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ACKNOWLEDGEMENTS. We thank Drs Jianwen Wei and Chunyan Mou, College of Life Science Zhongshan University for help in cDNA library construction. We are also grateful to the anonymous reviewers for their valuable comments. The work was supported by a grant (2002 AA 629190) from the Ministry of Science and Technology, China to S.Z.

Received 17 June 2002; revised accepted 8 October 2002

Osmium isotopic compositions in Ganga river sediments

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The Ganga river originates and flows through the Himalayas and then over the plains carrying enormous amount of sediment to the world's oceans. The suspended sediments from selected locations in the entire river basin are analysed for osmium isotopic composition and reported in this study. The sediments are characterized by high Re/Os ratios and are extremely radiogenic as evident from their ^{187}Os/^{188}Os isotopic ratios. Samples from the tributaries Alaknanda, Bhagirathi, Gandak and Ghaghra show pronounced ^{187}Os/^{188}Os. The integrated effect is seen at Farakka, the farthest downstream location of the Ganga in the present study. High Os concentrations combined with sediment flux makes the Ganga an important source for soluble Os isotopic evolution in the oceans.

INTEREST in rhenium–osmium (Re–Os) systematics in rivers has risen sharply in recent years due to the revelation of changes associated with sea water Os isotopic compositions during the past 70 Ma. Radiogenic ^{187}Os is produced from the β-decay of ^{187}Re with a half-life of 4.2×10^{10} years. Osmium isotopic composition in sea water is derived from the weathering of basaltic and peridotitic oceanic crust, hydrothermal solutions, additions from cosmic dust and continental weathering products. The ^{187}Os/^{188}Os ratios of submarine weathering and cosmic inputs are nearly identical (~ 0.13) and about ten times lower than that of average continental matter (~ 1.26). Because of the large isotopic variations between these different sources, Os isotopes in the oceans convey the then prevalent continental weathering processes. The osmium isotopic composition of the present-day sea water is markedly higher since the past 70 Ma[1], similar to the ^{87}Sr/^{86}Sr ratios in sea water. This enhancement in radiogenic Os in sea water is largely attributed to the Himalayan tectonics with its accompanying increased silicate weathering and in particular, chemical weathering of the extremely radiogenic black shales in the lesser Himalayan region[2,3]. Because of its low concentration and high ionization potential (8.7 eV), Re–Os isotopic measurements are carried out by Negative Thermal Ionization Mass Spectrometry (NTIMS)[4].

It is estimated that annually about 1.6×10^{16} g of sediment are transported to the oceans by rivers, approximately 10% of which is contributed by the Ganga–Brahmaputra river system[5]. The drainage basin of the Ganga occupies an area of 1.06×10^6 km^2; while more than 60% of water flowing into the Ganga comes from the Himalayan source, 40% is contributed from the peninsular region[6]. Briefly, lithology of the basin comprises[7] Kumaun Himalayas consisting of Siwalik sediments composed of coarse sandstone, clays and conglomerates, the central–lower Himalayas of Krol formation consisting of dolomitic limestones, shales, quartzites, granites and gneisses, and the lower reaches of the basin characterized by alluvial plains which consist of massive beds of clay, sand and gravel with extensive calcareous concretions and saline/alkaline soils. The suspended sediments in the river are mostly medium-to-coarse silt (mean size < 4.5 to 5.75 ϕ) and are poorly sorted. The clay minerals abundant in the sediments are mica followed by kaolinite in the upstream and mica followed by smectite in the downstream region[7]. Sedimentological and Sr isotopic data along with clay mineral composition of ODP Leg 116 and DSDP Leg 22 indicate the dominance of Ganga river sediments in the Bay of Bengal[8].

Suspended sediments from ten locations shown in Figure 1, covering the mainstream of the Ganga and all major tributaries were collected from 5 to 10 litres of water samples using sartorius 0.2 μm cellulose acetate filters and tangential filtration. Suspended sediments were then separated by centrifugation and desiccation at 80°C to remove the remaining water from the sediments. Re–Os isotopic measurement in sediments was carried out following the chemical procedures described by Birck *et al.*[9]

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*For correspondence. (e-mail: gjcurfes@iitr.ernet.in) and measured using Finnigan MAT262 mass spectrometer at IPG, Paris. Blank measurements during the analyses yielded 0.024 ± 0.007 pg Os.

Re, Os compositions and isotopic composition of Os in sediments are presented in Table 1. Re concentrations show higher values relative to Os, while Re/Os ratios range between 4.6 and 24.9. The tributaries in the upstream, Alaknanada and Bhagirathi flow through predominantly silicates (shales, phyllites, quartzites, crystallines) and show high Re/Os ratios of 24.9 and 19.8 respectively. Re is preferentially incorporated into the silicate minerals relative to Os[10]. A high dissolved Re concentration, greater by a factor of ~ 4 compared to the global average has been reported in the Yamuna river, which is attributed to have been derived from black shale/carbonaceous sediments in the basin[11]. The Lesser Himalaya is characterized by abundant black shales. The black shales have extremely radiogenic Os and contain appreciable sulphides which act as a major host for Re, similar to the association of Re in the mantle with magmatic sulphides. Ready oxidation of sulphides adds dissolved sulphate and Re into the fluid phase. The high sulphate concentrations (150–200 μmol/l) in Alaknanda and Bhagirathi may have sourced from the oxidation of sulphides in addition to the dissolution of gypsum. The mobilization rate of Re in the Ganga and Yamuna in the Himalayas is higher by a factor of > 10 compared to the global average[11]. The Bhagirathi–Alaknanda river system is also significant in terms of uranium weathering and mobilization[12]. Singh *et al.*[13] studied black shales from different regions of the Lesser Himalaya and observed Re/Os ratios ranging between 8 and 73, with Re concentrations up to 264 ngg^{-1}. Suspended sediments in Alakananda and Bhagirathi contain 0.5 to 0.65 ngg^{-1} respectively. Re concentration is least (0.2 ngg^{-1}) in Yamuna river at Auriya (Gan5S in Figure 1) and highest (1.1 ngg^{-1}) in Yamuna at Baghpat (Gan3S), whereas Os is least (13.5 pgg^{-1}) in Son river (Gan9S) and highest (64 pgg^{-1}) in Yamuna at Baghpat (Gan3S), which indicate contributions from the varied lithology. Re and Os concentrations are significantly higher (Re > 450 pgg^{-1}, Os > 40 pgg^{-1}) in Gandak and Ghaghra tributaries which flow through the Central Nepal Himalayas and show ^{187}Os/^{188}Os of 3.8 and 2.9 respectively. Such observations of high Os concentration and isotopic ratios have been reported[14] from the organic-rich metasediments (black shales) in the Lesser Himalayan unit of Nepal Himalayas. Large amounts of Re and Os are lost from black shales by low-temperature alteration and go into solution, which is primarily related to loss of organic carbon. The suspended sediments in the Ganga show low organic carbon contents (< 1%), which are probably the remains of

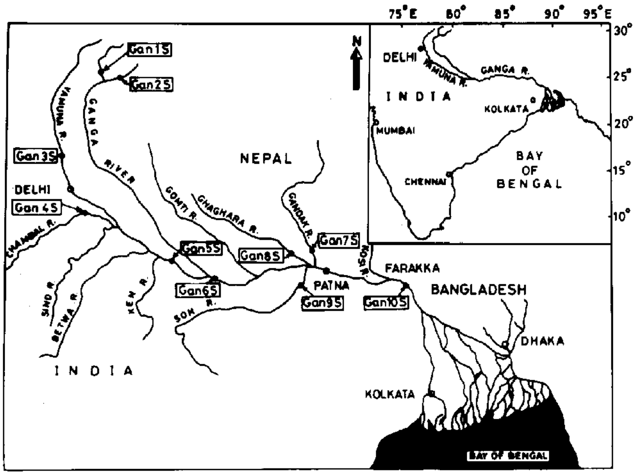

Figure 1. Sampling locations along Ganga river.

Table 1. Osmium isotopic composition in Ganga river suspensions

Sample no.	River	[Re]$_{ppt}$	[Os]$_{ppt}$	Re/Os	^{187}Os/^{188}Os	Organic C (%)
Gan1S	Bhagirathi	649.8	32.8	19.8	2.49	No data
Gan2S	Alaknanda	527.5	21.1	24.9	2.86	0.11
Gan3S	Yamuna	1103.8	64.3	17.2	2.48	0.13
Gan4S	Chambal	261.5	33.8	7.7	0.89	0.76
Gan5S	Yamuna	210.8	45.8	4.6	1.18	0.28
Gan6S	Ganga	585.0	37.7	15.5	2.41	0.44
Gan7S	Gandak	511.2	55.7	9.2	3.77	0.41
Gan8S	Ghaghra	355.3	42.8	8.3	2.90	0.54
Gan9S	Son	321.2	13.5	23.7	1.17	1.06
Gan10S	Ganga	631.1	51.7	12.2	2.42	0.69

Table 2. Re–Os load in Ganga river

Sample no.	River	Discharge (× 10^{12} l/yr)	Total suspended matter (mg/l)	Sediment load (× 10^{6} t/yr)	Re flux (kg/yr)	Os flux (kg/yr)
Gan1S	Bhagirathi	8.4	905.6	7.6	4.9	0.2
Gan2S	Alaknanda	14.0	1124.6	15.7	8.3	0.3
Gan4S	Chambal	30.0	3529.9	105.9	27.6	3.6
Gan5S	Yamuna	58.0	630.2	36.5	7.7	1.7
Gan6S	Ganga	52.0	650.0	33.8	19.7	1.3
Gan7S	Gandak	94.0	1943.0	182.6	93.3	10.1
Gan10S	Ganga	459.0	510.5	234.3	147.8	12.1

unoxidized residual organic carbon (non-metabolizable fraction). Studies on Late Devonian Ohio Shale[15] show a pronounced decrease of ~ 77% in organic carbon near soil profile accompanied by a pronounced decrease in Re (~ 99%) and to a lesser extent Os (~ 39%). The Ganga river at Farakka (Gan10S) where the sediments are derived from up-, mid- and downstream parts of the Ganga as well as all the major tributaries, show high Os ($51.7\,\mathrm{pg\,g^{-1}}$), Re ($0.63\,\mathrm{ng\,g^{-1}}$) and ^{187}Os/^{188}Os ratio (2.4) indicating the presence and transport of radiogenic sediments from all sources.

Table 2 presents Re and Os load in the Ganga at various locations based on discharge data of Rao[16] and Sarin *et al.*[12] (as recent discharge data are difficult to obtain), and suspended sediment concentration in the present samples. The Os flux by sediments in the upper reaches is around $0.3\,\mathrm{kg\,yr^{-1}}$, which increases to $12\,\mathrm{kg\,yr^{-1}}$ at Farakka (Gan10S), the farthest downstream location. This is an increase of about 40 times, which probably gets transported to the Bay of Bengal if there is no burial and other estuarine processes acting in the removal of Re and Os from the sediments.

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ACKNOWLEDGEMENTS. We are extremely grateful to J-L. Birck, F. Capmas, A. Ganoun and D. Lemarchand for help and cooperation at various stages of the work.

Received 13 March 2002; revised accepted 24 September 2002

Middle Eocene prosimian primate from the Subathu Group of Kalakot, northwestern Himalaya, India

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An upper molar tooth of a possibly new but unnamed prosimian primate (Mammalia, Primates) is described from the Middle Eocene, in the uppermost part of the Subathu Group exposed east of Babbian Gala near Kalakot (northwestern Outer Himalaya) in the Rajauri District, Jammu and Kashmir, India. To the best of our knowledge, this is the first pre-Siwalik primate from India and the only primate tooth identified thus far in a remarkably rich and varied land mammal fauna known from the red beds of the Subathu Group. Its occurrence is significant, as the Eocene primates of the Indian subcontinent are important for understanding the early primate radiation in Asia.

IN the last three decades, dental and skeletal remains of a number of small-to-medium-sized terrestrial mammals representing Creodonta, Condylarthra, Rodentia, Artiodactyla, Perissodactyla, Proboscidea, and basal Cetacea have been documented from the Middle Eocene horizons of the Subathu Group, northwestern Outer Himalaya, India[1–11]. In such varied and rich fauna, the absence of primates was intriguing, especially in view of the fact that largely similar fauna from the coeval beds of the Kuldana Formation in Pakistan includes at least five primate species, though based mostly on isolated teeth.

Here we report a possibly new but unnamed Eocene primate species from the red beds of the uppermost Subathu Group of Kalakot, Rajauri District, Jammu and Kashmir (India). The Kalakot primate is represented by a single molar tooth and its documentation is important because (i) to the best of our knowledge it is the first pre-Siwalik and Eocene primate from India (ii) it is based on an upper molar tooth, whereas the previously recorded Eocene primates from the coeval beds of Pakistan are known by lower teeth; (iii) it is metrically and morphologically distinct from the known Eocene primates, and (iv) it increases the known diversity, size range and geographic range of Indo-Pakistan Eocene primates. The report of an Eocene primate from India is also significant because early primates from Asia are less known in comparison to Europe and North America. Prior to this

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