that impact-induced seismicity increased eruption rates in the Deccan Traps and at mid-ocean ridges through evacuation of preexisting magma chambers in the upper mantle and lower crust (*12*, *22*, *27*). It is unlikely that our Deccan eruptive history is consistent with this model, given the high probability that the Poladpur pulse began before the impact by tens of thousands of years, followed by an eruption hiatus of ≤100 ka after the impact.

Estimates for the entire volcanic flux on Earth today are 3 to 4 km^3/year (*28*), indicating on average a doubling in global volcanic activity for ≤100 ka during each of the four high-volume Deccan eruptive events, but requiring periods of >5 to 10 times the global average. In fact, groups of flows within the Poladpur and Mahabaleshwar Formations, each potentially comprising >50,000 km^3, lack secular evolution in paleomagnetic poles, suggesting eruption over decades to centuries (*29*). Such high eruption rates of >1000 km^3/year are permitted by our U-Pb geochronology, requiring hiatuses of hundreds to thousands of years within our resolved pulses so as not to exceed total volume estimates. In addition to being consistent with brief but extreme eruption rates, our data demonstrate that the Deccan Traps erupted in pulses with durations of ~100 ka, providing insight into tempos of melt production and/or transport in the upper mantle and lower crust (*30*, *31*).

Our eruption rate model is a first step toward robustly evaluating the environmental impacts associated with Deccan volcanism. The most commonly cited contributors to environmental change associated with flood basalts are CO_2 (warming), SO_2 (cooling upon conversion to sulfate aerosols), and chemical weathering of fresh basaltic material (cooling via CO_2 drawdown). For single continental flood basalt flows that erupt over a few decades, volcanic SO_2 has been modeled to drive cooling of 5° to 10°C for the duration of the eruption (*5*), after which acid rain rapidly removes sulfur compounds from the atmosphere. For persistent cooling over many thousands of years, therefore, hiatuses of only several decades between eruptions are required (*5*).

In contrast to SO_2, the time scale of CO_2 removal from the ocean-atmosphere system is slow: ~1 ka, ~10 ka, and ~100 ka for mixing into the deep ocean, reaction with sediments, and removal by silicate weathering, respectively (*32*, *33*). As a result, although climate effects during an eruptive event may be dominated by cooling associated with elevated sulfate aerosols, accumulation of volcanic CO_2 emissions can lead to net warming on intermediate time scales between eruptive events. On time scales of hundreds of ka to >1 Ma, weathering of fresh basalt has been modeled to result in net CO_2 drawdown and cooling, especially if the basalt is at low latitudes, as were the Deccan Traps (*34*).

As an initial attempt to correlate our eruptive history with paleoenvironmental data, we used two proxy records across the K-Pg transition (Fig. 2B). Benthic foraminifera $\delta^{18}O$ compositions indicate ~2° to 4°C of deep ocean warming over ~150 ka, beginning at the C30n-C29r magnetic reversal (~66.3 Ma ago), followed by cooling over ~150 ka prior to the KPB (*35*–*37*). It has also been argued on the basis of $\delta^{18}O$ data from Elles, Tunisia, that renewed warming began tens of thousands of years before the KPB (*38*) (fig. S11).

Initial warming at ~66.3 Ma ago and a coeval increase in carbonate dissolution have been interpreted as resulting from volcanogenic CO_2 buildup and consequent ocean acidification (*35*), which our geochronology shows to have occurred during the initial pulse of Deccan eruptions. Warming curtailed toward the end of the first pulse, and cooling began before and continued through the initiation of the Poladpur Formation eruptions (Fig. 2). The extrusion of the voluminous Poladpur Formation may have resulted in short periods of SO_2-driven cooling that could have continued to promote the overall cooling trend, but cooling for tens of thousands of years due to SO_2 emissions is difficult to sustain given the predicted short residence time of sulfate aerosol (*1*, *5*). Alternatively, an increase in surface area of exposed basalt associated with the Poladpur eruptions is possible given current Deccan stratigraphic area/volume models (*22*),

resulting in enhanced basalt weathering, CO_2 drawdown, and continued global cooling during the tens of thousands of years before the extinction. If periods of cooling did result from sulfate aerosols during the Poladpur eruptions, the short intervals of temperature decrease could have slowed silicate weathering and associated CO_2 drawdown, thus permitting CO_2 buildup in the atmosphere that would be manifest between punctuated eruptions within the Poladpur Formation (*39*).

Testing whether basalt weathering was important leading up to the KPB is aided through study of the Os isotope system in marine carbonates because the ocean residence time of Os is short and basaltic $^{187}Os/^{188}Os$ is low [0.1 (*10*)] relative to late Mesozoic seawater [0.6 (*40*)]. Published Os isotopic data from marine carbonates (*40*) show a marked decrease toward mantle values beginning at the onset of Deccan volcanism (Fig. 2B). A second downturn in $^{187}Os/^{188}Os$, beginning tens of thousands of years before the KPB, has been interpreted as a downward redistribution of extraterrestrial Os derived from the Chicxulub impactor (*40*, *41*). However, this decrease is synchronous with the Poladpur eruption pulse and is thus also consistent with increased weathering of a more extensive Deccan basalt pile.

Post-extinction and post-Chicxulub benthic foraminifera $\delta^{18}O$ and carbonate Os isotopic records do not covary with the Deccan eruption record. However, the Os record does not recover to the pre-Deccan $^{187}Os/^{188}Os$ value either, perhaps indicating that a steady state was reached between basalt production and weathering despite continued eruptions. Regardless, the starkly different responses of O and Os isotope records during the post-extinction recovery require models that explicitly incorporate the effects of continued Deccan eruptions, the Chicxulub impact, and biotic effects on the carbon cycle in a world with devastated ecosystems.

Although the initiation of a massive eruptive pulse shortly before the Chicxulub impact and mass extinction supports a Deccan contribution to ecosystem collapse, much remains to be discovered as to how flood basalt magmatism contributes to mass extinctions. U-Pb geochronology has shown that, similar to the K-Pg extinction, the end-Permian (~252 Ma ago) and end-Triassic (~201 Ma ago) mass extinctions occurred on short time scales (< tens of ka), hundreds of thousands of years after the onsets of the Siberian Traps and Central Atlantic Magmatic Province flood basalt provinces, respectively (*42*–*44*). The eruptions and associated intrusive magmatism are presumed to have driven rapid extinction despite this time lag and the absence of bolide impacts. This lag between the onset of magmatism and extinction may be a result of highly nonlinear rates of magmatism, as documented here for the Deccan Traps. Continuing to study other flood basalt provinces will clarify the importance of eruptive and intrusive tempo in driving ecosystem collapse and extinction. Such an understanding of biosphere sensitivity and the importance of threshold processes during climate change is as relevant today as for these catastrophic events in Earth history.

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ACKNOWLEDGMENTS

This paper benefited from comments made by three anonymous reviewers and discussions with A. Maloof and J. Higgins. Field assistance was provided by M. Coronado, P. Kemeny, and V. Sordet. J. Punekar provided critical field assistance and sample recollection. We also thank A. Chen, S. Gwizd, A. Hager, and D. Okhai for tirelessly separating zircons from redbole samples. **Funding:** Field and lab work was supported by NSF grant EAR-1454430 (B.S. and G.K.) and by the Princeton Department of Geosciences Scott Fund. Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security LLC for the U.S. Department of Energy, National Nuclear Security Administration under contract DE-AC52-07NA27344. This paper is LLNL contribution LLNL-JRNL-755419. **Author contributions:** All authors except C.B.K. participated in fieldwork and sample collection; U-Pb geochronology was done by K.M.S., M.P.E., and B.S.; Bayesian modeling was done by C.B.K., K.M.S., and B.S.; and the manuscript and figures were prepared by B.S., M.P.E., and K.M.S. with input from G.K., T.A., C.B.K., and S.F.R.K. **Competing interests:** The authors have no competing interests to declare. **Data and materials availability:** All methods, data, and codes used for modeling are available in the manuscript or supplementary materials.

SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/363/6429/862/suppl/DC1
Materials and Methods
Supplementary Text
Figs. S1 to S11
Tables S1 to S3
References (*45*–*106*)

27 July 2018; accepted 8 January 2019
10.1126/science.aau2422

U-Pb constraints on pulsed eruption of the Deccan Traps across the end-Cretaceous mass extinction

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Science **363** (6429), 862-866.
DOI: 10.1126/science.aau2422

Two timelines for extinction

The Cretaceous-Paleogene extinction that wiped out the nonavian dinosaurs 66 million years ago was correlated with two extreme events: The Chicxulub impact occurred at roughly the same time that massive amounts of lava were erupting from the Deccan Traps (see the Perspective by Burgess). Sprain *et al.* used argon-argon dating of the volcanic ash from the Deccan Traps to argue that a steady eruption of the flood basalts mostly occurred after the Chicxulub impact. Schoene *et al.* used uranium-lead dating of zircons from ash beds and concluded that four large magmatic pulses occurred during the flood basalt eruption, the first of which preceded the Chicxulub impact. Whatever the correct ordering of events, better constraints on the timing and rates of the eruption will help elucidate how volcanic gas influenced climate.

Science, this issue p. 866, p. 862; see also p. 815

EARTH HISTORY

U-Pb geochronology of the Deccan Traps and relation to the end-Cretaceous mass extinction

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The Chicxulub asteroid impact (Mexico) and the eruption of the massive Deccan volcanic province (India) are two proposed causes of the end-Cretaceous mass extinction, which includes the demise of nonavian dinosaurs. Despite widespread acceptance of the impact hypothesis, the lack of a high-resolution eruption timeline for the Deccan basalts has prevented full assessment of their relationship to the mass extinction. Here we apply uranium-lead (U-Pb) zircon geochronology to Deccan rocks and show that the main phase of eruptions initiated ~250,000 years before the Cretaceous-Paleogene boundary and that >1.1 million cubic kilometers of basalt erupted in ~750,000 years. Our results are consistent with the hypothesis that the Deccan Traps contributed to the latest Cretaceous environmental change and biologic turnover that culminated in the marine and terrestrial mass extinctions.

The Deccan Traps are a continental flood basalt province that comprise >1.3 million km^3 of erupted lavas and associated rocks (*1*) that reach a total thickness of ~3000 m near the eruptive center in Western India (*2*, *3*). Paleomagnetic data (*4*–*7*) combined with K-Ar and ^{40}Ar/^{39}Ar geochronology of Deccan basalts (*8*, *9*) have been interpreted to indicate that >90% of the eruptive volume was emplaced rapidly (<1 million years), coincident with the Cretaceous-Paleogene boundary (KPB). This temporal relationship has long led to speculation that Deccan volcanism had a major role in the end-Cretaceous mass extinction (*10*, *11*), which saw the disappearance of nonavian dinosaurs and ammonoids, as well as major biotic turnovers in foraminifera, corals, land plants, reptiles, and mammals (*12*–*15*). However, age uncertainties from existing geochronology of the Deccan Traps (*6*, *8*, *9*) are larger than their estimated total duration, and thus the onset and duration of volcanism cannot be precisely compared to geologic, extinction, or environmental records from sedimentary sections spanning the KPB worldwide.

To better establish a high-resolution eruptive history of the main phase of Deccan volcanism, we sampled volcanic rocks from throughout the 10 formations that make up the Western Ghats (*2*, *3*, *16*) and dated them by U-Pb zircon geochronology using chemical abrasion–isotope dilution–thermal ionization mass spectrometry (CA-ID-TIMS) (*17*). Because zircon is rare in basaltic rocks, our sampling strategy targeted volcanic airfall deposits between basalt flows and high-silica and/or coarse-grained segregations within individual flows (fig. S1). The latter have been described previously in the lower half of the Deccan sequence (*18*), and we successfully extracted zircon from one such sample in the Jawhar Formation (Fm) (DEC13-30; Fig. 1). Zircon was also separated from three paleosol, or "redbole," horizons within the Ambenali and Mahabaleshwar Fms (samples RBP, RBE, and RBF; Fig. 1). These distinctive red horizons are interpreted to result from weathering of basalt during periods of volcanic quiescence (*5*). However, many also contain an evolved, high-SiO_2 volcaniclastic component (*19*), and we sampled these horizons to search for zircon-bearing volcanic ash that may have accumulated between basalt flows. Three additional zircon-bearing samples were collected from different intervals within a ~40-cm-thick green volcaniclastic bed in the Mahabaleshwar Fm. (DEC13-08, -09, and -10).

Each sample yielded a small number (typically <50) of euhedral zircon crystals with morphologies and internal zonation indicative of an igneous origin (fig. S3). Single grains were selected for analysis, photographed, pretreated, dissolved, and analyzed using CA-ID-TIMS (*17*). A subset of samples with an adequate number of grains was analyzed at both Princeton University (PU) and the Massachusetts Institute of Technology (MIT) to assess interlaboratory bias. Resulting ^{206}Pb/^{238}U dates from individual zircons from each sample scatter outside of analytical uncertainty (all uncertainties reported at the 2σ level; data shown in Fig. 2 and figs. S2 and S4 and reported in table S1) but show a similar spread in dates for samples analyzed at both MIT and PU. Given the excellent analytical reproducibility between laboratories (fig. S2), we discuss our results as a single data set below.

The spread in ^{206}Pb/^{238}U dates from our individual samples cannot be attributed to analytical uncertainties alone (fig. S2), and we interpret this dispersion to result from either prolonged growth of zircon before eruption and/or incorporation of zircon from slightly older eruptions at the same vent. This phenomenon is due to the ability of zircon to retain radiogenic Pb at magmatic temperatures (>700° to 900°C) and can result in zircon dates within volcanic deposits that predate eruption by 10^3 to 10^6 years (*20*, *21*). Given that our goal is to date the deposition of the volcanic ash, taking a weighted mean of all data from single samples is inappropriate and could bias our dates too old (*21*). Alternatively, the youngest zircon from each deposit may serve as a maximum age for deposition (*16*). However, this approach assumes that chemical abrasion has completely mitigated Pb loss (*17*) and could bias our dates too young if this assumption is not true.

To address these potential biases, we analyzed the trace element geochemistry of the dissolved zircon after routine ion exchange separation of U and Pb (*17*). By asserting that cogenetic zircons from an ashfall should have the same age and the same trace element signature, we identified the population of zircon from our data set that is amenable to statistical grouping (Fig. 2) while alleviating the concern that older, inherited zircon may bias weighted mean dates too old. We find that two or more zircons from each sample meet these criteria, and we calculate weighted means from those grains. Additionally, zircons from different samples have very different trace element signatures, supporting our interpretation that each dated horizon contains a distinct population of zircon with independent age information.

As a further means of refining our age model for the middle Ambenali–lower Mahabaleshwar Fms, we employed a Markov chain Monte Carlo analysis that imposes the law of superposition as a boundary condition (*17*). Given that stratigraphic horizons young upward, this Bayesian approach uses the ^{206}Pb/^{238}U dates for each horizon derived above as priors and calculates new uncertainty distributions for each sample that maximize and evaluate the probability that stratigraphically higher beds are younger. Two of three samples from the composite ashbed fail this test (DEC13-08 and -09), and thus the date arising from the third sample (DEC13-10) is used as our best estimate for the deposition of that composite ashbed. Dates derived from the redbole horizons pass the superposition test, consistent with our interpretation based on grain morphology and geochemistry that zircon from these horizons derive from primary volcanic ashfall rather than, for example, eolian transport. The depositional ages presented in Fig. 2 are those from the Monte Carlo analysis, whereas several different interpretations of the geochronological data are presented in table S3.

Regardless of the method used for U-Pb age interpretation, our main conclusions remain unaffected. The U-Pb dates reported here have corresponding uncertainties that are one to two orders of magnitude smaller than previously

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published geochronology from the Deccan Traps and can thus resolve age differences between the base and top of the main eruptive phase. Using the dates from the lower- and upper-most samples (Fig. 1), we calculate a duration of 753 ± 38 thousand years (ky) for an estimated 80 to 90% of the total eruptive volume of the Deccan Traps.

These data also calibrate the timing of magnetic polarity Chron 29r, which serves as a basis for global correlation of KPB sections. The C29r/C29n reversal was previously identified within the lower Mahabaleshwar Fm (*5*), from which we collected samples RBP, RBE, and RBF. We use the $^{206}Pb/^{238}U$ date of sample RBE of 65.552 ± 0.026/0.049/0.086 million years ago (Ma) (2σ uncertainties given here as internal only/with tracer calibration/with ^{238}U decay constant) as our best estimate for the age of C29r/C29n reversal because it was sampled from between two basalts with transitional polarity (Fig. 1) (*5*). The basal age of C29r is constrained by sample DEC13-30, which was collected from a basaltic segregation vein within the Jawhar Fm near the base of the main Deccan phase and yielded a $^{206}Pb/^{238}U$ date of 66.288 ± 0.027/0.047/0.085 Ma. From the same outcrop, Chenet *et al.* (*9*) reported transitional magnetic polarity just tens of meters beneath lavas containing reverse polarity (C29r); from this transitional horizon they reported a K-Ar date of 67.4 ± 2.0 Ma. Though their date was interpreted to represent the C30r/C30n or C31n/C30r transition, with a long hiatus in eruptions represented in that section (*9*), our U-Pb date from DEC13-30 is not consistent with a hiatus of that magnitude. A simpler interpretation is that the transitional polarity basalts represent the C30n/C29r transition. Thus, the age difference between DEC13-30 and RBE of 736 ± 37 ky is also the length of C29r. An independent estimate for the length of C29r from cyclostratigraphic analysis of marine Ocean Drilling Program (ODP) cores and the Zumaia section, Spain, yields durations of 713 to 725 ky (*22*), in good agreement with our calibration based on U-Pb geochronology.

Our results also have implications for the age of the KPB and associated mass extinction event, as several estimates for the duration of the Cretaceous portion of C29r of 300 to 340 ky have recently been published based on cyclostratigraphy of magnetically and biostratigraphically calibrated ODP sections (*23*). Using our date for the C30n/C29r reversal and the average cyclostratigraphic estimate yields an age for the KPB of 65.968 ± 0.085 Ma (including systematic uncertainties), which agrees well with a recently reported KPB age of 66.043 ± 0.086 Ma (also including full systematic uncertainties) from $^{40}Ar/^{39}Ar$ geochronology on tephras that bracket the terrestrial KPB near Hells Creek, Montana (*24*). Determining an age for the KPB by back-calculation from our estimate for the C29r/C29n reversal is more problematic in that estimates for the Paleogene portion of C29r based on cyclostratigraphy of the Zumaia KPB section range from 206 to 398 ky (*22*, *25*). Regardless, the combination of our geochronologic data with cyclostratigraphic estimates effectively rules out any age for the KPB younger than 65.740 ± 0.086 Ma.

Although the temporal relationship between large igneous provinces and mass extinctions is well established (*26*), the potential kill mechanisms remain a subject of debate. Models of proposed drivers focus on volcanically sourced CO_2, SO_2, and halogens, which can cause global warming and/or cooling on different time scales (*27*); acid

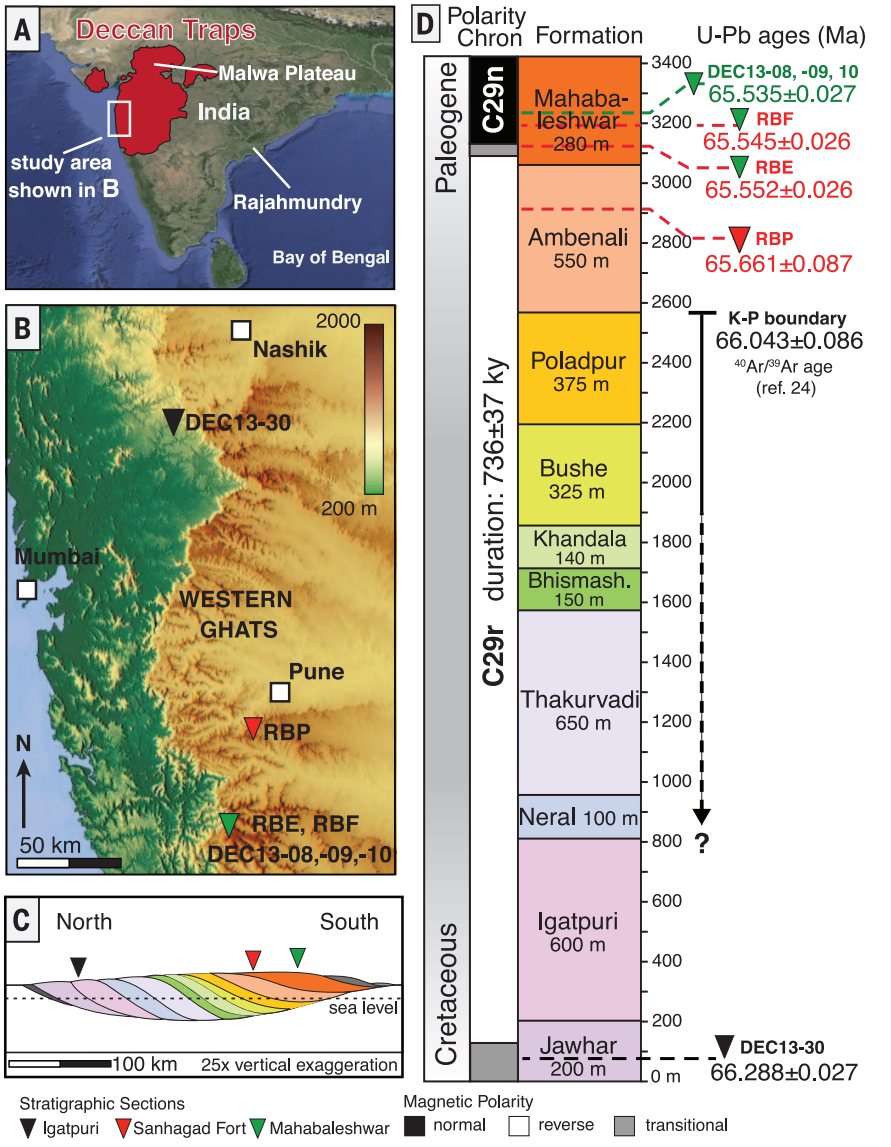

Fig. 1. Geography and stratigraphy of the Deccan Traps. (**A**) Aerial extent of the Deccan Traps colored in red. (**B**) Shaded relief map of study area in the Western Ghats. Major cities are indicated by white squares. Approximate locations of sampling transects and samples are indicated by colored triangles; transects are named at the bottom of the figure. The color bar (top right) shows elevation in meters, highlighting the escarpment where the best exposures of Deccan lavas occur. (**C**) Schematic cross section of Deccan lavas, from Chenet *et al.* (*4*), showing general southerly dip and younging to the south. Sampling transects are indicated by colored triangles. Colors correspond to the formations named in (D). (**D**) Composite stratigraphic section of the Deccan Traps in the Western Ghats, with approximate formation thicknesses shown. The geologic time scale is on the left, with the gray area corresponding to the unknown location of the KPB within the Deccan Traps. The geomagnetic polarity time scale is shown, with relevant chrons labeled and polarity indicated by black, white, or gray. The duration of C29r is the difference between the ages of DEC13-30 and RBE. U-Pb ages are shown on the right and are color-coded for sample type: black, segregation vein in basalt; red, volcanic material from paleosol; green, volcanic ashbed. Colored triangles correspond to sampling transects shown in (B) and (C). The date for KPB from Renne *et al.* (*24*) includes full systematic uncertainties. U-Pb age uncertainties are 2σ and include internal uncertainties only; ages with full systematic uncertainties are ~±0.085 Ma. See text and table S3 for full uncertainty budget and Fig. 2 and table S1 for data.

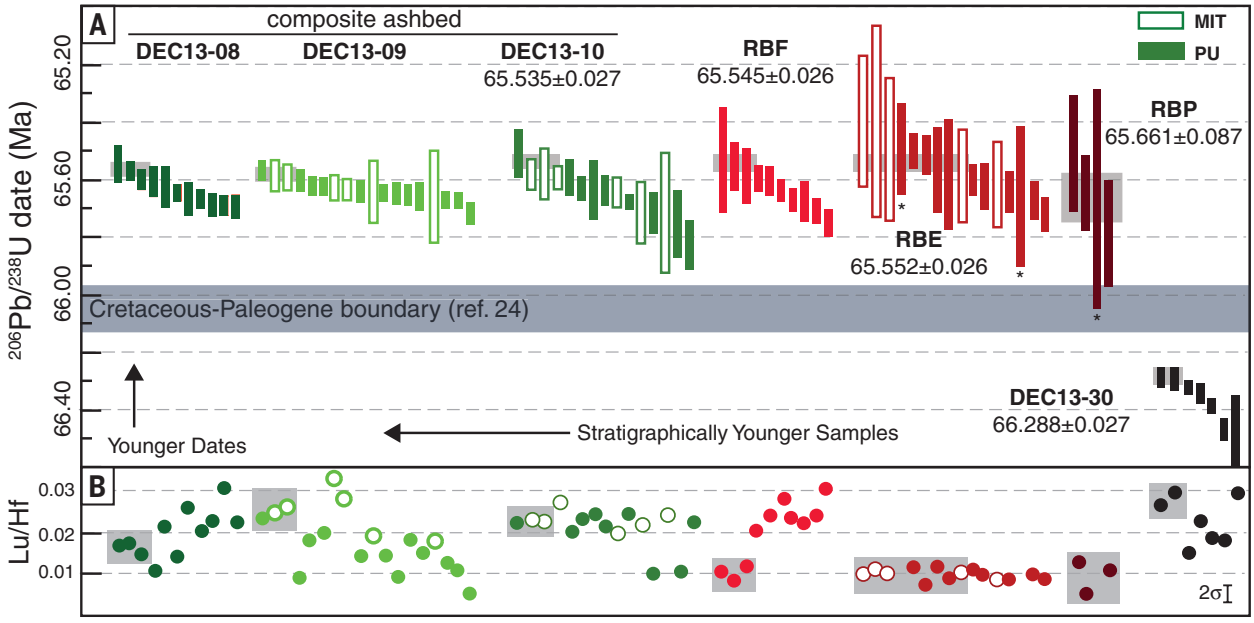

Fig. 2. U-Pb zircon CA-ID-TIMS geochronological data. (**A**) Rank order plot of U-Pb data presented in this study, color-coded by sample type in Fig. 1 and with sample name next to data. Sample locations are shown in Fig. 1. The vertical axis indicates $^{206}Pb/^{238}U$ date, and rectangle height corresponds to 2σ uncertainties for single-crystal zircon analyses, with internal uncertainties only. MIT and PU indicate the laboratory used. Stratigraphic younging is shown from right to left. The horizontal gray band shows the date for KPB from Renne *et al*. (*24*). Small gray rectangles behind the data indicate the youngest zircons that were indicated to be cogenetic by comparing dates and geochemistry in (B), from which weighted means were calculated. Dates indicated beneath sample names result from the Monte Carlo Markov chain simulation that uses weighted mean dates and imposes the law of superposition to arrive at our best estimates for the time of deposition of the dated horizons (*17*). Asterisks indicate zircon without trace element geochemistry. U-Pb data are given in table S1. (**B**) Lutetium/hafnium (Lu/Hf) ratios of the same volume of dated zircon, younging from right to left as in (A). Gray boxes indicate zircons determined to be cogenetic due to same age and geochemistry. The full geochemical data set is presented in table S2 and plotted in fig. S5.

rain and ozone reduction (*28*); and ocean acidification (*29*). Late Cretaceous records beginning near the C30n/C29r transition, and therefore near the onset of the main phase of Deccan volcanism, show a decrease in $\delta^{18}O$ values of foraminifera (*30*) and morphological changes in fossil leaves (*31*) that are consistent with instabilities in global temperature. A two-stage decline in seawater $^{187}Os/^{188}Os$ values initiating at the C30n/C29r reversal was interpreted to record weathering of the Deccan Traps, predating a second decline in $^{187}Os/^{188}Os$ and a synchronous Ir spike that were attributed to the Chicxulub impact (*32*). Furthermore, biostratigraphic records show increased rates of biotic turnover in mammals, amphibians, land plants, and foraminifera through the Cretaceous portion of C29r preceding the peak extinction interval (*12*, *13*, *15*, *31*, *33*). Additional testing of the influence of the Deccan Traps on these records will require further determination of eruption tempos and hiatuses coupled with realistic estimates of volatile release from individual eruptive phases (*34*) that can be temporally linked to paleoenvironmental proxies. Our results are a critical part of this discussion as they are consistent with the hypothesis that environmental and ecological deterioration began with eruption of the Deccan Traps before the Chicxulub impact and the end-Cretaceous mass extinction. Therefore, both the Chicxulub impact and eruption of the Deccan Traps should be considered in any model for the extinction.

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ACKNOWLEDGMENTS

This work was supported by the Department of Geosciences Scott Fund at Princeton University and the U.S. NSF through the Continental Dynamics Program, Sedimentary Geology and Paleobiology Program, and the Office of International Science and Engineering's India Program under grants EAR-0447171 and EAR-1026271 to G.K. P. Kemeny assisted with fieldwork and sample collection; A. Chen assisted with sample processing. MIT's analytical work was supported by the Robert Shrock chair. All data associated with this work can be found in the supplementary materials (*17*).

SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/347/6218/182/suppl/DC1
Materials and Methods
Figs. S1 to S5
Tables S1 to S3
References (*35–108*)

9 October 2014; accepted 26 November 2014
Published online 11 December 2014;
10.1126/science.aaa0118

Supplementary Materials for

U-Pb geochronology of the Deccan Traps and relation to the end-Cretaceous mass extinction

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This PDF file includes:

MATERIALS AND METHODS

S1 Sampling transects and sample descriptions

Samples presented in this study were collected from three stratigraphic sections exposed by road cuts (Fig 1, S1). Background information is given on these stratigraphic sections below, and this is followed by detailed sample descriptions.

S1.1 Igatpuri section

This section contains the lowermost exposures of the Deccan traps beginning in the Jawhar Fm, whose base is not well-exposed but appears to lie unconformably on Archean-Phanerozoic rocks (*1*). There are good exposures from the Jawhar Fm through the middle Igatpuri Fm along the Nashik-Mumbai expressway between Igatpuri and Kardi. $^{40}Ar/^{39}Ar$ (*8*) and K-Ar (*9*) geochronology, in addition to detailed geomagnetic transects (*4*) have been published from this section.

DEC13-30 (N19.62640˚, E73.46407˚, elevation 255 m)

This sample was collected from a roadcut within the lower Jawhar Fm ~200 m below the contact with the Igatpuri Fm, defined by the Thalghat Giant Plagioclase Basalt, which is a regionally continuous stratigraphic marker bed. DEC13-30 is about 50 m stratigraphically above the lower most exposed Deccan units in the western Ghats (*4, 9*), accounting for west dipping normal faults that cause stratigraphic repetition when driving east-west on the west-sloping highway (*4, 9*). The outcrop is ~3-4 m high and composed of massive fine-grained basalt cross-cut by sinuous veinlets of coarser-grained friable material (Fig. S1). Bondre et al. (*18*) describe such veins in detail as features exclusively found in composite flows, i.e., large flows that are composed of many smaller pahoehoe flows that override or inflate liquid portions of slightly older eruptions. Segregation veins are often associated with or grade into vesicular pipes that pierce the adjacent flow, which would not be expected if the segregation veins were very late dikes or hydrothermal in origin (*18*). The often sinuous nature of the veins led Bondre et al. (*18*) to speculate that they formed while the flow was still mobile and were thus deformed. We therefore interpret these veins to have crystallized very shortly after emplacement of the host flow and magmatic zircons from these veins therefore very closely date eruption of the lava.

DEC13-30 was collected from the same outcrop as samples S11 and S12 of Chenet et al. (*4*), which were analyzed for paleomagnetism and assigned a transitional polarity (i.e., during a normal to reverse polarity switch). This outcrop is ~10 m higher stratigraphically than sample NA03, dated by K-Ar at 67.4±2.0 Ma (2-sigma) (*9*) and which also contained a transitional polarity. These samples are ~40 m stratigraphically below a transition to reverse polarity in the middle Jawhar Fm, assigned to chron C29r (*4, 9*). K-Ar and $^{40}Ar/^{39}Ar$ dates within the reverse polarity Jawhar Fm range from 64.7±1.8 and 65.7±1.4 Ma (*4, 9*). Using updated knowledge of fluence monitors used for $^{40}Ar/^{39}Ar$ geochronology (e.g., the age of the Fish Canyon sanidine of 28.02 Ma (*35*) versus 28.2-28.3 Ma (*36, 37*)) could shift $^{40}Ar/^{39}Ar$ dates older by 400-500 ka, whereas different values of the ^{40}K decay constant would not significantly change the K-Ar dates of Chenet et al. (*9*). Regardless of these changes, nearly every published K-Ar or $^{40}Ar/^{39}Ar$ date from the Deccan traps overlaps within 2-sigma uncertainty of each other and with our U-Pb dates, so the ages of fluence monitors or chosen decay constant for ^{40}K from dates within the Jawhar Fm do not affect comparison to DEC13-30.

S1.2 Sinhagad Fort section

This section is located on Sinhagad road, which exposes fresh basalt on roadcuts up the Sinhagad ghat ~20 km SW of Pune. The section covers ~700 m vertically through the Deccan traps from the lower Poladpur Fm through the base of the Mahabaleshwar Fm, though the best exposures are restricted to the Ambenali Fm where roadcuts expose basalt of variable freshness. Detailed geochemical sampling and petrologic observations can be found in Beane et al. (*3*), which forms the basis for stratigraphic correlation with the Mahabaleshwar section located 40 km to the south.

RBP (N18.36173˚, E73.77290˚, elevation 1083 m)

This sample was taken from a redbole horizon in the middle Ambenali Fm ~160 m below the Ambenali-Mahabaleshwar Fm contact in the Sinhagad fort section SW of Pune (Fig. 1, S1). This section exposes the Bushe to the Mahabaleshwar Fms and has been described petrologically and geochemically in detail (*3*). The redbole is ~0.5 m thick and our sample combines material from the lower contact with weathered basalt through the upper paleosol layer (Fig. S1A), which evidently contains volcanic-derived material.

S1.3 Mahabaleshwar section

This section contains fabulous exposures of the Poladpur through Mahabaleshwar Fms as the road cuts >1000 m downward through the escarpment of the western Ghats between the towns of Mahabaleshwar and Poladpur (Fig. 1C). Detailed unit descriptions in addition to high-resolution geochemical and isotopic sampling have been reported (*16*) and these data help define the unit boundaries in this section and provide a basis for stratigraphic correlation with the Sinhagad Fort section, from which RBP was sampled. Chenet et al. (*5*) presented high-resolution magnetostratigraphic data and some stratigraphic observations from this section, including the positions of redboles.

RBE (N17.92550˚, E73.62360˚, elevation 999 m)

This sample was taken from a redbole horizon in the Mahabaleshwar Fm ~80 m above the Ambenali-Mahabaleshwar contact. This redbole is ~1.3 m thick and consists of red clay and silty horizons, and the entire horizon was sampled for geochronology (Fig. S1A). RBE was collected closest to samples MB17, -28, -07 and -09 of Chenet et al. (*12*), and is therefore within meters stratigraphically from the contact between lavas with transitional polarity and normal polarity of C29n.

RBF (N17.91957˚, E73.62745˚, elevation 1064 m)

This redbole horizon was sampled ~60 m stratigraphically above RBE within the Mahabaleshwar Fm. It contains an ~20 cm thick red weathering horizon with ~50 cm of dense lithified clay material underlying the base of the overlying flow (Fig. S1A). It was collected from between samples MB11 and MB17 of Chenet et al. (*5*) and therefore from within a reverse polarity section representing C29n within 20 meters above transitional polarity lavas.

DEC13-08, -09, -10 (N17.91671˚, E73.62527˚, elevation 1088 m) Three samples were collected from in or just below a ~30 cm thick green clastic horizon between two massive basalt flows (Fig. S1A). This green layer is unlithified, clay-rich and contains abundant clasts interpreted as phenocrysts and lithic fragments floating in a finer grained matrix. At the layer's top, the overlying basalt exhibits loadcast structures, generally interpreted as denser material sinking into less dense unlithified material. The base of the layer grades into brownish clay rich material and

altered basalt that is brecciated in places, though deep weathering obscures these contacts. This horizon is interpreted as a single or composite volcanic ashbed; numerous similar layers described throughout the Deccan are colloquially called greenboles. This particular greenbole appears on the stratigraphic column of Chenet et al. (*5*) between basalt samples MB08 and MB05, which are both normal polarity. Other greenboles are described throughout the region, though their origin is not likely always volcanic and may also be interpreted as paleosols similar to redboles (*38*). DEC13-08 was collected near the top of this ashbed which was dominated by fine-grained material and few phenocrysts; DEC13-09 was collected at the base of the ashbed in a coarser grained trough of crystal rich material ~40 m laterally from DEC13-08. DEC13-10 was collected from a brown clay rich layer ~10 cm below the base of the green ash from within a zone of broken up heavily altered basalt.

S2 Methods: U-Pb geochronology

S2.1 Zircon separation and imaging

Zircons were extracted from their host rocks at Princeton University (PU) and the Massachusetts Institute of Technology (MIT) by standard crushing, gravimetric- and magnetic-separation techniques using a Bico Braun "Chipmunk" Jawcrusher, discmill, Wilfley table or hand pan, methylene iodide, hand magnet, and Frantz isodynamic separator. For unlithified clay rich samples, the crushed material was either placed into a blender or an ultrasonicator to separate zircon from clay prior to density and magnetic separation. Zircons were picked in reagent-grade ethanol from the least magnetic mineral separate. Redbole samples (RBE, RBF, and RBP) and the segregation vein sample (DEC13-30) had very low zircon yield, so most or all were picked for analysis. The greenbole samples (DEC13-08, -09, -10) contained abundant zircon (>100). A subset of zircon from RBE, DEC13-09 and -10 were picked and sent to the other lab for duplicate analysis. Picked zircons were transferred in bulk to quartz crucibles, loaded in a muffle furnace, and annealed at 900 °C for 48 hours (*39*). Annealed grains were then transferred in ethanol into plastic petri dishes from which single grains were chosen for U-Pb geochronology. Selected grains were photographed and then transferred using stainless steel picking tools into separate 3-ml Savillex PFA hex beakers containing distilled acetone and taken to the clean lab.

S2.2 U-Pb zircon ID-TIMS analysis

Zircons were rinsed in hex beakers in either distilled acetone or MQ H_2O. Single grains were loaded into 200 μl Savillex "micro"-capsules with 100 μl 29 M HF + 15 μl 3 N HNO_3 for a single leaching step in high-pressure Parr bombs at 195 °C for 12 h to remove crystal domains affected by Pb loss (*39, 40*). Grains were rinsed post-leaching with 6 N HCl, MQ H_2O, and 3 N HNO_3 prior to spiking with the EARTHTIME (^{202}Pb-)^{205}Pb-^{233}U-^{235}U tracer and addition of 100 μl 29 M HF + 15 μl 3 N HNO_3. Zircons were then dissolved to completion in Parr bombs at 210 °C for 48 h. Dissolved zircon solutions were subsequently dried down, redissolved in 100 μl 6 N HCl and converted to chlorides in Parr bombs at 195 °C for 12 h, after which solutions were dried again and brought up in 50 μl 3 N HCl. The U-Pb and trace element aliquots were then separated by anion exchange column chromatography using 50 μl columns and AG-1 X8 resin (200-400 mesh, chloride form from Eichrom) (*41*) and dried down with a microdrop of 0.05 M H_3PO_4. The dried U and Pb aliquot was loaded in a silica gel emitter (*42*) to an outgassed, zone-refined Re filament. Isotopic determinations were performed using an IsotopX PhoeniX-62 TIMS at PU or a VG Sector 54 TIMS at MIT, with Pb analyses performed in peak-hopping mode on a Daly-photomultiplier ion counting detector. A correction for mass-dependent Pb fractionation was applied cycle-by-cycle, calculated from the deviation of measured ^{202}Pb/^{205}Pb from the known tracer ^{202}Pb/^{205}Pb (0.99924 ± 0.00054 (2σ)). A Daly-photomultiplier Pb dead time of 40.5 ns was used at PU, as determined by >100 measurements of NBS981 and NBS982 standards and using a least squares fit to measured data over the range of 100 kcps to 2.5 Mcps ^{208}Pb. Corrections for interfering isotopes under masses 202, 204, and 205 were made cycle-by-cycle by measuring masses 201 and 203 and assuming they represent $^{201}BaPO_4$ and ^{203}Tl and using natural isotopic abundances to correct for $^{202}BaPO_4$, $^{204}BaPO_4$, $^{205}BaPO_4$, and ^{205}Tl. Though mass 201 peaks can be in the hundreds to thousands of cps, this correction is nearly negligible. More importantly, though peaks under mass 203 were typically <10 cps, higher abundances can have an important effect on the 205 peak. Despite the assumed accuracy of the correction, it was found at PU that very large 203 peaks often correlate with negatively discordant data. In such cases, these data are reported but not used in age interpretations (e.g., several analyses from sample DEC13-30 in this study). Typical ion yields for ^{205}Pb were 100-200 kcps for ~20 pg ^{205}Pb, sustainable for 3-4 hours of analysis (160-220 ratios collected) and typical ^{206}Pb/^{205}Pb ratios were 0.1-2.0.

UO_2 measurements at PU were performed in static mode on Faraday cups with 10^{12} ohm resistors using an oxide composition of $^{18}O/^{16}O$ of 0.00205 (*43, 44*). Mass fractionation of U was determined cycle-by-cycle, calculated from the deviation of measured $^{233}U/^{235}U$ from the known tracer $^{233}U/^{235}U$ (0.995062 ± 0.000108 (2σ)) and assuming a $^{238}U/^{235}U$ of 187.818 ± 0.045 (2σ) for sample U (*45*). Typical U ion beams on 10^{12} ohm resistors at PU were 200-1000 mV of ^{233}U at PU and 25-150 mV of ^{233}U on 10^{11} resistors at MIT for ~1 ng ^{233}U, resulting in measurement precision of 0.004-0.02% (2 SE) for $^{270}U/^{265}U$ ranging from 2 to 0.06

Data reduction was performed using the programs Tripoli and U-Pb_Redux (*46, 47*) and the U decay constants of Jaffey et al. (*48*). All Pb_c was attributed to laboratory blank with a mean isotopic composition determined by total procedural blank measurements, carried out separately for each analyst and dissolution set. The composition of the tracer used at both MIT and PU is that for ET2535 v. 3.0:

Composition	Value	±1σ (abs)
$^{202}Pb/^{205}Pb$	0.99924	0.00027
$^{204}Pb/^{205}Pb$	0.000105	0.000009
$^{206}Pb/^{205}Pb$	0.00048	0.00017
$^{207}Pb/^{205}Pb$	0.00043	0.00014
$^{208}Pb/^{205}Pb$	0.00104	0.00033
$^{233}U/^{235}U$	0.995062	0.000054
$^{238}U/^{235}U$	0.00307993	4.0E-7
Concentration of ^{205}Pb (mol/g)	1.0312E-11	2.6E-14
Concentration of ^{235}U (mol/g)	1.0336E-9	2.6E-12

A thorough discussion of the Th-disequilibrium correction is given in section S6.1. Uncertainties in reported U-Pb zircon dates are reported at the 2σ or 95% confidence level and exclude uncertainties in tracer calibration and decay constants unless otherwise noted.

In addition to semi-weekly measurements of Pb standards NBS981 and 982 to monitor Pb fractionation and ion counter deadtime, we generated U-Pb and trace element standard data for natural zircon standard AUS-Z2 (*49*) to monitor laboratory reproducibility and interlaboratory bias (Fig. S2). Data from PU yield a statistically significant cluster in concordia space with a weighted-mean $^{206}Pb/^{238}U$ CA-ID-TIMS age of 38.905 ± 0.013/0.017/0.045 Ma

(MSWD = 1.0, n = 9/10; 2σ uncertainties stated as internal/+tracer calibration/+decay constant); data from MIT give 38.879 ± 0.020/0.022/0.047 Ma (MSWD = 1.6, n = 3/3). These values are in excellent agreement with the published age of 38.8963 ± 0.0044/0.012/0.043 Ma (MSWD = 1.0, n = 12/12) (*49*).

S3 Methods: Zircon trace element geochemistry

The trace element compositions of the same zircon fragments dated by ID-TIMS were characterized following the analytical protocol of Schoene et al. (*50*) at PU. Trace element washes isolated during U-Pb column chemistry were dried down in pre-cleaned 2.0 ml polypropylene vials (CETAC #SP5540) and redissolved in 1.0 ml 1.5 M HF + 0.1 M HNO_3 + 1 ppb Ir. Measurements were performed on a Thermo Fisher ELEMENT2 sector field-inductively coupled plasma-mass spectrometer (SF-ICP-MS) with a sample introduction system consisting of a CETAC Aridus II desolvation nebulizer + ASX-100 autosampler with an uptake rate of 100 μl/min. Measured elements included Zr, Hf, Y, Nb, Ta, REEs, Pb, U, Th and Ir, with iridium monitored as an internal standard during mass spectrometry. The instrument was tuned in low resolution mode with an optimal signal intensity of 0.5–2 Mcps on the peak height (not the integrated signal) for 1 ppb Ir. A matrix-matched, gravimetric external calibration solution was prepared with the relative abundance of targeted elements representing that observed in natural zircon (e.g., Zr/Hf = 50). A dilution series was generated using this solution to cover the range of concentrations observed in unknowns (e.g., [Zr] = 10^1–10^4 ppb solution), which was then used to generate a concentration-intensity calibration curve for each trace element at the beginning of the analytical session. Samples and interspersed instrumental and total procedural blanks were analyzed in sets of 24 over ~3 h, with a line washtime of 120 s and uptake time of 90 s. Following data acquisition, solution concentrations were converted to stoichiometric concentrations in zircon by normalizing solution concentration data assuming all trace elements partition into the Zr^{4+} site in $ZrSiO_4$, where Σ Zr+Hf+…+Th = 497,646 ppm. Uncertainties are reported at the 95% confidence level and include subtraction of the mean and standard deviation of blank measurements. Uncertainties in ratios were calculated using standard uncertainty propagation techniques and assuming uncorrelated uncertainties in measured elemental abundances. Trace element data were also produced for AUS-Z2 during the course of this study,

which show excellent reproducibility and identical concentrations on Zr, Hf, and the REE compared to published laser ablation ICPMS data (*49*) (Fig. S2).

S4 Results: U-Pb geochronology

Results from U-Pb geochronology for each dated sample are presented below. Because of very limited zircon yield, these grains were not imaged by cathodoluminescence prior to analysis. Photographs of nearly all the zircons were taken (except on a day when the camera was malfunctioning), and these are presented in Fig. S3. Concordia plots are in Fig. S4 and rank order plots are in Fig. 2. Given the complicated nature of this dataset, only qualitative descriptions are presented below, and the age interpretations are discussed section S6. All uncertainties are reported at the 2σ level with internal errors only except where indicated. Age interpretations are presented in the main text as ±X/Y/Z where X indicates internal uncertainties only for comparison with $^{206}Pb/^{238}U$ dates from labs using the ET(2)535 tracer solution, Y includes tracer calibration uncertainties for comparison with other $^{206}Pb/^{238}U$ dates determined with a different tracer solution, and finally Z includes full systematic uncertainties including decay constants for comparison with other radioisotopic dates or astrochronologically-determined timescales that may be pinned to radioisotopic dates other than the $^{206}Pb/^{238}U$ system (*35, 51*).

DEC13-30

This sample yielded <30 zircons with several morphologies. One was a population of subhedral, clear grains <200 μm in length; 5 of these were sampled for analysis and were inherited, ranging in age from 160-1500 Ma (Table S1, Fig. S3). A second population of grains were euhedral and stubby but coated in brown material (perhaps hematite; Fig. S3) such as to conceal these grains upon first viewing. Blocky fragments of zircon containing euhedral crystal terminations were also in this population and were often adhered to clayey material likely deriving from weathered glass or feldspars. Less than twenty of these zircons were recovered and 11 were successfully dated. All 11 were ca. 66 Ma but spanned over ~180 ka. Three were slightly to very negatively discordant, and these analyses also contained abnormally high count rates under masses 201 and 203, which typically indicates that interferences other than $BaPO_4$ and Tl are present in the sample (so-called "organics"); those three analyses are not included in age interpretations or on Fig. 1, but are in Table S1.

RBP

This sample yielded dozens of very small (<50 μm) euhedral zircons. Eleven grains were successfully dated, two were inherited ca. 2500 Ma, and nine were ca. 65 Ma. In addition to being small, these grains were low-U and despite very low analytical blanks (≤0.33 pg) had low radiogenic to blank Pb ratios, such that the data are less precise than other samples. Analyses with Pb^*/Pb_c (radiogenic to common Pb) ≤1 were not considered in age interpretations. Despite the larger uncertainties, a weighted mean of the 4 most precise analyses gives a date of 65.651±0.091 Ma, whose mean is older than the overlying samples RBE, RBF and DEC13-08, -09, and -10.

RBE

This sample yielded abundant euhedral prismatic zircons that varied in length from about 50-100 μm, and these are interpreted to be volcanic in origin. Eleven grains were dated at PU and five were dated at MIT; all analyses were concordant. The zircons show ~250 ka of dispersion in $^{206}Pb/^{238}U$ dates, which is well beyond the analytical precision. Both labs show similar dispersion and both the youngest and oldest grains from each lab overlap with each other.

RBF

Less than 20 euhedral prismatic zircons 50-200 μm in length were recovered from ~1 kg of material collected throughout the redbole horizon, and these are interpreted to be volcanically derived. Ten of the most pristine zircons were selected for geochronology and all were successfully analyzed. All are concordant and spread over ~200 ka, which is well beyond analytical uncertainty.

DEC13-08, -09, -10

Each sample from this volcaniclastic horizon yielded abundant euhedral prismatic zircon 50-400 μm in length that are interpreted to be of volcanic origin. The morphology and size of grains from DEC13-08 and -09 are identical though zircon from DEC13-10 is on average smaller. One xenocrystic grain was analyzed in DEC13-08, at 680 Ma; the rest of the 44 grains analyzed are

ca. 65.5 Ma. Mean dates from each sample have a 150-300 kyr range, which is well beyond analytical uncertainties, and is seen by both MIT and PU laboratories.

S5 Results: Zircon trace element geochemistry

Trace element data were obtained on the exact same volume of material dated by U-Pb in this study for all but three zircons presented (*50, 52*). These are plotted as element ratio cross plots in Fig. S5A and against $^{206}Pb/^{238}U$ date in Fig. S5B. Most important for this study is that when plotted as trace element cross plots, zircon from some samples plot in very different fields, consistent with their origination from different igneous sources. We use Zr/Hf in zircon as a proxy for igneous differentiation, similar to SiO_2 in whole rock geochemical data (*53*). Zr/Hf in our zircon suite varies between ~65 and 35, typical of igneous zircon. DEC13-30 zircons have Zr/Hf >50, consistent with their derivation from a less differentiated magma (*30*). Zircons from RBE, and a subset of zircons from RBF and RBP, also have high Zr/Hf, suggesting they originated from a relatively mafic volcanic ash, though the chemistry of their host magma is unknown. Zircons from the green ashbed samples DEC13-08, -09, and -10 have lower Zr/Hf and decreasing Zr/Hf correlates with increasing Nb/Gd and Yb/Gd. Increasing Nb/Gd with decreasing Zr/Hf, due the very incompatible nature of Nb, is also consistent with igneous differentiation controlling the geochemistry of zircons in the green ashbed and more generally for all zircons in this study.

When plotted against crystallization age (Fig. S5B), it can be observed that despite having prolonged crystallization in zircon from each sample that largely overlap, the geochemistry of the zircons distinguishes the stratigraphically older samples RBP and RBE from the green ashbed samples DEC13-08, -09, and -10. The older samples generally have higher Zr/Hf, lower Lu/Hf and Nb/Hf ratios than the younger ones. Several samples show weak correlations between age and geochemistry (also evident in Fig. 2), such as RBF, DEC13-08 and -09, that may result from fractional crystallization, magma mixing or assimilation in the magmatic system during zircon crystallization prior to eruption. This can affect zircon geochemistry either by mixing cores and rims of grains with different geochemical compositions or through equilibrium partitioning in an evolving liquid (*50, 52-59*). Outliers from geochemically equivalent clusters or from trends in time may be due to incorporation of zircon from a slightly older or geochemically distinct batch of magma – which are often called

antecrysts (*60*) – and the significance of such grains for our age interpretations are discussed in section S6.3.

S6 U-Pb Age interpretations

The zircons from all of our samples except for DEC13-30 are interpreted as deriving from ashfall during periods of quiescence of basaltic volcanism. Though the source of the (presumably moderately silicic) volcanism is unknown, both the external morphology, internal textures, and magmatic Th/U of the zircons (Fig. S3) are consistent with this interpretation. Zircons show no evidence for pitting or rounding associated with alluvial or eolian transport, though inherited grains (i.e. >100 Ma) are markedly less euhedral than ca. 66 Ma grains. Previous studies on the geochemistry and petrography of redbole and greenbole horizons have concluded that a high-Si volcanic component can be found in a subset of boles (*19, 38, 61, 62*). Furthermore, our greenbole samples (DEC13-08, -09, -10) come from a bed that contains phenocrysts and small lithic fragments consistent with derivation from ashfall. That (euhedral) zircons from the redbole horizons yield consistent dates yet unique geochemistry compared to the greenbole also argues for a non-detrital source for those zircons. Ongoing work on the mineralogy and geochemistry of our samples will be used to assess the amount of volcanic material within the boles.
Following a volcanic interpretation for our zircons, there are two steps in achieving accurate depositional ages for our samples, and thus for bounding flows of the Deccan Traps. The first is to obtain accurate crystallization ages for each zircon grain and the second is to interpret those data in terms of depositional ages. We discuss those in sequence below and present multiple different interpretations of our data in Table S3. We show that the major conclusions about the age and duration of the Deccan Traps are unaffected by our data interpretations.

S6.1 Th/U disequilibrium correction in zircon

It is well documented that during crystallization of minerals useful for U-Th-Pb geochronology, fractionation of Th from U can cause the ^{238}U decay chain to depart from secular equilibrium (*63-65*). In the case of zircon, where U is preferentially incorporated in its lattice over Th, this can result in a depletion of ^{206}Pb and therefore ages that are too young by up to ~110 kyr (*66-68*). A nominal correction can be made for this by measuring or assuming a Th/U of the liquid from which the zircon crystallized and thus calculating a partition coefficient based on the Th/U of the

zircon (it is standard to calculate a model Th/U for each zircon based on the $^{208}Pb/^{206}Pb$ and assuming concordance between the U-Pb and Th-Pb systems). Alternatively, one can assume a constant partition coefficient for Th/U between the liquid and zircon and calculate the resulting Th/U of the liquid. For recent discussions and approaches, see also refs. (*67, 69-73*). For most zircon and magma compositions, the difference between these approaches makes negligible difference in the resulting ages, but for young or high-precision ages this correction is an important contributor to the overall uncertainty budget (*73-75*). Because we have no information about the liquid from which our zircons crystallized, we explore both "constant magma Th/U" and "constant Th/U partition coefficient" approaches. We reduced our data in its entirety using both approaches and report the differing age interpretations in Table S3. The constant magma Th/U approach assumes and Th/U of the liquid to be 2.8±0.5, as this encompasses the majority of igneous liquids. For the constant partition coefficient approach, we use the average partition coefficient determined experimentally by Rubatto and Hermann (*76*) for andesitic to dacitic magmas of 0.33. In the end we prefer the constant partition coefficient approach because it seems more parsimonious to suggest that highly variable Th/U in zircons from single handsamples results from changing magma compositions and/or incorporation of antecrystic zircon rather than rapidly fluctuating partition coefficients. However, there is not sufficient experimental or empirical data for zircon/liquid partitioning over a wide range in temperatures and liquid compositions to permit a totally satisfactory interpretation (*77*). For our dataset, the choice between these models results in a negligible difference in dates for individual zircons or weighted mean dates for all samples except DEC13-30. Zircons from this sample have relatively high Th/U (1.9-2.6) compared to the other samples (which are ~1) such that the liquid Th/U resulting from a constant partition coefficient approach is ~5-7 as opposed to an assumed 2.8. This results in a difference of 10s of kyr for DEC13-30 zircons; the importance of this difference is best illustrated in the calculated duration of magnetic polarity Chron 29r, which differs by ~30 kyr. While the resulting durations overlap within uncertainty for both approaches (see Table S3), we regard this as the largest uncertainty in this study. All the ages presented in the main text, Figs. 1 and 2 and Table S1 use the constant partition coefficient approach.

S6.2 Interpretation of zircon crystallization age spectra

Each of the samples in this study except RBP show a spread in ages that is larger than analytical uncertainty. This phenomenon is well-documented in igneous systems and can result from prolonged crystallization of zircon within a magmatic system or inheritance of much or slightly older zircons into a younger batch of magma or eruptive column (*20, 21, 52, 57-59, 78-88*). We interpret our data to be the result of a similar phenomena and provide very reproducible dates from zircon standard AUS-Z2 as a contrasting example (Fig. S2) to illustrate that the observed spread in dates in Deccan samples is not the result of analytical error.

Further constraints on the origin of the zircon age spectra come from the geochemistry of the dated zircons (Table S3, Fig. 1, S5). If the spread in zircon dates were a result of analytical error in the U-Pb geochronology of an otherwise homogeneous population of zircons, such a population also should have identical trace element characteristics, e.g., if they crystallized at the same time from a homogeneous liquid. While three of our seven samples exhibit this behavior, most do not. The observation of heterogeneous trace element characteristics in a suite of zircons that have a spread in dates is consistent with their derivation from liquids with different compositions or at different temperatures (*50, 52, 54, 55, 58, 59*). In several samples (RBF, DEC13-08, and -09), there are crude trends in zircon geochemistry with time (Fig. 1, S5) suggesting zircon was derived from an evolving system. Alternatively, such data could be interpreted as mixing of cores of older zircon with rims of younger zircon that each have distinct geochemistry. In either case, it implies that the observed spread in dates is real and not the result of analytical error in U-Pb systematics. It also implies that the youngest grain or grains from the volcanic derived zircons in each sample are the best estimate of the deposition of the material. We expand on this interpretation in the following section.

While pre-eruptive zircon growth is commonplace in moderate to high-silica volcanic systems, prolonged growth of zircon in a segregation vein represented by DEC13-30 is more peculiar. These veins are interpreted to represent in situ segregation of fluid-rich and/or silica-rich liquid from a rapidly crystallizing basalt flow. Such veins have been observed in a number of thick basaltic flows or shallow-level intrusions (*69, 89-91*) and also in lava lakes in Hawaii (*92*). Thermal arguments easily rule out that these lava flows crystallized in 200 kyr, which is the range in zircon dates observed in our sample of the Jawhar Fm. However, this sample also has abundant xenocrystic zircon ranging in age up to 1600 Ma. This observation argues against

a purely fractionation-derived origin for the segregation veins and thus the origin of these veins may involve localized shallow crustal melting. If the sampled igneous zircons that crystallized ca. 66.2 Ma contained even micron-scale cores of 1600 Ma material, the ages could be shifted older as observed. Such inclusions would not be large enough to change the trace elements of the zircon (i.e. a difference in 0.5% in U-Pb date is easily measureable, but is not in our geochemical data). Because there were too few zircons, we did not collect CL images to confirm this speculation but these grains were full of inclusions of dark brown material that would conceal any cores optically (Fig. S3). We thus interpret the spread in dates in DEC13-30 as mixing of older cores within euhedral igneous zircon, suggesting the youngest grains are the best estimates of deposition and rapid crystallization of the host basalt.

Finally, another possibility is that the spread in zircon dates results from Pb-loss. Diffusion of Pb in radiation-damaged zircon is likely the cause of Pb-loss in natural zircon (*93-95*). The ability to remediate Pb-loss has recently been revolutionized by the chemical abrasion technique (*39*), which has become common practice in ID-TIMS laboratories and modified into a single-stage leaching technique (*40, 96, 97*). Though some age scatter in chemically abraded zircons has still been attributed to Pb-loss (*21, 97*), especially in highly metamict samples (*98, 99*), it is generally assumed that in young samples subjected to chemical abrasion, Pb-loss is negligible. For the data presented here, we can make several arguments to support this claim. The first is that in general stratigraphic order is maintained in our geochronologic dataset (with the exception of the composite ashbed sample, where two of three give slightly older dates; see discussion below), which would be quite fortuitous given the anticipated non-systematic nature of Pb-loss in grains with widely varying U-content and size. Second is in samples that exhibit trends in geochemistry with time, Pb-loss cannot be the cause of spread in dates and must result from some zircon growth/inheritance process. We thus discount Pb-loss as an important mechanism of generating the spread in dates in our dataset.

S6.3 Best estimates for deposition of dated horizons

The previous section outlined the reasoning for interpreting the observed spread in zircon dates as a real geologic phenomena involving prolonged growth, mixing of cores and rims of zircons, and/or inheritance of slightly older grains into a volcaniclastic deposit. Recent approaches to arrive at depositional ages for volcanic deposits exhibiting this behavior, assuming negligible Pb-

loss, are to use the youngest zircon date as the best estimate or a small subset of the youngest grains for a weighted mean (*21, 100, 101*). The former method is the more conservative of the two in that it will always overlap with the latter interpretation but have larger uncertainties. This method also minimizes any effects of pre-eruptive zircon on the accuracy of the resulting depositional age. The benefit of the latter approach is that it provides a higher-precision result and if anticipated analytical scatter has resulted from a homogeneous true age spectra, this method will maximize the accuracy of the result. Here, we build upon the previous discussion that integrated U-Pb data and geochemical data from the same zircons to arrive at age interpretations that capitalizes on both approaches.

Accurate weighted means require that the data in fact represent a single population and that all scatter is analytically derived. Simply because a set of geochronological datapoints can be used to calculate a weighted mean with a reasonable MSWD (as defined by Wendt and Carl (*102*)) does not mean they meet that criteria given the possibility of subtle geologic dispersion that is masked by large analytical uncertainties (*75, 103*). Bringing geochemical data to the problem can add confidence that a population of zircon is in fact uniform in that if such a population crystallizes from a melt at exactly the same time, it should have the same geochemical signature (*50, 52, 58, 59*). From our dataset, a subset of the youngest zircons from each sample are the same in both age and geochemistry. In several cases (DEC13-09, RBF, Fig. 1, S5), increasing N would not jeopardize the MSWD of the weighted mean $^{206}Pb/^{238}U$ date, but would violate geochemical equivalence, and so N is limited. We thus have an independent means of determining which subset of U-Pb analyses are most likely to represent a population amenable to weighted means without biasing ages too old due to antecrystic zircons. Weighted-means for these samples are calculated and the analyses chosen are outlined by gray boxes in Fig. 2 and in bold in Table S1. A full assessment of using the alternative youngest single grain approach is given in Table S3 and the choice of method does not effect the main conclusions of this paper.

As a final step in building an age model for the middle Ambenali Fm through the lower Mahabaleshwar Fm, we use a Markov Chain Monte Carlo simulation that imposes stratigraphic order onto the existing geochronological dataset (*104*). This Bayesian approach is able to refine uncertainty estimates for depositional ages given that it is impossible for lower beds to be younger than higher ones and by using the geochronological data as estimated priors. Similar

models have been used to calibrate the radiocarbon timescale (*105*), and have been used recently to integrate radioisotopic dates with timescales derived from orbital tuning of cyclic stratigraphic sections (*100*). Our model produces some number (typically a million) of data points for each sample with a Gaussian distribution and standard deviation equal to that of the uncertainties from the weighted means described above. It then randomly selects one datum from each sample. If the sequence of data points follows stratigraphic order, the path is kept, if it does not (i.e. one or more stratigraphically higher datapoints is older than those beneath), it throws out the result. This is repeated a million times and the resulting paths are used to define new means and standard deviations of each dated bed. This method is especially useful if beds have largely overlapping uncertainties as with our data from the upper Deccan, but has no effect if the beds do not overlap within uncertainties such as with DEC13-30. It is worth noting that this model does not make any assumptions about sedimentation rate, only superposition.

This model can also be used to explore the probability that stratigraphic order is violated if the model produces no, or an exceedingly small number of, acceptable paths. In our dataset, this is the case for DEC13-08 and -09, for which less than five out of a million acceptable paths are produced if they are included in the model. We hence conclude that of the three samples collected from this thick ashbed, the stratigraphically lowest, DEC13-10, sampled the youngest part of the magmatic system or at least the population of zircons that crystallized the latest on average in the system. Whole zircon grains record an average time of growth that may span over tens or hundreds of thousands of years depending of the zircon saturation temperature (*106, 107*), cooling rate of the magmatic system or incorporation of antecrystic material (*58, 72*). Given the potentially complex amalgamation history of the sample tuff, we interpret the older dates found in DEC13-08 and -09 to represent some combination of all these processes manifest within the age spectra. Geochemistry of the zircons from each sample are also different: DEC13-10 has zircon that are relatively homogeneous except for two analyses with low Lu/Hf (Fig. 2), DEC13-09 exhibits a lot of scatter but a generally increasing trend in Lu/Hf with time, while DEC13-08 shows the opposite trend. This provides evidence that each sample is in fact recording a different part of an eruptive system and the differences in age is not just a sampling artifact. We therefore use the age of DE13-10 as our best estimate for the deposition of that tuff and link it to the Monte Carlo age model derived using the other samples as well. The resulting dates from the Monte Carlo model are plotted in Fig. 1 and also in Table S3, which also provides a

comprehensive view of alternative age interpretations and their effect on the duration of C29r and the minimum duration of the Deccan Traps.

On a final note, it is worth discussing alternative interpretations of the zircon date and geochemical data. For example, we could have increased the number of zircons from RBE and DEC13-10 included in their weighted means while still retaining geochemical and date equivalence (the former being a mostly qualitative assessment, while the latter is evaluated by the acceptable range of MSWDs (*102*)). If we maximize the number of grains included in the acceptable weighted means for RBE (N=12) and DEC13-10 (N=9), the resulting ages become older and more precise. These ages become exceedingly unlikely to pass the superposition test from the Monte Carlo analysis with <10 of one million paths being acceptable, and as such we err on the side of including fewer zircons in our weighted means given the potential for pre-eruptive zircon growth that is unresolvable even with our very precise data. However, if that interpretation was chosen, it would shorten our calculated duration of C29r by ~35 kyr but still overlap within uncertainty with our preferred interpretation. In no reasonable interpretation do DEC13-08 and -09 pass the superposition test, so we regard their omission as unavoidable.

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See main text for references 1-34

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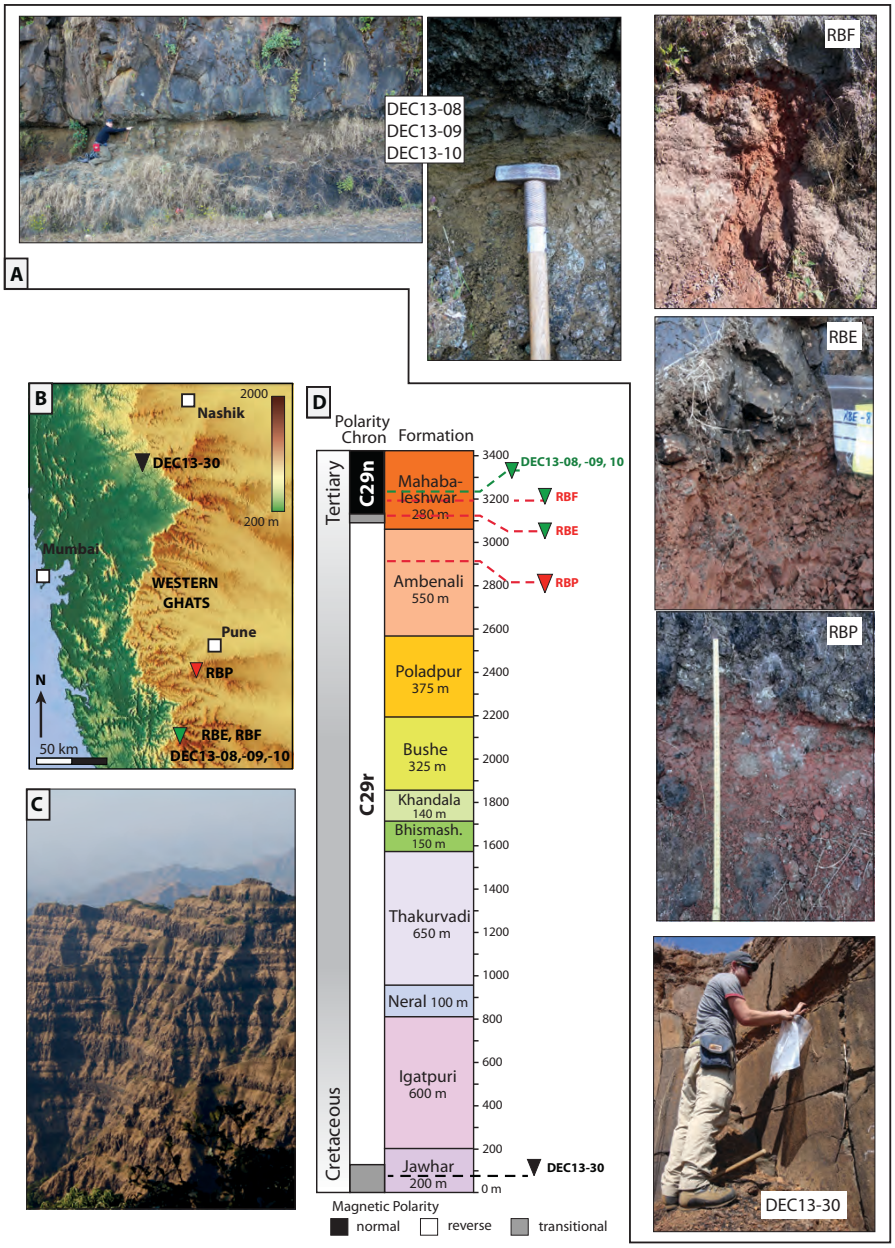
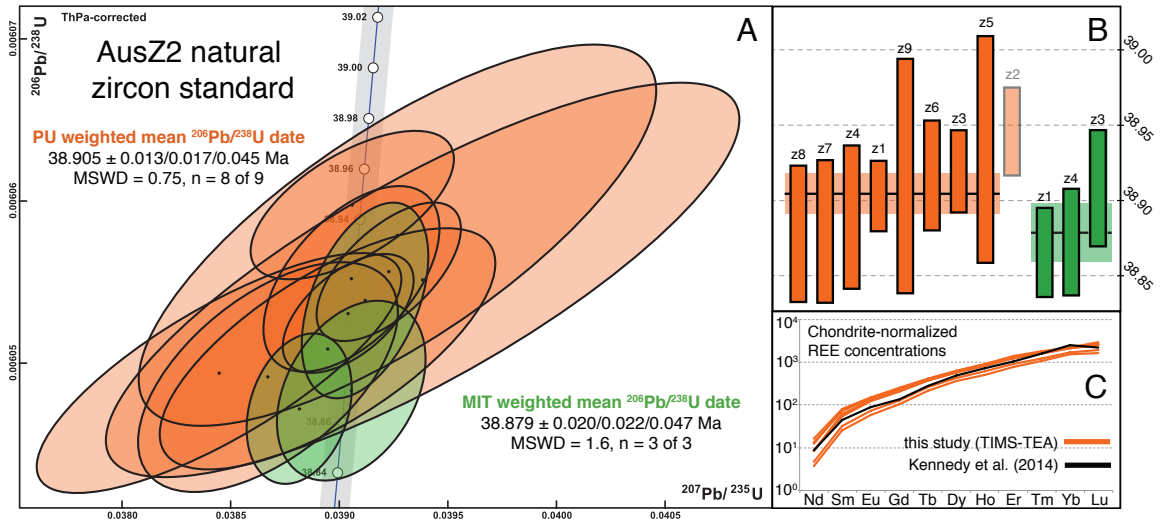


Fig. S1: Sample locations and outcrop photos. A. photos of sample locations as described in text. DEC13-08, -09, 10; shown is ~40 cm thick green horizon located at flow boundary. RBF, RBE, RBP: redbole horizons also located at flow boundaries, note that RBF has red paleosol falling into cracks in underlying basalt flow. In each, unaltered basalt flow bottom is observed at top of photo. DEC13-30: BS sampling freshly hammered friable segregation vein within massive basalt flow. Note vein is ~10 cm thick subhorizontal band in photo but other veins in the same outcrop are subvertical. B. shaded relief map of Western Ghats with sample locations. Color bar is altitude in meters, white squares are major cities. C. View from Mahabaleshwar of typical outcrop pattern of the Deccan Traps on weathered hillsides. Easily accessible exposures are located along roadcuts running up the cliff faces. D. Composite stratigraphic column showing sample locations, magnetic polarity timescale. See main text for references.



AusZ2 TEA solutions	Zr (ppm)	Hf (ppm)	Sc (ppm)	Y (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
Soln 1	489874	5028	87.1	1747.3	3.87	8.10	6.87	41.4	13.6	141.7	45.2	200.2	40.0	346.6	62.1
±1σ	9055	64	35.6	33.6	0.70	0.18	0.18	0.2	0.2	0.2	0.4	1.1	0.5	3.3	0.9
Soln 2	489235	5213	146.7	2052.4	7.43	12.07	8.36	51.1	14.9	155.1	50.1	221.0	45.5	361.3	72.4
±1σ	3281	13	52.9	26.0	0.93	0.93	0.93	0.9	0.9	2.8	0.9	3.7	0.9	1.9	0.9
Soln 3	489964	4953	67.8	1758.5	3.88	8.58	6.96	42.1	13.4	141.1	45.0	195.2	40.1	344.5	61.7
±1σ	7697	23	1.8	21.4	0.16	0.16	0.16	1.1	0.2	0.5	0.8	0.8	0.3	8.7	0.5
Soln 4	490937	5172	43.4	902.0	1.69	3.81	3.33	20.6	7.7	89.5	27.9	124.2	26.2	245.5	40.9
±1σ	7325	27	6.7	4.5	0.06	0.06	0.06	0.2	0.2	1.1	0.2	1.0	0.2	0.7	0.1
Soln 5	489469	5264	54.5	1897.2	6.13	10.97	8.06	47.7	14.5	149.7	47.1	209.0	42.9	357.4	67.1
±1σ	7590	143	9.0	59.3	0.32	0.32	0.32	0.6	0.3	3.2	1.6	1.3	0.3	8.1	0.6
Soln 6	489638	5088	59.9	1902.9	5.64	11.07	7.93	46.6	14.2	151.2	47.8	206.5	42.2	358.1	65.8
±1σ	592	66	31.9	22.1	0.21	0.42	0.21	0.4	0.2	3.1	0.8	4.0	0.2	3.1	0.4
Soln 7	490717	5095	66.1	1083.3	2.14	4.72	4.12	25.5	9.3	105.1	33.6	147.1	30.5	274.7	47.2
±1σ	13007	75	25.6	2.1	0.09	0.09	0.09	0.1	0.1	1.4	0.1	0.3	0.2	8.1	0.3
Soln 8	489696	5165	75.0	1771.7	3.88	9.14	7.13	42.9	13.5	144.8	46.1	202.6	41.0	363.3	64.1
±1σ	1046	143	15.6	4.4	0.13	0.13	0.13	0.6	0.1	0.3	0.9	4.5	0.3	2.9	0.4

	Dates (Ma)									Composition					Isotopic Ratios									
Fraction	206Pb/238U <Th>[a]	±2σ abs	207Pb/235U <Pa>[b]	±2σ abs	207Pb/206Pb <ThPa>[ab]	±2σ abs	207Pb/206Pb[c]	±2σ abs	% disc [d]	Th/U[e]	Pb* (pg) [f]	Pbc (pg) [g]	Pb*/Pbc[h]	206Pb/204Pb[c]	208Pb/206Pb[j]	206Pb/238U <Th>[ja]	±2σ %	207Pb/235U <Pa>[jb]	±2σ %	207Pb/206Pb <ThPa>[jab]	±2σ %	Corr. coef.
Princeton University AusZ2 analyses (ET2535-spiked)																						
z1	38.90295	0.02348	38.89	0.29	38	18	44.0	17.7	11.81	0.41	5.26	0.34	15.53	982	0.131	0.006053	0.061	0.039041	0.77	0.046800	0.74	0.569
z2	38.94578	0.02933	38.91	0.46	36	28	42.5	27.5	8.59	0.41	7.13	0.66	10.76	686	0.131	0.006060	0.076	0.039060	1.2	0.046770	1.2	0.627
z3	38.91941	0.02737	39.07	0.32	48	19	54.4	19.2	28.60	0.41	4.58	0.32	14.37	910	0.130	0.006056	0.071	0.039228	0.85	0.047003	0.80	0.629
z4	38.88896	0.04767	38.79	0.75	33	45	39.0	45.4	0.62	0.41	1.89	0.32	5.94	387	0.131	0.006051	0.12	0.038946	2.0	0.046702	1.9	0.713
z5	38.93386	0.07534	39.1	1.2	50	69	55.9	68.9	30.55	0.41	1.43	0.35	4.03	268	0.131	0.006058	0.19	0.039268	3.0	0.047034	2.9	0.762
z6	38.91662	0.03667	38.90	0.40	38	24	44.1	23.6	11.95	0.40	3.23	0.26	12.34	784	0.130	0.006055	0.095	0.039056	1.0	0.046801	0.99	0.548
z7	38.87939	0.04742	38.31	0.82	3	50	8.7	50.2	-347.03	0.40	2.10	0.37	5.71	374	0.129	0.006049	0.12	0.038447	2.2	0.046115	2.1	0.785
z8	38.87779	0.04541	38.53	0.58	17	36	22.8	35.6	-70.02	0.40	2.37	0.29	8.20	528	0.129	0.006049	0.12	0.038672	1.5	0.046387	1.5	0.571
z9	38.91620	0.07794	39.2	1.4	58	84	64.0	84.3	39.37	0.41	1.49	0.47	3.16	214	0.131	0.006055	0.20	0.039384	3.7	0.047194	3.5	0.817
Massachusetts Institute of Technology AusZ2 analyses (ET2535-spiked)																						
z1	38.86532	0.02973	38.67	0.24	26	15	32.5	14.5	-19.38	0.40	8.20	0.28	29.76	1823	0.129	0.006047	0.077	0.038816	0.62	0.046574	0.61	0.266
z3	38.90808	0.03866	38.96	0.28	42	17	48.4	16.8	19.85	0.41	7.17	0.25	28.33	1734	0.130	0.006054	0.10	0.039119	0.74	0.046886	0.70	0.450
z4	38.87244	0.03553	38.90	0.33	41	20	46.8	20.2	17.05	0.41	7.17	0.34	20.89	1283	0.131	0.006048	0.092	0.039055	0.88	0.046853	0.85	0.354

a Corrected for initial Th/U disequilibrium using radiogenic 208Pb and Th/U[magma] = 3.0.
b Corrected for initial Pa/U disequilibrium using initial fraction activity ratio [231Pa]/[235U] = 1.1.
c Isotopic dates calculated using the decay constants λ238 = 1.55125E-10 and λ235 = 9.8485E-10 (Jaffey et al. 1971).
d % discordance = 100 - (100 * (206Pb/238U date) / (207Pb/206Pb date))
e Th contents calculated from radiogenic 208Pb and the 207Pb/206Pb date of the sample, assuming concordance between U-Th and Pb systems.
f Total mass of radiogenic Pb.
g Total mass of common Pb.
h Ratio of radiogenic Pb (including 208Pb) to common Pb.
i Measured ratio corrected for fractionation and spike contribution only.
j Measured ratios corrected for fractionation, tracer and blank.

Fig. S2. U-Pb geochronological and trace element geochemical data for natural zircon standard AUS-Z2. A. Concordia diagram for U-Pb data from MIT and PU. For comparison, $^{206}Pb/^{238}U$ age reported by (*49*) was 38.896 ± 0.004/0.012/0.043 Ma (MSWD = 1.0, n = 12/12). All uncertainties stated at the 2s level. B. Rank-order plot of AUS-Z2 $^{206}Pb/^{238}U$ dates (same analyses as plotted in A) with axis in millions of years. C. Spider diagram of chondrite-normalized REE (*108*) concentrations (Nd to Lu) in AUS-Z2, from solution ICPMS (this study; using methods of (*50*)) and LA-ICPMS (*49*). Note that the solution ICPMS data are not the exact same zircons shown in A and B. The single black curve represents the mean of 10 LA-ICPMS analyses from (*49*).

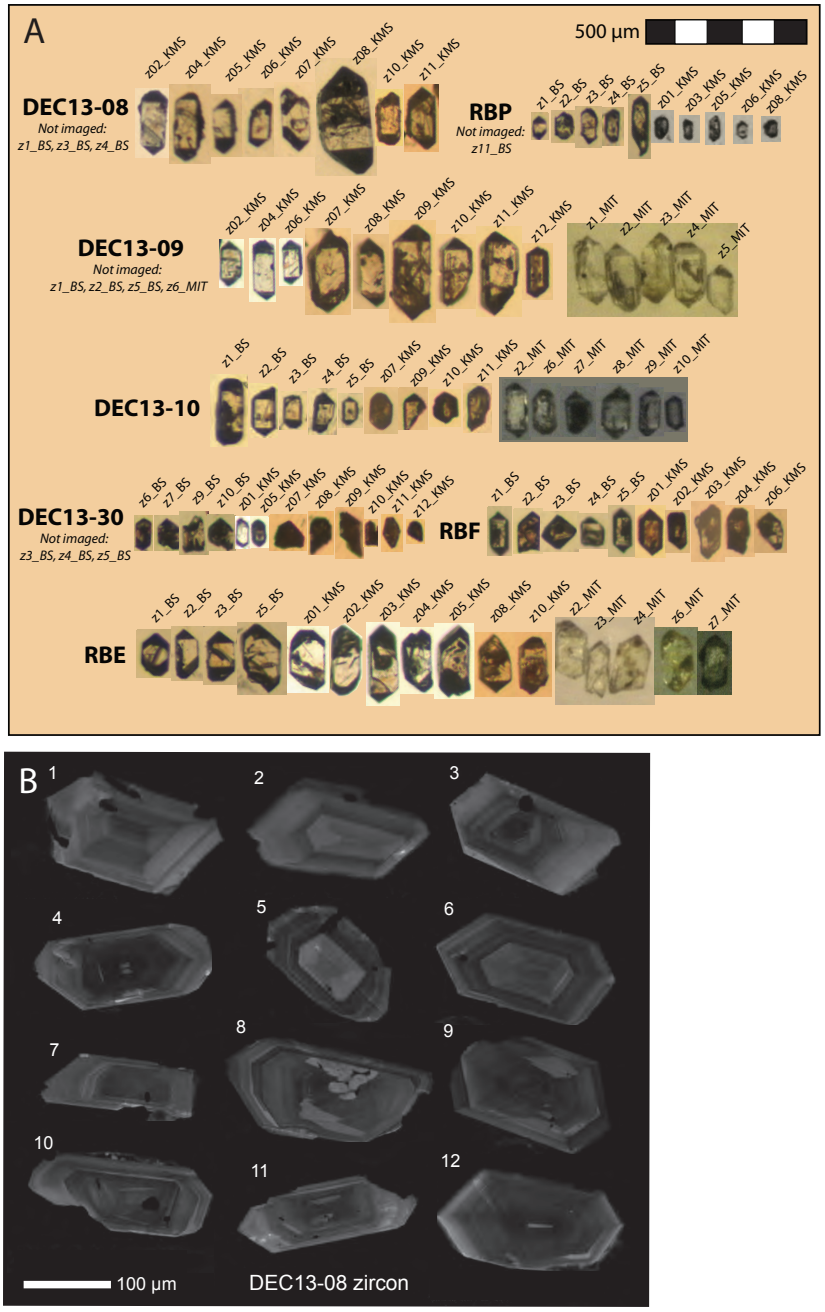


Fig. S3. Photographs of zircons from this study. A. Optical images of zircons under transmitted or reflected light from PU and MIT, respectively. Note sharp crystal terminations are interpreted to reflect igneous growth with negligible "reworking" or sedimentary transport. Hence, these are interpreted as deriving from igneous segregations (for DEC13-30) or ashfalls (all others). U-Pb data given in Table S1 and geochemical data for the same zircons is given in Table S2. B. Cathodoluminescence images of zircons from DEC13-08, illustrating oscillatory zoning indicative of igneous growth. A lack of obvious resorbed cores indicates that inheritance of much older grains is probably not the cause of spread in measured dates.

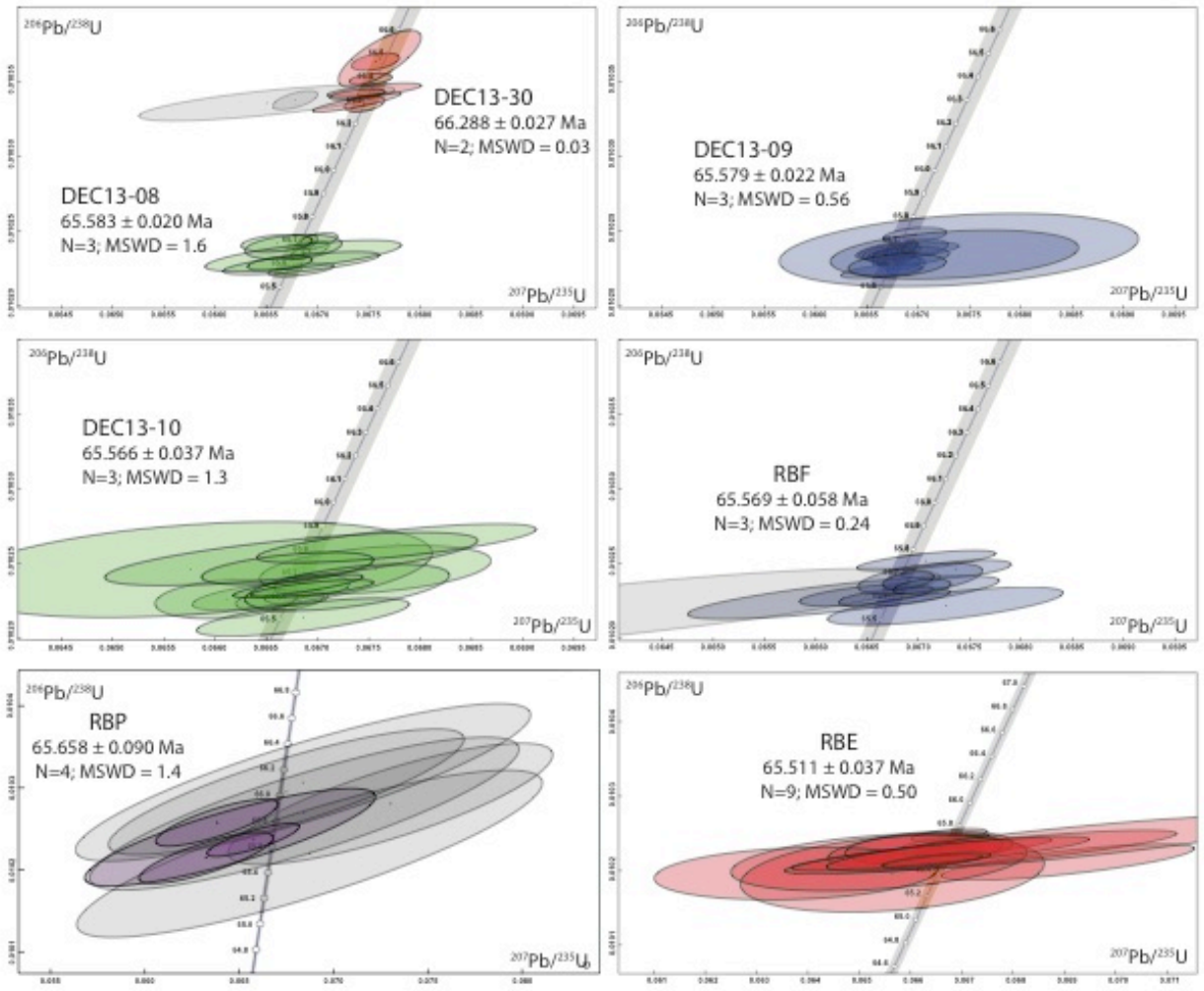


Fig. S4: Concordia plots for U-Pb ID-TIMS geochronological data. Data provided in Table S1. Note the scales for top four plots are the same, as are scales for bottom two plots. Grayed out ellipses are those not included in age interpretations due to large uncertainties or reverse discordance. Gray band around concordia curve includes uncertainties in the U decay constants. Age interpretations shown are based on the data illustrated alone, not the ages resulting from the Monte Carlo simulations (see text). See Table S3 for alternative age interpretations. All uncertainties are at the 2σ level.

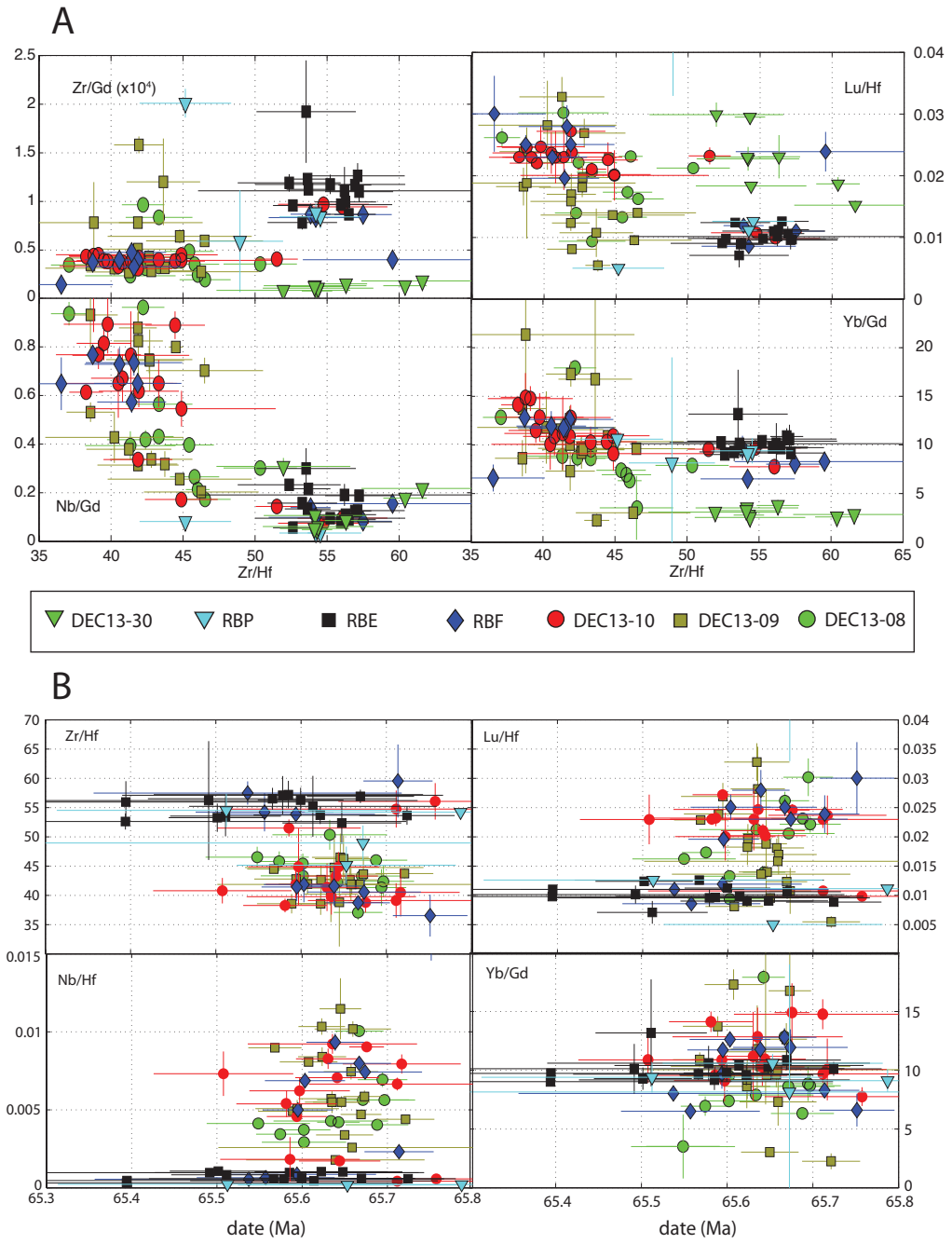


Fig. 5: Trace element data for zircons dated in this study. A. Element ratio cross-plots using Zr/Hf as an igneous differentiation index. Important here is that different samples plot in different spaces in these plots, illustrating that zircons from different hand samples derived from different sources. Also important is that the dataset as a whole follows trends consistent with igneous differentiation (e.g. Nb/Gd vs. Zr/Hf). B. geochemical data plotted versus ID-TIMS $^{206}Pb/^{238}U$ date. Again, note that despite largely overlapping age distributions between samples, zircons have distinct geochemical differences and thus reflect different volcanic sources. Scale only goes up to 65.8 Ma, so DEC13-30 is not plotted.

Table S1. U-Pb isotopic data obtained by CA-ID-TIMS at MIT and PU. See text for details. Included at *Science Online* as .xlsx file.

Table S2. Zircon trace element obtained by solution ICP-SF-MS. Trace element data obtained for same volume of dissolved zircon analyzed for U-Pb isotopes. See text for details. Included at *Science Online* as .xlsx file.

Table S3. Age interpretation table. Multiple interpretations of U-Pb data given as discussed in text.
Included at *Science Online* as .xlsx file.

Table S1: U-Pb isotopic data

Sample name	Dates (Ma)							Composition			Isotopic Ratios									
	206Pb/ 238U	±2σ absolute	207Pb/ 235U	±2σ absolute	207Pb/ 206Pb	±2σ absolute	% disc	Th/ U	Pbc (pg)	Pb*/ Pbc	206Pb/ 204Pb	208Pb/ 206Pb	206Pb/ 238U	±2σ %	207Pb/ 235U	±2σ %	207Pb/ 206Pb	±2σ %	Corr. coef.
m	a		b		a,b		d	e	g	h	j	k	a,k		b,k		a,b,k		
DEC13-08																			
z4_BS	**65.549**	**0.061**	**65.6**	**1.0**	**66.0**	**36.6**	**4.9**	**1.09**	**0.57**	**8.51**	**464**	**0.35**	**0.0102201**	**0.093**	**0.0666984**	**1.608**	**0.0473538**	**1.537**	**0.772**
z3_BS	**65.574**	**0.028**	**65.69**	**0.30**	**69.9**	**10.8**	**9.9**	**1.10**	**0.63**	**29.10**	**1538**	**0.35**	**0.0102241**	**0.044**	**0.0668331**	**0.477**	**0.0474306**	**0.454**	**0.557**
z10_KMS	**65.602**	**0.031**	**65.49**	**0.30**	**61.5**	**10.8**	**-1.9**	**1.05**	**0.34**	**31.05**	**1657**	**0.34**	**0.0102285**	**0.048**	**0.0666274**	**0.472**	**0.0472646**	**0.450**	**0.476**
z08_KMS	**65.602**	**0.049**	**65.69**	**0.72**	**69.0**	**25.9**	**8.7**	**0.85**	**0.85**	**11.58**	**659**	**0.27**	**0.0102285**	**0.076**	**0.0668358**	**1.139**	**0.0474124**	**1.087**	**0.704**
z06_KMS	65.634	0.067	65.71	0.91	68.5	32.3	8.0	1.22	0.60	10.10	531	0.39	0.0102334	0.103	0.0668542	1.428	0.0474026	1.359	0.689
z1_BS	65.643	0.025	65.688	0.089	67.3	3.1	6.5	0.94	0.42	98.80	5367	0.30	0.0102348	0.038	0.0668308	0.140	0.0473795	0.127	0.356
z11_KMS	65.667	0.029	65.83	0.12	71.6	4.2	11.8	0.96	0.41	91.44	4939	0.31	0.0102386	0.044	0.0669765	0.193	0.0474651	0.175	0.447
z05_KMS	65.671	0.054	65.62	0.45	63.7	16.4	1.3	1.09	0.60	20.93	1111	0.35	0.0102393	0.083	0.0667581	0.709	0.0473071	0.688	0.298
z02_KMS	65.688	0.037	65.46	0.33	57.3	12.1	-9.2	1.01	0.53	26.96	1454	0.32	0.0102419	0.056	0.0665967	0.521	0.0471808	0.505	0.311
z07_KMS	65.694	0.029	65.761	0.080	68.2	2.7	7.5	1.12	0.33	141.30	7345	0.36	0.0102429	0.045	0.0669075	0.125	0.0473963	0.108	0.446
z04_KMS	65.697	0.036	65.84	0.19	70.9	6.5	10.9	1.07	0.50	50.59	2674	0.34	0.0102433	0.055	0.0669864	0.300	0.0474505	0.271	0.560
z12_KMS	682.81	0.20	1180.56	0.35	2260.28	0.60	69.8	0.08	0.42	904.66	56608	0.026	0.1117344	0.031	2.198492	0.050	0.1427684	0.012	0.729
DEC13-09																			
z12_KMS	**65.568**	**0.031**	**65.50**	**0.37**	**63.0**	**13.3**	**0.5**	**1.02**	**0.48**	**23.62**	**1273**	**0.33**	**0.0102231**	**0.048**	**0.0666339**	**0.586**	**0.0472939**	**0.559**	**0.587**
z2_MIT	**65.589**	**0.041**	**65.73**	**0.18**	**70.8**	**6.4**	**11.0**	**0.92**	**0.42**	**77.24**	**4159**	**0.29**	**0.0102264**	**0.062**	**0.0668746**	**0.282**	**0.0474495**	**0.267**	**0.306**
z5_MIT	**65.594**	**0.049**	**65.65**	**0.45**	**67.6**	**16.6**	**6.9**	**1.20**	**0.49**	**30.31**	**1540**	**0.38**	**0.0102272**	**0.075**	**0.0667882**	**0.714**	**0.0473844**	**0.695**	**0.283**
z2_BS	65.608	0.034	65.67	0.20	67.8	7.4	7.2	1.11	0.43	80.05	4187	0.35	0.0102293	0.052	0.0668095	0.311	0.0473898	0.311	0.060
z02_KMS	65.623	0.027	65.64	0.17	66.2	6.1	5.0	0.97	0.27	56.70	3064	0.31	0.0102318	0.042	0.0667800	0.273	0.0473577	0.253	0.501
z10_KMS	65.623	0.028	65.52	0.11	61.9	3.9	-1.3	1.05	0.39	90.75	4802	0.34	0.0102318	0.043	0.0666592	0.174	0.0472717	0.162	0.328
z1_MIT	65.634	0.038	65.77	0.36	70.8	13.2	10.8	1.15	0.51	36.93	1894	0.37	0.0102335	0.059	0.0669184	0.565	0.0474478	0.552	0.252
z3_MIT	65.635	0.032	65.59	0.22	64.0	8.0	1.9	1.01	0.35	60.70	3203	0.32	0.0102336	0.049	0.0667303	0.349	0.0473137	0.335	0.329
z4_MIT	65.64	0.10	66.2	1.2	85.8	41.7	25.9	0.92	0.36	11.03	609	0.29	0.0102343	0.160	0.0673474	1.796	0.0477484	1.757	0.288
z07_KMS	65.645	0.024	65.596	0.057	63.8	2.0	1.5	0.97	0.34	216.98	11674	0.31	0.0102352	0.037	0.0667342	0.090	0.0473093	0.078	0.356
z04_KMS	65.646	0.033	65.55	0.22	62.0	7.8	-1.3	1.13	0.26	43.28	2262	0.36	0.0102354	0.051	0.0666840	0.348	0.0472729	0.326	0.465
z08_KMS	65.650	0.034	65.56	0.30	62.4	10.8	-0.6	1.02	0.41	29.37	1579	0.33	0.0102360	0.051	0.0667004	0.474	0.0472818	0.450	0.485
z5_BS	65.657	0.032	65.82	0.40	71.8	14.2	12.1	1.10	0.78	22.21	1178	0.35	0.0102371	0.049	0.0669722	0.625	0.0474690	0.596	0.608
z6_MIT	65.66	0.16	66.2	1.7	86.5	60.1	26.6	0.99	0.60	7.74	426	0.31	0.0102373	0.240	0.0673902	2.599	0.0477644	2.535	0.308
z06_KMS	65.659	0.045	65.71	0.41	67.5	14.8	6.7	1.04	0.34	22.16	1189	0.33	0.0102375	0.069	0.0668528	0.652	0.0473829	0.620	0.497
z1_BS	65.669	0.024	65.766	0.077	69.3	2.4	9.0	0.94	0.50	126.23	6845	0.30	0.0102390	0.037	0.0669135	0.121	0.0474189	0.097	0.652
z09_KMS	65.673	0.025	65.760	0.067	68.9	2.3	8.5	1.06	0.33	164.82	8689	0.34	0.0102396	0.038	0.0669074	0.106	0.0474116	0.090	0.431
z11_KMS	65.721	0.034	65.81	0.29	69.1	10.5	8.7	1.11	1.31	31.04	1633	0.36	0.0102472	0.052	0.0669622	0.458	0.0474155	0.441	0.375
DEC13-10																			
z11_KMS	**65.508**	**0.081**	**65.72**	**0.99**	**73.4**	**34.8**	**14.1**	**0.93**	**0.93**	**8.96**	**505**	**0.30**	**0.0102137**	**0.125**	**0.0668623**	**1.549**	**0.0474999**	**1.466**	**0.696**
z9_MIT	**65.581**	**0.049**	**65.49**	**0.41**	**62.3**	**14.9**	**-0.7**	**0.98**	**0.32**	**32.87**	**1756**	**0.31**	**0.0102252**	**0.075**	**0.0666260**	**0.645**	**0.0472787**	**0.623**	**0.335**
z7_MIT	**65.586**	**0.084**	**65.00**	**0.66**	**43.4**	**24.6**	**-41.9**	**1.16**	**0.27**	**21.05**	**1086**	**0.37**	**0.0102259**	**0.129**	**0.0661054**	**1.052**	**0.0469060**	**1.028**	**0.242**
z2_MIT	65.594	0.035	65.65	0.30	67.6	11.0	6.9	1.01	0.27	50.68	2677	0.32	0.0102272	0.054	0.0667882	0.466	0.0473847	0.460	0.145
z4_BS	65.597	0.059	65.27	0.59	53.5	21.1	-16.5	1.11	0.45	16.04	854	0.35	0.0102277	0.090	0.0663972	0.937	0.0471049	0.886	0.596
z3_BS	65.630	0.038	65.80	0.57	72.1	20.3	12.5	1.01	0.51	14.97	815	0.32	0.0102329	0.058	0.0669534	0.892	0.0474752	0.852	0.708
z5_BS	65.636	0.099	66.13	0.95	84.0	33.4	24.4	1.00	0.34	11.12	612	0.32	0.0102337	0.152	0.0672930	1.480	0.0477123	1.406	0.524
z2_BS	65.641	0.049	65.67	0.60	66.8	21.1	5.8	1.13	0.91	14.90	789	0.36	0.0102346	0.075	0.0668145	0.946	0.0473690	0.885	0.826
z8_MIT	65.644	0.048	65.79	0.35	71.1	12.9	11.3	0.99	0.27	42.29	2245	0.32	0.0102350	0.073	0.0669388	0.550	0.0474550	0.540	0.190
z1_BS	65.676	0.020	65.75	0.11	68.4	4.2	7.8	0.96	0.31	75.77	4098	0.31	0.0102400	0.031	0.0668934	0.178	0.0473999	0.172	0.182
z10_MIT	65.71	0.10	66.4	1.1	90.5	38.4	29.7	0.91	0.30	12.04	665	0.29	0.0102456	0.158	0.0675587	1.671	0.0478450	1.619	0.370
z6_MIT	65.712	0.205	64.7	2.2	26.2	83.5	-126.4	0.91	0.24	5.90	335	0.29	0.0102457	0.314	0.0657593	3.577	0.0465705	3.481	0.348
z10_KMS	65.717	0.069	65.58	0.80	60.4	28.7	-3.8	1.00	0.47	11.33	623	0.32	0.0102465	0.106	0.0667136	1.255	0.0472427	1.203	0.530
z07_KMS	65.76	0.11	65.6	1.7	60.2	62.1	-4.3	1.50	0.58	5.85	297	0.48	0.0102528	0.174	0.0667485	2.722	0.0472382	2.604	0.696
z09_KMS	65.824	0.083	66.6	1.3	94.0	45.4	32.1	0.94	0.69	6.80	386	0.30	0.0102633	0.127	0.0677748	2.008	0.0479155	1.918	0.726
RBF																			
z2_BS	**65.54**	**0.18**	**63.0**	**3.1**	**-33.1**	**116.5**	**316.6**	**0.92**	**0.36**	**2.82**	**172**	**0.29**	**0.0102183**	**0.277**	**0.0639925**	**5.024**	**0.0454405**	**4.804**	**0.803**
z03_KMS	**65.557**	**0.081**	**66.1**	**1.1**	**85.6**	**38.5**	**25.9**	**0.87**	**0.26**	**7.88**	**452**	**0.28**	**0.0102214**	**0.124**	**0.0672589**	**1.705**	**0.0477454**	**1.621**	**0.701**
z3_BS	**65.594**	**0.093**	**65.1**	**1.4**	**48.9**	**52.1**	**-26.9**	**0.99**	**0.33**	**6.11**	**345**	**0.32**	**0.0102272**	**0.142**	**0.0662656**	**2.292**	**0.0470138**	**2.183**	**0.778**
z06_KMS	65.595	0.041	65.62	0.52	66.6	18.6	5.5	0.95	0.39	16.80	926	0.30	0.0102274	0.063	0.0667612	0.812	0.0473646	0.779	0.541
z4_BS	65.603	0.047	65.36	0.62	56.5	22.4	-10.5	0.97	0.37	14.26	784	0.31	0.0102287	0.072	0.0664886	0.979	0.0471652	0.939	0.585
z5_BS	65.639	0.034	65.88	0.26	74.7	9.4	15.4	1.04	0.44	35.48	1893	0.33	0.0102342	0.052	0.0670338	0.415	0.0475262	0.396	0.410
z01_KMS	65.667	0.037	65.75	0.24	68.8	8.4	8.3	0.92	0.51	37.42	2052	0.30	0.0102386	0.057	0.0668959	0.374	0.0474080	0.351	0.449
z02_KMS	65.674	0.067	65.86	0.58	72.7	20.4	13.1	0.98	0.32	17.84	976	0.31	0.0102397	0.102	0.0670142	0.908	0.0474867	0.859	0.519
z04_KMS	65.714	0.041	66.20	0.51	83.7	18.0	24.1	1.43	0.22	19.58	967	0.46	0.0102460	0.062	0.0673657	0.791	0.0477068	0.759	0.540
z1_BS	65.751	0.044	65.92	0.64	72.0	22.8	12.1	1.03	2.23	13.19	718	0.33	0.0102519	0.067	0.0670726	1.007	0.0474718	0.960	0.713
RBE																			
z6_MIT	**65.39**	**0.33**	**64.6**	**2.8**	**33.6**	**105.5**	**-79.5**	**0.92**	**0.46**	**5.09**	**291**	**0.29**	**0.0101959**	**0.507**	**0.0656420**	**4.514**	**0.0467146**	**4.403**	**0.274**
z7_MIT	**65.39**	**0.22**	**62.8**	**2.6**	**-36.5**	**104.0**	**294.0**	**0.94**	**0.54**	**5.04**	**287**	**0.30**	**0.0101959**	**0.345**	**0.0637613**	**4.332**	**0.0453757**	**4.283**	**0.183**
z3_MIT	**65.49**	**0.25**	**64.3**	**2.8**	**20.4**	**103.3**	**-181.7**	**0.92**	**0.37**	**5.00**	**287**	**0.29**	**0.0102112**	**0.376**	**0.0653804**	**4.416**	**0.0464586**	**4.300**	**0.347**
z03_KMS	**65.49**	**0.16**	**67.8**	**2.3**	**150.4**	**79.5**	**57.2**	**1.01**	**1.05**	**3.70**	**215**	**0.32**	**0.0102113**	**0.239**	**0.0690638**	**3.569**	**0.0490752**	**3.393**	**0.757**
z10_KMS	**65.502**	**0.057**	**65.30**	**0.92**	**57.9**	**33.2**	**-7.7**	**1.06**	**0.42**	**9.47**	**516**	**0.34**	**0.0102128**	**0.088**	**0.0664242**	**1.453**	**0.0471930**	**1.390**	**0.737**
z5_BS	**65.511**	**0.065**	**65.4**	**1.0**	**60.2**	**36.3**	**-3.8**	**0.94**	**0.69**	**8.31**	**469**	**0.30**	**0.0102143**	**0.100**	**0.0664982**	**1.592**	**0.0472386**	**1.523**	**0.702**
z2_BS	**65.57**	**0.15**	**65.4**	**2.8**	**61.1**	**99.2**	**-2.5**	**1.02**	**0.50**	**3.06**	**181**	**0.33**	**0.0102229**	**0.224**	**0.0665788**	**4.352**	**0.0472559**	**4.164**	**0.845**

z1_BS	**65.58**	**0.19**	**66.2**	**3.6**	**88.5**	**128.6**	**28.3**	**0.88**	**0.43**	**2.25**	**142**	**0.28**	**0.0102248**	**0.289**	**0.0673641**	**5.669**	**0.0478046**	**5.426**	**0.849**
z2_MIT	**65.59**	**0.16**	**65.0**	**1.6**	**42.8**	**59.8**	**-43.6**	**0.96**	**0.35**	**8.28**	**458**	**0.31**	**0.0102258**	**0.242**	**0.0660892**	**2.584**	**0.0468950**	**2.502**	**0.377**
z01_KMS	65.600	0.050	65.65	0.55	67.4	19.4	6.6	0.95	0.18	16.72	922	0.30	0.0102281	0.077	0.0667886	0.864	0.0473808	0.815	0.660
z4_MIT	65.61	0.15	65.2	1.6	51.5	57.4	-20.8	0.92	0.36	8.18	457	0.29	0.0102303	0.223	0.0663588	2.461	0.0470655	2.405	0.294
z08_KMS	65.622	0.078	66.2	1.3	88.3	45.2	28.0	0.93	0.37	6.95	395	0.30	0.0102317	0.120	0.0674029	1.997	0.0477998	1.905	0.787
z04_KMS	65.648	0.070	65.49	0.75	59.8	27.0	-4.8	0.88	0.19	12.40	699	0.28	0.0102357	0.107	0.0666245	1.189	0.0472294	1.134	0.547
z05_KMS	65.66	0.24	67.7	4.4	142.2	150.5	54.8	0.91	1.08	1.90	122	0.29	0.0102370	0.369	0.0689961	6.721	0.0489040	6.413	0.844
z3_BS	65.670	0.063	65.68	0.67	66.1	23.0	4.8	0.95	0.23	13.83	765	0.30	0.0102391	0.096	0.0668254	1.048	0.0473561	0.965	0.875
z02_KMS	65.724	0.056	65.61	0.70	61.4	25.3	-2.4	0.90	0.20	13.83	774	0.29	0.0102476	0.086	0.0667470	1.109	0.0472609	1.062	0.574
RBP																			
z1_BS	**65.51**	**0.20**	**62.3**	**3.4**	**-60.5**	**131.5**	**213.5**	**1.08**	**0.32**	**2.74**	**162**	**0.34**	**0.0102144**	**0.305**	**0.0632501**	**5.631**	**0.0449305**	**5.391**	**0.797**
z05_KMS	*65.55*	*0.65*	*67.5*	*11.7*	*137.1*	*402.2*	*53.2*	*1.03*	*0.43*	*0.75*	*58*	*0.33*	*0.0102196*	*0.997*	*0.0687291*	*17.956*	*0.0487979*	*17.119*	*0.849*
z4_BS	**65.65**	**0.13**	**64.7**	**2.3**	**27.8**	**85.4**	**-114.0**	**1.19**	**0.31**	**3.83**	**214**	**0.38**	**0.0102365**	**0.197**	**0.0657456**	**3.718**	**0.0466026**	**3.560**	**0.814**
z5_BS	**65.67**	**0.38**	**63.5**	**7.3**	**-18.2**	**277.2**	**528.3**	**1.17**	**0.33**	**1.26**	**83**	**0.37**	**0.0102395**	**0.581**	**0.0645214**	**11.941**	**0.0457212**	**11.461**	**0.834**
z2_BS	**65.79**	**0.18**	**62.8**	**3.1**	**-49.0**	**118.3**	**242.4**	**1.02**	**0.27**	**3.38**	**198**	**0.33**	**0.0102575**	**0.279**	**0.0638180**	**5.079**	**0.0451436**	**4.860**	**0.795**
z06_KMS	*65.86*	*0.59*	*67.2*	*10.8*	*116.3*	*374.3*	*44.8*	*1.26*	*0.36*	*0.84*	*61*	*0.40*	*0.0102685*	*0.908*	*0.0684517*	*16.629*	*0.0483693*	*15.870*	*0.845*
z03_KMS	*65.93*	*0.47*	*71.6*	*8.1*	*263.8*	*257.3*	*75.3*	*1.00*	*0.30*	*1.07*	*75*	*0.32*	*0.0102805*	*0.719*	*0.0730180*	*11.783*	*0.0515359*	*11.210*	*0.810*
z08_KMS	*66.03*	*0.49*	*66.3*	*9.0*	*76.9*	*317.1*	*17.2*	*1.02*	*0.43*	*1.02*	*73*	*0.32*	*0.0102951*	*0.745*	*0.0674950*	*13.965*	*0.0475700*	*13.346*	*0.841*
z11_BS	*66.10*	*0.61*	*67.2*	*11.5*	*105.2*	*398.3*	*38.9*	*0.95*	*0.36*	*0.73*	*58*	*0.30*	*0.0103066*	*0.931*	*0.0683833*	*17.646*	*0.0481425*	*16.854*	*0.859*
z3_BS	*1830.44*	*0.54*	*2093.88*	*0.52*	*2363.87*	*0.82*	*22.6*	*0.14*	*0.32*	*362*	*22189*	*0.040*	*0.3283635*	*0.034*	*6.8629084*	*0.059*	*0.1516517*	*0.035*	*0.572*
z01_KMS	*2512.95*	*1.57*	*2595.67*	*0.89*	*2660.88*	*0.82*	*5.6*	*0.30*	*0.40*	*105*	*6068*	*0.083*	*0.4767175*	*0.075*	*11.8886797*	*0.095*	*0.1809533*	*0.037*	*0.856*
DEC13-30																			
z7_BS	*66.249*	*0.0489*	*65.34*	*0.38*	*32.2*	*12.3*	*-89.2*	*2.22*	*0.33*	*48.46*	*2028*	*0.71*	*0.0103298*	*0.074*	*0.0664657*	*0.594*	*0.0466874*	*0.514*	*1.056*
z4_BS	**66.286**	**0.0347**	**66.28**	**0.19**	**66.1**	**6.6**	**3.8**	**2.33**	**0.34**	**72.51**	**2968**	**0.74**	**0.0103356**	**0.053**	**0.0674534**	**0.292**	**0.0473545**	**0.274**	**0.397**
z10_KMS	*66.289*	*0.0770*	*65.4*	*1.2*	*32.0*	*42.9*	*-90.4*	*2.62*	*0.43*	*10.31*	*417*	*0.84*	*0.0103361*	*0.117*	*0.0665010*	*1.873*	*0.0466839*	*1.789*	*0.732*
z5_BS	**66.291**	**0.0420**	**66.21**	**0.41**	**63.2**	**13.8**	**-0.3**	**1.69**	**0.29**	**27.06**	**1260**	**0.54**	**0.0103364**	**0.064**	**0.0673787**	**0.636**	**0.0472983**	**0.580**	**0.871**
z9_BS	*66.300*	*0.0406*	*65.64*	*0.21*	*41.5*	*7.1*	*-49.5*	*2.22*	*1.10*	*56.92*	*2380*	*0.71*	*0.0103379*	*0.062*	*0.0667778*	*0.331*	*0.0468700*	*0.295*	*0.619*
z6_BS	66.325	0.0238	66.21	0.26	62.2	9.1	-2.0	2.47	0.33	45.67	1830	0.79	0.0103417	0.036	0.0673843	0.399	0.0472780	0.381	0.512
z10_BS	66.343	0.0306	66.37	0.43	67.4	15.4	5.5	1.90	0.53	26.51	1186	0.61	0.0103445	0.046	0.0675484	0.676	0.0473804	0.645	0.678
z08_KMS	66.390	0.0243	66.34	0.20	64.4	7.1	1.3	2.27	0.31	60.43	2501	0.73	0.0103520	0.037	0.0675129	0.309	0.0473215	0.295	0.381
z07_KMS	66.465	0.0372	66.38	0.22	63.4	7.7	-0.4	2.35	0.47	58.69	2394	0.75	0.0103637	0.056	0.0675602	0.344	0.0473010	0.321	0.456
z09_KMS	66.48	0.12	66.42	0.38	64.3	11.4	1.0	2.13	0.66	52.64	2236	0.68	0.0103658	0.184	0.0676013	0.597	0.0473202	0.476	0.741
z01_KMS	*159.92*	*0.10*	*160.11*	*0.77*	*162.9*	*11.6*	*2.5*	*1.17*	*0.29*	*27.45*	*1427*	*0.37*	*0.0251173*	*0.064*	*0.1707917*	*0.520*	*0.0493388*	*0.497*	*0.405*
z11_KMS	*230.90*	*0.70*	*232.8*	*3.5*	*251.9*	*36.4*	*8.6*	*0.94*	*0.43*	*8.40*	*473*	*0.30*	*0.0364672*	*0.308*	*0.2576671*	*1.699*	*0.0512684*	*1.580*	*0.463*
z3_BS	*242.48*	*0.30*	*237.8*	*3.7*	*191.4*	*38.9*	*-26.2*	*0.98*	*0.30*	*7.66*	*430*	*0.31*	*0.0383311*	*0.126*	*0.2638500*	*1.736*	*0.0499459*	*1.674*	*0.523*
z12_KMS	*795.10*	*0.42*	*815.0*	*2.0*	*869.6*	*6.8*	*8.6*	*0.01*	*0.59*	*22.51*	*1555*	*0.003*	*0.1312680*	*0.056*	*1.2313501*	*0.355*	*0.0680639*	*0.326*	*0.551*
z05_KMS	*1496.1*	*1.4*	*1509.2*	*2.6*	*1527.7*	*5.6*	*2.1*	*0.79*	*0.38*	*27.58*	*1534*	*0.23*	*0.2612288*	*0.106*	*3.4210552*	*0.332*	*0.0950240*	*0.296*	*0.467*

m sample name followed by specific zircon name. _KMS, and _BS are analyses from PU; _MIT are analyses from MIT
a Corrected for initial Th/U disequilibrium using radiogenic 208Pb and using the average (Th/U) partition coefficient between silicate melt of zircon from Rubatto and Hermann (2007) of 0.33.
b Corrected for initial Pa/U disequilibrium using initial fraction activity ratio [231Pa]/[235U] = 1.10000.
c Isotopic dates calculated using the decay constants λ238 = 1.55125E-10 and λ235 = 9.8485E-10 (Jaffey et al. 1971).
d % discordance = 100 - (100 * (206Pb/238U date) / (207Pb/206Pb date))
e Th contents calculated from radiogenic 208Pb and the 207Pb/235U date of the sample, assuming concordance between U-Th and Pb systems.
f Total mass of radiogenic Pb.
g Total mass of common Pb, assuming all common Pb is from blank. Blank compositions are reported in the methods section.
h Ratio of radiogenic Pb (including 208Pb) to common Pb.
j Measured ratio corrected for fractionation and spike contribution only.
k Measured ratios corrected for fractionation, tracer and blank.

Table S2: zircon trace element data

	date	±2sig	Th/U	Y-89	±2sig	Zr-91	±2sig	Nb-93	±2sig	La-139	±2sig	Ce-140	±2sig	Pr-141	±2sig	Nd-146	±2sig	Sm-152	±2sig	Eu-151	±2sig	Gd-158	±2sig	Tb-159	±2sig	Dy-163	±2sig	Ho-165	±2sig	Er-166	±2sig
a	b		b	c	d																										
DEC13-08																															
z4_BS	65.549	0.061	1.09	5481	137	474669	2085	42.1	0.7	443.2	12.2	733.5	16.1	61.1	1.8	195.2	3.0	41.0	0.8	0.55	0.04	243.4	21.2	33.9	0.04	359.8	11.1	129.6	0.6	588.3	8.4
z3_BS	65.574	0.028	1.10	5360	486	475777	14451	35.7	0.3	132.3	12.7	265.7	23.1	24.0	2.1	86.2	11.8	26.2	1.6	0.68	0.25	134.5	1.7	33.2	2.0	373.0	23.1	135.9	5.6	628.7	34.7
z10_KMS	65.602	0.031	1.05	4512	50	477730	16131	39.0	0.2	50.5	6.5	143.9	0.4	12.4	1.0	50.3	5.0	22.8	2.3	0.42	0.06	98.5	5.2	26.7	1.2	298.5	0.2	108.5	2.5	496.1	1.9
z08_KMS	65.602	0.049	0.85	3298	83	479596	24341	32.4	0.5	23.7	5.7	74.5	0.6	4.7	0.1	19.4	0.2	11.5	1.6	0.50	0.04	57.4	1.1	18.5	0.8	211.0	2.4	77.0	1.2	355.6	10.7
z06_KMS	65.634	0.067	1.22	7068	3	473207	19455	40.2	0.5	8.9	12.6	76.8	3.2	4.3	0.5	26.2	1.5	30.1	2.6	0.92	0.08	133.2	1.6	43.3	1.3	475.9	14.8	172.3	0.3	753.4	21.4
z1_BS	65.643	0.025	0.94	3698	89	478035	10702	47.6	0.8	1.1	3.1	20.9	0.2	0.9	0.1	5.7	0.4	8.0	0.9	0.31	0.11	49.5	1.5	23.6	0.6	316.9	14.5	116.0	0.4	546.2	3.5
z11_KMS	65.667	0.029	0.96	10361	128	459159	15138	124.3	3.0	0.9	5.5	66.4	4.8	1.5	0.1	11.5	2.5	22.7	1.2	0.84	0.01	132.8	6.1	51.6	2.2	630.7	23.8	239.8	2.1	1137.1	20.7
z05_KMS	65.671	0.054	1.09	7922	38	468676	3463	61.0	0.1	28.9	8.9	96.7	1.9	9.9	0.4	50.3	1.6	33.9	1.8	0.64	0.02	141.4	7.5	45.9	0.04	513.7	21.5	185.5	0.6	832.1	12.0
z02_KMS	65.688	0.037	1.01	9843	382	467459	3827	41.0	1.2	72.2	10.0	160.5	8.5	23.2	1.2	111.4	5.9	52.9	2.5	1.51	0.01	192.3	8.6	51.0	2.4	538.2	0.5	194.7	5.3	868.4	52.8
z07_KMS	65.694	0.029	1.12	12059	863	459030	22292	77.0	2.6	11.4	5.1	99.8	18.7	7.1	1.4	40.7	8.9	40.2	8.4	0.99	0.09	195.3	28.4	67.6	6.1	742.8	64.6	276.5	30.5	1234.9	160.0
z04_KMS	65.697	0.036	1.07	8682	587	467157	24734	62.0	1.3	21.6	6.1	81.6	3.7	9.2	1.0	48.8	3.4	34.0	2.8	0.76	0.09	148.4	13.7	48.6	3.4	550.6	35.9	201.0	5.5	903.2	35.8
DEC13-09																															
z12_KMS	65.568	0.031	1.02	7912	63	469799	3283	94.8	0.6	6.3	10.5	68.4	4.3	2.5	0.1	16.8	2.2	22.8	1.8	0.69	0.30	118.5	1.0	43.2	0.7	491.1	7.7	186.0	0.1	849.9	23.8
z2_MIT	65.589	0.041	0.92	9226	1558	463870	4632	59.1	4.1	b.d.l.	b.d.l.	54.4	1.7	0.5	0.1	6.4	0.7	17.2	1.3	0.63	0.07	111.1	3.3	44.2	2.1	539.6	12.1	208.2	7.5	971.3	47.0
z5_MIT	65.594	0.049	1.20	10259	1029	462625	1016	54.9	4.8	b.d.l.	b.d.l.	89.9	7.3	0.4	0.1	8.5	0.4	26.8	1.9	0.59	0.10	162.5	9.4	57.8	2.8	650.8	112.0	236.1	22.4	1041.7	56.7
z2_BS	65.608	0.034	1.11	2244	347	480417	18435	92.4	2.2	b.d.l.	b.d.l.	7.0	0.6	0.2	0.0	1.9	0.1	4.5	0.2	0.34	0.11	30.4	1.2	15.2	0.4	185.7	7.1	67.8	2.3	316.8	4.9
z02_KMS	65.623	0.027	0.97	6866	221	468820	8142	125.6	2.8	27.1	11.4	115.5	3.8	12.9	1.4	67.0	0.2	35.9	0.9	0.60	0.36	134.9	19.5	41.7	3.9	461.9	59.9	174.5	24.0	777.7	121.7
z10_KMS	65.623	0.028	1.05	6705	1421	472700	4819	93.1	4.2	15.3	5.7	83.1	20.7	8.8	2.0	45.2	10.3	31.3	6.4	0.86	0.14	125.1	20.6	44.4	7.1	480.2	55.4	171.6	26.2	757.1	144.1
z1_MIT	65.634	0.038	1.15	13199	1216	456780	30544	63.3	2.7	b.d.l.	b.d.l.	67.9	5.5	0.5	0.1	7.9	0.2	27.9	0.1	0.81	0.15	167.0	3.9	64.7	5.3	772.0	35.7	284.2	11.5	1307.9	95.5
z3_MIT	65.635	0.032	1.01	11652	3552	459081	21639	62.7	4.0	b.d.l.	b.d.l.	73.0	15.1	0.4	0.2	7.0	1.4	23.8	5.7	0.81	0.28	146.5	34.8	57.0	11.1	674.4	135.4	246.7	53.7	1139.7	206.5
z4_MIT	65.639	0.105	0.92	4867	27	477202	53223	19.1	0.4	b.d.l.	b.d.l.	48.5	3.5	0.2	0.1	4.7	0.8	13.9	0.1	0.29	0.12	74.5	0.5	25.6	1.1	299.3	3.4	110.3	3.2	502.1	23.4
z07_KMS	65.645	0.024	0.97	5205	3309	473948	73437	140.1	17.3	b.d.l.	b.d.l.	10.3	5.5	0.1	0.1	1.9	0.9	7.8	4.3	0.44	0.37	60.7	31.0	32.9	16.5	420.3	185.5	160.3	71.0	763.5	344.8
z04_KMS	65.646	0.033	1.13	4754	385	477314	33091	56.4	2.5	4.8	6.3	46.4	7.6	1.8	0.2	12.5	0.9	17.1	0.4	0.56	0.27	80.3	4.9	28.8	2.2	307.7	15.2	114.0	4.4	506.1	24.1
z08_KMS	65.650	0.034	1.02	2919	17	480047	39244	35.2	1.2	372.9	6.8	515.9	9.3	64.4	2.4	208.0	2.0	40.6	5.3	0.54	0.35	173.4	7.5	23.1	0.5	206.4	25.2	74.9	5.9	337.6	33.2
z5_BS	65.657	0.032	1.10	6741	689	471779	29356	82.3	4.9	2.7	16.6	68.1	3.9	2.6	0.3	17.3	2.5	21.6	0.4	0.53	0.04	110.1	5.0	39.7	3.6	426.1	39.7	155.4	13.6	700.7	104.9
z6_MIT	65.659	0.157	0.99	5803	165	473505	31873	29.2	2.2	b.d.l.	b.d.l.	58.3	2.3	0.6	0.3	6.8	3.7	14.6	0.7	0.24	0.13	93.0	2.1	32.2	0.5	380.3	23.7	136.7	3.0	622.5	3.5
z06_KMS	65.659	0.045	1.04	6136	983	472215	15927	114.7	4.9	44.8	16.6	158.9	40.2	16.4	2.7	79.6	19.3	40.6	14.6	0.67	0.06	139.2	24.2	40.2	7.0	416.7	89.2	151.1	24.9	682.6	136.6
z1_BS	65.669	0.024	0.94	3498	113	477821	8216	53.7	0.7	44.3	3.8	87.0	5.1	5.3	0.4	17.1	1.3	9.7	0.6	0.34	0.25	61.2	4.4	22.2	0.9	292.6	21.7	105.7	11.7	481.7	30.5
z09_KMS	65.673	0.025	1.06	2810	873	480546	769	64.4	2.0	0.5	1.4	8.7	3.3	0.4	0.2	2.8	1.2	6.2	2.4	0.30	0.02	40.0	14.9	20.2	7.0	245.4	87.6	88.7	32.6	401.5	148.8
z11_KMS	65.721	0.034	1.11	1298	396	482499	4245	48.5	1.1	337.2	85.3	562.0	121.2	61.3	13.1	201.7	39.9	37.2	4.6	0.66	0.06	152.4	25.1	15.2	3.3	138.0	27.2	45.9	6.7	217.3	40.7
DEC13-10																															
z11_KMS	65.508	0.081	0.93	8546	1832	467144	20322	83.8	2.4	b.d.l.	b.d.l.	58.9	7.4	1.9	0.3	12.7	1.1	19.5	4.4	0.42	0.14	124.8	18.0	45.6	6.2	562.0	46.1	202.7	25.1	916.6	122.9
z9_MIT	65.581	0.049	0.98	8629	72	463771	5642	65.5	1.2	b.d.l.	b.d.l.	49.9	2.3	0.4	0.1	4.5	1.6	17.0	1.5	0.53	0.02	106.8	3.5	40.5	0.2	537.4	0.2	205.9	7.5	970.5	1.9
z7_MIT	65.586	0.084	1.16	6787	156	474325	614	16.8	1.4	b.d.l.	b.d.l.	57.6	5.8	1.7	0.6	10.0	3.3	22.3	0.8	1.64	0.23	116.7	8.5	36.5	7.1	443.7	1.7	158.9	10.0	717.7	37.1
z2_MIT	65.594	0.035	1.01	10123	42	464132	25557	50.7	1.4	b.d.l.	b.d.l.	78.7	0.8	1.3	0.2	12.3	0.3	28.6	0.6	0.72	0.11	150.6	7.5	52.4	0.3	662.9	14.1	245.1	3.9	1115.1	23.0
z4_BS	65.597	0.059	1.11	6711	1233	472289	47703	65.4	5.7	6.9	23.2	89.9	13.4	5.5	1.4	29.9	6.6	25.4	6.3	0.35	0.04	119.9	12.3	40.5	4.1	466.0	75.7	169.8	28.6	731.1	133.9
z3_BS	65.630	0.038	1.01	8754	2567	466445	35451	93.2	4.6	b.d.l.	b.d.l.	62.3	14.2	1.5	0.5	10.0	0.8	20.5	8.2	0.36	0.03	121.8	28.2	45.6	13.7	540.1	103.2	201.5	44.7	912.9	179.5
z5_BS	65.636	0.099	1.00	9504	1344	463283	29220	107.4	5.7	b.d.l.	b.d.l.	65.8	9.7	2.5	0.5	13.2	3.0	17.3	3.9	0.47	0.88	120.3	14.9	46.4	8.2	569.1	74.3	215.4	37.2	975.4	170.3
z2_BS	65.641	0.049	1.13	7361	404	469736	5341	76.6	0.6	b.d.l.	b.d.l.	58.8	1.4	0.7	0.2	8.7	1.4	20.1	0.4	0.40	0.06	117.9	17.5	43.3	1.0	509.1	8.2	188.7	7.8	836.5	35.0
z8_MIT	65.644	0.048	0.99	7087	115	472851	18702	18.1	0.3	0.5	7.2	56.9	2.0	1.2	0.1	11.8	0.8	23.0	0.2	0.69	0.21	105.0	6.8	35.2	0.0	446.8	2.0	163.7	5.5	758.7	3.2
z1_BS	65.676	0.020	0.96	9101	737	466692	19773	108.7	0.3	b.d.l.	b.d.l.	31.2	6.0	0.4	0.1	4.9	1.0	18.2	2.0	0.66	0.01	105.6	17.2	45.3	5.0	549.6	47.6	214.0	10.7	991.9	78.6
z10_MIT	65.712	0.104	0.91	8449	274	465770	20260	79.2	0.5	b.d.l.	b.d.l.	48.9	1.9	0.7	0.3	3.9	1.2	16.9	1.8	0.83	0.05	103.1	7.9	39.8	0.7	525.2	24.6	198.7	19.3	931.4	33.9
z6_MIT	65.712	0.205	0.91	2809	41	483750	20657	3.7	0.4	1.2	14.0	24.9	0.8	1.6	0.2	10.9	1.5	12.2	2.5	1.62	0.07	49.8	3.6	15.5	0.4	179.5	10.3	66.6	3.9	304.5	9.5
z10_KMS	65.717	0.069	1.00	9310	1187	464094	31230	91.0	1.6	b.d.l.	b.d.l.	74.1	17.6	2.3	0.5	12.2	3.9	20.0	2.4	0.45	0.09	140.0	30.4	50.0	10.5	593.9	115.5	214.2	41.8	988.4	64.0
z07_KMS	65.757	0.114	1.50	2269	260	482484	3357	4.9	0.6	4.1	40.2	64.4	6.1	4.0	0.4	19.8	1.3	14.2	0.5	1.17	0.78	51.1	0.8	13.4	2.9	133.3	9.0	49.0	4.1	227.3	21.7
z09_KMS	65.824	0.083	0.94	7733	31	470271	3644	108.4	1.3	b.d.l.	b.d.l.	64.7	2.8	26.4	18.9	129.0	161.6	21.6	3.8	0.24	0.32	121.9	7.7	42.6	0.7	508.5	49.4	187.6	2.3	834.7	47.2
RBF																															
z2_BS	65.537	0.181	0.92	2520	49	484682	7633	4.6	0.3	14.7	19.9	52.2	0.9	5.8	0.2	25.0	0.6	15.7	1.1	1.54	0.12	56.0	4.2	16.5	1.3	183.1	8.5	64.7	1.1	292.6	34.3
z03_KMS	65.557	0.081	0.87	2200	116	484661	14618	5.8	0.4	29.8	8.3	85.6	8.2	10.1	1.1	45.0	1.8	16.8	0.1	1.53	0.25	58.2	0.7	13.7	0.9	146.3	1.9	51.5	2.2	235.5	8.4
z3_BS	65.594	0.093	0.99	3227	23	482756	12337	7.7	0.3	b.d.l.	b.d.l.	14.8	1.3	0.6	0.1	6.7	0.3	12.6	0.3	1.40	0.16	55.6	6.7	18.6	0.2	217.0	11.1	76.3	5.1	343.4	24.6
z06_KMS	65.595	0.041	0.95	6964	401	471277	22802	56.7	4.4	22.8	26.4	42.6	3.6	0.7	0.2	4.1	0.8	16.1	0.2	0.62	0.08	99.0	0.9	35.7	1.3	445.7	24.3	166.1	10.0	766.7	47.5
z4_BS	65.603	0.047	0.97	8936	679	466867	21655	76.6	3.6	b.d.l.	b.d.l.	51.1	6.5	2.1	0.2	12.9	2.2	22.3	2.8	0.87	0.03	117.8	5.8	43.9	1.3	539.8	25.9	210.4	7.9	958.5	72.4
z5_BS	65.639	0.034	1.04	10517	828	461585	27732	103.6	2.6	b.d.l.	b.d.l.	65.1	8.8	0.5	0.1	7.1	0.8	22.9	3.8	0.75	0.07	140.9	9.7	52.7	5.6	658.5	31.5	242.7	16.2	1130.6	83.0
z01_KMS	65.667	0.037	0.92	9590	125	463394	3792	95.4	1.1	b.d.l.	b.d.l.	50.8	3.6	0.7	0.2	6.9	0.5	20.0	3.3	0.79	0.25	124.3	5.2	47.5	4.4	595.5	1.4	223.0	12.9	1027.4	66.6
z02_KMS	65.674	0.067	0.98	8713	535	465423	17287	85.2	0.5	b.d.l.	b.d.l.	54.6	7.7	1.1	0.3	7.1	3.7	16.2	1.3	0.54	0.09	116.9	10.9	43.0	4.8	532.7	46.1	204.7	30.7	915.2	36.9
z04_KMS	65.714	0.041	1.43	6262	486	477521	33166	18.5	1.0	b.d.l.	b.d.l.	35.5	3.3	1.0	0.1	13.3	0.3	26.4	2.3	1.97	0.69	119.4	2.6	40.0	4.9	445.3	12.6	155.0	11.7	667.5	43.5
z1_BS	65.751	0.044	1.03	12156	2716	450004	29474	201.8	16.9	b.d.l.	b.d.l.	205.5	41.4	3.7	0.7	29.0	3.8	55.6	4.2	1.82	0.44	311.3	44.9	99.6	18.0	1090.7	178.4	371.5	44.4	1540.9	262.8
RBE																															
z6_MIT	65.394	0.330	0.92	2721	118	483597	4825	2.8	0.2	4.4	14.5	30.0	0.6	2.3	0.2	13.3	3.0	12.6	1.0	1.51	0.40	50.5	1.0	16.1	1.3	175.6	2.9	62.6	0.9	281.7	0.4
z7_MIT	65.394	0.225	0.94	2899	91	483672	30160	4.0	0.3	b.d.l.	b.d.l.	23.7	1.8	1.2	0.3	9.6	0.8	11.3	2.0	1.34	0.37	50.0	0.4	17.3	0.6	186.7	8.9	66.9	1.5	301.4	12.8
z3_MIT	65.492	0.245	0.92	2765	996	484385	76218	8.3	1.5	b.d.l.	b.d.l.	11.6	2.8	0.5	0.1	6.6	1.2	10.7	2.7	1.61	0.40	43.7	6.8	15.8	1.8	172.2	25.7	61.2	7.4	274.9	35.5
z10_KMS	65.502	0.057	1.06	3347	102	482581	12246	9.7	0.4	2.6	5.8	19.6	2.8	2.0	0.4	13.2	0.3	15.5	0.3	2.11	0.39	61.6	5.5	21.3	0.7	228.7	7.2	82.0	4.9	374.1	10.2
z5_BS	65.511	0.065	0.94	1737	830	485549	12035	7.6	0.4	0.5	3.2	12.7	1.6	0.5	0.1	3.2	1.3	4.5	1.6	0.85	0.18	25.3	6.9	10.2	2.4	121.6	34.0	43.3	11.4	202.9	61.5
z2_BS	65.566	0.146	1.02	3374	48	483345	3571	5.0	0.4	b.d.l.	b.d.l.	12.2	1.6	0.8	0.1	8.0	0.8	14.4	1.2	2.09	0.23	55.8	2.6	18.7	1.1	226.3	11.8	78.3	3.7	352.5	2.7
z1_BS	65.578	0.188	0.88	2395	217	485037	22963	4.9	0.6	b.d.l.	b.d.l.	7.1	1.4	0.3	0.2	4.1	0.3	9.4	0.2	1.45	0.44	38.4	3.6	12.8	1.7	158.0	14.8	55.4	3.1	249.4	17.0
z2_MIT	65.585	0.158	0.96	2783	719	484443	17614	8.3	0.1	b.d.l.	b.d.l.	9.1	2.0	0.6	0.1	5.9	0.8	10.7	1.3	1.54	0.16	44.0	3.9	14.7	0.4	162.2	3.8	57.7	4.0	256.7	13.7
z01_KMS	65.600	0.050	0.95	2853	173	484015	7253	5.4	0.1	b.d.l.	b.d.l.	12.9	0.5	0.9	0.2	7.2	0.1	11.8	1.4	1.72	0.06	48.7	1.8	15.6	0.5	187.0	7.1	67.1	4.9	297.3	9.0
z4_MIT	65.614	0.145	0.92	2734	418	484191	37629	3.9	0.6	b.d.l.	b.d.l.	7.7	1.8	0.3	0.1	3.9	1.0	9.0	2.3	1.36	0.09	41.2	1.4	15.3	0.1	164.8	5.0	59.5	0.2	267.9	6.5
z08_KMS	65.622	0.078	0.93	2267	152	484556	10843	9.3	0.1	3.4	6.4	19.6	0.6	1.8	0.1	12.1	1.3	10.3	1.0	1.54	0.41	43.1	0.1	14.0	1.9	159.4	17.3	56.7	6.0	259.6	30.5
z04_KMS	65.648	0.070	0.88	2347	107	484312	31932	9.5	0.5	0.7	6.2	9.2	2.1	1.2	0.4	7.9	0.8	9.1	1.1	1.35	0.05	40.7	1.5	14.4	1.8	163.7	13.0	56.9	4.7	267.4	20.5
z3_BS	65.670	0.063	0.95	2659	152	484524	2033	5.2	0.3	b.d.l.	b.d.l.	4.8	1.3	0.3	0.0	3.8	0.5	9.4	0.9	1.54	0.29	41.5	2.3	15.0	1.2	179.2	12.7	62.9	6.1	286.1	15.0
z02_KMS	65.724	0.056	0.90	2315	118	484522	10263	5.3	0.1	1.2	5.2	10.3	1.9	1.0	0.3	7.3	0.4	8.7	2.0	1.21	0.03	39.4	0.7	12.9	0.5	152.0	0.2	54.4	2.3	247.2	6.3
DEC13-30																															
z4_BS	66.286	0.035	2.33	9432	1445	414504	7254	23.4	0.3	b.d.l.	b.d.l.	137.9	17.6	2.7	0.5	31.3	4.2	69.2	12.5	2.17	0.83	272.3	31.6	84.6	11.1	809.5	85.3	236.7	33.4	897.9	89.4
z10_KMS	66.289	0.077	2.62	15016	976	399515	35614	144.4	2.6	b.d.l.	b.d.l.	204.4	15.1	3.9	2.4	37.3	12.6	119.8	22.4	4.67	3.41	468.2	52.0	145.1	9.3	1275.0	173.7	366.8	3.8	1337.2	68.8
z5_BS	66.291	0.042	1.69	7478	569	433312	22966	51.7	1.0	b.d.l.	b.d.l.	108.8	7.7	4.3	1.4	27.2	6.7	66.8	5.3	2.26	1.00	237.5	12.9	69.3	0.6	636.6	6.4	173.4	0.2	642.4	40.2
z6_BS	66.325	0.024	2.47	11086	813	409009	9809	32.9	0.8	b.d.l.	b.d.l.	164.8	9.5	2.6	0.3	37.6	6.6	77.6	0.6	2.21	0.21	308.7	1.2	98.0	6.6	914.4	32.7	267.9	15.0	989.0	9.5
z10_BS	66.343	0.031	1.90	8856	47	430999	1885	57.6	1.1	b.d.l.	b.d.l.	112.6	3.7	3.8	0.7	50.8	1.3	97.4	9.6	3.84	1.27	323.5	4.1	98.0	0.6	821.2	2.9	223.3	1.6	789.2	7.7
z08_KMS	66.390	0.024	2.27	10979	622	414471	29239	23.6	0.4	b.d.l.	b.d.l.	121.9	3.6	4.7	0.3	65.1	5.1	118.4	9.3	6.41	1.31	385.5	19.7	115.3	1.1	1017.0	17.7	274.2	9.1	953.9	47.9
z07_KMS	66.465	0.037	2.35	15036	276	399181	3415	24.7	0.4	b.d.l.	b.d.l.	226.8	2.6	9.5	0.2	93.8	7.1	149.0	4.9	12.86	0.35	507.6	11.4	155.1	1.4	1368.3	59.1	373.2	6.9	1365.7	20.8
z09_KMS	66.478	0.122	2.14	10805	451	413427	14488	17.8	0.3	b.d.l.	b.d.l.	95.1	2.7	8.0	0.4	74.1	4.2	103.6	1.7	12.15	0.95	334.5	4.7	104.1	1.7	937.0	13.3	269.3	2.6	1023.4	15.5
RBP																															
z1_BS	65.512	0.199	1.08	3574	19	481590	19178	2.0	0.6	b.d.l.	b.d.l.	20.1	2.7	1.2	0.8	9.0	1.1	11.8	2.1	2.09	0.15	57.3	7.7	19.9	2.9	229.8	7.9	80.4	3.0	361.0	19.7
z4_BS	65.653	0.128	1.19	1427	7	483983	30868	2.0	0.2	b.d.l.	b.d.l.	14.3	0.9	0.5	0.2	3.0	0.9	4.2	0.9	1.09	0.61	24.1	0.9	7.5	0.1	81.7	6.5	31.8	1.7	147.6	10.4
z5_BS	65.673	0.380	1.17	4521	144	481110	28066	b.d.l.	44.6	b.d.l.	b.d.l.	b.d.l.	b.d.l.	3.9	29.3	b.d.l.	b.d.l.	b.d.l.	b.d.l.	32.91	6.18	81.6	72.3	26.1	4.3	61.9	28.1	148.2	6.1	266.2	24.6
z2_BS	65.787	0.183	1.02	3191	3	482336	1443	1.9	0.4	b.d.l.	b.d.l.	23.2	2.1	1.3	0.3	7.8	0.9	12.5	0.6	2.04	0.52	54.6	5.7	18.2	1.5	205.4	1.8	74.7	2.3	331.9	13.6

a. sample name followed with specific zircon listed beneath. _BS and _KMS indicate grains measured at PU and _MIT are those measured at MIT.
b. dates and Th/U derived from TIMS analysis; see Table S1
c. total concentration of element listed with isotope measured indicated. Data are presented as ppm in zircon, by using concentrations measured in solutions and normalizing to stoichiometric Zr+Hf+REE...
d. uncertainties include analytical uncertainties and blank subtraction, based on measured variability in total procedural blanks

Tm-169	±2sig	Yb-172	±2sig	Lu-175	±2sig	Hf-178	±2sig	Ta-181	±2sig	Th-232	±2sig	a
												DEC13-08
110.0	2.0	854.1	22.5	165.6	0.7	10200	386	5.7	0.1	3286	34	z4_BS
114.8	5.7	934.3	110.2	180.1	9.6	10388	227	5.5	0.3	3008	88	z3_BS
93.2	1.4	727.8	21.2	139.6	1.1	10516	177	6.5	0.1	2547	18	z10_KMS
66.0	3.0	545.7	14.6	103.8	1.9	11067	186	8.3	0.1	2059	32	z08_KMS
135.4	0.4	1051.4	45.2	199.6	1.0	9397	277	5.4	0.1	4750	100	z06_KMS
104.2	5.9	886.6	17.2	158.1	5.8	11319	303	7.8	0.4	2298	53	z1_BS
215.3	8.6	1704.4	28.3	324.0	18.8	12380	92	19.4	0.3	10957	285	z11_KMS
150.7	0.2	1218.2	37.3	222.6	2.4	10822	245	9.5	0.1	6536	221	z05_KMS
152.8	3.8	1216.1	17.0	235.1	1.8	10158	163	6.6	0.1	6246	109	z02_KMS
220.2	27.2	1728.9	139.0	335.2	29.9	11103	649	12.9	0.6	10327	690	z07_KMS
164.7	9.3	1287.9	70.6	244.1	12.9	11019	377	10.2	0.2	6924	416	z04_KMS
												DEC13-09
158.5	1.7	1291.2	73.6	241.7	2.1	10557	87	13.0	1.5	5672	108	z12_KMS
186.9	9.9	1526.2	83.3	287.5	11.9	12024	506	14.9	0.5	8498	260	z2_MIT
194.6	8.6	1546.0	107.6	290.8	16.0	10810	721	12.8	0.7	9569	833	z5_MIT
61.1	0.3	525.4	33.4	92.8	1.5	11455	170	12.2	0.6	2102	74	z2_BS
140.5	15.5	1163.8	187.0	221.8	35.7	12155	560	17.4	0.4	6247	858	z02_KMS
140.6	19.2	1150.9	80.1	218.1	24.8	11075	612	13.2	0.0	3710	627	z10_KMS
241.2	17.5	1932.4	163.4	363.2	34.4	11076	280	11.9	0.1	11242	535	z1_MIT
215.8	42.7	1727.8	360.0	321.7	74.4	11411	1250	15.7	2.1	10784	2284	z3_MIT
93.4	2.8	769.9	12.6	145.2	1.2	10659	68	5.8	0.1	2805	59	z4_MIT
149.7	71.5	1295.2	557.9	229.8	106.6	12213	1439	18.2	1.9	2875	1143	z07_KMS
91.7	0.6	772.1	2.8	143.7	0.9	10266	545	7.7	0.5	3091	197	z04_KMS
62.5	4.4	525.8	28.7	99.2	8.2	10376	278	5.6	0.1	1546	74	z08_KMS
131.0	8.1	1062.1	110.6	200.3	16.3	11061	359	11.0	0.6	5034	895	z5_BS
114.6	1.0	934.3	38.3	179.0	5.8	11308	7	8.4	0.1	4412	373	z6_MIT
124.9	17.0	1017.7	218.9	191.4	38.0	11272	260	12.2	0.2	4780	961	z06_KMS
94.1	12.3	773.2	62.3	140.9	14.2	11413	299	9.5	0.4	2701	63	z1_BS
76.1	26.1	670.6	246.9	118.4	42.6	11013	645	8.5	0.6	1503	542	z09_KMS
40.0	7.0	343.3	85.4	60.4	10.9	11032	196	7.8	0.1	505	73	z11_KMS
												DEC13-10
178.5	23.5	1357.9	143.2	263.1	47.9	11450	357	15.5	1.5	6618	923	z11_KMS
187.8	0.5	1508.2	78.7	278.9	8.7	12117	340	13.9	1.0	9140	437	z9_MIT
141.2	4.5	1116.2	33.1	213.7	11.1	9209	261	4.8	0.5	4263	110	z7_MIT
206.9	9.9	1639.7	51.5	301.5	8.7	11085	169	8.7	0.1	7750	255	z2_MIT
140.8	26.3	1091.6	178.8	211.0	36.7	10521	1104	11.0	1.0	4920	832	z4_BS
173.6	35.0	1362.1	337.1	259.5	57.7	11273	697	16.6	1.1	7332	1769	z3_BS
190.0	23.8	1545.3	229.7	287.6	38.0	11648	510	19.0	1.0	9023	1410	z5_BS
152.4	0.9	1211.4	62.5	228.4	11.5	10845	220	13.5	0.1	6222	848	z2_BS
144.8	0.8	1149.2	29.4	212.8	5.2	10536	422	2.0	0.2	4042	249	z8_MIT
187.8	9.3	1574.6	59.2	295.7	11.5	12031	154	14.9	0.1	5674	863	z1_BS
185.5	3.3	1522.8	59.9	273.7	5.3	11904	732	16.0	1.9	7567	422	z10_MIT
59.4	1.8	482.9	13.9	95.1	5.8	8836	342	1.2	0.1	940	43	z6_MIT
185.8	17.9	1409.1	203.8	271.5	32.9	11458	861	17.5	0.4	8626	2016	z10_KMS
46.9	5.1	396.3	40.4	84.7	3.5	8605	475	1.9	0.8	3154	156	z07_KMS
158.6	7.6	1259.1	32.4	238.5	28.1	10581	487	12.4	0.9	5291	258	z09_KMS
												RBF
56.7	1.7	449.4	4.8	92.8	2.2	8430	261	1.3	0.2	682	23	z2_BS
46.1	3.4	379.1	23.5	76.7	7.1	8940	467	1.8	0.0	639	74	z03_KMS
65.5	3.8	538.6	25.1	106.8	0.5	8964	32	2.2	0.2	1230	33	z3_BS
147.6	15.1	1161.1	5.6	222.8	16.2	11374	358	11.2	0.2	4791	326	z06_KMS
183.3	3.3	1486.8	22.0	279.5	18.7	11154	620	12.6	1.5	6690	555	z4_BS
205.0	18.6	1658.9	87.2	310.5	34.4	11098	596	16.6	0.1	9815	874	z5_BS
200.1	15.2	1591.6	71.0	299.9	18.3	11965	103	16.8	0.9	8376	850	z01_KMS
180.3	18.0	1395.5	124.8	264.0	9.6	11469	535	16.0	0.2	8162	978	z02_KMS
127.7	7.8	989.8	47.9	191.6	21.0	8019	628	3.6	0.1	2985	238	z04_KMS
268.7	54.4	2055.1	315.0	369.9	70.8	12313	897	12.3	0.4	16510	2431	z1_BS
												RBE
54.2	1.7	455.8	7.9	90.0	0.3	9189	223	1.8	0.1	883	75	z6_MIT
57.5	1.0	486.7	9.6	95.4	1.9	8645	116	2.0	0.2	1116	67	z7_MIT
51.6	8.4	442.1	61.7	87.4	10.8	8618	768	2.0	0.1	687	98	z3_MIT
69.2	3.2	572.1	28.8	112.4	1.7	9058	341	1.7	0.1	1066	28	z10_KMS
39.4	11.0	332.6	70.5	64.3	17.3	9068	539	1.6	0.1	416	92	z5_BS
66.1	1.9	539.0	8.8	107.8	1.5	8553	274	1.5	0.1	884	56	z2_BS
47.9	5.3	407.4	42.3	81.3	12.6	8492	274	1.7	0.1	639	56	z1_BS
49.0	1.6	403.8	13.0	81.7	1.8	8466	166	1.9	0.0	846	75	z2_MIT
58.5	0.4	475.7	30.5	96.7	1.9	8601	298	1.8	0.0	885	59	z01_KMS
51.1	0.4	428.5	8.0	86.3	0.3	8769	469	1.5	0.1	808	139	z4_MIT
49.5	5.2	413.5	37.5	81.4	8.5	9023	157	1.5	0.1	659	16	z08_KMS
50.4	3.3	417.8	17.4	83.7	6.6	9248	165	1.7	0.0	597	24	z04_KMS
54.9	5.1	450.6	25.0	90.4	10.0	8512	167	1.6	0.2	739	63	z3_BS
46.9	1.0	398.5	22.1	80.0	0.1	9031	186	1.8	0.1	703	38	z02_KMS
												DEC13-30
154.5	18.3	1029.9	102.2	169.9	25.6	7361	142	2.7	0.3	62393	8886	z4_BS
222.7	8.9	1444.7	73.0	229.9	15.1	7688	50	2.7	1.2	69147	3676	z10_KMS
105.8	5.2	676.7	1.5	167.1	2.8	7033	309	1.9	0.5	46857	1830	z5_BS
162.6	17.6	1089.9	71.1	171.7	10.0	7551	463	3.1	0.5	65563	2322	z6_BS
129.6	5.9	842.5	3.7	133.3	7.2	7134	176	1.9	1.0	46846	120	z10_BS
148.7	4.3	980.9	19.6	139.8	3.6	7622	15	1.7	0.2	59880	1653	z08_KMS
214.8	2.6	1415.1	0.1	217.0	2.3	7351	129	3.0	0.4	69759	1131	z07_KMS
161.7	8.7	1086.4	25.2	175.8	2.7	7639	207	1.8	0.1	61196	466	z09_KMS
												RBP
70.5	5.0	538.3	17.0	111.5	2.2	8832	298	1.5	0.4	2126	126	z1_BS
30.8	2.3	255.2	16.4	53.8	3.4	10717	320	1.7	0.1	834	29	z4_BS
249.8	106.7	664.8	660.5	552.0	228.1	9828	17941	b.d.l.	b.d.l.	b.d.l.	b.d.l.	z5_BS
61.7	2.2	497.2	3.9	99.3	3.3	8896	89	1.3	0.2	1814	39	z2_BS

Table S3: U-Pb age interpretation

Constant (Th/U) partition coefficient between magma and zircon of 0.33 and imposed uncertainty of ±0.3 on Th/U of resulting magma (preferred interpretation)

	# of analyses	deltaT (ka)	Youngest grain date (Ma)	± 2σ	Weighted mean date (Ma)	± 2σ	N	MSWD	Geochemically-guided weighted means (IWMs) date (Ma)	± 2σ	N	MSWD	PREFERRED INTERPRETATION Monte Carlo ages from IWMs age (Ma)	± 2σ	Monte Carlo ages from single grain age (Ma)	± 2σ
DEC13-08 (PU)	11	150	65.574	0.028	65.586	0.018	4	1.2	65.583	0.020	3		failed superposition		failed superposition	
DEC13-09 (PU)	12	150	65.568	0.031	65.606	0.015	4	2.9								
DEC13-09 (MIT)	6	70	65.589	0.041	65.619	0.019	6	1	65.579	0.022	3	0.56	failed superposition		failed superposition	
DEC13-10 (PU)	9	320	**65.508**	**0.081**	65.608	0.028	4	2.6								
DEC13-10 (MIT)	6	220	65.581	0.049	65.602	0.024	5	1.6	65.566	0.037	3	1.3	**65.535**	**0.027**	65.477	0.059
RBF (PU)	10	200	**65.557**	**0.081**	65.592	0.027	5	0.34	65.569	0.058	3	0.24	**65.545**	**0.026**	65.513	0.045
RBE (PU)	11	250	**65.502**	**0.057**	65.512	0.039	5	0.5	65.511	0.037	9	0.50	**65.552**	**0.026**	65.532	0.044
RBE (MIT)	5	220	65.39	0.33	65.54	0.09	5	1.0								
RBP (PU)	5	270	**65.51**	**0.20**	65.658	0.09	4	1.4	65.658	0.09	4	1.4	**65.661**	**0.087**	65.60	0.11
DEC13-30 (PU)	15	180	66.286	0.035	66.309	0.017	3	2.1	66.288	0.027	2	0.03	**66.288**	**0.027**	66.286	0.035

Total number of analyses, including xenocrysts, but deltaT - the difference between the oldest and youngest grain - does not include xenocrysts

Dates in bold are used for Monte Carlo simulations. For RBE, RBF, the youngest mean dates were significantly less precise than the 2nd youngest, so the 2nd youngest was chosen

Analyses included in these weighted means are chosen based age equivalence including the youngest grain.

Analyses included in these weighted means are chosen based on both age and geochemical equivalence of the selected grains. Reported dates for each sample represent combined weighted-means of analyses from MIT and PU. IWM = intelligent weighted means.

Ages reported here are outputs from the Monte Carlo Markov Chain model that imposes the constraint of stratigraphic continuity - namely that stratigraphically higher beds must be younger. "Failed superposition" indicates that <0.1% of randomly chosen paths met these criteria for these samples, and were thus discarded. Monte Carlo IWMs are the preferred interpretation that appear in the text and in Figs. 1,2

Calculated durations and ages of imporant events

	duration (kyr) or age (Ma)	± 2σ
duration of C29r (Monte Carlo single grain)	754	56
Minimum duration of Deccan (Monte carlo single grain)	809	69
PREFERRED INTERPRETATION (from Monte Carlo of IWMs)		
duration of C29r	**736**	**37**
Minimum duration of Deccan	**753**	**38**
Age of C30n/C29r reversal	**66.288**	**0.027/0.047/0.085**
Age of C29r/C29n reversal	**65.552**	**0.026/0.047/0.085**

Calculated durations for C29r are age of DEC13-30 minus RBE. Minimum duration of Deccan is calculated as DEC13-30 minus DEC13-10. Uncertainties are added in quadrature. Uncertainties for ages are given as ±X/Y/Z, where X = analytical, Y= +tracer calibration, Z = +decay constants

Constant magma Th/U of 2.8 ± 0.5 (NOT preffered interpretation)

	# of analyses	deltaT (ka)	Youngest grain date (Ma)	± 2σ	Weighted mean date (Ma)	± 2σ	N	MSWD	Geochemically-guided weighted means (IWMs) date (Ma)	± 2σ	N	MSWD	Monte Carlo ages from IWMs age (Ma)	± 2σ	Monte Carlo ages from single grain age (Ma)	± 2σ
DEC13-08 (PU)	11	150	**65.543**	**0.062**	65.585	0.019	5	1.3	65.577	0.021	3	1.5	failed superposition		65.496	0.043
DEC13-09 (PU)	12	150	65.565	0.033	65.604	0.016	4	2.5								
DEC13-09 (MIT)	6	70	65.584	0.051	65.615	0.02	6	0.93	65.577	0.023	3	0.47	failed superposition		failed superposition	
DEC13-10 (PU)	9	320	**65.508**	**0.082**	65.561	0.048	2	2.6								
DEC13-10 (MIT)	6	220	65.577	0.085	65.599	0.025	4	1.3	65.563	0.039	3	1.2	65.532	0.027	65.514	0.041
RBF (PU)	10	200	**65.560**	**0.081**	65.592	0.029	5	0.29	65.57	0.058	3	0.2	65.542	0.026	65.531	0.04
RBE (PU)	11	250	**65.497**	**0.059**	65.512	0.039	5	0.5	65.51	0.037	9	0.47	65.550	0.026	65.545	0.042
RBE (MIT)	5	220	65.39	0.33	65.54	0.09	5	1.0								
RBP (PU)	5	270	**65.51**	**0.20**	65.651	0.09	4	1.4	65.651	0.09	3	1.4	65.543	0.087	65.62	0.11
DEC13-30 (PU)	15	180	66.232	0.047	66.269	0.022	4	1.9	66.247	0.034	2	0.78	66.247	0.034	66.232	0.047

Total number of analyses, including xenocrysts, but deltaT - the difference between the oldest and youngest grain - does not include xenocrysts

Dates in bold are used for Monte Carlo simulations. For RBE, RBF, the youngest mean dates were significantly less precise than the 2nd youngest, so the 2nd youngest was chosen

Analyses included in these weighted means are chosen based age equivalence including the youngest grain.

Analyses included in these weighted means are chosen based on both age and geochemical equivalence of the selected grains. Reported dates for each sample represent combined weighted-means of analyses from MIT and PU. IWM = intelligent weighted means.

Ages reported here are outputs from the Monte Carlo Markov Chain model that imposes the constraint of stratigraphic continuity - namely that stratigraphically higher beds must be younger. "Failed superposition" indicates that <0.1% of randomly chosen paths met these criteria for these samples, and were thus discarded.

Calculated durations

	duration (kyr)	± 2σ
duration of C29r (Monte Carlo single grain)	687	63
Minimum duration of Deccan	736	64
duration of C29r (monte carlo from IWM)	697	43
Minimum duration of Deccan	715	43

Calculated durations for C29r are age of DEC13-30 minus RBE. Minimum duration of Deccan is calculated as DEC13-30 minus DEC13-10. Uncertainties are added in quadrature. Uncertainties for ages are given as ±X/Y/Z, where X = analytical, Y= +tracer calibration, Z = +decay constants

साहित्य अकादेमी

आणि

संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

ह्यांच्या संयुक्त विद्यमाने आयोजिलेल्या

आधुनिक मराठी साहित्यावर लोकसाहित्याचा प्रभाव

विषयक चर्चासत्रास आपण सादर आमंत्रित आहात.

सोमवार, 22 जानेवारी 2018

दृकश्राव्य सभागृह, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

कार्यक्रम

उद्घाटनाचे सत्र	:	स.10.00 ते 11.00 वा.
स्वागताचे भाषण	:	कृष्णा किंबहुने *प्रादेशिक सचिव, साहित्य अकादेमी, मुंबई*
प्रास्ताविक	:	मनोज तायडे *मराठी विभाग प्रमुख, संत गाडगे बाबा अमरावती विद्यापीठ*
उद्घाटनाचे भाषण	:	मुरलीधर चांदेकर *मा. कुलगुरु, संत गाडगे बाबा अमरावती विद्यापीठ*
अध्यक्षीय भाषण	:	विश्वनाथ शिंदे *सुप्रसिद्ध मराठी साहित्यिक*
		आभार
चहा	:	स. 11.00 वा.
पहिले सत्र	:	सकाळी 11.30 ते दुपारी 1.30 वा. *कथनात्म साहित्य*
अध्यक्ष	:	शशिकांत सावंत
निबंध	:	दा.गो. काळे, रणधीर शिंदे
जेवण	:	दु. 1.30 ते 2.30 वा.
दुसरे सत्र	:	दुपारी 2.30 ते 4.00 वा. *नाटक आणि कविता*
अध्यक्ष	:	मधुकर वाकोडे
निबंध	:	प्रकाश खांडगे, गणेश चंदनशिवे, रफिक सुरज
		आभार

या चर्चासत्राच्या निमित्ताने साहित्य अकादेमी आपल्या प्रकाशनांचे प्रदर्शन व विक्रीही आयोजित करीत आहे

संपर्क : (022)-24135744, 24131948 / (0721) 2662173

ई-मेल : rs.rom@sahitya-akademi.gov.in

साहित्य अकादेमी

तथा

संत गाडगे बाबा अमरावती विश्वविद्यालय, अमरावती

के संयुक्त तत्त्वावधान में आयोजित

आधुनिक मराठी साहित्यपर लोकसाहित्य का प्रभाव

विषयक परिसंवाद में आप सादर आमंत्रित हैं.

सोमवार, 22 जनवरी 2018

दृकश्राव्य सभागार, संत गाडगे बाबा अमरावती विश्वविद्यालय, अमरावती

कार्यक्रम

उद्घाटन सत्र : पूर्वाह्न 10.00 से 11.00 बजे

स्वागत भाषण : कृष्णा किंबहुने
क्षेत्रीय सचिव, साहित्य अकादेमी, मुंबई

आरंभिक वक्तव्य : मनोज तायडे
मराठी विभाग प्रमुख, संत गाडगे बाबा अमरावती विश्वविद्यालय

उद्घाटन वक्तव्य : मुरलीधर चांदेकर
मा. कुलगुरु, संत गाडगे बाबा अमरावती विश्वविद्यालय

अध्यक्षीय वक्तव्य : विश्वनाथ शिंदे
सुप्रसिद्ध मराठी साहित्यकार

धन्यवाद ज्ञापन

चाय : पूर्वाह्न 11.00 बजे

प्रथम सत्र : पूर्वाह्न 11.30 से अपराह्न 1.30 बजे
कथनात्म साहित्य

अध्यक्ष : शशिकांत सावंत

आलेख : दा.गो. काळे, रणधीर शिंदे

भोजन : अपराह्न 1.30 से 2.30 बजे

द्वितीय सत्र : अपराह्न 2.30 से 4.30 बजे
नाटक एवं कविता

अध्यक्ष : मधुकर वाकोडे

आलेख : प्रकाश खांडगे, गणेश चंदनशिवे, रफिक सुरज

धन्यवाद ज्ञापन

इस अवसर पर साहित्य अकादेमी अपने प्रकाशनों की प्रदर्शनी एवं बिक्री भी आयोजित कर रही है

उत्तरापेक्षी : 022-24135744, 24131948 / (0721) 2662173
ई-मेल : rs.rom@sahitya-akademi.gov.in

क्र.संगाबाअवि/५१७/ 108 /२०१८
दिनांक :- २८/०७/२०१८

विषय :- नुक्कड कथा अभिवाचन कार्यक्रम आयोजित करण्याबाबत.

डिजिटल साहित्य विश्वात सुमारे दिडशे लेखक आणि सव्वा लाखाहून अधिक वाचकांनी चालवलेली अनोखी चळवळ म्हणजे 'नुक्कड... !' नुकतेच औरंगाबाद येथे नुक्कड साहित्य लेखकांचे साहित्य संमेलन दिमाखात संपन्न झाले आणि याच सोहळ्यात जानेवारी २०१९ मध्ये तिसरे नुक्कड साहित्य संमेलन विदर्भात घेण्याचे निश्चित झाले आहे.संपूर्ण विदर्भातील नव्या लेखक-वाचकांपर्यंत नुक्कड साहित्य संमेलनाचा संदेश पोचवण्यासाठी नुक्कड कथा अभिवाचन मालिका करण्याचे योजिले आहे. त्यात वाशिम, बुलढाणा, अकोला, अमरावती व यवतमाळ यांचा समावेश आहे. या मालिकेतील एक भाग म्हणजेच नुक्कड कथा अभिवाचनाचा कार्यक्रम अमरावतीत घ्यावयाचा आहे. सदर कार्यक्रम पदव्युत्तर मराठी विभाग, संत गाडगे बाबा अमरावती विद्यापीठ व विदर्भ साहित्य संघ, शाखा अमरावती यांच्या संयुक्त विद्यमाने घ्यावयाचे योजिले आहे.

या कार्यक्रमाचे खास वैशिष्ट्ये हे की, सादर होणाऱ्या कथा वैदर्भीय लेखक-लेखिकांनी लिहिलेल्या आहेत आणि अभिवाचकही विदर्भातीलच आहे. त्यामध्ये साहित्यिक-नाटककार-मालिका लेखक विक्रम भागवत यांचा समावेश आहे. यांच्यासोबत डॉ. स्वाती धर्माधिकारी, प्रतिमा पंकज, आशा अभिजित मुळे, अभिषेक बेल्लारवार आणि अभय नवाथे यांचा सहभाग असणार आहे.

सादर कार्यक्रम १८ ऑगस्ट २०१८ रोजी सायंकाळी ५.०० वाजता विमलाबाई श्रोतृगृह येथे संपन्न होईल.

या कार्यक्रमाच्या आयोजनासाठी विद्यापीठाला करावयाचा खर्च खालीलप्रमाणे आहे.

१) सभागृह भाडे	-	६,५००/-
२) ध्वनिव्यवस्था	-	४,०००/-
३) बॅनर	-	२,०००/-
४) हार-पुस्तके	-	५००/-
५) आनुषंगिक खर्च	-	२,०००/-
एकूण	-	१५,०००/-

उपरोक्त खर्च **रु. १५,०००/-** हा विद्यापीठाच्या **4) साधारण निधी H) बेस्ट प्रॅक्टिसेस इन युनिव्हर्सिटी viii) मराठी भाषा संवर्धन उपक्रम** या शीर्षातून करण्यात येईल. कृपया, उपरोक्त कार्यक्रमाच्या आयोजनास व खर्च **रु. १५,०००/-** ह्यास **प्रशासकीय व वित्तीय मान्यता मिळावी**, ही विनंती.

पुढील कार्यवाहीसाठी सादर.

मराठी विभागप्रमुख

मा. कुलसचिव

30/7/18

मा. कुलगुरू

30.07.18

दि. १८ ऑगस्ट, २०१८ रोजी नुक्कड कथा अभिवाचन कार्यक्रमास प्रशासकीय मान्यता प्राप्त झाली आहे. वित्तीय मान्यता मिळण्यासाठी सादर.

[signature]

M/109
01/08/2018

मा. वित्त व लेखा अधिकारी.
स. कु. अंके. 01.8.18

F4632
1/8/18

Ku. MUD
[signature] 3/8/18

नियमाने पालन अपेक्षून प्रस्तावित प्रस्तावास 2018-19 मध्ये रु. 15000/- ची नोंद घेवून वित्तीय मान्यतेस्तव सादर

[signature] 10/8/18

F2778
2/8/18

अधीक्षक

A-288
02/8

स. कु. अंकेक्षण

वि. व ले. अ.

[signature] 11/8/18

[signature] 11/8/18

[signature] 11/08/18

उ. कु. लेखा

शिरवडकर 14.8.18

A-919
18/08

वि.प्र. मराठी ह्यांनी नुक्कड कथा अभिवाचन करीता अग्रिम रु 15000/- ची मागणी केली असून अग्रिम मंजुरीस्तव सादर

[signature] 14/8

अधीक्षक 14.8.18

[signature] 14/08/18

उप मुख्य लेखा

[signature] 16/08/18

मु. व ले. अ.

संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

आणि

मराठी विज्ञान परिषद, मुंबई

यांच्या संयुक्त विद्यमाने आयोजित

विज्ञान कथालेखन कार्यशाळेचे उद्घाटन

दिनांक : 30 ऑगस्ट, 2018

वेळ : सकाळी 11.00 वाजता

उद्घाटक : **प्रा. डॉ. मुरलीधर चांदेकर**

कुलगुरू, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

अ.पां. देशपांडे

कार्यवाह

मराठी विज्ञान परिषद, मुंबई

डॉ. मनोज तायडे

मराठी विभागप्रमुख, पदव्युत्तर मराठी विभाग,

संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

स्थळ : दृकश्राव्य सभागृह, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

मराठी विभाग, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

आणि

मराठी विभाग, श्री शिवाजी महाविद्यालय, आकोट, जि. अकोला

संयुक्त विद्यमाने आयोजित

विद्यापीठ अनुदान आयोग पुरस्कृत

कवितालेखन कार्यशाळा

शहानूर

दि. १ फेब्रुवारी ते ३ फेब्रुवारी २०१९

कार्यक्रमाची रूपरेषा

दि. १.२.२०१९

सकाळी १२.३० ते २ : उद्घाटन समारंभ

अध्यक्ष : मा. डॉ. मुरलीधर चांदेकर, कुलगुरू, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

उद्घाटक : मा. श्री. हर्षवर्धन देशमुख, अध्यक्ष, श्री शिवाजी शिक्षण संस्था, अमरावती

प्रमुख अतिथी : कवी विठ्ठल वाघ, अकोला

प्रमुख उपस्थिती : प्राचार्य डॉ. ए. एल. कुलट, श्री शिवाजी महाविद्यालय, आकोट

सूत्रसंचालन: डॉ. प्रणव कोलते

दुपारी २ ते २.३० : भोजन

दुपारी २.३० ते ३.४५ : मार्गदर्शन सत्र

वक्ते : बालिका ज्ञानदेव, पुणे

सूत्रसंचालन: डॉ. मोना चिमोटे

दुपारी ३.४५ ते ४ : चहापान

दुपारी ४ ते ५.३० : मार्गदर्शन सत्र

वक्ते : संतोष पद्माकर पवार

सूत्रसंचालन: डॉ. मोना चिमोटे

रात्री ५.३० ते ६.३० : खुली चर्चा

रात्री ८.३० ते ९.३० : कवितावाचन

दि. २.२.२०१९

सकाळी ७ ते १०	:	जंगल सफारी
सकाळी १० ते १०.३०	:	नाश्ता-चहा
सकाळी १०.३० ते १२	:	मार्गदर्शन सत्र
वक्ते	:	बबन सराडकर, अमरावती *सूत्रसंचालनः डॉ. हेमंत खडके*
दुपारी १२ ते १.३०	:	मार्गदर्शन सत्र
वक्ते	:	बालिका ज्ञानदेव, पुणे
दुपारी १.३० ते २.३०	:	भोजन
दुपारी २.३० ते ४	:	मार्गदर्शन सत्र
वक्ते	:	डॉ. विठ्ठल वाघ, अकोला *सूत्रसंचालनः डॉ. हेमंत खडके*
दुपारी ४ ते ४.१५	:	चहापान
दुपारी ४.१५ ते ५.४५	:	मार्गदर्शन सत्र
वक्ते	:	संतोष पद्माकर पवार
संध्या. ५.४५ ते ६.३०	:	खुली चर्चा
रात्री ८.३० ते ९.३०	:	कवितावाचन

दि. १.२.२०१९

सकाळी १२.३० ते २ : उद्घाटन समारंभ

प्रतिमापूजन :
१) संत गाडगे बाबा
२) डॉ. पंजाबराव देशमुख

स्वागत
१) अध्यक्ष : मा. डॉ. मुरलीधर चांदेकर, कुलगुरू, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती
२) उद्घाटक : मा. श्री. हर्षवर्धन देशमुख, अध्यक्ष, श्री शिवाजी शिक्षण संस्था, अमरावती
३) प्रमुख अतिथी : कवी विठ्ठल वाघ, अकोला
४) प्रमुख उपस्थिती : श्री. गजानन पुंडकर, उपाध्यक्ष, श्री शिवाजी शिक्षण संस्था, अमरावती
५) प्रमुख उपस्थिती : श्री. केशवराव मेतकर, उपाध्यक्ष, श्री शिवाजी शिक्षण संस्था, अमरावती
६) प्रमुख उपस्थिती :
७) प्रमुख उपस्थिती : प्राचार्य डॉ. ए. एल. कुलट
८) प्रमुख उपस्थिती : डॉ. मनोज तायडे, मराठी विभागप्रमुख
९) प्रमुख उपस्थिती : डॉ. विलास तायडे
१०)

प्रास्ताविक : डॉ. मनोज तायडे, मराठी विभागप्रमुख, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

मनोगत:
१) स्वागतपर : प्राचार्य डॉ. ए. एल. कुलट, श्री शिवाजी महाविद्यालय, आकोट
२) शुभेच्छापर : श्री. केशवराव मेतकर, उपाध्यक्ष, श्री शिवाजी शिक्षण संस्था, अमरावती
३) शुभेच्छापर : श्री. गजानन पुंडकर, उपाध्यक्ष, श्री शिवाजी शिक्षण संस्था, अमरावती
४) प्रमुख अतिथी : कवी विठ्ठल वाघ, अकोला
५) उद्घाटनपर : मा. श्री. हर्षवर्धन देशमुख, अध्यक्ष, श्री शिवाजी शिक्षण संस्था, अमरावती
६) अध्यक्षीय भाषण : मा. डॉ. मुरलीधर चांदेकर, कुलगुरू, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती
७) *आभारप्रदर्शन:* डॉ. विलास तायडे, मराठी विभागप्रमुख, श्री शिवाजी महाविद्यालय, आकोट

सूत्रसंचालन: डॉ. प्रणव कोलते

दि. ३.२.२०१९

सकाळी ८.३० ते ९ : चहा-नाश्ता

सकाळी ९.३० ते ११ : मार्गदर्शन सत्र

वक्ते : बबन सराडकर, अमरावती

सकाळी ११ ते १२.३० : समारोप समारंभ

अध्यक्ष : मा. डॉ. राजेश जयपूरकर, प्र-कुलगुरू, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती

प्रमुख अतिथी : कविवर्य विठ्ठल वाघ

प्रमुख उपस्थिती : डॉ. मनोज तायडे, प्राचार्य डॉ. ए. एल. कुलट, डॉ. विलास तायडे,

सूत्रसंचालनः डॉ. हेमंत खडके

दुपारी १२.३० ते १२.४५ : प्रमाणपत्र वाटप

दुपारी १२.४५ ते १.३० : भोजन

पदव्युत्तर मराठी विभाग, संत गाडगेबाबा अमरावती विद्यापीठ, अमरावती
पदव्युत्तर मराठी विभाग, शासकीय विदर्भ ज्ञान विज्ञान संस्था, अमरावती
आणि विदर्भ साहित्य संघ, शाखा : अमरावती यांचे संयुक्त आयोजन

।। कवितासमय ।।

(सात समकालीन कवींचे कवितावाचन)
अध्यक्ष : चंद्रकान्त पाटील (पुणे)

। सहभागी कवी ।

वसंत आबाजी डहाके (अमरावती) । प्रभा गणोरकर (अमरावती)
प्रफुल्ल शिलेदार (नागपूर) । श्रीधर नांदेडकर (औरंगाबाद)
राजा होळकुंदे (लातूर) । रवी कोरडे (जिंतूर)
सूत्रसंचालन: प्रो. हेमंत खडके (अमरावती)

। विशेष उपस्थिती ।

प्रो. रणधीर शिंदे (कोल्हापूर) । डॉ. आसाराम लोमटे (परभणी)
डॉ. रामचंद्र काळुंखे (औरंगाबाद) । श्री. तुषार बोडखे (औरंगाबाद)
प्रो. मनोज तायडे (अमरावती)
कवितावाचनाच्या या कार्यक्रमास आपली उपस्थिती प्रार्थनीय आहे.

।। विनीत ।।

प्रो. मोना चिमोटे
प्रमुख, पदव्युत्तर मराठी विभाग
संत गाडगेबाबा अमरावती
विद्यापीठ, अमरावती.

प्राचार्य डॉ. रमेश अंधारे
अध्यक्ष, विदर्भ साहित्य संघ
शाखा : अमरावती

प्रो. केशव तुपे
प्रमुख, पदव्युत्तर मराठी विभाग
शासकीय विदर्भ ज्ञान
विज्ञान संस्था, अमरावती.

स्थळ : टाऊन हॉल, राजकमल चौक, अमरावती.
दिनांक : ०७ सप्टेंबर २०१९, शनिवार / सायंकाळी ६.०० वाजता.

पुस्तक प्रकाशन : रई - प्रा. महादेव लुले, व-हाडधन - शिवलिंग काटेकर, सातबारा कोरा - दयाराम निंबोळकर, जागल - अरुण विघ्ने

संमेलन आयोजन समिती: डॉ.मोना चिमोटे, डॉ.मनोज तायडे, डॉ.माधव पुटवाड, डॉ.हेमंत खडके, डॉ. प्रणव कोलते, पुष्पराज गावंडे, प्रा.सदाशिव शेळके, दयाराम निंबोळकर, श्याम ठक, प्रा.महादेव लुले, निलेश कवडे.

समन्वयक: निलेश कवडे, रविंद्र दळवी, तेजस्वी बारब्दे, सौ.अनुराधा धामोडे, सौ.उज्ज्वला कांबळे, विजय पळसपगार, उमेश थोरात, अजय माटे, डॉ. पांडुरंग हटकर

कोषाध्यक्ष: प्रा.महादेव लुले

स्वागत समिती: आबासाहेब कडू, भास्करराव अरबट, शिवलिंग काटेकर, डॉ प्रमोद काकडे, नितिन वरणकार, प्रा.डॉ.सुनिल पखाले, निलेश देवकर, निलू मानकर, ॲड.मोहन जाधव, ॲड.गजेंद्र हिंगणकर, ॲड.ललित कदम, नितेश राऊत, अनिल लाले, विजय बिन्दोड, निळू तायडे, वीणा डिक्कर, युवराज टोपले, सुबोध दळवी , निलेश देशमुख, महेश मुळे

सभागृह तथा मंच व्यवस्थापन समिती: मनीषा माटे, ॲड.रजनी बावस्कर, धनश्री पाटील, सरिता बायस्कर, विद्या बनाफर, अश्विनी घुले, मधुराणी बन्सोड, डॉ. मीना सोसे, डॉ.पुजा फाळके, वनिता गावंडे, माधुरी चौधरी, अलका बोर्डे , कल्पना डोईफोडे, प्रणिता धोटे, रजनी चौखंडे

भोजन समिती: उज्वल विभुते , लक्ष्मण दारमोडे, नितिन वानखडे, सुनिल जुमळे, नितिन बाहकर, भागवत वाढोकार, राम पळसकर

संमेलन समिती सदस्य, मंदा पडवेकर, मनोज मेंडके, अभिजीत मुरूमकर, स्वप्नील इंगळे, धीरज चावरे, अजय इंगळे, किशोर पवार, वैभव इंगळे, प्रज्योत देशमुख, प्रशांत भोंडे, अशोक उघडे , डॉ. शांतीलाल चव्हाण, डॉ. स्वप्नील मानकर गजानन उगले, निखिल गावंडे, राजेश गिऱ्हे, हर्षा वाघमारे ,ईश्वर मते, राम जाधव, मधुकर तराळे ,मिलिंद हिवराळे, नितीन ठाकरे, प्रवीण बोपुलकर, रामदास गायधनी, राजेश काटोले, सागर लाहोळकर , संजय रोंगे, प्रा.अशोक सारडा, स्वप्निल कुलकर्णी, जावेद शेख

ध्यास वऱ्हाडी बोलीभाषेचा
सातासमुद्रापार नेन्याचा..!

कार्याध्यक्ष
श्याम ठक
(अध्यक्ष, अ.भा. वऱ्हाडी साहित्य मंच)

३ तिसरे
अखिल भारतीय
वऱ्हाडी साहित्य संमेलन अमरावती-२०२०
बोलू वऱ्हाडी, लिहू वऱ्हाडी, जगू वऱ्हाडी

संपर्क:
श्याम ठक: ९९७५७९२५२०
निलेश कवडे : ९८२२३६७७०६

ज्येष्ठ सल्लागार
प्रा.सदाशिव शेळके
(अ.भा. वऱ्हाडी साहित्य मंच)

आवतन

संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती व
'अखिल भारतीय वऱ्हाडी साहित्य मंच, अकोला' द्वारा
संयुक्त आयोजन

अखिल भारतीय वऱ्हाडी साहित्य मंच

३ तिसरे
अखिल भारतीय
वऱ्हाडी साहित्य संमेलन अमरावती-२०२०
बोलू वऱ्हाडी, लिहू वऱ्हाडी, जगू वऱ्हाडी

तिसरे अखिल भारतीय वऱ्हाडी साहित्य संमेलन

अमरावती -२०२०

संमेलनाध्यक्ष
मा. नरेंद्र इंगळे
(जेष्ठ वऱ्हाडी साहित्यिक)

स्वागताध्यक्ष
मा.डॉ. मुरलीधर चांदेकर
कुलगुरू
(संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती)

संमेलन उद्घाटक
मा. प्रा.मधुकर वाकोडे
(सदस्य महाराष्ट्र राज्य साहित्य संस्कृती मंडळ)

प्रमुख अतिथी
मा. शिरीषदादा धोत्रे
(सभापती, कृषी उत्पन्न बाजार समिती, अकोला.)

मावळते संमेलनाध्यक्ष
मा.प्रकाश पोहरे
(संपादक दै. देशोन्नती)

प्रमुख अतिथी
मा. संदीपजी भारंबे
(कार्यकारी संपादक दै.सकाळ, अकोला आवृत्ती)

प्रमुख अतिथी
सौ. अनुराधा कृ. धामोडे
(लेखिका, चाणक्यांव जि. यवतमाळ)

४ जानेवारी-२०२०
वार : शनवार
ठावठिकाना :
स्व.उद्धव शेळके साहित्य नगरी,
स्व.मनोहर तल्हार विचारपीठ
दृकश्राव्य सभागृह,
संत गाडगे बाबा अमरावती विद्यापीठ,
अमरावती

पयले संमेलनाध्यक्ष
मा. पुष्पराज गावंडे
(पुवा व-हाडी कादंबरीकार)

निमंत्रक
डॉ.मोना चिमोटे
मराठी विभागप्रमुख, संत गाडगे बाबा अमरावती विद्यापीठ अमरावती

आवतन

संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती व
'अखिल भारतीय वऱ्हाडी साहित्य मंच, अकोला' द्वारा
संयुक्त आयोजन

तिसरे अखिल भारतीय वऱ्हाडी साहित्य संमेलन अमरावती-२०२०

मा. श्री /सौ. .....

अखिल भारतीय वऱ्हाडी साहित्य मंच, अकोला या आमच्या साहित्यिक मंचानं, वऱ्हाडी बोलीभाषेले जतन कऱ्याचं काम हाती घेतलं ! म्हनून बारोमास काईना काई उपक्रम राबोनं चालूच असते. या सालातई ता .०४ जानेवारी-२०२० शनवार रोजी स्व.उध्दव शेळके साहित्य नगरी, स्व.मनोहर तल्हार विचारपीठ दृकश्राव्य सभागृह, मराठी विभाग परिसर, संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती. अथी तिसरे अ . भा . वऱ्हाडी साहित्य संमेलन होनार हाय ! तुमाले या कारेक्रमात या लागते म्हनजे याच लागते ! कोनताबी बायना चालनार नाई .

कारेक्रमाचा आराधुरा

१ सत्र पयले
उद्घाटन सत्र
सकावुन १० वा. ते दुपारी १२ वाजेलोग

संमेलनाध्यक्ष : मा. नरेंद्र इंगळे (ज्येष्ठ वऱ्हाडी साहित्यिक)
स्वागताध्यक्ष : मा.डॉ. मुरलीधर चांदेकर, कुलगुरू
(संत गाडगे बाबा अमरावती विद्यापीठ, अमरावती)
उदघाटक : मा. प्रा.मधुकर वाकोडे, मावळते अध्यक्ष : मा.प्रकाश पोहरे
प्रमुख अतिथी: मा. शिरीषदादा धोत्रे, प्रमुख अतिथी: मा. संदिपजी भारंबे
प्रमुख अतिथी: सौ. अनुराधा धामोडे
पयले संमेलनाध्यक्ष: मा.पुष्पराज गावंडे, सल्लागार: प्रा.सदाशिव शेळके,
मराठी विभागप्रमुख: डॉ.मोना चिमोटे, कार्याध्यक्ष: श्याम ठक,
संचालन: डॉ.प्रा.हेमंत खडके आभार: दयाराम निंबोळकर

२ सत्र दुसरे
परिसंवाद
दुपारी १२ ते १ वाजेलोग

विषय : संस्कृती संवर्धनासाठी बोलीचे उपयोजन
अध्यक्षा : डॉ. अलका गायकवाड
सहभाग: प्रा.डॉ. रावसाहेब काळे, डॉ. मीनाताई गावंडे
संचालन: निलेश कवडे, आभार: डॉ.मीना सोसे

३ सत्र तिसरे
कथाकथन
दुपारी १ ते २ वाजेलोग

अध्यक्ष : डॉ.प्रा.अनुराधा वऱ्हाडे
सहभाग: विजय पाटील, प्रा.अशोक मानकर
संचालन : निलेश देवकर, आभार: संजय नेमाडे

जेवनखावन : दुपारी २ ते ३ वाजेलोग

४ सत्र चौथे
कवि संमेलन
दुपारी ३ ते ४:३० वाजेलोग

अध्यक्ष: मीराताई ठाकरे
प्रमुख अतिथी: विजया मारोतकर (नागपूर), अरुण विन्हे (वर्धा),
सहभाग: नितिन वरणकार (शेगांव), शिवलिंग काटेकर (अकोला), ,
विजय सोसे (परतवाडा), संदिप धावडे (वर्धा), प्रमोद अंबडकार
(नाशिक), विजय ढाले (आर्णी), डॉ. संघमित्रा खंडारे (दर्यापूर),
रवींद्र दळवी (नाशिक), डॉ.लक्ष्मण उगले (खामगाव)
डॉ. अंबादास घुले, डॉ. गजानन बनसोड, गजानन मानकर
संचालन: प्रा.महादेव लुले, पवन नालट आभार: अंकुश इंगळे (मुंबई)

५ सत्र पाचवे
समारोप
संध्याकाई ४:३० ते ५:३० वाजेलोग

अध्यक्ष: डॉ.प्रा.राजेश जयपूरकर प्र.कुलगुरू
संमेलनाध्यक्ष: नरेंद्र इंगळे, प्रमुख अतिथी: आबासाहेब कडू,
दयाराम निंबोळकर, डॉ.ममता इंगोले, निलू मानकर,
तेजस्वी बारब्दे,
संचालन: साधना काळबांडे आभार: उमेश थोरात

६ सत्र सहावे
खुले कवि संमेलन
संध्याकाई ५:३० ते ७:३० वाजेलोग

अध्यक्ष: किशोर मुगल
प्रमुख अतिथी: विजय बिन्दोड, डॉ.प्रा.सुनिल पखाले, भास्कर इंगळे
सहभाग: अजय इंगळे, अजय माटे, अजय इंगळे, जावेद शेख, पवन
वसे, विनायक काळे, अंकुश इंगळे, श्रीराम वाघ, के. एस. इंगोले
अँड. रजनी बावस्कर, सौ. अनुराधा धामोडे, प्रा.अशोक सारडा,
सौ.जयश्री रोहनकर, युवराज टोपले, तुकाराम काटे,
मधुराणी बन्सोड, उमेश थोरात, खुशाल गुल्हाणे, श्याम राऊत,
मोहन जाधव, अजय राऊत, वर्षा बोध, दिनेश सातव,वीणा डिक्कर,
दीपकराज खवशी, धीरज चावरे, संजय रोंघे, जितेश इंगळे, हर्षल
साखरे, वैष्णवी सानप, शालिनी बेलसरे, अभिजीत इंगळे, प्राची
अडलोक, डॉ. शांतीलाल चव्हाण, आशिष कांबळे, सारिका वनवे, प्रशांत
भोंडे, अलका देशमुख, मधुकर तराळे, प्रशांत ढोले, सरिता बायस्कर,
डॉ. पूजा फाळके, अंकुश चौरपगार
संचालन: अनिकेत देशमुख, स्वप्नील इंगळे, आभार: संजय गावंडे

ध्यास वऱ्हाडी बोलीभाषेचा
सातासमुद्रापार नेन्याचा..!

वऱ्हाडरत्न पुरस्कार: समाजसेवा: महेंद्र राऊत, मुंबई, डॉ. विलास सवई, मुंबई
जीवनगौरव: देवकाताई देशमुख, पुष्पराज गावंडे "यलाई" पुरस्कार: उज्ज्वल विभुते

क्र.संगाबाअवि/५१७/ १६५ /२०१९
दिनांक :- २३/१२/२०१९

विषय :- 'मराठी शुद्धलेखन कार्यशाळे'चे संयुक्त विद्यमाने आयोजन करण्याबाबत.

संदर्भ :- शासन परिपत्रक क्र.मभापं-२०१९/प्र.क्र.९३/भाषा-२ दि. ०३.१२.२०१९.

संत गाडगे बाबा अमरावती विद्यापीठाच्या पदव्युत्तर मराठी विभागाद्वारे दरवर्षी दिनांक ०१ जानेवारी ते १५ जानेवारी या कालावधीत **मराठी भाषा संवर्धन पंधरवाडा** साजरा केला जातो. याही वर्षी मराठी भाषा संवर्धन पंधरवाडा साजरा करण्यासंदर्भात शासन आदेश वरील संदर्भाकित पत्रान्वये प्राप्त झाले आहेत.

यावर्षी पदव्युत्तर मराठी विभाग, सं.गा.बा.अमरावती विद्यापीठ व मराठी विभाग शासकीय ज्ञान-विज्ञान संस्था, अमरावती यांच्या संयुक्त विद्यामाने दिनांक ७, ८ व ९ जानेवारी, २०२० रोजी **मराठी शुद्धलेखन कार्यशाळा** आयोजित करण्यासंदर्भात ठरविले आहे. या संदर्भात डॉ. केशव तुपे, विभागप्रमुख शासकीय ज्ञान-विज्ञान संस्था, अमरावती यांच्याशी चर्चा झाली असून त्यांनी संयुक्तपणे कार्यशाळा आयोजित करण्याची संमती दिली आहे. त्यांनी कार्यशाळेसाठी एकूण येणाऱ्या अंदाजे रुपये १,००,०००/- खर्चापैकी अर्धा खर्च म्हणजेच ५०,०००/- रुपये खर्च उचलण्याची तयारी दर्शविली आहे आणि त्या संदर्भात लेखी पत्र मराठी विभागप्रमुख संत गाडगे बाबा अमरावती विद्यापीठाकडे सुपूर्त केले आहे.

त्या अनुषंगाने पद. मराठी विभागाला कार्यशाळेचे प्रमुख मार्गदर्शक डॉ. अरुण फडके यांचे मानधन व इतर अनुषंगिक खर्च वहन करावयाचा असून तो खालीलप्रमाणे राहील.

१)	मानधन	-	३५,०००.००
२)	बॅनर	-	५,०००.००
३)	हार व ग्रंथ भेट	-	५००.००
४)	छायाचित्रे	-	१,५००.००
५)	प्रमाणपत्र	-	२,०००.००
६)	इतर अनुषंगीक खर्च	-	६,०००.००
	एकूण रूपये		५०,०००.००

उपरोक्त खर्च रुपये ५०,०००/- हा विद्यापीठ अंदाजपत्रकीय तरतूद ४) साधारण निधी (जनरल फंड) अंतर्गत (H) बेस्ट प्रॅक्टिसेस इन युनिव्हर्सिटी (vi) मराठी भाषा संवर्धन उपक्रम या उपशीर्षांतर्गत करण्यात येईल.

सदर कार्यशाळा आयोजित करण्यासाठी प्रशासकीय व वित्तीय मान्यता मिळावी, ही विनंती.

23/12/19

मोना चिमोटे
मराठी विभागप्रमुख

27/12/19

मा. कुलसचिव

मा. कुलगुरू

28.12.19

प्रशासकीय मान्यता मिळाली असल्याने वित्तीय मान्यतेसाठी सादर.

मोना चिमोटे
मराठी विभाग, प्रमुख

M/168
30/12/19

- वित्त व लेखा अधिकारी
DR(Audit) 30/12/19

F-7100
30/12/19

F-841
30/12/19

A-2744
31/12/19

Ku. MD 31/12/19

नियमाचे पालन अपेक्षून प्रस्तावित तरतुदीस 2019-20 मध्ये (रु. 50,000/- ची नोंद घेवून वित्तीय मान्यतेस्तव सादर

अधिसभा सदस्य (मिलिंद माने) 3.1.20

03/01/2020

31/1/20

(वित्त व लेखा अधिकारी) -

4/1

A-269
03/01/20

मराठी

प्रशासकीय व वित्तीय मान्यता मिळाली आहे, अग्रीम मिळण्यास्तव सादर.

मोना चिमोटे

- वित्त व लेखा अधिकारी

महाराष्ट्र शासन

शासकीय विदर्भ ज्ञान-विज्ञान संस्था, अमरावती
पदव्युत्तर मराठी विभाग व
सं.गा.बा.अमरावती विद्यापीठ, मराठी विभाग

आयोजित

विस्तार व्याख्यानमाला

मराठी भाषा, साहित्य, आणि संस्कृती विषयक चिंतन

स्थळ :- पदव्युत्तर मराठी विभाग, शासकीय विदर्भ ज्ञान-विज्ञान संस्था, अमरावती

सोमवार दि.०३/०२/२०२० वेळ : सकाळी ११ वा.

उद्घाटन

अध्यक्ष :- **मा. डॉ. वसंत हेलावी रेड्डी**
(संचालक, शा.वि.ज्ञा.वि. संस्था, अमरावती)

उद्घाटक :- **प्रा. डॉ. केशव तुपे**
(सहसंचालक, उच्चशिक्षण, अमरावती विभाग)

दुपारी १२ ते १.३० आणि दु. २ ते ३.३०

विषय :- मराठी साहित्य आणि संस्कृती : काही दिशा

* प्रमुख मार्गदर्शक *

मा. रवींद्र इंगळे चावरेकर (साहित्य व संस्कृतीचे अभ्यास)

दु. १.३० ते २.०० :- चहापान

मंगळवार दि. ०४/०२/२०२० दु. १२ ते १.३० आणि दु. २ ते ३.३०

विषय :- मराठी कादंबरी समजून घेताना

* प्रमुख मार्गदर्शक *

मा. रमेश इंगळे उत्रादकर (प्रसिद्ध कादंबरीकार, बुलढाणा)

दु. १.३० ते २.०० :- चहापान

बुधवार दि. ०५/०२/२०२० दु. १२ ते १.३०

विषय :- वैचारिक साहित्य : कालचे आणि आजचे

* प्रमुख मार्गदर्शक *

प्रा. डॉ. माधव पुटवाड (मराठी विभाग, अमरावती विद्यापीठ)

दु. १.३० ते २.०० :- चहापान

दुपारी २ ते ३.३०

विषय :- भाषाविज्ञान : स्वरुप आणि संकल्पना

* प्रमुख मार्गदर्शक *

प्रा. डॉ. काशीनाथ बन्हाटे, परतवाडा

गुरूवार दि. ०६/०२/२०२० दु. १२ ते १.३०

विषय :- समीक्षेच्या नव्या दिशा

* प्रमुख मार्गदर्शक *

प्रा. डॉ. हेमंत खडके (अमरावती विद्यापीठ, मराठी विभाग)

दु. १.३० ते २.०० :- चहापान

दुपारी २ ते ३.३० :- **समारोप**

अध्यक्ष :- प्रा. डॉ. मनोज तायडे

प्रमुख पाहुणे :- प्रा. डॉ. केशव तुपे

प्रा. डॉ. मोना चिमोटे

* समन्वयक *

संपर्क

प्रा. डॉ. प्रणव कोलते ९६५७५४९०७६ डॉ. संतोष चव्हाण

डॉ. संजय लोहकरे ९८२२९४५९४३ डॉ. अलका हिवाळे

Sant Gadge Baba Amravati University

NAAC Accredited with "A" Grade

Wildlife Week-2017

Certificate

This is to certify that Mr./Ms./ Mrs.---------- of----------

----------has actively participated/won First/Second/Third prize in **SEMINAR/POSTER COMPETITION (UG / PG Category)** organized on the eve of **Wildlife Week-2017** by Department of Zoology, Sant Gadge Baba Amravati University Amravati, in collaboration with Melghat Tiger Reserve, Amravati and Center for Animal Rescue and Study, Amravati on 6th October 2017.

Dr. Ajay Deshmukh	**Mr. M. S. Reddy**	**Dr. Mrs. H. P. Nandurkar**	**Shri.S. M. Deshmukh**
Registrar	**Melghat Tiger Reserve**	**Head, Deptt. of Zoology, SGBAU**	**CARS, Amravati**

Poster

Wild Life Week 2015- Poster Presentation Competition
Sant Gadge Baba Amravati University, Amravati
Department of Zoology

S. N.	Name of the Student	Name of College/Deptt.	Way of Presentation (05)	Discussion (05)	Total Marks (10)
1	pooja Kale, Radhika Dahasne Triveni dharmasane	SSS College, Amravati			
2	Kshitij Wankhade	—do—			
3	Hemant Pande	PR Pote college			
4	~~Prakhar~~ Pratiksha Kapade Anuradha Nistane	—do—			
5	Shubham Wagh	SSS College, Amt			
6	pavan Thakare Mayuri Naukari	Dept of Zoology SGBAU, Amt			
7	Namrata Lakde	SSS. Amt.			
8	Anuja Petkar	—do—			
9	Varsha Newase	Dept of Zoology SGB, Amt.			

Absent ✓

Absent ✓

—(2)

10	Deepaka Sonar	Dept of Zoology SCB, Amt			
11	Diksha Shrivas Radhika dhage	Ram Meghe CoE Amt			
12	Madhuri chaukade Arti Charhan	Dept of Zoology SCB, Amt.			
13					
14					
15					
16					
17					
18					
19					
20					

(1)

(3)

Signed

16/10/15

Wild Life Week 2015
Sant Gadge Baba Amravati University, Amravati
Department of Zoology

S. N.	Name of the Student	Name of College/Deptt.	Time for presentation (05) 7+3	Content of the Topic (05)	Way of Presentation (05)	Discussion (05)	Total Marks (20)
1	Ishfaq Ahmed Malik	Vidyabharti college Amt	2	4	2	2	10 (3)
2	Salim Malik	VBMV, Amravati	3	1	2	1	8
3	Ashwini Kale	VBMV, Amravati	3	2	1	–	6
4	Shahid Mir	VBMV, Amravati	2	2	2	1	7
5	Grishma Shind	Biotech - SGB, Amt.	1	1	1	1	4
6	Ayush Bajaj	Ram Meghe CE, Amt	2	01	4	2	9
7	Devashish Meshram	Shri Shivaji COH, Amt	3	1	1	–	4
8	Akhilesh Belore	Sipna EC, Amt	1	1	2	1	5
9	Sumit Thakare	Shivaji CH, Amt.	3	3	4	3	13 (1)
10	Ajinkya Gajre	~~Shivaji Agricult~~ e Amt	3	2	2	-	7
11	pranali Solanke	RDIK, Badnera	3	2	2	2	9
12	Rushikesh Narkhed	chemtech SGB, Amt	3	2	3	1	9
13	Shweta Ramteke	RDIK, Badnera	2	2	2	-	6
14	Ashwini Kawangale	Shri. SSC, Amt	1	2	2	-	5

15	Diksha Gawai	Shiwaji College Amt	3	2	2	2	9
16	Kiran Jadhav	——"——	2	2	4	0	8
17	Vishal Bhise	LRT college Akola	2	2	3	2	9
18	Aishwarya Bhujade	PGDZ, SGB, Amt	2	2	3	2	9
19	chandani kumari	——"——	1	3	2	–	6
20	Dharam Naik	——"——	3	3	2	2	10
21	Prathmesh Tiwari	Shiwaji Science, Amt	2	2	2	–	6
22							
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31							

②

(Yadav Tarte)

SANT GADGE BABA AMRAVATI UNIVERSITY, AMRAVATI

DEPARTMENT OF ZOOLOGY

WILDLLIFE WEEK – 2017

POSTERPRESENTATION

S. N.	Name of Student	College	Content	Style of Presentation	Time Taken	Appearance	Total Marks
			5 Marks	5 Marks	5 Marks	5 Marks	
1	Suwarna Pawar						
2	Pragati Wankhade						
3	Nidhi Kale	Bot PGTD	04	02	04	04	14
4	Bhagyashri Raut		02	03	03	03	11
5	Kunal Gedam		04	03	02	04	13
6	Nitin Suryawanshi						
7	Joshi						
8	Chaudhari Aadesh	Shivaji Biotech Agri	05	05	04	05	19 – (2)
9	Daidar						
10	Pranita Sawarkar		02	02	04	05	13

Manoj
06/10/17

SANT GADGE BABA AMRAVATI UNIVERSITY, AMRAVATI

DEPARTMENT OF ZOOLOGY

WILDLLIFE WEEK – 2017

POSTERPRESENTATION

S. N.	Name of Student	College	Content	Style of Presentation	Time Taken	Appearance	Total Marks
			5 Marks	5 Marks	5 Marks	5 Marks	
11	Manisha Wankhade	VBMV	02	03	04	02	11
12							
13							
14							
15	Mr. Aashish Daydar	Bhartiya Maha.	04	03	03	04	14
16	Ms Mahima choudhary	11	05	05	05	04	19 → (2)
17	Vaishnavi Ghime	Karanja	02	03	03	04	12
18	Nupur Bapat	sipna	05	05	05	05	20 → (1)
19	Sneha kamble	Biyani	03	03	03	03	12
20	1) Mahima choudhary	Bhartiy Maha.	04	04	04	05	17 → (3)
21	2) Sapna C. Joshi	-11-	11	11	11	11	

Manoj
06/10/17

Heavy

Capture & boy sw benefits

~~Invasive species~~
DNA fingerprinting

SANT GADGE BABA AMRAVATI UNIVERSITY, AMRAVATI

DEPARTMENT OF ZOOLOGY

WILDLLIFE WEEK – 2017

S E M I N A R C O M P E T I T I O N

S. N.	Name of Student	College	Content	Style of Presentation	Time Taken	Appearance	Total Marks
			5 Marks	5 Marks	5 Marks	5 Marks	
1	Nidhi Kale	Biodiversity and conservation					
2	Zahir Abass						
3	Megha Dharawat	Biodiversity					
4	Akshay Sawai	Ganapati idols POP					
5	Akshay Ramteke	Wild life Conservation					
6	Sweety Sontakke						
7	Gaurave Joshi						
8	Sedham Jadhav	Human-animal conflict.					
9	Shivani Yawalkar	New technologies in green Energy.					
10	Sakshi Wasani	Re-introduction of cheetah in India					
11	Vinay Mahod	Innovations that are changing wildlife conservation					

Rajiv Gandhi Science and Technology Commission
Government of Maharashtra

No.RGSTC/File-2011/DPP-166/CR-42 /169
Apeejay House, 3rd Floor,
Dinshaw Vaccha Road,
Near K.C. College,
Churchgate, Mumbai-400 020.
Tel No:-022-22024755/22024711
Email :-rgstcmaha@rediffmail.com
Date:- 24th March, 2021.

To whomsoever it may concern

For advancement, propagation and promotion of applications of Science and Technology for development and to tackle various problems facing the society, Rajiv Gandhi Science and Technology Commission, Government of Maharashtra, Mumbai have evolved a scheme titled, "Assistance for Science and Technology Applications". Under this scheme the Commission had sanctioned a project titled, "An inexpensive method for the determination of oxalate in urine and assessment of hyperoxaluria by nano- based paper strip technique", vide sanction Order No. RGSTC/File-2016/DPP-166/CR-42, dated, 27th March, 2017 to Sant Gadge Baba Amravati University (SGBAU), Amravati.

The following faculty members had worked on the said project,

(1) Dr. Anita Patil, Professor Dept. of Biotechnology - Principal Investigator
(2) Dr. Gajanan Muley, Associate Professor, Department of Physics - Co-Investigator
(3) Dr. Hariprasad Paikrao, Assistant Professor, Dept. of Forensic Biology, Govt. Institute of Science Aurangabad-Co Investigator

(A. S. Manekar)
Member Secretary

भारतीय चरागाह एवं चारा अनुसंधान संस्थान
INDIAN GRASSLAND AND FODDER RESEARCH INSTITUTE
निकट पहुज बॉध, ग्वालियर रोड, झाँसी (उ.प्र.) – 284003 भारत
Near Pahuj Dam, Gwalior Road, JHANSI – 284 003 (U.P.) INDIA
Phone : 0510-2730666 Fax : 0510-2730833 email : igfri.director@gmail.com

Dr. Manoj Kumar Srivastava
Principal Scientist (Biochemistry-Plant sciences)

03.04.2018

To
The Head,
Department of Biotechnology
Sant Gadge Baba Amravati University,
Amravati, Maharastra.

Subject: Request for characterization of nano silver (AgNPs) synthesized using fodder grasses.

Dear Sir,

This is to state that we are working of biosynthesis of silver nano particles using extract of fodder grasses. As your Department has excellence in the facility to characterize nano particles, we request your support in characterization of nanoparticles synthesized here in your lab. For this purpose Mr. Anand Soni, M. Sc. (Biotechnology), who is working for his dissertation work under my supervision will be at your University from **14.04.2018 to 23.04.2018**. In this regard kindly permit him to work under the able supervision of Dr. Aniket Gade, Associate Professor at your Department.

This will be an academic collaboration between both the Institutes.

Thanking you,

With regards,

M.K. Srivastava
03/04/2018

(Manoj Kumar Srivastava)
Principal Scientist (Biochemistry- Plant Sciences)
CI Division

srimanoj2009@gmail.com ☎ 0091-9450067179