coefficients. An effective and efficient strategy must be used for the heritage paintings of India in view of their chemical composition and long-term preservation; otherwise they will permanently fade.

1. Chakravarty, K. K. and Bednarik, R. G., *Indian Rock Art and its Global Context*, Motilal Banarsidass Publ., Bhopal, India, 1997.
2. Blinkhorn, J., *Rock Art Studies: News of the World VI*, Archaeo Press, Oxford, 2021, p. 137.
3. Kumar, V., *Indian J. Archaeol.*, 2021, **7**(1), 1203–1878.
4. Mathpal, Y., *Prehistoric Painting of Bhimbetka*, Abhinav Publications, 1984.
5. Mondillo, N. *et al.*, *Minerals*, 2019, **9**, 504.
6. Kokh, M. A., Luais, B., Truche, L., Boiron, M. C., Peiffert, C. and Schumacher, A., *Geostand. Geoanal. Res.*, 2021, **45**, 341–358.
7. Casadio, F., Giangualano, I. and Piqué, F., *Stud. Conserv.*, 2004, **49**, 63–80.
8. Cuní, J., *Heritage Sci.*, 2016, **4**, 1–13.
9. Oeter, M. and Skedzuhn-Safir, A., *The Three Storied Temple of Wanla*, Graz University of Technology, Graz, 2015, pp. 174–189.
10. Aceto, M., *Archaeol. Anthropol. Sci.*, 2021, **13**, 1–23.
11. Grzywacz, C. M., Wouters, J., Bomin, S. and Yuquan, F., In *Conservation of Ancient Sites on the Silk Road: Proceedings of the Second International Conference on the Conservation of Grotto Sites*, Getty Publications, Los Angeles, USA, 2010, pp. 450–456.
12. Yü, F.-A., Silbergeld, J. and McNair, A., *Chinese Painting Colors: Studies of Their Preparation and Application in Traditional and Modern Times*, University of Washington Press, 1988.
13. Cardon, D., *Tradition, Technology and Science*, Archetype, London, USA, 2007, pp. 322–334.
14. Osticioli, I., Pagliai, M., Comelli, D., Schettino, V. and Nevin, A., *Spectrochim. Acta, Part A*, 2019, **222**, 117273.
15. Jorge-Villar, S. E., Rodríguez Temiño, I., Edwards, H. G., Jiménez Hernández, A., Ruiz Cecilia, J. I. and Miralles, I., *Archaeol. Anthropol. Sci.*, 2018, **10**, 1207–1223.
16. Akrawi, A. and Shekede, L., *Stud. Conserv.*, 2010, **55**, 214–219.
17. Feller, R. L., *Artist's Pigments: A Handbook of their History and Characteristics, Vol. 1*, Archetype Publications, London, 1986.

Received 27 January 2022; revised accepted 4 August 2022

CHANDRA SEKHAR MOHANTY[1,*]
ROJALIN PATTANAYAK[2]

[1]*CSIR-National Botanical Research Institute,*
Rana Pratap Marg,
Lucknow 226 001, India
[2]*College of Basic Sciences and Humanities,*
Odisha University of Agriculture and Technology,
Bubaneswar 751 003, India
**For correspondence.*
e-mail: cs.mohanti@nbri.res.in

Coloured bivalves from the Middle Eocene of Kutch, India

Fossiliferous, shallow marine Palaeogene rocks are well exposed in Kutch, Gujarat, India[1]. Among diverse Paleogene fossils of Kutch, the Middle Eocene bivalves have been studied by several workers in the context of systematics, ontogeny and biostratinomy[2–5]. In the present study, we report pigment-bearing Middle Eocene ostreid bivalve *Flamingostrea* sp. Vredenburg from western Kutch (Figure 1). The previously reported coloured mollusc from Kutch was from the Jurassic age[6].

Spats (L = 0.54–1.13 cm, H = 0.52–1.37 cm) of pigment-bearing *Flamingostrea*[5] were collected from the *obtusus* bed (a marker bed) occurring in the upper part of the Harudi Formation[1] in Harudi village (23°30′30″, 68°41′10″), western Kutch (Figure 2). The present collection consists of 25 pigment-bearing, dissociated, left-valve specimens of *Flamingostrea*. This bivalve grows by cementing its left valve on a hard substratum. Tests of larger foraminifera *Nummulites obtusus* (Sowerby) Form B are commonly used as a substrate by *Flamingostrea*[5]. The attachment site of the left valve is markedly thin compared to the rest of the valve. The pigment-bearing valves of *Flamingostrea* exhibit various shades of red colour; darker specimens exhibit deep purple colour. The shell coloration is restricted to the inner surface of the valves. Portions of the valves lacking the pigment appear dull brown. External factors such as taphonomic iron staining of the *Flamingostrea* specimens may be ruled out as a possible cause for valve colouration because such staining would equally affect both the inner and outer surfaces of the bivalve along with the foraminiferal substrate[7]. In this context, it may be noted that the outer valve surface of the bivalve and the foraminiferal substrate are devoid of colour and appear dull brown. Platinum-coated SEM study of the pigment-bearing *Flamingostrea* specimens revealed the presence of preserved, elongated, block-like melanosomes within the valve (Figure 3). Such melanosomes are conspicuously absent in the non-pigmented shells (Figure 4).

In fossilized shells spanning the entire Phanerozoic, pigment preservation has been a rare phenomenon[8]. Traces of original pigment could be preserved as molecular fossil[9]. Shell pigments in the living molluscs are considered as metabolic waste that gets incorporated within the shell[10,11]. It has been observed that in the present-day gastropod *Haliotis asinine*, pigments originate from the invaginations of the epithelial

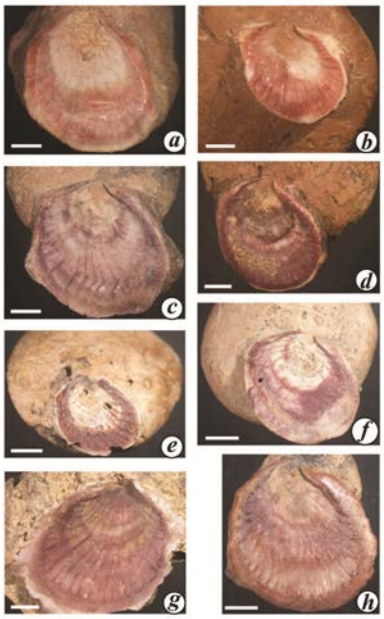

Figure 1. Various shades of red colour preserved in the left valve of *Flamingostrea* sp. Specimens collected from the *obtusus* bed of Harudi Formation, Harudi village area, western Kutch, Gujarat, India. ***a*–*f***, ***h***, *Flamingostrea* sp. attached to larger foraminifera *Nummulites obtusus* (Sowerby) Form B. ***g***, *Flamingostrea* sp. attached to a broken bioclast (fragmented bivalve?). Specimens in (***a***) and (***e***) were earlier illustrated in grey scale[5]. Scale bar = 2 mm for all figures.

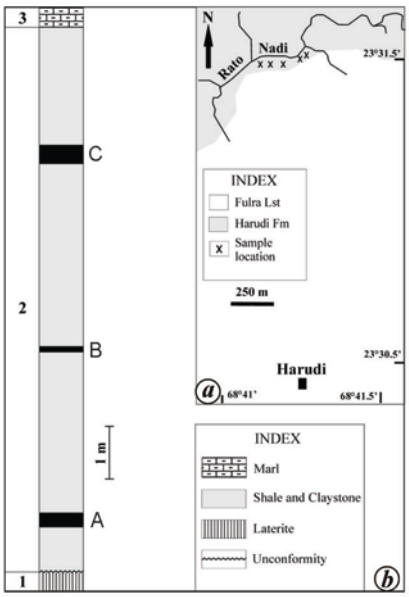

Figure 2. ***a***, Geological map of the area around Harudi village showing sampling locations from the *obtusus* bed. ***b***, Litholog of Harudi Formation from the type locality. Beds A and B represent macroinvertebrate shell beds, while bed C represents the *obtusus* bed. Stratigraphic intervals 1, 2 and 3 represent the upper part of Naredi Formation, Harudi Formation and lower part of Fulra Limestone respectively.

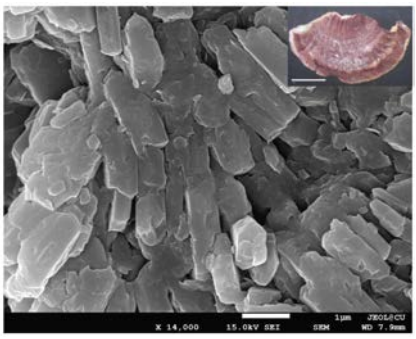

Figure 3. Platinum-coated SEM photograph of pigmented (purple colour), broken specimens of *Flamingostrea* sp. collected from the *obtusus* bed of Harudi Formation, Kutch. Note dense packing of elongated block-like melanosomes. They compare well with the illustrations of experimentally mature melanosomes from extant taxa[21]. (Inset) Broken specimen of *Flamingostrea* sp. under a binocular microscope before platinum coating for SEM examination. Scale bar = 2 mm.

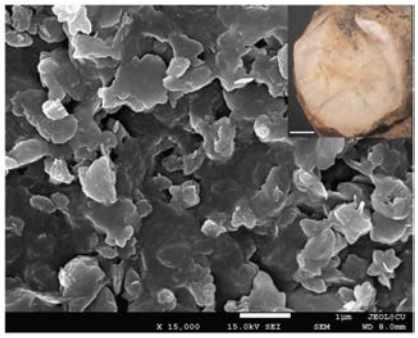

Figure 4. SEM photograph of a colourless specimens of *Flamingostrea* sp. collected from *obtusus* bed of Harudi Formation, Kutch. Note conspicuous absence of melanosomes within the valve. (Inset) Specimen of *Flamingostrea* sp. under a binocular microscope before platinum coating for SEM examination. Scale bar = 2 mm.

mantle cells[12]. Shades of red colour in the presently studied *Flamingostrea* specimens likely indicate differential preservation of the pigment melanin – a complex biopolymer comprising dark brown–black eumelanin and orange–red pheomelanin[13]. This pigment exhibits high resistance to decay and has been encountered in Eocene, Jurassic and Triassic vertebrate and invertebrate fossils[14–18].

The *obtusus* bed of the Harudi Formation was formed under a low sedimentation regime[19], resulting in the accumulation of larger foraminiferal bioclasts and a host of sclerobionts (epibenthic worms, endolithic fauna and algae, attached bivalve and coral, encrusting bryozoa and unidentified foraminiferal predator). While sclerobionts thrive under oxic conditions, light and oxygen are known to degrade pigment fossilization[20]. It appears that rare sediment influxes may have locally entombed the *Flamingostrea* specimens and successfully preserved their pigment content. Further studies are required to understand the nature and preservation of the pigment present in the *Flamingostrea* specimens.

1. Biswas, S. K., *J. Palaeontol. Soc. India*, 1992, **37**, 1–29.
2. Chattopadhyaya, D., *Indian Miner.*, 2004, **58**, 169–182.
3. Kachhara, R. P., Jodhawat, R. L. and Bigyapati Devi, K., *J. Palaeontol. Soc. India*, 2011, **56**, 17–28.
4. Halder, K. and Bano, S., *Arab. J. Geosci.*, 2014, **8**, 2019–2034.
5. Sengupta, S., Syed, R., Sarkar, S. and Halder, K., *Indian J. Geosci.*, 2011, **65**, 265–274.
6. Bardhan, S., Jana, S. K. and Datta, K., *J. Paleontol.*, 1993, **67**, 140–143.
7. Curry, G. B., *Palaeontol. Electron.*, 1999, **2**, ISSN 1935-3952; http://palaeo-electronica.org/1999_2/curry/issue2_99.htm
8. Hoare, R. D., *The Compass of Sigma Gamma Epsilon*, 1978, **55**, 39–63.
9. Blumer, M., *Science*, 1965, **149**, 722–726.
10. Comfort, A., *Proc. Malacol. Soc. London*, 1950, **28**, 79–85.
11. Kriz, J. and Lukes, P., *J. Paleontol.*, 1974, **48**, 41–48.
12. Budd, A., McDougall, C., Green, K. and Degnan, B. M., *Front. Zool.*, 2014, **11**, 62.
13. Bandaranayake, W. M., *Nat. Prod. Rep.*, 2006, **23**, 223–255.
14. Kelley, P. H. and Swann, C. T., *J. Paleontol.*, 1988, **62**, 83–87.
15. Barden, H. E., *Palaeontology* (*Online*), 2012, **2**, 1–16; http://www.palaeontology-online.com/articles/2012/fossil-focus-the-preservation-of-colour/.
16. Glass, K. *et al.*, *Proc. Natl. Acad. Sci. USA*, 2012, **109**, 10218–10223.
17. Lindgren, J. *et al.*, *Proc. R. Soc. London, Ser. B.*, 2015, **282**, 20150614.
18. Lindgren, J., *Curr. Biol.*, 2016, **26**, R451–R452.
19. Syed, R., Sarkar, S. and Sengupta, S., *J. Geol. Soc. India*, 2015, **85**, 586–590.
20. Cheesman, D. F., Lee, W. L. and Zagalsky, P. F., *Biol. Rev.*, 1967, **42**, 131–160.
21. Colleary, C. *et al.*, *Proc. Natl. Acad. Sci. USA*, 2015, **112**, 12592–12597.

Received 27 April 2022; revised accepted 2 August 2022

ROSINA SYED
SAMPA SARKAR
S. SENGUPTA*

Department of Geology,
University of Calcutta,
35 Ballygaunge Circular Road,
Kolkata 700 019, India
**For correspondence.*
e-mail: ssggeol@gmail.com